GPCB

BEST AVAILABLE TECHNIQUES

Reference Document for The Textiles Industry of Gujarat





BREF - Textile

A Sustainable road map for textile industries

2024

Abstract:

Governments worldwide are increasingly embracing the Best Available Techniques (BAT) approach as an integral part of their regulatory frameworks to curb and manage industrial emissions. This strategy gains traction due to its notable implementation success, attributed to the active involvement of industries throughout the process.

The Best Available Techniques (BAT) Reference Document (BREF) for the Textiles Industry of Gujarat has evolved through collaboration led by the Gujarat Pollution Control Board (GPCB) with Gujarat Cleaner Production Centre (GCPC), German Federal Environment Agency (Umweltbundesamt-UBA), Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, industries, industry associations, non-governmental organizations (NGOs), and academia.

This BREF amalgamates practical experiences, processes, and technologies from the textile industry. The BREF document not only guides textile industries and associated entities on BAT implementation but also contributes to safeguarding human health, the environment, and fostering a level playing field among industries in Gujarat. The document serves as a potential reference for regulators when prescribing consent conditions.

The BREF primarily aims at promoting environmental protection, resource efficiency, and sustainable production processes. It delves into applied techniques, current emissions and consumption levels, considerations for determining best available techniques, BAT conclusions, and emerging techniques within the textile sector.

Key coverage areas within the BREF encompass pre-treatment of grey fabric and processes at different stages like scouring, bleaching, mercerization, dyeing, printing, finishing etc. The document addresses the combined treatment of wastewater from different stages in the textile industry in terms of pollution load and combustion processes associated with textile activities. Emission reduction, chemical usage, energy consumption, and compliance with environmental regulations emerge as crucial considerations for successful BAT implementation in the textile sector.

The document is structured into chapters, offering a comprehensive guide:

- General Information (Chapter 1): Provides an overview of the textile sector.
- Applied Processes and Techniques (Chapter 2): Details the processes and techniques employed in the textile industry.
- Current Emission and Consumption Levels (Chapter 3): Presents information on emissions and consumption in the textile sector.
- Techniques for Determining BAT (Chapter 4): Explores techniques to consider during the determination of best available techniques.
- BAT Conclusions (Chapter 5): Outlines conclusions derived from best available techniques.
- Emerging Techniques (Chapter 6): Explores innovations and emerging techniques in the textile sector.

- Concluding Remarks and Recommendations (Chapter 7): Offers conclusions and recommendations for future work.
- Additionally, annexes provide details on participating installations and specific technical issues.

Focusing specifically on Gujarat's textile sector, the BATs for fiber, yarn, and fabric production and processing address critical concerns such as water and air emissions, chemical use, energy consumption, waste management, water consumption, regulatory compliance, and implementation strategies for businesses of varying sizes i.e. small, medium and large scale industries.

The BAT Reference Document stands as a comprehensive resource, guiding textile companies in Gujarat toward environmental best practices. By incorporating the document's recommendations, businesses can enhance their environmental sustainability, adhere to regulations, and potentially realize environmental and economic benefits through improved efficiency and reduced resource consumption.

MULUBHAI BERA



No.: T./C.A./F & E/C.C./ 117 /2024

Minister,
Tourism, Cultural Activities,
Forest and Environment,
Climate Change,
Government of Gujarat
Swarnim Sankul-1, 2nd Floor,
Sachivalaya, Gandhinagar-382010
Phone No. : 079-232-50116
Fax No. : 079-232-50120

Date : 02 JAN 2024

MESSAGE

The textile industry, a crucial component of the Indian economy, faces the dual challenge of meeting growing demands and mitigating environmental impact. It is imperative that we learn to navigate and operate this sector for a sustainable and responsible future. This pioneering work on sustainable production in the textile sector of Gujarat is extremely valuable considering the volume of textile industries set up in the state. This document has set a precedent with the intensive participatory approach used by the Gujarat Pollution Control Board (GPCB) to foster sustainable industrial processes. The document is a great step towards the measures encouraged by the State Government under 'Mission LIFE', nudging individual and collective actions to promote sustainable production processes.

This reference document will be valuable in providing guidance to the state on developing inclusive environmental directives and to the industries on how to employ cleaner and more resource efficient production processes. It demonstrates that sustainable practices are not only environmentally responsible but also crucial for the long-term viability of businesses and industries.

This reference document also leads by example to show how international co-operation can support our nation's actions towards a sustainable and resilient future. I commend the Authors and all the key stakeholders involved in the development of this reference document. May this reference document inspire a new approach towards environmental regulation and compliance in India.

(Mulubhai Bera)

MUKESH PATEL



सत्यमेव जयते

No.: Min/F.E./C.C./W.R./W.S./57/021 /2024

Minister of State,
Forest and Environment,
Climate Change, Water resources and Water Supply,
Government of Gujarat
Swarnim Sankul-2, 2nd Floor,
Sachivalaya, Gandhinagar-382010
Phone No. : 079-23250205/209
Fax No. : 079-23250285
Email : mos-forest@gujarat.gov.in

Date :

MESSAGE

In a world where the need for environmentally conscious solutions is increasingly evident, this reference document serves as a guide for industries to navigate the complex intersection of business and sustainability. It emphasizes the importance of adopting best practices to not only meet current demands but also to secure a resilient and sustainable future for the textile sector in Gujarat.

The comprehensive and elaborate structure of the reference document reveals how much effort has been put into including contributions from all the key stakeholders in preparing this document. Its insights into resource efficiency, cleaner production, sustainable production processes, and innovative technologies resonate with the spirit of 'Make in India' — a call to not only manufacture but to manufacture responsibly.

I extend my appreciation to the Gujarat Pollution Control Board for their dedication to this important subject. Their work is not just a contribution to the textile industry; it is a step towards a sustainable industrial development.

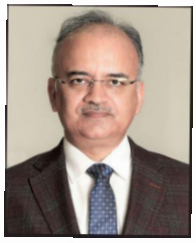
I urge all stakeholders in the textile sector – from large mills to small dyeing units – to actively engage with this valuable resource. Utilize various BAT recommendations to upgrade operation, minimize environmental impact, and contribute to a greener Gujarat. Remember, adopting sustainable practices is not just an environmental imperative, but also a sound business decision.

Let us join hands to ensure that Gujarat's textile industry continues to thrive, while also prioritizing environmental responsibility. Together, we can weave a brighter and more sustainable future

(Mukesh Patel)

Bunglow No.20, Raj Bhavan, Sector-20, Gandhinagar-382020
Phone : 079-23259706/707

Sanjeev Kumar, IAS
Principal Secretary



No.
Government of Gujarat
Forest and Environment Department

FOREWORD

It is a matter of great pleasure to introduce the Best Available Techniques (BAT) Reference Document for the Textile Industry **(BREF-Textile)** in Gujarat. This document emphasizes the importance of adopting best practices to not only address current challenges but also to lay the groundwork for a sustainable future.

This is the first time that a State Pollution Control Board (SPCB) has taken the initiative to prepare such a reference document. This participatory approach was successfully followed in Gujarat because of the efforts and contribution of **Gujarat Pollution Control Board** (GPCB), Gujarat Cleaner Production Centre (GCPC), Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, Umweltbundesamt (UBA) (German Environment Agency), Technical Working Group (TWG) Members, Textile industries of Gujarat and other key stakeholders.

This document will help industries to gain some practical knowledge on adopting best practices and technologies. We hope that this participatory process and result-oriented method adopted by GPCB gets internalized and continued for other sectors.

Sanjeev Kumar

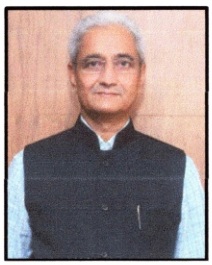
(Sanjeev Kumar)

Block No. 14, 8th Floor, Sardar Bhavan, Gandhinagar-382010, Gujarat (India)
Phone: (079) 232 51051, 232 51053, **Fax:** 232 52156, **E-mail:** secfed@gujarat.gov.in

सत्यमेव जयते

R. B. Barad, IAS
Chairman

Gujarat Pollution Control Board
Paryavaran Bhavan Sector-10-A,
Gandhinagar - 382 010, Gujarat



MESSAGE

Gujarat's textile industry is a cornerstone of our state's economy, it weaves success stories and vibrant fabrics. However, with great progress comes an equal responsibility to safeguard our environment and therefore, there is a need for Sustainable Textile Production. It is immense pride to present the Best Available Technique (BAT) Reference Document Book for the Textile Sector of Gujarat **(BREF-Textile)**. This comprehensive resource marks a significant milestone in our shared effort to achieve sustainable and responsible textile production in our state.

The Gujarat Pollution Control Board (GPCB) has used an intensive participatory approach in preparing this document, with multiple rounds of deliberate information exchange with key stakeholders. This document has been prepared with the dedicated efforts and contributions from the Gujarat Pollution Control Board (GPCB), Gujarat Cleaner Production Centre (GCPC), Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, Umwelt bundesamt (UBA) (German Environment Agency), Technical Working Group (TWG) Members, international experts, industry representatives and environmental NGOs.

The focus of the document is also to highlight a different approach to understand the production process and environmental impact. This is done by looking at process-oriented techniques at each stage of the production process instead of solely looking at end-of-pipe techniques. Hence, this reference document will help to provide robust and practical guidance to industries on adopting cleaner and resource efficient technologies and processes. The recommendations and conclusions of the reference document also provide us with the opportunity to revisit consent conditions and environmental directives for the textile sector.

We hope for this reference document to spark a change in how we understand environmental regulation and sustainable production. The Gujarat textile industry will be an exemplary model of how an inclusive and participatory approach can weave a sustainable future together.

(R.B.Barad, IAS)
Chairman, GPCB

GPCB

Tel.: (0) 079-23222425 Email : chairman-gpcb@gujarat.gov.in
web : http ://gpcb.gujarat.gov.in

CONTENTS

1. GENERAL INFORMATION 1
- 1.1 Distribution of Textile Industries in India 4
- 1.2 Textile Industry in Gujarat 5
- 1.3 Textile Clusters of Gujarat 6
  - 1.3.1 Ahmedabad 7
  - 1.3.2 Surat 8
  - 1.3.3 Jetpur 8
- 1.4 Main Environmental Issues 9
  - 1.4.1 Environmental issues of wet processing 11
    - 1.4.1.1 Air emissions (waste gase) 11
    - 1.4.1.2 Waste water emissions 12
    - 1.4.1.3 Solid waste 13
    - 1.4.1.4 Hazardous chemicals 13

2. APPLIED PROCESSES & TECHNIQUES 15
- 2.1 Introduction 15
- 2.2 Raw materials 15
  - 2.2.1 Fibre 16
    - 2.2.1.1 Natural Fibres 17
    - 2.2.1.2 Man-Made Fibres 20
- 2.3 Chemicals and Auxiliaries 23
- 2.4 Fibre manufacturing 28
  - 2.4.1 Fibre manufacturing: chemical (man-made) fibres 28
    - 2.4.1.1 Cellulosic polymers 29
      - 2.4.1.1.1 Regenerated Cellulose 29
      - 2.4.1.1.2 Cellulose ester 29
    - 2.4.1.2 Non-cellulosic (synthetic) fibre 30
      - 2.4.1.2.1 Polyamide 30
      - 2.4.1.2.2 Aramid 30
- 2.5 Production Process in Textile industry 31
  - 2.5.1 Yarn Manufacturing 31
    - 2.5.1.1 Yarn manufacturing processes for man-made fibres 31
      - I. Spinning 31
        - a. Melt spinning 33
        - b. Dry Spinning 33
        - c. Wet spinning 34
        - d. Reaction spinning 34
    - 2.5.1.2 Fibre processing 34
      - I. Drawing 35
  - 2.5.2 Fabric formation 35
    - 2.5.2.1 Woven Fabric 36
    - 2.5.2.2 Knitted Fabric 38
  - 2.5.3 Pre-treatment of Grey Fabric 39

2.5.3.1 Singeing 41
2.5.3.2 Desizing 42
2.5.3.2.1 Enzymatic Desizing 43
2.5.3.2.2 Oxidative Desizing 43
2.5.3.2.3 Washing 44
2.5.3.3 Scouring 44
2.5.3.4 Bleaching 44
2.5.3.5 Mercerizing 49
2.5.3.6 Washing/Scouring(synthetic fabrics) 49
2.5.3.7 Weight Reduction 49
2.5.3.8 Raw wool scouring 50
2.5.3.9 Carbonizing 50
2.5.3.10 Heat Setting 50
2.5.3.11 Environmental issues related to pre-treatment 51
2.5.4 Dyeing 53
2.5.4.1 Environmental issues related to Dyeing 63
2.5.5 Printing 66
2.5.5.1 Printing with Pigments 66
2.5.5.2 Printing with Dyes 67
2.5.5.3 Ancillary operations 69
2.5.5.4 Environmental issues related to Printing 69
2.5.6 Finishing 70
2.5.6.1 Mechanical Finishing 70
2.5.6.2 Chemical Finishing 72
2.5.6.3 Environmental issues related to Finishing 73
2.5.7 Drying 73
2.5.7.1 Hydro-extraction by squeezing 73
2.5.7.2 Stenter 73
2.5.7.3 Contact dryer(heated cylinder) 73
2.6 Cotton Textile Processing 74
2.6.1 Woven Cotton Pre-treatment 75
2.6.2 Dyeing 76
2.6.3 Printing 77
2.6.4 Finishing 77
2.7 Polyester Textile Processing 77
2.7.1 Polyester Pre-treatment 78
2.7.1.1 Desizing 79
2.7.1.2 Scouring 80
2.7.1.3 Drumming 80
2.7.1.4 Bleaching 80
2.7.1.5 Weight reduction 81
2.7.1.6 Heat setting 81
2.7.2 Dyeing 83

2.7.3 Printing 84
2.7.4 Finishing 84
2.8 Blends -Processing 84
2.8.1 Polyester/Cotton Blends 85
2.8.2 Polyester/Wool Blends 85
2.9 Denims 86
2.9.1 Spinning 86
2.9.1.1 Rotor or Open-End(OE)System 87
2.9.1.2 Ring System 88
2.9.1.3 Compact System 89
2.9.2 Dyeing Ranges 91
2.9.2.1 Rope Dyeing Range 92
2.9.2.2 Loop Dye Range 92
2.9.3 Pre-treatment for Denim 93
2.9.3.1 Pre-wetting 93
2.9.4 Dyeing & Sizing 93
2.9.5 Sizing 95
2.9.6 Weaving 95
2.9.7 Finishing of Denim 96
2.10 Textile Industry Categories 96
2.10.1 Cotton Process House 97
2.10.2 Polyester Process House 99
2.11 Boilers 99
2.11.1 Introduction 99
2.11.2 Types of Boilers 101
2.11.2.1 Fire Tube Boiler 101
2.11.2.2 Water Tube Boiler 101
2.11.2.3 Packaged Boiler 101
2.11.2.4 Fluidized Bed(FBC)Boiler 102
2.11.2.5 Stoker Fired Boiler 103
2.11.2.6 Pulverized Fuel Boiler 103
2.11.2.7 Waste Heat Boiler 103
2.11.3 Steam System Efficiency 104
2.11.3.1 Boiler Efficiency 104
2.11.3.1.1 Boiler Feed Water Treatment 106
2.11.3.1.2 Steam Generation 108
2.11.3.2 Steam Distribution System Efficiency 111
2.11.3.2.1 Steam Leaks 111
2.11.3.2.2 Steam Traps 112
2.11.3.2.3 Condensate Recovery 113
2.11.3.2.4 Heat Transfer Loss Through Insulation 114
2.11.4 Energy Saving Opportunities 114
2.11.4.1 Monitoring Steam Traps 114

2.11.4.2 Continuous steam blow and no flow indicate, there is a problem in the trap 114
2.11.4.3 Avoiding Steam Leakages 115
2.11.4.4 Providing Dry Steam for Process 115
2.11.4.5 Utilizing Steam at the Lowest Acceptable Pressure for the process 115
2.11.4.6 Proper Utilization of Directly Injected Steam 116
2.11.4.7 Minimizing Heat Transfer Barriers 116
2.11.4.8 Proper Air Venting 116
2.11.4.9 Condensate Recovery & Piping Insulation 117
2.11.4.10 Flash Steam Recovery 117
2.11.5 Air Pollution control equipment 117
2.11.5.1 Online Emission Monitoring 118
2.11.5.1.1 Sampling Technology 119
2.11.6 Ash Control 122
2.12 Waste water Treatment 124
2.12.1 Treatment Levels 133
2.12.1.1 Flow Equalization 135
2.12.1.2 Neutralization 136
2.12.1.3 Biological Treatment 137
2.12.1.4 Solids processing and disposal 144
2.12.1.5 Hybrid Treatment of textile wastewater 144
2.12.1.6 CETPs across Gujarat 146
2.12.1.6.1 Ahmedabad 146
2.12.1.6.2 Surat 148

3. CURRENT EMISSION AND CONSUMPTION LEVELS 150
3.1 Woven Cotton Processing House (CPH) 151
3.1.1 CPH specific resource consumption 153
3.1.1.1 Small Scale CPH 153
3.1.1.1.1 Ahmedabad Cluster 153
Chemical Consumption 154
Water Consumption 156
Utilities 157
3.1.1.1.2 Jetpur Cluster 159
Chemical Consumption 160
Water Consumption 161
3.1.1.2 Medium Scale CPH 162
3.1.1.2.1 Ahmedabad Cluster 162
Chemical Consumption 163
Water Consumption 165
Utilities 166
3.1.1.2.2 Jetpur Cluster 169

Chemical Consumption 169
Water Consumption 169
3.1.1.3 Large Scale CPH 170
3.1.1.3.1 Chemical Consumption 170
3.1.1.3.2 Water Consumption 171
3.2 Woven Polyester Processing House (PPH) 172
3.3 Emissions to water 179

4. TECHNIQUES TO CONSIDER IN THE DETERMINATION OF BAT 180
4.1 General Techniques 184
4.1.1 General Management techniques 184
Technique 1 Environmental Management System 186
Technique 2 Resource Efficiency & Cleaner Production 190
Technique 3 Monitoring and control of operational parameters 196
Technique 4 Textile Production Planning & Scheduling 198
Technique 5 Certifications for Textile Industry 200
4.1.2 Water Efficiency 205
Technique 6 Condensate Recovery System 206
Technique 7 Utilization of Reverse Osmosis (RO) Plant's Concentrate in washing application 208
Technique 8 Reuse of Cooling Water from Singeing Machines 210
Technique 9 Reuse of Post Bleaching Washes as Pre-Washes at Pre-treatment Machine 212
Technique 10 Reuse of Neutralization Wash from Mercerizer & CBR 214
Technique 11 Reuse of Vapor Condensate of Caustic Recovery Plant 216
Technique 12 Installation of Automatic Water Shut-Off Valves at Rotary and Flatbed Printing Machines' Blanket Washing Water 218
Technique 13 Water Management through Water Monitoring 220
Technique 14 Partial/Full Waste Water Recovery in Rotary Relax Drum Washer 222
Technique 15 Installation of Squeeze Roller for liquid removal in the open width washing 224
4.1.3 Energy Efficiency 226
Technique 16 Energy efficiency plan and energy audits 227
Technique 17 Cogeneration with Low-Pressure Steam Turbine 230
Technique 18 Replace Reciprocating Compressor with Screw Compressor and Installation of Air Pressure Monitoring to reduce air leakages and maintain optimum pressure 232
Technique 19 Installation of Demand Controller and reduce 234

contract demand
Technique 20 Installation of Variable Frequency Drive (VFD) and Soft Starter 236
Technique 21 Power Factor Correction 239
Technique 22 Self-Cleaning Heat Exchanger 242
Technique 23 Heat Recovery from Hot Wastewater in Continuous Process 245
Technique 24 Heat Recovery from Hot Wastewater in Jigger Dyeing Machine 248
Technique 25 Heat recovery from exhaust dyeing bath 250
Technique 26 Minimisation of energy consumption of stenter frmaes and dryers 252
Technique 27 Heat Recovery from Stenter Flue Gas 256
4.1.4. Process Optimization and Equipment Modification 259
Technique 28 Mechanical Dewatering of the Fabric 260
Technique 29 Replacement of Open Jigger with Closed Maxi Jigger 262
Technique 30 Installation of Temperature Controller in Processing Machine 264
Technique 31 Residual Moisture (Bound moisture) control in Drying Cylinders 266
Technique 32 Automated Colour Kitchen for Dyeing Section 268
Technique 33 Automation in Jet Dyeing and Drum Machine 271
Technique 34 Airflow Jet Dyeing Machine 273
Technique 35 Cold Pad Batch Dyeing 275
Technique 36 Continuous Dyeing Processes (PAD-DRY and PAD-STEAM process 279
Technique 37 Automated Colour Kitchen for Printing Section 282
Technique 38 Digital Printing 285
4.1.5. Chemical Management System 287
Technique 39 Chemicals management system 288
Technique 40 Selection of process chemicals 291
Technique 41 Chemical Storage and Handling 293
Technique 42 Chemicals inventory 296
4.2 Pre-treatment 300
Technique 43 Minimising sizing agent add-on by pre-wetting the warp yarns 301
Technique 44 Oxidative Desizing 303
Technique 45 Bio Scouring 305
Technique 46 Enzymatic washing to remove residual Hydrogen Peroxide after bleaching 307
Technique 47 Recovery of caustic soda used for mercerising 309
Technique 48 Replacing Acetic Acid with Mix. of Organic Acids 311

(Formic Acid and Acetic Acid Solution) during neutralization
Technique 49 Environment-friendly surfactants 313
Technique 50 Low emission preparation agents 316
Technique 51 Substitution of phosphorus or nitrogen-containing complexing agents 318
4.3 Dyeing 321
Technique 52 Use of Glauber salt instead of common salt and its recovery and reuse 322
Technique 53 Replacing Soda Ash with Liq. Alkali Solution in dyeing liquor 325
Technique 54 Minimisation of dye liquor uptake in pad dyeing techniques 328
Technique 55 Exhaust dyeing of cellulosic fibres with polyfunctional reactive dye stuffs 330
Technique 56 Optimized removal of unfixed dyestuff in reactive dyeing 332
Technique 57 Optimised parameters for rinsing of cotton dyed with reactive dyes 334
Technique 58 Dispersing agents with higher bio-eliminability in dye formulations 335
Technique 59 Dyeing with levelling agents made from recycled vegetable oil 337
Technique 60 Environment-friendly reductive treatment post polyester dyeing 339
4.4 Printing 342
Technique 61 Volume minimisation of printing paste supply systems in rotary screen-printing machines 343
Technique 62 Recovery of residual printing paste in rotary screen printing 346
Technique 63 Reuse of residual printing pastes 347
Technique 64 Use of printing chemicals with improved environmental performance 348

5. BEST AVAILABLE TECHNIQUES (BAT) CONCLUSION 350
5.1 Scope 352
5.2 General considerations 357
5.2.1 BAT-associated environmental performance levels 357
5.3 General BAT conclusions 359
5.3.1 Overall environmental performance 359
BAT 1 To improve the overall environmental performance, BAT is to elaborate and implement an environmental management system (EMS) 359

BAT 2 BAT is to build, maintain, and periodically review (including when a significant change happens) an inventory of inputs and outputs as part of the environmental management system (see BAT 1) 361
BAT 3 To improve the overall environmental performance, BAT is to use advanced process monitoring and control systems 362
BAT 4 To improve the overall environmental performance 362
5.3.2 Monitoring 362
BAT 5 BAT is to monitor resource input and output at least once every year 362
BAT 6 For wastewater streams identified by the inventory of inputs and outputs (see BAT 2), the BAT is to monitor key parameters (like the flow, pH, and temperature of the wastewater) at key locations (like the entrance and/or exit of the pre-treatment, the entrance to the final treatment, and the point where the emission leaves the installation) 363
BAT 7 BAT is to monitor emissions to water with at least the frequency given below and as per Central Pollution Control Board standards. If CPCB standards are unavailable, BAT is to use ISO, national or other international standards that ensure the provision of data of equivalent scientific quality 363
BAT 8 BAT is to monitor channeled emissions to air with at least the frequency given below and as per Central Pollution Control Board standards. If CPCB standards are unavailable, BAT is to use ISO, national or other international standards that ensure the provision of data of equivalent scientific quality 364
5.3.3 Water consumption and wastewater generation 365
BAT 9 To reduce water consumption and wastewater generation, 365
BAT 10 To prevent or reduce emissions to soil and groundwater 366
BAT 11 To reduce emissions to water from the use of sizing chemicals 367
5.3.4 Energy efficiency 369
BAT 12 To use energy efficiency techniques like Management , Process and Equipment selection and optimization & heat recovery 369
BAT 13 To increase energy efficiency when using compressed air 370
BAT 14 To increase the energy efficiency of thermal treatment 370
5.3.5 Chemicals 371
BAT 15 To improve the overall environmental performance, BAT is to elaborate and implement a chemicals management system (CMS) as part of the EMS (see BAT 1) 371
BAT 16 To improve the overall environmental performance, BAT is to elaborate and implement a chemicals inventory and 372

tracking system as part of the CMS.
BAT 17 In order to reduce emissions to water from the use of sizing chemicals affecting desizing process in woven cotton 372
BAT 18 To reduce the consumption of chemicals 373
BAT 19 To improve the overall performance of the handling and storage of process chemicals 374
BAT 20 To eliminate or minimize the release of poorly biodegradable materials into the water by preventing or reducing use of poorly biodegradable substances during fabric wt processing 374
5.4 BAT conclusions for the fabric pre-treatment 376
BAT 21 To use resources and energy efficiency and reduce water consumption and wastewater generation 376
BAT 22 To use resources efficiently and to reduce the amount of alkali discharged to wastewater treatment 376
BAT 23 To reduce emissions to air and to water from the use of oils, BAT is to avoid the use of mineral oils in spinning and knitting. 376
BAT 24 To prevent or reduce emissions to water of chlorine-containing compounds and complexing agents 376
5.5 BAT conclusions for dyeing 377
BAT 25 To use resources efficiently and to reduce emissions to water from dyeing 377
BAT 26 To use resources efficiently and to reduce emissions to water from the dyeing of cellulosic materials 377
BAT 27 To reduce emissions to water from the dyeing of polyester with disperse dyes 378
5.6 BAT conclusions for printing 378
BAT 28 BAT optimises the printing equipment's cleaning to reduce water consumption and wastewater generation. 378
BAT29 To use resources efficiency techniques like printing, design & operation and recovery & reuse of printing paste 379
BAT 30 To reduce emissions of organic compounds (e.g. formaldehyde) and ammonia to air from printing with pigments, BAT is to use printing chemicals with improved environmental performance. 379

6. EMERGING TECHNIQUES 380

6.1 Use of chitosan-based auxiliaries and/or finishing agents 381
6.2 Use of ozone for bleaching cotton fabrics 381
6.3 Ultrasonic Washing 382
6.4 Use of biodegradable complexing agents based on poly aspartic acid and 383

salts
6.5 Use of natural or biosynthetic dyes 384
6.6 Alkali Clearable Disperse Dyes 386
6.7 Pad Dry Process for Continuous Dyeing 387
6.8 Use of casein-based printing binders 388
6.9 Cool Transfer Printing 389

7. CONCLUDING REMARKS & RECOMMENDATIONS FOR FUTURE WORK 390

ANNEXURE A: TEXTILE AUXILIARIES 395

ANNEXURE B: TEXTILE WET PROCESSES TESTING AND QUALITY CONTROL 424

ANNEXURE C: DYES, PIGMENTS AND INKS 443

ANNEXURE D: DIGITAL TEXTILE PRINTING 479

ANNEXURE E: WET PROCESSES MACHINERY AND TECHNIQUES 490

ANNEXURE F: ZERO DISCHARGE OF HAZARDOUS COMPOUND MATERIALS RESTRICTED SUBSTANCE LIST 513

Acronyms 518

References 526

LIST OF FIGURES

Figure 1.1	Yarn Production(million square metre)	3
Figure 1.2	The textile value-added chain with indication of inputs and outputs at every stage	3
Figure 1.3	Distribution of Textile Factories in India(State-wise)	4
Figure 1.4	Geographical distribution of textile industries	4
Figure 1.5	Textile Clusters in Gujarat	6
Figure 1.6	Solid Waste	10
Figure 1.7	Process Textile Waste (fiber and yarn waste)	11
Figure 1.8	Wet Processes Inputs & Outputs	11
Figure 1.9	Lint waste	13
Figure 2.1	Schematic flow Diagram of Textile Processing	15
Figure 2.2	Natural Fibres	16
Figure 2.3	Man-made Fibres	17
Figure 2.4	Series of fibre formation	18
Figure 2.5	Farm to Fibre - Jute	19
Figure 2.6	Polymerization of Polyethylene from its monomer	21
Figure 2.7	Dyeing of polyester with disperse dye	21
Figure 2.8	Stages in viscose manufacturing	23
Figure 2.9	Fibre to Fabric	28
Figure 2.10	Process Diagram for Melt, Wet and Dry Spinning	32
Figure 2.11	Modern Power Loom	36
Figure 2.12	Primary operations during weaving	37
Figure 2.13	Shuttle for loom	37
Figure 2.14	Circular Knitting Machine	39
Figure 2.15	V shaped knitting Machine	39
Figure 2.16	Main Pre-treatment processes	40
Figure 2.17	Gas Flame Singeing of grey fabric	41
Figure 2.18	Desizing Machine	43
Figure 2.19	Continuous Bleaching Range of grey fabric	44
Figure 2.20	Mercerizing machine	49
Figure 2.21	Overview of Jigger Dyeing Machine (b) real machine	53
Figure 2.22	Dis-continuous Dyeing Machine (Softflow machine)	55
Figure 2.23	Mechanism of dye fixation during printing on grey fabric	68
Figure 2.24	Calendering Process	70
Figure 2.25	Stenter Machine (a) Real picture (b) Sketch of the machine	73
Figure 2.26	Process Flow Diagram for Cotton Woven Fabric Processing	76
Figure 2.27	Overview of Jigger Dyeing Machine (b) real machine	77
Figure 2.28	Process Flow diagram for Man-made Fibre processing	78
Figure 2.29	Pre Treatment of polyester	79
Figure 2.30	Scouring agent Mechanism	80
Figure 2.31	Drum Machine Cross-sectional view	80
Figure 2.32	Production phases of the two most important types of thread	86
Figure 2.33	Operating diagram of a rotor spinning	87

Figure 2.34	Operating diagram of ring spinning	88
Figure 2.35	Z & S twist directions	90
Figure 2.36	Types of warp yarn preparation	91
Figure 2.37	Rope Dyeing Range	92
Figure 2.38	Slasher Range	92
Figure 2.39	Loop Range	92
Figure 2.40	Flowchart of Weaving Process	95
Figure 2.41	Typical process sequence for cotton finishing mills	98
Figure 2.42	Typical process sequence in the polyester textile industries	99
Figure 2.43	Steam System	100
Figure 2.44	Boiler Heat losses	104
Figure 2.45	Loss due to excess air	106
Figure 2.46	Blowdown Energy Recovery	109
Figure 2.47	Recommended Arrangement for Directly Injected Steam	116
Figure 2.48	Draining and Venting at the End of a Steam Main	117
Figure 2.49	PM CEMS Technology Applications and Limitations	120
Figure 2.50	Grouping the different techniques for treating textile wastewater	133
Figure 2.51	Heat exchange of hot wastewater with cold freshwater directly at a finishing machine	133
Figure 2.52	Activated sludge process	139
Figure 2.53	Step feed process	140
Figure 2.54	Tapered aeration process	140
Figure 2.55	Contact stabilization process	141
Figure 2.56	Staged activated sludge process	141
Figure 2.57	Oxidation ditch.	142
Figure 2.58	Flow diagram for sludge treatment and disposal	144
Figure 2.59	System for integrating chemical oxidation with biological process for wastewater treatment from textile effluent	145
Figure 2.60	Layout of the NTIEM CETP	146
Figure 2.61	NTIEM CETP flow diagram	147
Figure 3.1	Process route of woven cotton CPH in Ahmedabad Cluster	153
Figure 3.2	Overall Water Consumption in Small Scale CPH of Ahmedabad Cluster	155
Figure 3.3	Low Liquor ration maintained in Jigger Machine	156
Figure 3.4	Process sequence for wet processes for the finishing of woven fabric in Jetpur Cluster	159
Figure 3.5	Maxi Jigger	162
Figure 3.6	Schematic of Desizing Machine	164
Figure 3.7	Total water consumption in process in Medium Scale CPH of Ahmedabad Cluster	165
Figure 3.8	Overall Water Consumption in Large Scale CPH of Ahmedabad Cluster	171
Figure 3.9	Continuos Rotary Drum Washer	172

Figure 3.10	Process route of woven PPH in Surat Cluster	**173**
Figure 3.11	Overall Water Consumption in PPHs	**177**
Figure 4.1	Different sections of Chapter	**181**
Figure 4.2	Main steps in the ISO 140001 EMS	**186**
Figure 4.3	Main steps in the ISO 140001 EMS	**186**
Figure 4.4	Scheme for annual input/output overview at site level	**190**
Figure 4.5	Example of Process Flow Diagram of Reference Polyester Processing House	**192**
Figure 4.6	Electronically controlled Parameters	**196**
Figure 4.7	Graphical display showing in a single view the list of jobs to be assigned and the queue of jobs already programmed for each machine	**198**
Figure 4.8	Various Certifications in Textile Industries	**200**
Figure 4.9	Typical Steam Flow Process with condensate recovery	**206**
Figure 4.10	Reverse osmosis plant for preparing water for wet finishing processes and boilers	**208**
Figure 4.11	Water cooled roller	**210**
Figure 4.12	Cooling water drainage from singeing machine	**210**
Figure 4.13	Schematic of CBR Machine	**212**
Figure 4.14	Water reuse diagram in CBR Machine	**212**
Figure 4.15	Schematic of Mercerization Machine	**214**
Figure 4.16	Schematic of CBR Machine	**214**
Figure 4.17	Schematic of CRP System	**216**
Figure 4.18	Printing blanket washing device	**218**
Figure 4.19	Waste water recovery in Relax Drum Machine	**222**
Figure 4.19 (a)	Squeeze liquor removal	**224**
Figure 4.19 (b)	Open width washing machine with counter current flow Squeeze liquor removal	**224**
Figure 4.20	Power generation through HP Steam	**230**
Figure 4.21	Co-Generation Model	**230**
Figure 4.22	Back Turbine Installed for cogeneration at reference unit	**231**
Figure 4.23	Screw Compressor Vs Reciprocating Compressor	**232**
Figure 4.24	Maximum Demand Controller	**234**
Figure 4.25	Schematic of Soft Starter and VFD	**236**
Figure 4.26	Before & After PF correction scenario	**239**
Figure 4.27	Lag between Voltage & Current	**239**
Figure 4.28	Shell and Tube Heat Exchanger	**242**
Figure 4.29	Different Packing used in Heat Exchanger	**242**
Figure 4.30	Heat Recovery from Hot Wastewater in Continuous Process	**245**
Figure 4.31	Shell and tube Heat Exchanger installed at continuous Pre-treatment machine	**246**
Figure 4.32	Common Heat Recovery System Layout	**248**
Figure 4.33	Schematic representation of Utility in Jet Dyeing Machine	**250**

Figure 4.34	Stenter with Heat Recovery Unit	**256**
Figure 4.35	Unbound Moisture Removal Vacuum system	**260**
Figure 4.36	Unbound Residual Moisture	**260**
Figure 4.37	Open Jigger	**262**
Figure 4.38	Closed maxi jigger	**262**
Figure 4.39	PLC on Maxi-Jigger	**262**
Figure 4.40	Schematic diagram of TIC controller for processing	**264**
Figure 4.41	PLC controller for Vertical Drying Range	**266**
Figure 4.42	Steps in Automated Dyeing Section	**268**
Figure 4.43	Automated Dyeing System	**268**
Figure 4.44	Barcode Scanned Recipe from Automated Kitchen	**269**
Figure 4.45	Batch Controller for Jet Dyeing Machine	**271**
Figure 4.46	PLC controller installed on Jet Dyeing Machine	**271**
Figure 4.47	PLC Controller installed on Drum Machine	**271**
Figure 4.48	Schematic of Airflow Jet Dyeing Machine	**273**
Figure 4.49	Dosing System for CPB Dyeing	**275**
Figure 4.50	Pad Dyeing	**275**
Figure 4.51	Post CPB Batching wash	**275**
Figure 4.52	PAD-STEAM continuous dyeing process	**279**
Figure 4.53	PAD-DRY and PAD-STEAM continuous dyeing process	**279**
Figure 4.54	Schematic diagram of TIC controller for processing	**282**
Figure 4.55	Digital Printer	**285**
Figure 4.56	Chemical Labelling (left) and good chemical handling at reference plant (right)	**293**
Figure 4.57	Chemical Inventory list	**296**
Figure 4.58	Prewetting of warp yarn before sizing	**301**
Figure 4.59	A schematic representation of cotton fibre showing its various layers	**305**
Figure 4.60	Enzymatic washing to remove residual Hydrogen Peroxide after bleaching	**307**
Figure 4.61	Caustic Recovery System	**309**
Figure 4.62	Comparison of COD of different organic acids	**311**
Figure 4.63	Origin of Eco-friendly Surfactants	**313**
Figure 4.64	Chemical structure of some N- or P-containing complexing agents (left) Chemical structure of some N- and P-free complexing agents (right)	**318**
Figure 4.65	Soda Ash Powder (left) and Liq. Alkali Solution (right)	**325**
Figure 4.66	Representation of U-shaft (A) and nip (B) dye liquor application systems	**328**
Figure 4.67	Examples of Reactive Dyeing Mechanisms of Bifunctional Reactive Dyes	**330**
Figure 4.68	Action of dispersing agent	**335**
Figure 4.69	Working of rotary screen printing	**343**

Figure 4.70	Recovery of printing paste from the paste supply system by back-pumping an inserted ball	**346**
Figure 5.1	Different sections of Chapter 5	**353**
Figure 6.1	Schematic of the Ultrasonic washing process.	**382**
Figure 6.2	Polyaspartic acid	**383**
Figure 6.3	Fully traceable biosynthetic dyes derived from natural waste products of the agriculture and herbal industries	**384**
Figure 6.4	Start to End Process route for natural dye manufacturing	**384**
Figure 6.5	Schematic of Econtrol Process	**387**
Figure 6.6	Schematic of cool transfer printing	**389**
Figure a.1	Classification of Textile Auxiliaries	**397**
Figure a.2	Representation of different types of surfactant molecules	**398**
Figure a.3	Structure of various types of anionic surfactants	**398**
Figure a.4	Structure of cationic surfactants	**399**
Figure a.5	Structure of Amphoteric surfactants	**400**
Figure a.6	Structure of hydrophilic behaviour of nonionic surfactants	**401**
Figure a.7	Sizing preparation	**402**
Figure a.8	Structure of cellulose unit of cotton	**403**
Figure a.9	Structure of carboxymethyl starches	**404**
Figure a.10	Resin for shape retention finishes	**419**
Figure b.1	Inspection machine at Reference Unit	**424**
Figure b.2	Test Report Card Sample	**424**
Figure c.1	Examples of acid dyes	**446**
Figure c.2	Examples of typical basic dyes	**449**
Figure c.3	Examples of typical direct dyes	**451**
Figure c.4	Examples of molecular structures typical of 1.1 metal-complex dyes	**455**
Figure c.5	Molecular structure typical of 1.2 metal-complex dyes	**455**
Figure c.6	Representation of possible ionic and coordination bonds between wool and chromedyes	**458**
Figure c.7	Examples of typical coupling components for naphthol dyes	**460**
Figure c.8	Examples of typical developing agents (fast colour base) for naphthol dyes	**461**
Figure c.9	Examples of typical fast colour salts	**462**
Figure c.10	Structure of reactive dye	**464**
Figure c.11	Examples of typical vat dyes	**471**
Figure c.12	Classification of Pigmants	**475**
Figure d.1	Vertical view of the shape of ink drop	**484**
Figure d.2	Contiunous Inkjet Schematic	**486**
Figure d.3	Drop on Demand Schematic	**487**
Figure: e.1	Schematic layout of a conical pan loose fibre dyeing machine	**492**
Figure: e.2	Schematic diagram of a Hussong type hank dying machine	**493**
Figure e.3	Schematic layout of a package dyeing machine	**494**

Figure e.4	Schematic representation of a winch beck dyeing machine	**495**
Figure e.5	Schematic representation of a jet dyeing machine	**496**
Figure e.6	Schematic representation of an overflow dyeing machine	**497**
Figure e.7	Soft flow machines	**498**
Figure e.8	Schematic representation of jet dyeing machine	**498**
Figure e.9	Example of continuous process for knitted fabric in rope form	**499**
Figure e.10	Schematic representation of a beam dyeing machine	**500**
Figure e.11	Schematic representation of a jigger	**501**
Figure e.12	Foulard types	**502**
Figure e.13	Illustration of some of the most important dye/finish applicators	**503**
Figure e.14	Schematic layout of a pad-batch plant	**504**
Figure e.15	Schematic representation of a PAD-DRY and PAD-STEAM plant (wet steam) for dyeing with vat dyes	**505**
Figure e.16	Stencil Printing	**507**
Figure e.17	Block Printing	**508**
Figure e.18	Hand Screen-Printing	**509**
Figure e.19	Flat Bed Screen Printing	**510**
Figure e.20	Rotary Screen Printing	**511**
Figure e.21	Digital Printing	**511**

LIST OF TABLES

Table 1.1	Textile clusters and respective segments in Gujarat	6
Table 1.2	Typical Pollution Characteristic of wastewater streams resulting from cotton farbric wet processing	13
Table 2.1	Auxiliary & Chemicals used in Cotton Woven Fabric Processing	25
Table 2.2	Typical Spinning Parameters for Selected Fibres	33
Table 2.3	Difference between Plate, Roller, and Gas singeing Processes	42
Table 2.4	Classification of dyes according to usage	55
Table 2.5	The key issues concerned for dye selection	56
Table 2.6	Application of dyes on Various Fibres	60
Table 2.7	List of Chemicals & Auxiliaries used in dyeing	61
Table 2.8	Pollution associated with Dyes	64
Table 2.9	Fixation percentage of dyes	65
Table 2.10	Pollutants Associated with Textile Printing and Sources	69
Table 2.11	Selection of steam trap	113
Table 2.12	Quantity of heat lost at different temperatures	114
Table 2.13	Overview of Technical Selection & Suitability for Gaseous CEMS Technology	121
Table 2.14	Ranges of analytical results of textile wastewater for conventional parameters	124
Table 2.15	Specific COD and BOD5 values for the most common sizing agents	126
Table 2.16	Chemical compounds in textile wastewater which usually do not have an adverse impact on wastewater treatment	128
Table 2.17	Chemical compounds in textile wastewater which are heavily or non-biodegradable but may adsorb to activated sludge to a certain extent	129
Table 2.18	Standards for discharge of effluents from the textile industry	131
Table 3.1	Industry Coding System	151
Table 3.2	Cluster wise no of CPH	151
Table 3.3	Industry-wise reference code	152
Table 3.4	Industry wise End Product Application	152
Table 3.5	Definition of MSME	153
Table 3.6	Process-wise Machines used in Small Scale CPH of Ahmedabad Cluster	154
Table 3.7	List of Chemicals added per process in Small Scale CPH 8	154
Table 3.8	Process wise Water Consumption in Small Scale CPH of Ahmedabad Cluster	156
Table 3.9	Process wise Machines used in Small Scale CPH of Jetpur Cluster	160
Table 3.10	List of Chemicals added per process in Small Scale CPH of Jetpur Cluster	160
Table 3.11	Process wise Water Consumption in Small Scale CPH of Jetpur Cluster	161
Table 3.12	Process-wise Machines used in Medium Scale CPH of Ahmedabad Cluster	162

Table 3.13	List of Chemicals added per process in Medium Scale CPH of Ahmedabad Cluster	**163**
Table 3.14	Process wise water consumption in Medium Scale CPH of Ahmedabad Cluster	**165**
Table 3.15	Process-wise Machines used in Medium Scale CPH of Jetpur Cluster	**169**
Table 3.16	List of Chemicals added per process in Medium Scale CPH of Jetpur Cluster	**169**
Table 3.17	Process-wise Water Consumption in Medium Scale CPH of Jetpur Cluster	**169**
Table 3.18	Process-wise Machines used in Large Scale CPH of Ahmedabad Cluster	**170**
Table 3.19	List of Chemicals added per process in Large Scale CPH30	**170**
Table 3.20	Process wise Water Consumption in Large Scale CPH of Ahmedabad Cluster	**172**
Table 3.21	Cluster-wise no of PPH	**172**
Table 3.22	Industry-wise reference code	**173**
Table 3.23	Process wise Machines used in Polyester Processing House	**174**
Table 3.24	Overall Mahine wise Chemical Consumption in PPHs of Surat Cluster	**175**
Table 3.25	Machine wise water consumption	**177**
Table 4.1	Information for each technique	**181**
Table 4.2	Process wise waste water characteristics of woven cotton CPH	**194**
Table 4.3	Example for monitoring the water consumption for different continuous wet processing machines	**220**
Table 4.4	Natural moisture level of some fibres	**254**
Table 4.5	Emission factors and corresponding Organic-C concentration in the off-gas (Preparation add-on: 2%; air/textile ratio: 20 m^3/kg; heat setting temperature: 190 °C; curing time 1.5 min)	**317**
Table 4.6	Qualitative assessment of commercially available complexing agents	**319**
Table 4.7	Effectiveness of complexing agents	**319**
Table 4.8	Comparison between Sodium Chloride and Glauber salt	**322**
Table 4.9	Comparison of Soda ash and Liquid Alaki Solution	**326**
Table 4.10	Comparison of the sequence steps between a conventional and an enzymatic after-soaping treatment (exhaust dyeing)	**332**
Table 4.11	Comparison of the sequence steps between a conventional soaping treatment and a soaping treatment with vinyl polymers (exhaust dyeing)	**333**
Table 4.12	Aquatic toxicity (algae) of raw materials used for the formulation of levelling agents for PES dyeing	**337**
Table 4.13	Bioeliminability of selected levelling and dispersing agents	**338**
Table 4.14	Volume of conventional and optimised printing paste supply	**344**

Table 5.1	BAT-associated environmental performance levels (BAT-AEPLs) for specific water consumption	**367**
Table 5.2	Specific water consumption in continuous machines [L/kg]	**368**
Table 7.1	Key milestones of the TXT BREF review process	**391**
Table 7.2	Representative various institute and their role	**392**
Table a.1	Amounts of sizing agents applied on different types of substrates	**408**
Table a.2	Specific COD and BOD5 values for the most common sizing agents	**409**
Table a.3	Possible surfactant components compatible with respective dyes and fibres	**413**
Table b.1	Staining sizes and the corresponding detections	**426**
Table b.2	List of Test paramneter and their testing standards	**441**
Table c.1	Classification of dyes according to chemical composition	**445**
Table c.2	Overview of the ecological properties of acid dyes	**448**
Table c.3	Overview of the ecological properties of direct dyes	**452**
Table c.4	Overview of the ecological properties of disperse dyes	**454**
Table c.5	Overview of the ecological properties of metal complex dyes	**457**
Table c.6	Overview of the ecological properties of chrome dyes	**459**
Table c.7	Overview of the ecological properties of naphthol dyes	**463**
Table c.8	Typical anchor systems for cellulose fibres	**465**
Table c.9	Typical anchor systems for wool and polyamide fibres	**465**
Table c.10	Overview of the ecological properties of reactive dyes	**467**
Table c.11	Overview of the ecological properties of sulphur dyes	**470**
Table c.12	Overview of the ecological properties of vat dyes	**473**
Table c.13	Types of inks used for digital printing	**476**
Table d.1	Ink types and Applications	**481**



CHAPTER 01

GENERAL INFORMATION

1. General Information

India's textiles and clothing industry are one of the mainstays of the national economy. The domestic textiles and apparel industry stood at $108.5 bn in 2019-20 of which $75 bn was domestically consumed while the remaining portion worth $28.4 bn was exported to the world market. It is the 2nd largest producer of Man Made Fibre after China. India is the 6th largest exporter of Textiles & Apparel in the world. The share of textile and apparel (T&A), including handicrafts in India's total exports, stands at a significant 11.8% in 2019-20. India contributes 5% of the global trade in textiles and apparel. The industry's uniqueness lies in its strength in the hand-woven and capital-intensive mill sectors. The mill sector is the second largest in the world.

Apart from providing one of the necessities of life, i.e., clothing, the textile industry plays a pivotal role through its contribution to multiple aspects like industrial output, employment generation, and the country's export earnings.

The textile sector contributes in various zones as cited below :

- 13% to industrial production,
- 12% to country's export and
- 2.3% to the gross domestic product (GDP)

The size of India's textile market is expected to touch US$ 223 billion by 2021, growing at a CAGR of 10.23 % over 2016 as represented in fig. 1.1. While, Exports of textiles (RMG of all textiles, cotton yarn/fabs./made-ups/handloom products, man-made yarn/fabs./madeups, handicrafts excl. handmade carpets,carpets and jute mfg. including floor coverings) stood at US$ 2.99 billion, as of June 2021.

The Indian textile industry is one of the oldest industrial sectors. It unveils the country's rich cultural heritage with various fabrics, techniques, and hues that reflect ethnic and traditional diversity. It covers an extensive spectrum of segments extending from an unorganised segment of hand-woven/hand-spun on the one hand to capital and a technology-intensive organised segment on the other. It provides direct employment of over 45 million people and a source of livelihood for over 100 million people indirectly, including a large number of women and rural population. Traditional sectors like handloom, handicrafts and small scale power-loom units are the most significant source of employment for millions of people in a rural and semi-urban areas.

The fundamental strength of the textile industry in India is its strong production base of wide range of fibre/ yarns from natural fibres like cotton, jute, silk and wool to synthetic/man-made fibres like polyester, viscose, nylon and acrylic. India is the largest producer of jute globally; however, it is the second leading producer of silk and cotton globally.

In the raw material consumption basket of the Indian textile industry, cotton's proportion is around 60%. Cotton production is expected to reach 37.10 million bales, and consumption is expected to reach 114 million in FY21—13% growth over the previous year. The production of raw cotton in India had reached 35.4 million bales in FY20. During FY19, fibre production in India stood at 1.44 million tonnes (MT) and reached 2.40 MT in FY21 (till January 2021). The production stood at 4,762 million kgs for yarn during the same period. Despite the pandemic, India's home textile exports grew at a healthy rate of 9% in Fy21[4].



Figure 1.1 Yarn Production (million square metre)
Source: Textiles and Apparel, IBEF
[4]*https://www.ibef.org/industry/indian-textiles-and-apparel-industry-analysis-presentation*

The textile industry is one of the most extended and most sophisticated industrial chains in the manufacturing industry. It is a fragmented and heterogeneous sector, accomplishing the demand for three end uses viz. Clothing, Technical textile & Home textile.

The textile and clothing chain is composed of a vast number of sub-sectors covering the entire production cycle from the production of raw materials (natural/man-made fibres) to semi-processed materials yarns, woven and knitted fabrics with their finishing process) and final/consumer products (carpets, home textiles, clothing and industrial use textiles) as shown below.

The scope of this document is confined to those activities in the textile industry that involve wet processes. i.e. fabric processing and majorly focuses on cotton, polyester and denim.

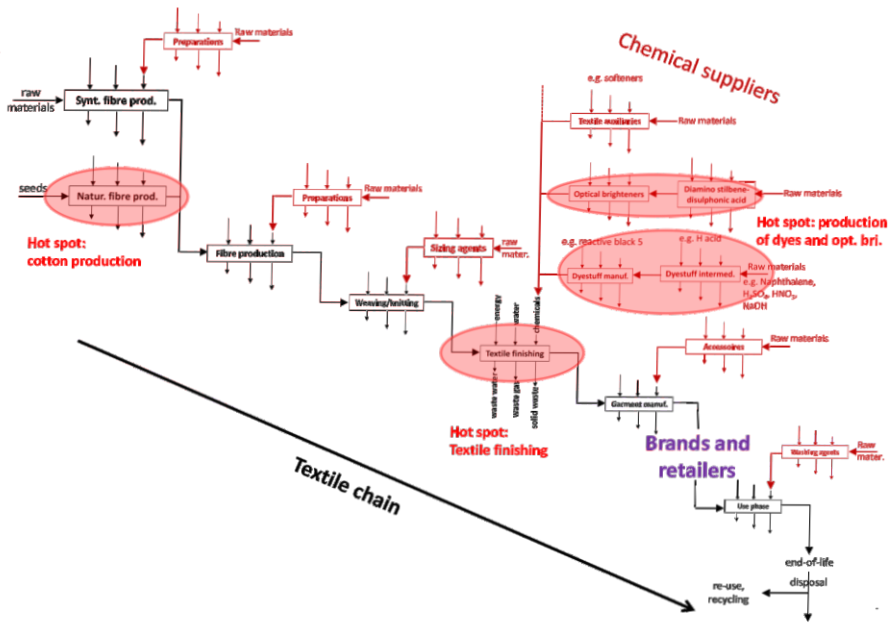
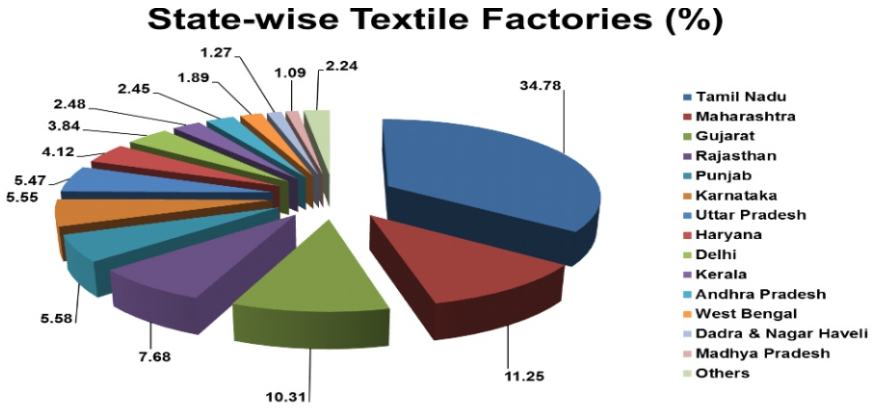


Figure 1.2 The textile value-added chain with indication of inputs and outputs at every stage
(input: water, energy, chemicals; output: wastewater, solid waste, waste gas) and of the environmental hot spots (Schoenberger, 2018)

1.1 DISTRIBUTION OF TEXTILE INDUSTRIES IN INDIA

Figure 1.3 represents the geographical distribution of textile industries in India. Tamil Nadu is India's leading State regarding the number of textiles and garments factories.

The average national invested capital (registered factory-wise) was low at Rs. 4.7 crores per factory, indicating the fragmented nature of India's textiles and garments industry. The average invested capital, registered factory-wise, was even lower in Tamil Nadu at Rs. 3.2 crores per factory. The average invested capital, registered factory-wise, was more than the national average in the states of Maharashtra and Gujarat at Rs. 5.5 crores and Rs. 6.2 crores, respectively.



Source: CRISIL report on "Enhancing Competitiveness of Indian Manufacturir Industry: Assistance in Policy Making, 2009".

Figure 1.3 Distribution of Textile Factories in India (State-wise)
Source: Situation Analysis / Baseline Study on "Environment-friendly Techniques for Textile Sector" Report by GIZ, June 2013

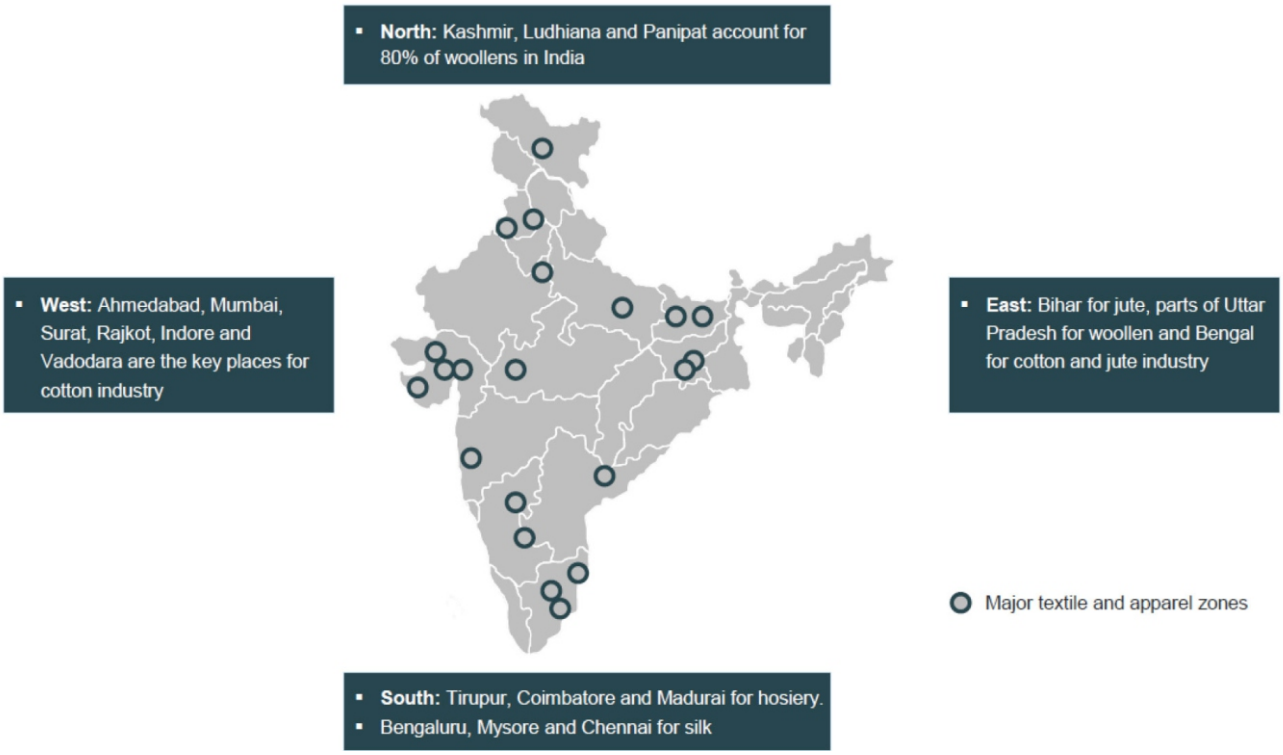


Figure 1.4 Geographical distribution of textile industries
Source: Textiles and Apparel, IBEF

The states of Andhra Pradesh, Telangana, and Haryana are on the top in the ranking of ease of doing business. The list is released by the Department of Industrial Policy and Promotion (DIPP), Ministry of Commerce and Industry (MoCI). DIPP & MoCI in collaboration with the World Bank conducted an annual reform exercise for all States and UTs under the Business Reform Action Plan (BRAP). These states are also strong hubs for textile and apparel manufacturing. Industry reforms to ease regulations and systems in areas such as labour regulation, environmental clearances, single window system, construction permits, contract enforcement, registering property, and inspections were focussed in this ranking. Another fastest growing apparel manufacturing hub Jharkhand is on no. 4 while Gujarat is on 5th rank.[6]

1.2 TEXTILE INDUSTRY IN GUJARAT

Gujarat's textile industry can be traced back to the 19th century when the British Raj established the textile sector. Textile mills employed thousands of people, and the cotton garments manufactured were exported across the world.

In today's era, Gujarat has unique strengths for the textile industry. It is one of India's leading industrial states. The textile industry, in particular, has made a substantial contribution to the industrialisation of the State. The fabrics and textiles produced here are much appreciated all over India and abroad.

Furthermore, it is now the largest producer of cotton in India, with a share of over one-third of the total cotton production. It is the largest man-made and filament fabric manufacturer and the second-largest cotton fabric manufacturer.

It also has a dominant share in denim production with a one billion meter capacity. The State contributes to over one-fourth of the country's technical textiles output.

In a nutshell, the below facts shows the contribution of Gujarat in the Indian textile sector further:

- 33% cotton production
- 65% denim production.
- 25% technical textile production
- 38% man-made fabric production
- 2nd largest manufacturer of cotton fabric, with 390 million meters/annum

The entire textile and clothing chain comprises various sub-sectors covering the entire production cycle. This cycle gets initiated from the production of raw materials (man-made fibres), semi-processed materials (yarns, woven and knitted fabrics with their finishing process) to final/consumer products (home textiles, clothing, and technical textiles).

Based on the activities undertaken by the industry, they are classified into four major categories:

1. Spinning mills – Manufacturing the yarn from fibres
2. Powerlooms/Handlooms – Manufacturing of fabric by weaving the yarns
3. Textile processing mills – Processing the grey fabric for dyeing & printing
4. Composite mills – Multiple activities begin from spinning, weaving / knitting, processing to dyeing, printing & finishing of the fabric

1.3 TEXTILE CLUSTERS OF GUJARAT

The State leads in the textile sector with more than 1500 medium and large-scale textile mills. Firstly, Large Fabric Processing Houses are concentrated in two major cities of the State, viz. Surat (350) and Ahmedabad (250). Moreover, the State has 18 textile-related project clusters. The chief ones are clustered at Surat, Ahmedabad, and Jetpur (discussed below in the present chapter).

Table 1.1 : Textile clusters and respective segments in Gujarat

Sr. No.	Cluster	Segment
1	Ahmedabad	Cotton & Blended fabric, denim, made-ups, ladies' garments, machinery & parts
2	Surat	Art Silk Fabric, Synthetic Textiles, Zari Manufacturing, Embroidery, Textile Machinery & Parts
3	Kutch	Textile Handicrafts
4	Surendranagar, Manavadarand & Gondal	Cotton Ginning
5	Saurashtra, Jetpur	Hand Printing & Processing Units

Source: Textile Sector Profile, Vibrant Gujarat 2017



Figure 1.5 Textile Clusters in Gujarat
Source: Environment Friendly Techniques for Textiles Industries Report by GIZ, June 2015

1.3.1 Ahmedabad

Ahmedabad is an urban city of Gujarat and is an industrial centre with large-scale cotton textile firms, which lay the city's economic foundation. The city has a concentration of 66 textile mills within a radius of 8 to 10 kilometres, out of which 62 are composite mills.

Specific factors that make Ahmedabad a favourable city for the establishment of textile mills are listed below:

- It is situated in a cotton-growing area; hence the primary raw material is readily available.
- The humid climate of the place is ideal for spinning and weaving.
- The flat terrain is suitable for the establishment of the mills.
- The densely populated states of Gujarat and Maharashtra provide both skilled and semi-skilled labour.
- Well-developed road and railway network permits easy transportation of textiles to different parts of the country, thus providing easy access to the market.
- The seaport is situated nearby, facilitating the import of machinery and the export of cotton textiles.

Major medium and large-scale industrial units in the region process cotton, blends, and denim and includes well-known textile players like Reliance, Arvind mills, Welspun. However, Ranchhodlal Chhotalal was the pioneer to establish a textile mill in Ahmedabad (Shahpur) in 1861. Bechardas Ambaidas Lakshkari started the second textile mill in 1867. Later, Mansukhbhai, Manganbhai, and Lalbhai followed them. Thus Ahmedabad became a leading center of industrial and commercial activities.

In the bygone period, Mahatma Gandhi, the father of our nation, was an ardent advocate of khadi and a strong denouncer of foreign goods. He used his Swadeshi movement as a vital weapon in his struggle against British rule. Ultimately, this movement also facilitated the progression of the domestic textile industry to a great extent. Under such a favourable economic, political and social climate, the textile industry of Ahmedabad soared to such heights that the city earned the title of "Manchester of India." The fine local qualities of cloth manufactured by Textile Mills like Calico, Arvind, Jubilee, Ambica quickly replaced the British cloth in the Indian markets. The quality of Indian cloth was so impressive that it enabled it to enter and rule the foreign markets. The European countries used to buy 'Khinkhab' from Ahmedabad as a gift for the Queen of England. For this meteoric rise of the textile industry in Ahmedabad, the city owes two great personalities, namely Ranchhodlal Chhotalal and Mahatma Gandhiji.

Most textile processing industries are engaged in dyeing and/or printing on a job work basis, i.e., not directly purchasing cotton cloth but receiving from traders for dyeing and/or printing. Majorly, these processing houses are processing denim, bed sheets, shirts, suiting for domestic and abroad markets.

1.3.2 Surat

Surat, also known as Silk City, is one of the major textile clusters in Gujarat. It is well known for its synthetic products market and is mainly engaged in the production and trading of synthetic textile products. This cluster is one of the oldest and the most widespread sector in Surat. The city is well known for its synthetic products and the trading of textile goods across India. The textile industry in Surat is mainly engaged in yarn production, weaving, processing, and embroidery. India and other Asian countries are the chief arcades for Surat's textile products. During the 18th century, the first major step in textiles was taken by Zafarali Mills, which started operations in 1861. Later in 1891, Surat had one weaving mill, one spinning mill, four gin presses, one iron factory, and one paper mill. During Second World War, the nucleus of power looms started building up in the city. Consequently, around 1200 power looms were installed in Surat. The arrival of Japanese machines for weaving and twisting gave a further impetus. In 1965 a cooperative spinning mill was set up in Surat. In most enterprises, silk saree and cloth were woven on handloom. A few entrepreneurs modified power looms to weave silk sarees and fabrics ahead. Presently, Surat city has state-of-the-art power looms, texturising machines, and textile processing units. Industrial units ranging from one loom unit to giant power loom units with semi-automatic, automatic, and shuttle-less power looms, and water-jet looms. Even today, primitive and hi-tech technologies co-exist in textile processing units in the city. The Textile market in Surat has introduced the new trendy sarees and fabrics to the Middle East countries. This demand for the material increased in the international market, inspiring other Processing houses in Surat to expand and compete globally. In India, around 80% of sarees and dress material in this iconic design is supplied to the key markets in Maharashtra, Madhya Pradesh, Karnataka, Punjab, Tamil Nadu, Kerala, Punjab, and Delhi. At the National level, Surat has a praiseworthy share in the sector. The city contributes about;

- 30% to the country's total man-made fibre production,
- 20% to the total man-made fibre exports and
- 38% of the country's total man-made fabric production.

Today, the significant clusters active in manufacturing in and around Surat include Pandesara, Sachin, Kadodara, and Palsana. They, in total, have about 450 dyeing - printing units and nearly 6.5 lakh power loom. These dyeing and printing units are engaged in processing synthetic sarees and dress materials , i.e., dyeing, bleaching, printing, and finishing grey fabrics. Majorly, these units are processing the grey fabrics on a job work basis. Ultimately, the textile sector of Surat employs 7.5 lakh people.

1.3.3 Jetpur

Jetpur lies in the heart of Saurashtra, and it is recognised for cotton dyeing & printing. About 70% of the manufactured products are export orders. The rest, mainly printed sarees & dress material, are sold in the domestic market. The main products for the export market are Khanga, Kitanga, used in the African continent. The khanga is a colourful fabric worn by women and occasionally by men. It is a printed cotton fabric, having dimensions of 1.5 m by 1 m, often with a border on all four sides (called pindo in Swahili). A central part that differs in design from the borders can be used as a skirt, head-wrap, apron, pot-holder, towel, and much more. In contrast, Kitanga is a more traditional fabric used for nice clothing.



Kitanga Dress

Initially, the Jetpur economy bloomed on its printing activities, perfected by Brahma Kshatriya community, who first started dyeing cotton cloth in 1950. Gradually hand block printing of cloth started in the year 1955 – 56. Screen printing was introduced in Jetpur between 1968 – 1972. In the year 1995 – 96, Semi-automatic flatbed printing machines were introduced. Local industrialists Gordhandas Karsanji Bosamia and Chunilal Karsanji Bosamia of Jagdish Mills set up the first Textile Mill in Jetpur and later in Ahmedabad and Mumbai. The grey fabric for printing and dyeing is brought from other states (Maharashtra &Tamilnadu) because dyeing & printing require water in large quantities. Water availability in the region is insufficient to fulfill the requirement of individual units.



Khanga Dress

Therefore, the fabric is sent to washing ghats after the printing and silicate padding process. Around 80 –100, Washing Ghats are connected to Effluent Treatment Plants (ETPs).

In addition, Jetpur Dyeing and Printing Association (JDPA) has been operating (since 1990) a Common Effluent Treatment Plant (CETP) of 20 MLD. Total effluent of industry and sewage of Jetpur are conveyed to the CETP. Precisely, the CETP receives 4 million litres of domestic effluent and 2 million litres of effluent from silicate padding, printing process, screen washing. The treated water is stored in Fatal Talab (a natural pond) and used for irrigation of about 800 acres of land. Subsequently, sludge generated in CETP is packed in HDPE bags and sent to the landfill site.

Overall, around 1,120 dyeing and printing units in the town have an average annual turnover of more than Rs 1500 million. Apart from this, there are around 500 ancillary units combined to produce, on average, two million metres of printed cloth per day which is enough to make 40,000 cotton saris. Apart from direct employment, the Textile dyeing & printing cluster provides indirect employment to about 40,000 people.[11]

1.4 MAIN ENVIRONMENTAL ISSUES

The Ministry of Environment, Forest and Climate Change (MoEFCC) had brought out notifications in 1989, with the purpose of prohibition/ restriction of operations of certain industries to protect ecologically sensitive Doon Valley. The notification introduced the concept of categorization of industries as " Red", "Orange" and "Green" with the purpose of facilitating decisions related to location of these industries. Subsequently, the application of this concept was extended in other parts of the country not only for the purpose of location of industries, but also for the purpose of Consent management and formulation of norms related to surveillance / inspection of industries.

The concept of categorization of industries continued to evolve and as different State Pollution Control Boards interpreted it differently, a need arose to bring about necessary uniformity in its application across the country. In order to harmonize the "Criteria of categorization", Directions were issued by CPCB under Section 18(1)(b) of the Water (Prevention & Control of Pollution) , Act, 1974 to all SPCBs/PCCs to maintain uniformity in categorization of industries as red, green and orange as per list finalized by CPCB, which identified 85 types of industrial sectors as "Red", 73 industrial sectors as "Orange" and 86 sectors as "Green".

The process of categorization thus far was primarily based on the size of the industries and consumption of resources. The pollution due to discharge of emissions & effluents and its likely impact on health was not considered as primary criteria. To make the system more transparent and rational, the Working Group constituted by CPCB developed the criteria of categorization of industrial sectors based on the Pollution Index which is a function of the emissions (air pollutants), effluents (water pollutants), hazardous wastes generated and consumption of resources. For this purpose the references are taken from the the Water (Prevention and Control of Pollution) Cess (Amendment) Act, 2003, Standards so far prescribed for various pollutants under Environment (Protection) Act , 1986 and Doon Valley Notification, 1989 issued by MoEFCC. The Pollution Index PI of any industrial sector is a number from 0 to 100 and the increasing value of PI denotes the increasing degree of pollution load from the industrial sector. Based on the series of brain storming sessions among CPCB, SPCBs and MoEFCC , the following criteria on "Range of Pollution Index" for the purpose of categorization of industrial sectors.

- Industrial Sectors having Pollution Index score of 60 and above - Red category
- Industrial Sectors having Pollution Index score of 41 to 59 - Orange category
- Industrial Sectors having Pollution Index score of 21 to 40 - Green category
- Industrial Sectors having Pollution Index score incl.&upto 20 - White category

The purpose of categorization is to ensure that the industry is established in a manner which is consistent with the environmental objectives.

As per the categorization of industries, "Yarn/ textile processing involving any effluent/ emission-generating process ,bleaching, dyeing, printing and scouring" comes under red category.



Figure 1.6 Solid Waste

Textile and garment production is diverse in terms of raw material processed, chemicals used & techniques employed. It has pros and cons where the production is positively related to the country's economic growth. Textile wet processing is associated with significant in and out of water, energy and chemical products. In case of inadequate treatment of wastewater, uncontrolled dumping of waste and controil of emissions to air, significant environmental pollution can occur.As a consequence, these emissions can result in a threat to sustainable development of the Indian economy. All natural fibres contain a certain amount of impurities and associated materials (e.g., grease for wool, pectin and hemicelluloses for cotton, lignin for flax, and sericin for silk). The impurities are metals, minerals, and pesticides. They have the potential for considerable adverse environmental impact. All these substances have to be removed from the fiber before it undergoes finishing processes. The natural impurities removal process for cotton has been described in next chapter. The primary residual solid wastes generated from the textile industry are non-hazardous. These include scraps of fabric and yarn, off-specification yarn and fabric, and packaging waste. There are also wastes associated with the storage and production of yarns and textiles, such as chemical storage drums, cardboard reels for storing fabric, and cones used to hold yarns for dyeing and knitting. Cutting room waste generates a high volume of fabric scraps, which can often be reduced by increasing fabric utilisation efficiency in cutting and sewing.

[11] *"Cluster Profile Jetpur Profile Industries" TERI, Sameeeksha (2015) http://www.sameeeksha.org/pdf/clusterprofile/Jetpur_Textiles_Gujarat.pdf*

Process textile waste

Process textile waste includes all waste generated during textile production, where the fibers are cleaned, straightened, and aligned. Subsequently, they are drawn out and twisted into yarn. It is collectively formed during fiber preparation and yarn formation. Both washing and rinsing are standard processes in textile processing, during which impurity levels on fabric must be reduced to a predetermined level. Most of the waste can be recycled or reclaimed. Treatment of very short mixed fiber waste of less than 12mm long by mechanical means is unviable. There is a great need for a low-cost method of recycling short fiber waste to convert into fabric form, which is 'generic' and compatible with a wide range of fiber types. Therefore, the physical properties of the recycled fibers are significant as this partly decides the suitability of the fabric for particular end-use applications.



Figure 1.7 Process Textile Waste (fiber and yarn waste)

1.4.1 Environmental issues of wet processing

Out of all the steps in the textile value chain (see Figure 1.8), wet processing generates the largest volume of wastewater. Additionally, waste gas emissions have been identified as the textile industry's second biggest pollution concern, after effluent quality.

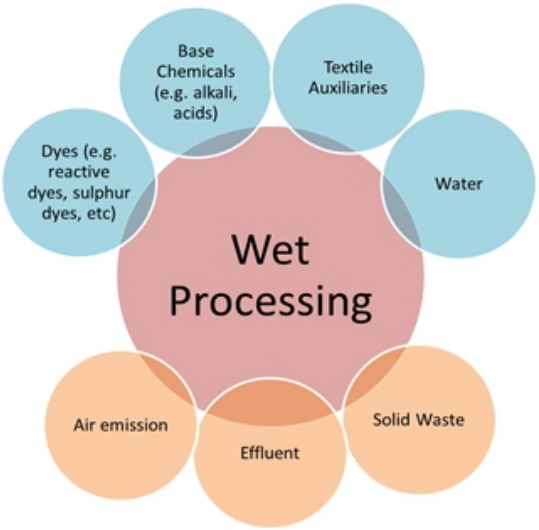


Figure 1.8 Wet Processes Inputs & Outputs

1.4.1.1 Air Emissions (Waste Gas)

Textile mills usually generate nitrogen and sulphur oxides from boilers. Other significant sources of air emissions in textile operations include resin finishing and drying operations, printing, dyeing, fabric preparation, and wastewater treatment plants. Hydrocarbons are emitted from drying ovens and mineral oils in high-temperature drying/curing. These processes can emit formaldehyde, methanol, acids, softeners, and other volatile compounds. Residues from fibre preparation sometimes emit pollutants during heat-setting processes. Carriers and solvents may be emitted during dyeing operations depending on the processes used and from wastewater treatment plant operations. Carriers used in batch dyeing of disperse dyes may lead to volatilisation of aqueous chemical emulsions during heat setting, drying, or curing stages. Acetic acid and formaldehyde are two significant concerns about emissions in textiles.

1.4.1.2 Wastewater Emissions

The textile industry uses abundant water throughout its operations, especially in wet processing, i.e. textile pre-treatment, dyeing, printing and final finishing. The specific water consumption is between 50 and 250 l/kg textile processed depending on the process sequence and water efficiency . The large volumes of wastewater generated also contain a wide range of chemicals which are either removed from the incoming textile substrates (such as preparations and sizing agents) or which are used for wet processing which can be grouped into textile auxiliaries, basic chemicals and dyestuffs. Wastewater emissions from textile wet processing are most important by far, both for inorganic and organic compounds. If not properly treated, these can cause damage before being discharged into the environment.

With respect to cotton fabrics and its blends (mainly with polyester), the emission of sizing agents is of high relevance. Their percentage of them of the overall COD load is very high (30 – 70 %) and thus of particular interest. The sizing agents comprise natural products (starch and starch derivatives), fully synthetic products (polyvinyl alcohols and polyacrylates), semi-synthetic products (carboxyl methylcellulose, hydroxyl ethyl cellulose, etc.), adhesives, and binders. All these enter into the wastewater stream from de-sizing operation.

Scouring is a cleaning process of cotton textiles to remove mainly natural (waxes, proteins, pectines etc.) but also other impurities such as lubricants and dirt. Scouring uses alkali chemicals to saponify natural oils and surfactants emulsifies and suspend non-saponifiable impurities in the scouring bath. The wastewater stream fromm scouring also contains high concentrations of organic compounds, measured as COD.[16]

The aquatic toxicity of textile industry wastewater varies considerably among production facilities. The sources of aquatic toxicity can include neutral salt, surfactants, complexing agents, dispsersing agents, reducing agents, oxidizing agents, dyes (few of them are metal complex dyes), and a huge range of finishing agents (including biocides, flame retardents, easy care finishing, water and oil repellants and many others).

Table 1.2 provides the characteristics of the different processes of finishing cotton yarn and fabrics. Many of the organic compounds present in wastewater are biodegradable but a significant number of them are heavily or non-biodegradable and can thus cause ecotoxic effects in the receiving natutal water.

[13] *Thangavel, Karthik & Duraisamy, Gopalakrishnan. (2014). Environmental Analysis of Textile Value Chain: An Overview.*

[14] *C Parvathi, T Maruthavanan and C Prakash. (2009). Environmental impacts of textile industries*

[15] *European Commission, Best Available Techniques Reference Document on the Textiles Industry, 2003*

[16] *Chaitanna Sarkar & Muhammad Abdur Rashid,(2021) "Estimation of Scouring Effect on Cotton by Varying Concentration of Caustic Soda"*

Table 1.2 Typical Pollution Characteristic of wastewater streams resulting from cotton farbric wet processing

Sr. No	Process	Composition	Nature
1.	Desizing	Sizing agents, surfactants, sulfate or hydrogen peroxide(depending on the process)	High COD and BOD, synthetic sizing agents are difficult to biodegrade (polyvinyl achohol)or are non-biodegradable)
2.	Scouring	Caustic soda, waxes, grease, soda ash, sodium silicate, fibers, surfactants, sodium phosphate.	Dark coloured, high pH, high COD, dissolved solids
3.	Bleaching	Caustic soda, hydrogen peroxide, acids, surfactants, wetting agent, sodium silicate, complexing agents, (hypochlorite in some cases)	Alkaline, suspended solids, medium COD
4.	Mercerizing	Caustic soda, wetting agent	High pH, low COD, high dissolved solids
5.	Dyeing	Various dyes, for cotton mainly reavtive, direct, sulphur and vat dyes and in case of CO/PES blends also disperse dydes, reducing agent, acetic acid, Surfactants, levelling agents, dispersing agents.	Strongly coloured, medium COD, dissolved solids and low suspended solids, copper or nickel in case of related phthalocyanine chromphores
6.	Printing	Printing paste (pigment or reactive for cotton), surfactants in case of after-washing.	Highly coloured, medium COD, oily appearance suspended solids (for pigment printing).
7.	Finishing	Inorganic salts, softeners, easy care chemicals and others	Slightly alkaline, low BOD

The detailed water & energy consumption and wastewater generation of textile wet processing industries are presented in Chapter 3 in detail.

1.4.1.3 Solid Waste

Lint Waste

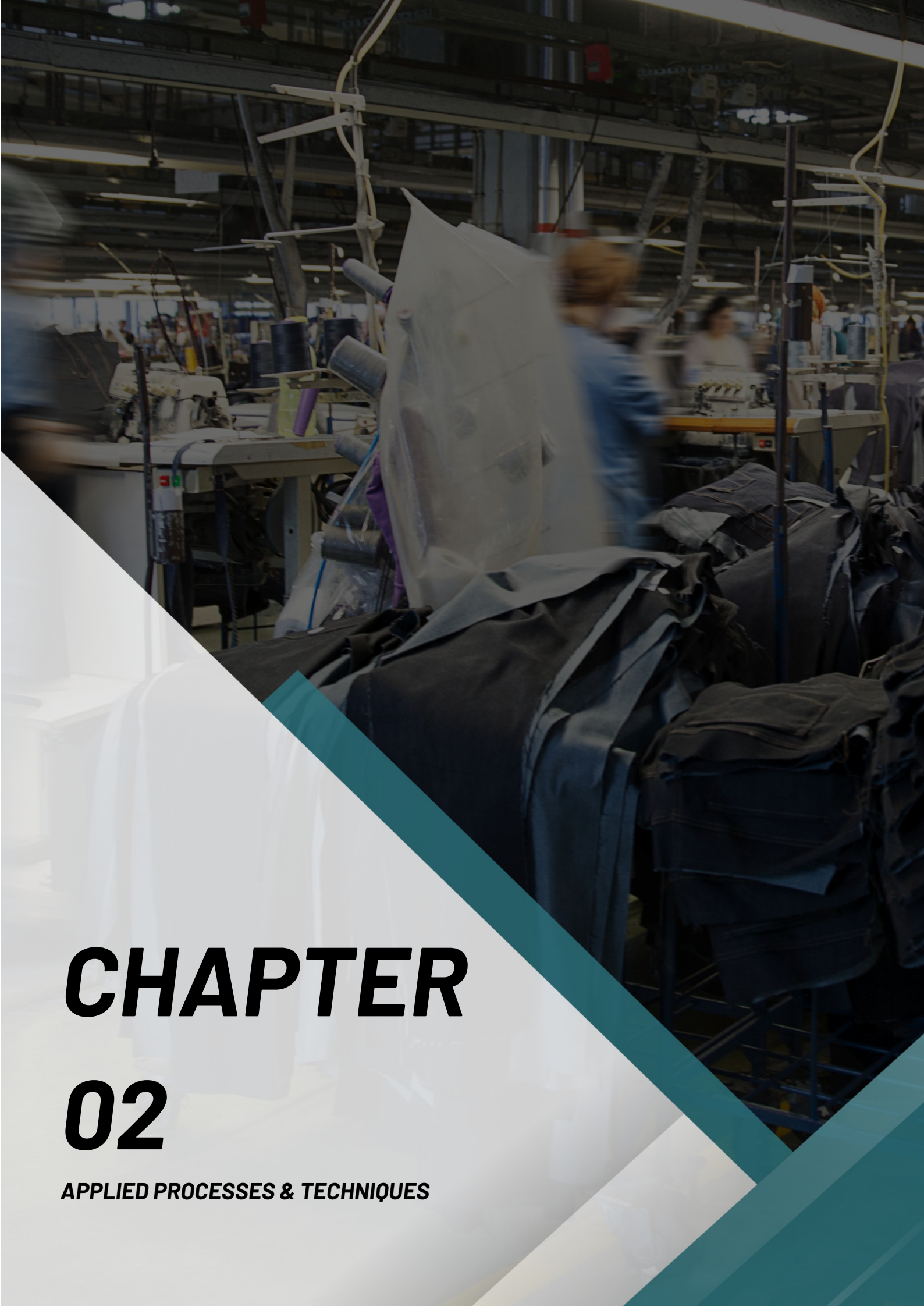
Lint can originate from many textile production steps, particularly from preparation, dyeing and washing operations. Usually, removing lint is relatively easy, using primary control measures such as filters, which can be placed in the circulation line of dyeing and other equipment. The filters must be well maintained and cleaned out regularly to ensure proper filtering. The collected lint is dried and either sent to a landfill or incinerated. Good quality lint can be marketed.



Figure 1.9 Lint waste

1.4.1.4 Hazardous Chemicals

Textile processing involves many intermediary tasks like bleaching, dyeing, printing, and other chemical treatments to furnish the cloth. All these processes can involve hazardous chemicals, which aggravate pollution.



CHAPTER 02

APPLIED PROCESSES & TECHNIQUES

2. Applied Processes and Techniques

2.1. Introduction

The textile industry covers a wide range of activities, beginning from raw fibres, yarn manufacturing, fabric production from yarn to its processing and finishing.

The diagram schematically represents the basic steps involved in textile processing.

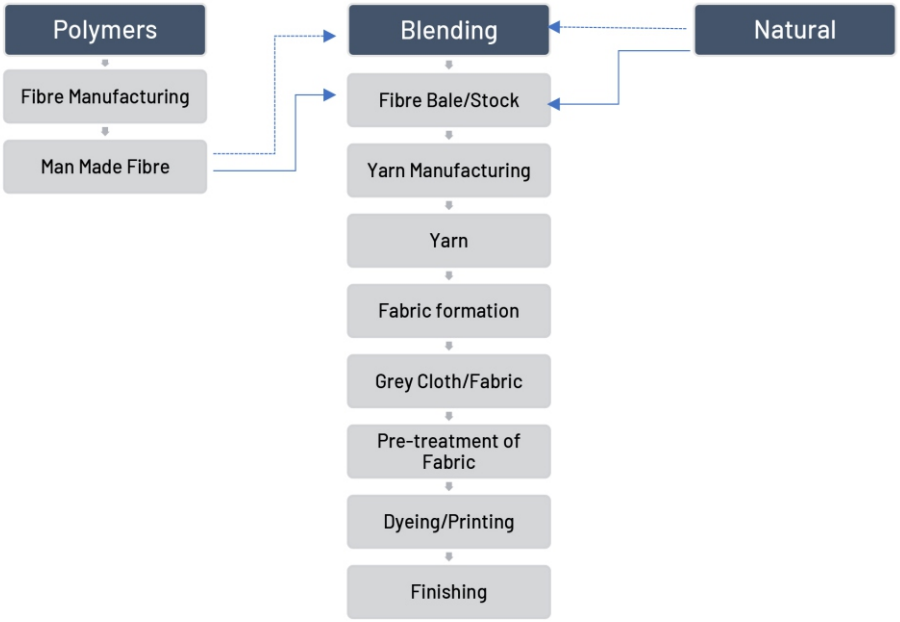


Figure 2.1 Schematic flow Diagram of Textile Processing

This chapter labels the concept of "Applied process and techniques" into various sub-sections.

Firstly, the in-general production process (see section 2.5), then further subsections elaborate on the processing of cotton, polyester, blends, and denim (see sections 2.6, 2.7, 2.8, and 2.9). Additionally, the last sections of this chapter discuss the categorical houses (see section 2.10) and a description of boilers and CETP (see sections 2.11 and 2.12).

Fibres, the textile industry's raw materials (See section 2.2), include a wide range of chemicals and auxiliaries. These are often not process-specific and can be found in different stages within the process cycle. For this reason, separate annexes describe chemicals and auxiliaries. The chapter discusses only general information about textile raw materials and standard procedures for storage and handling.

In the same way, since most machines are multifunctional within the production cycle, the equipment description also appears in a specific annexe (ANNEX 5: Wet Processes: Machinery and Techniques).

2.2. Raw materials

The raw material is the primary substance used as an input to a production process for subsequent modification and finally reformed into a finished good. It plays a vital role in continuous production and for high-quality fabric. Raw materials may be in a processed or unprocessed state. Most of the time, raw materials are natural resources such as Cotton, flax, jute etc. They are also altered to be used in different processes before being used in the final manufacturing process.

Yarn is made using about 15 different types of fibres. These fibres fall into two categories, natural and synthetic. Natural fibres are obtained from plants or animals and are mainly used in weaving textiles. The most abundant and commonly used plant fibre is cotton, which is gathered from the cotton boil or seed pod when it is mature.[1]

Fibres considered in this document are discussed in section 2.2.1, along with the major impurities present in them. Part of these impurities enter the textile processing and influence the associated emissions.

2.2.1. Fibre

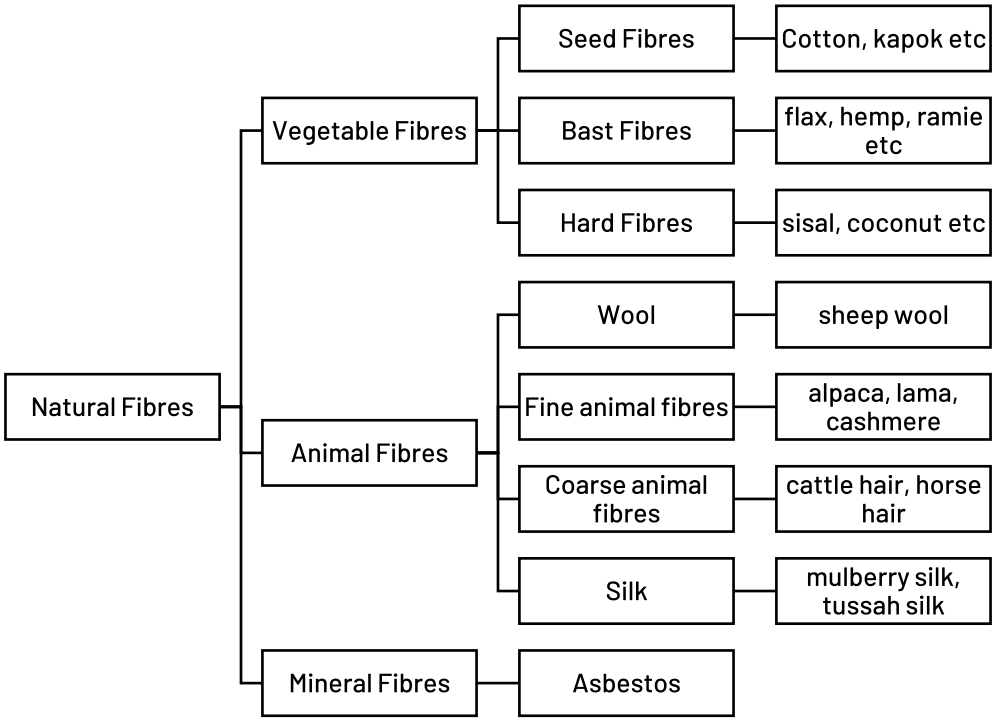
Matter having a length-to-diameter ratio of at least 1000 is considered a fibre.

The textile industries use different fibres derived from nature or manually produced accordingly divided into:

I. Natural fibres – These fibres are those produced by plants, animals and geological processes.
ii. Man-made fibres – These fibres are industrially produced textile fibres obtained from a natural or synthetic polymer.

Factors influencing the development and utilization of all fibres include their ability to be spun, their availability in sufficient quantity, the cost or economy of production, and the desirability of their properties to consumers. Textile fibres require some additional characteristics, such as stability at high temperature, a particular minimum strength & extensibility.

Detailed classification of the fibres is as given below;



Source: Best Available Techniques in Textile Industry by Dr. Harald Schönberger, Gottenheim and Dr. Thomas Schäfer EnviroTex GmbH, Augsburg, pg 23

Figure 2.2 - Natural Fibres

[1] http://www.madehow.com/Volume-3/Yarn.html#ixzz77Mc4Lv5q

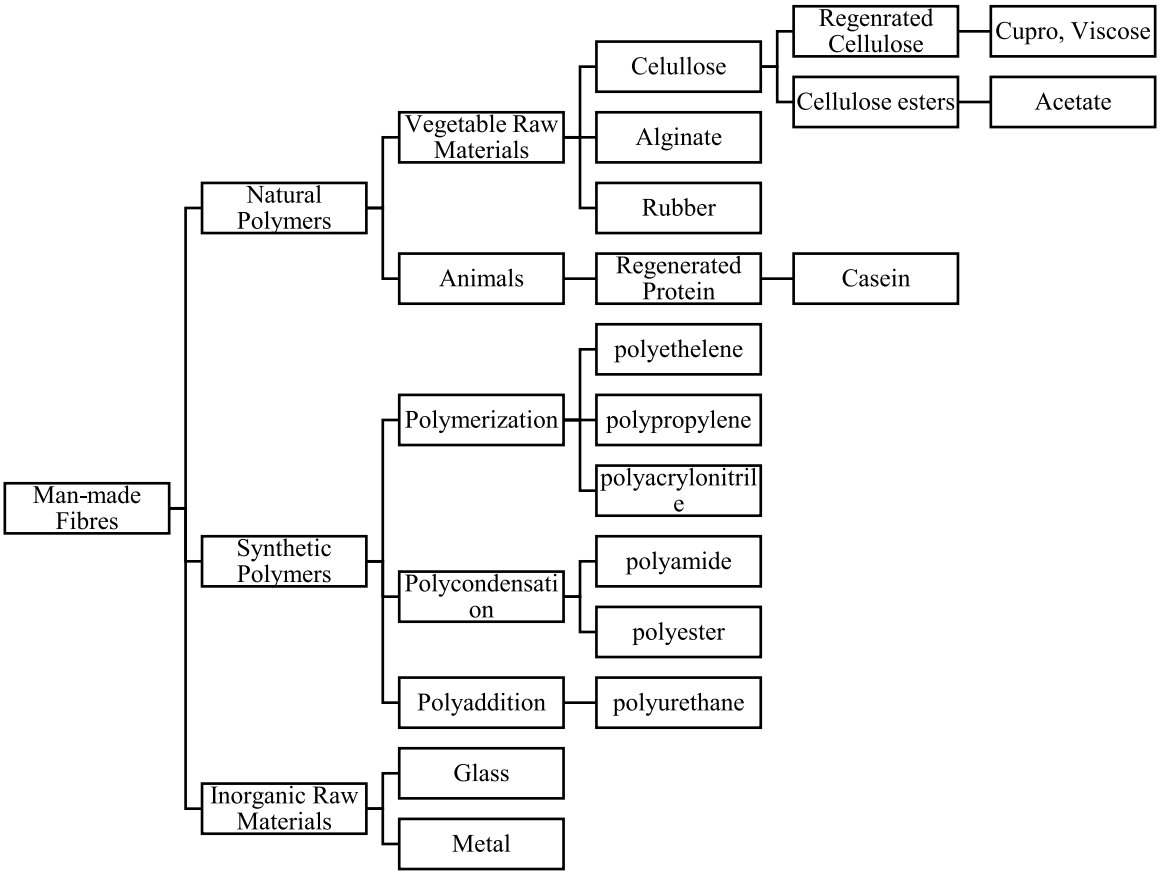


Figure 2.3 Man-made Fibres

Source: Best Available Techniques in Textile Industry by
Dr. Harald Schönberger, Gottenheim and Dr. Thomas Schäfer EnviroTex GmbH, Augsburg, pg 23

2.2.1.1. Natural Fibres

Fibres taken from the plant leaf or stern are generally used for rope. Other plant fibres include acetate (made from wood pulp or cotton linters) and linen, made from flax, a vegetable fibre. Animal fibres include wool from sheep hair and mohair from angora goats and rabbits. Silk is a protein extruded in long, continuous strands by the silkworm as it weaves its cocoon.

a) Cotton:

Cotton is a cellulosic fibre. Cotton is the most used fibre for producing various types of fabrics. The chemical composition[2] of the cotton fibre is:

- Cellulose: 88 - 96%
- Pectin substances: 0.7 – 1.2%
- Proteins: 1.1 – 1.9%
- Wax & fatty acids: 0.40 – 1.0%
- Other organic components: 0.5 – 1.0%

[2]Degani, O. Synergism between Cutinase and Pectinase in the Hydrolysis of Cotton Fibres' Cuticle. Catalysts 2021, 11, 84. https://doi.org/10.3390/ catal11010084

Looking at this chemical composition, it is evident that in Cotton, natural impurities are present to the extent of 4% of its total weight. These impurities are formed naturally during the growth of cotton fibres. The organic materials in natural cotton are released during pre-treatment processes (pectins, proteins, waxes, seed capsules, etc.), contributing to COD in the wastewater. Also, inorganic substances (salts of K, Na, Fe etc.) are removed from Cotton during the pre-treatment processes.

b) Flax

Flax fibers have been utilized for textiles, including woven, knitted, and technical textiles.. Raw materials from flax can be applied in bio-polymers, aerospace and automotive industries, and agro fine chemicals

The chemical compositio[3]n of different compounds is given below:

- Cellulose: 75%
- Hemicellulose: 5%
- Lignin: 4%
- Fat/Wax: 3%
- Ash: 0.5%
- Water: 12.5%



Figure 2.4 Farm to Fibre - Jute

Physical properties of flax fibre:

- **Length:** The average length of flax fibre varies from 90-125 centimetres. The length of individual fibre cells varies from 6-65 mm, with an average diameter of 0.02mm.
- **Colour:** Brownish, ivory, grey, light, yellowish.
- **Tensile strength:** Tenacity varies from 6.5 to 8 gm/denier.
- **Elongation:** Elongation at break is approximately 1.8 % (dry) and 2.2% (wet).
- **Specific gravity:** 1.54
- **Effect of moisture:** M.R = 12% (std)
- **Effect of heat:** Highly resistant to decomposition up to 12°C. Heat conductance is good. The fibres begin to discolour after crossing the temperature limit.

[3]Flax Fibre (https://textilestudycenter.com/flax-fibre-properties/)

- **Abrasion resistance:** Moderate
- **Dimension stability:** Good but tends to crease easily.

Chemical properties of flax fibre

1. **Effect of acids:** high concentrated acids easily damage flax fibre. However, it is not affected by low, dense acids if washed immediately.
2. **Effect of alkalis:** Flax fibre has excellent resistance to alkalis. Strong alkalis do not degrade it.
3. **Effects of bleaches:** Cool chlorine and hypo chloride bleaches do not affect flax fibre.
4. **Dyes:** It is not suitable for dyeing. However, it can be dyed with direct or vat dyes.

c) Jute

Jute fibre is a long, soft, shiny fibre that can be cut into thick, strong threads. It is mainly produced from the genus Corcharas. Jute is one of the most affordable natural fibres and is second only to Cotton in quantity and variety. Jute fibres are mainly composed of plant materials cellulose and lignin. It falls into the category of bust fibre along with kenaf, industrial hemp, flax (linen), ramie, etc. The industrial term for jute fibre is raw jute fibres white-brown and 1-4 m long. Jute is also called golden fibre for its colour and high cash quality.

Chemical composition[4] of jute fibre

- Cellulose – 65.2%
- Hemi-cellulose – 22.2%
- Lignin – 10.8%
- Water-soluble material – 1.5%
- Fat and wax – 0.3%



1 2 3 4

Figure 2.5 Farm to Fibre - Jute

Physical properties of jute fibre

- **Fibre length** 1-4 metres
- **Strength or tenacity** 3-4gm/den
- **Elongation at break** - 1.7%

[4]Sweety Shahinur, Mahbub Hasan, Qumrul Ahsan, Dilip Kumar Saha, Md. Saiful Islam, "Characterization on the Properties of Jute Fibre at Different Portions", International Journal of Polymer Science, vol. 2015, Article ID 262348, 6 pages, 2015. https://doi.org/10.1155/2015/262348

iv. **Specific gravity** - 1.5
v. **Moisture Regain** - 13.75%
vi. **Dimensional stability** - good
vii. **Color**- Brown, grey, yellow, white, off-white, golden, etc.

Chemical properties of jute fibre

1. **Effects of Acid**- Easily damaged by hot dilute acid and cold conc. Acid.
2. **Effects of Alkali**- Easily damaged by strong alkali.
3. **Effects of Bleach**- Resistant to all types of bleaching agents.
4. **Effects of mildew**- Prevention of mildew is better than Cotton.
5. **Dyeing ability**- Easy to dye. The basic dye is used.

d) Wool:

Wool fibre is another common type of fibre used in the textile industry. It is typically more expensive than Cotton and in a more limited supply.

This fibre is hair from sheep's bodies, and sheep are reared to obtain. Its quality and quantity vary widely, depending on the breed of sheep and the environment wool. This hair is usually sheared once, or sometimes twice, a year. Wool is possibly the oldest fibre known to humans. It was one of the first fibres to be spun into yarn and woven into a fabric. It mostly comes from sheep but can also be obtained from alpacas, camels, and goats.

The percentage of the components mentioned may vary widely depending on the origin of wool. The natural by-products of wool are grease, suint, dirt, vegetable matters. Greasy wool contains residues of biocidal chemicals used to prevent or treat infestations of sheep by external pests (ectoparasites), such as ticks, mites and blowflies. These are removed during wool scouring. Suint is water-soluble material arising from the secretion of the sweat glands in the skin. Suint is soluble in a polar solvent such as water and alcohol.

Dirt includes various materials such as mineral dirt, sands, clay, dust and organic materials. Dirt and vegetable matter on the raw wool, together with short fibre fragments, are removed mechanically during carding or chemically by carbonizing. The washing of fabrics during pre-treatment removes preparation agents (spinning oils, combing oils, etc.). The presence of ectoparasiticides in the discharge of raw wool scouring effluent and disposal of the sludge generated by the effluent treatment has severe environmental impacts.

2.2.1.2. Man-Made Fibres

Synthetic fibres are made by forcing a thick polymerised chemical solution through spinneret nozzles and hardening the resulting filament in a chemical bath. These include acrylic, nylon, polyester, polyolefin, rayon, spandex, and triacetate. Some of these fibres have similar characteristics to the natural fibres without shrinkage problems. Other fibres have unique properties for specific applications. For instance, spandex can be stretched over 500% without breaking.[5] The spinning process used for a particular polymer is determined by the polymer's melting point, melt stability, and solubility in organic and/or inorganic (salt) solvents, as well as the end use of the fibres. Wastes generated during spinning operations include VOC emissions and wastewater contaminated with solvents.

[5] http://www.madehow.com/Volume-3/Yarn.html#ixzz77Mc4Lv5q

including the source of waste generation during manufacturing of man-made fibres is explained in section 2.4.1.

a) Polyester (PES):

As shown in Fig 2.6, polyester is a long-chain polymer chemically composed of 85% by weight of an ester and dihydric alcohol and a terephthalic acid. Three polyester polymers are commercially available:

- Polyethylene terephthalate (PET), which is based on ethylene glycol
- Polybutylene terephthalate (PBT), which is based on butyl glycol
- Polytrimethylene terephthalate (PTT), is based on trimethylene glycol.

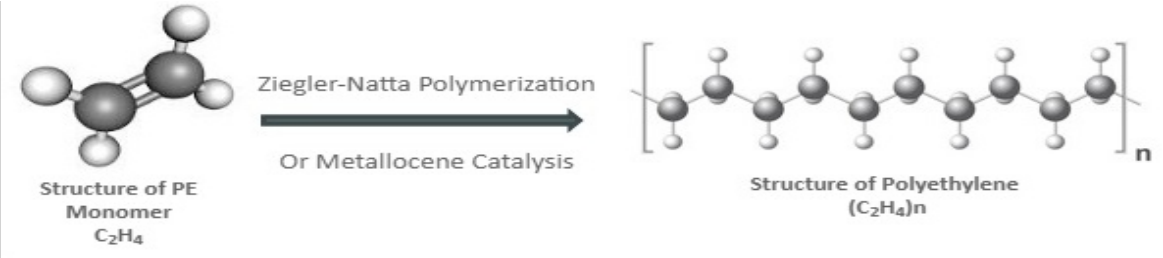


Figure 2.6 Polymerization of Polyethylene from its monomer

However, only one of these three polymers, polyethylene terephthalate, also known as PET, has so far been widely applied in the textile industry.

PET fibres have a very high degree of crystallinity, which allows for excellent heat resistance and other mechanical properties.

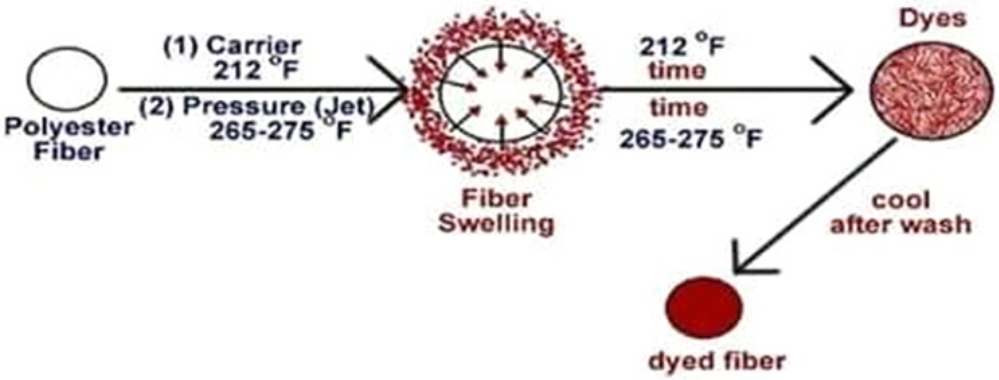


Figure 2.7 Dyeing of polyester with disperse dye
Source: hindawi.com

On the contrary, this compact structure inhibits the diffusion of the colourants into the fibre during dyeing. As a result, PET fibres cannot be dyed below 100 °C, unless dyeing accelerants (so-called carriers as shown in Fig 2.7) are used.

b) Polyamide fibres (PA)

The polycondensation reaction between a diamine and a dicarboxylic acid produces starting polymer. According to the number of carbon atoms of the end-product, one can speak of PA 6,6 or PA 6.

Thermal polycondensation of equimolecular amounts of adipic acid and 1,6- hexamethylenediamine produces PA 6,6. The equilibrium condensate contains a small number of monomers and cyclic dimers (2 %).

PA 6 is made by polymerisation of the cyclic monomer epsilon-caprolactam.

c) Acrylic fibres (PAC)

The polymer is obtained by radical polymerisation of acrylonitrile in an aqueous emulsion or solvent. The obtained polymer, made of 100 % acrylonitrile (also called PAN), gives fibres insufficient dye-binding capability due to the high glass transition temperature (above 100 °C). For this reason, this polymer is no longer used in the textile industry.

d) Polypropylene fibres (PP)

The isotactic polymer is used for fibre production. Due to the tertiary carbon atom, PP is very sensitive to high temperature and oxidation. Alkylated phenols or p-xylols, together with sulphides or thio-derivatives (dilauryl- or distearyl thiopropionate) are used as stabilisers. UV-absorbents are Benzotriazole groups, Ni complexes, anthraquinone derivatives and sterically hindered diamines substances. These low-molecular-weight substances remain in the PP fibres and are considered possible emission-relevant substances.

e) Elastane (EL)

Elastane fibres are made out of an elastomer containing at least 85 % polyurethane (PU). The polymer is dissolved in dimethylacetamide for fibre production (dry spinning). Solvent Residues remain in the fibre (< 1 % weight) and are found in the waste water from pre-treatment.

Preparation agents are applied to the fibre to reduce the high adhesive characteristics and guarantee good gliding properties during Processing (approximately 6-7 % add-on). These auxiliaries contain 95 % silicone oils and 5 % surfactants. The high percentage of silicone oils causes environmental concerns during pre-treatment of the textile material when these substances have to be removed.

f) Cupro (CU)

Cellulose (wood pulp) can also be dissolved in an aqueous solution of ammonia and copper sulphate Cupro fibres are produced by wet spinning.

g) Viscose (CV)

It is basically the cellulose extracted from coniferous timber and supplied to the fibre manufacturers in sheet of about 1cm thick.



Figure 2.8 Stages in viscose manufacturing

The above figure displays the farm to fibre process of viscose.

The wood contains ca. 40 – 50 % cellulose that is useable to make viscose. The cellulose is first allowed to swell in a NaOH solution. The white flakes obtained thus are treated with carbon disulphide until the sodium cellulose xanthate is formed. The xanthate is soluble in diluted sodium hydroxide, and the formed solution (pulp) is already called viscose. The pulp then needs to be spun. Spinning consists of coagulating the xanthate solution at the outlet of the spinneret in an acid bath containing sulphuric acid, sodium sulphate and zinc sulphate[6].

h) Acetate fibres

The cellulose molecule contains three alcohol groups. Diacetate polymer is formed when 2 or 2.5 of the three groups are esterified with acetic acid. Triacetate polymer is formed when all three alcohol groups are esterified. The acetate fibres contain at least 74 % of the acetylated hydroxylic groups with overall cellulose acetate content less than 92 %.

2.3. Chemicals and Auxiliaries

Numerable organic dyestuffs/pigments and auxiliaries are utilized in the textile industry. They are divided into the following categories:

I. Dyestuffs and pigments
II. Organic auxiliaries for all stages of wet textile processing
III. Basic chemicals (all inorganic compounds, organic reducing and oxidizing agents, short-chain organic acids and urea)

Manufacturing in textile consists of a long process involving chemical and non-chemical treatments. The textile wet processing comprises preparation and pre-treatment, dyeing, printing and final finishing of yarns and fabrics.

The present-day plethora of dyes, fibres and coloration processes has created additional reasons for the use of auxiliaries. Moreover, a vastly more comprehensive understanding of the physio-chemical processes involved has enabled auxiliaries to be precisely engineered for specific purposes.

[6]*Rana, Sohel & Pichandi, Subramani & Parveen, Shama & Fangueiro, Raul. (2014). Regenerated Cellulosic Fibres and Their Implications on Sustainability. 10.1007/978-981-287-065-0_8.* `

With each dye–fibre system and dyeing or printing process having particular needs. The primary functions of auxiliaries are:

- ▶ To prepare or improve the substrate in readiness for coloration by
  - Scouring, bleaching and desizing
  - Wetting
  - Enhancing the whiteness by a fluorescent brightening effect
- ▶ To modify the sorption characteristics of colorants by
  - Acceleration
  - Retardation
  - Creating a blocking or resist effect
  - Providing sites for sorption
  - Unifying otherwise divergent rates of sorption
  - Improving or resisting the migration of dyes
- ▶ To stabilise the application medium by
  - Improving dye solubility
  - Stabilising a dispersion or solution
  - Thickening a print paste or pad liquor
  - Inhibiting or promoting foaming
  - Forming an emulsion
  - Scavenging or minimising the effects of impurities
  - Preventing or promoting oxidation or reduction
- ▶ To protect or modify the substrate by
  - Creating or resisting dyeability
  - Lubricating the substrate
  - Protecting against the effects of temperature and other processing conditions
- ▶ To improve the fastness of dyeing, as in
  - The after treatment of direct or reactive dyes
  - The after treatment of acid dyes on nylon
  - The chroming of mordant dyes on wool or nylon
  - Giving protection against atmospheric influences, as in UV absorbers or inhibitors of gas-fume fading
  - Back-scouring or reduction clearing
- ▶ To enhance the properties of laundering formulations (fluorescent brightening agents).

The chemicals in the textile industry range from highly specialized chemicals to basic chemicals or mixtures. Basic chemicals include soda ash, hydrochloric, sulphuric acid, acetic acid, hydrogen peroxide, formic acid, and caustic soda.

Table 2.1 exemplifies an overview of the various chemicals & auxiliaries used in cotton woven fabric processing along with their functions and chemical composition.

Table 2.1 : Auxiliary & Chemicals used in Cotton Woven Fabric Processing

Process	Auxiliary & Chemicals used	Function	Chemical Composition
Fabric manufacturing			
Sizing	Sizing agents, sizing additives	Protection of warp yarns during weaving (Applied in weaving mills)	• Macro-molecular natural or synthetic products (starch, modified starch, modified celluloses, polyvinyl alcohol, polyacrylates, polyesters) • Additives (oils, waxes, starch solubilizing agents (peroxides))
Pre-treatment processes			
Desizing	Desizing agents, Wetting agent	Removal of sizing agents	• Enzymes (amylases) for enzymatic desizing; • Hydrogen peroxide and/or persulfates for oxidative desizing; • surfactants, complexing agents
Scouring	Scouring agent	Removal of fibre by-products (fats, waxes, pectins, inorganics etc.) from cellulose fibres in cellulose materials or blends of cellulose fibres with synthetic fibres	• Strong alkali; • Alkaline-resistant and electrolyte • Resistant surfactants (fatty alcohol ethoxylates, alkane sulfonates), complexing agents

	Bleaching auxiliaries Hydrogen Peroxide	Bleaching, whitening	Hydrogen peroxide, sodium chlorite (usually not), sodium hydroxide, complexing agents, surfactants stable in acidic or alkali conditions, silicates, polycarboxylic acids, sugar polymers as peroxide stabilizers, nitrates(anti-corrosion), polyacrylamide (crease preventing) sodium sulfite, enzymes (catalyses)to remove surplus peroxide
Mercerizing	Caustic soda, wetting agent	Increase in dyestuff uptake and tensile strength of textiles through alkali treatment under tension	Strong alkali (sodium hydroxide; ammonia); wetting agents, stable in highly concentrated lye (low molecular weight alkyl sulfates, alkane sulfonates), antifoaming agents as shorter-chain alkyl phosphates, complexing agents
Dyeing/Printing			
Dyeing	Dyes	Colouring the Textile substrate	
	Dye fixing agents	As an assistant for the maximum dye uptake on the substrate	
	Levelling agent	Promotion of an even distribution of dyestuffs on textiles	
	Wetting agent	Increase of wetting capacity of the dye liquors; improvement of dye penetration in padding processes; the increase of dye absorption	Alkyl sulfates, alkane sulfonates, alkyl aryl sulfonates, alkyl ether sulfates, alkyl esters of Sulfosuccinic acid, ethoxylation products, phosphoric acid esters
	Acid & alkali	For adjusting the pH	Organic acids (mainly acetic acid, formic acid, oxalic acid), inorganic acids (sulfuric acid, hydrochloric acid); sodium hydroxide, ammonia (in water), sodium carbonate
	Salts	Increase the substantivity for reactive and direct dyes; levelling effect on acid dyes, etc.	Sodium chloride, sodium sulphate, etc.

Dyeing	After-treatment agents for fastness improvement	Improve rubbing fastness, wet fastness and light fastness	Soaping after treatment with detergents or dye affinitive polymers. Cationic fixing agents for direct and reactive dyes (poly-quaternary ammonium compounds, cationic formaldehyde condensates. Poly-sulfonates for improvement of polyamide dyeing with anionic dyestuffs.
Printing	Thickeners	Adjusting of viscosity required in printing pastes	Alginates, galactomannans, modified starch, polyacrylates, polysaccharide combinations, additives, esp. mineral oils
	Binders	Promotion of fibre bonding	Polymers of acrylic acid esters, acrylonitrile, ethylene, butadiene, styrene, vinyl chloride, vinyl acetate, Latex, starch etc.
	Pigments	Colouring the Textile substrate	
Discharge printing	Discharging agents Discharging assistants	Discharging agents are printed onto a pre-dyed textile material for the destruction of the dyes and thus cause a pattern	

2.4. Fibre manufacturing

Fibre is a long fine continuous thread or filament that can be spun into yarn such as Cotton, jute, polyester, nylon etc. Its length is a thousand times longer than its width. To be a textile fibre, it should have definite properties like length, fineness, softness, crimp, flexibility, elongation, strength etc. So all the fibres cannot be defined as textile fibres. Textile fibres can be divided into two major categories. One is natural, and another is man-made or artificial.

Textile fibres can be both staple and filament. All the natural fibres are staples except silk. Staple fibres have a definite length and are shorter. However, filament fibres are longer and don't have any definite length. Synthetic fibres can be staples or filaments.

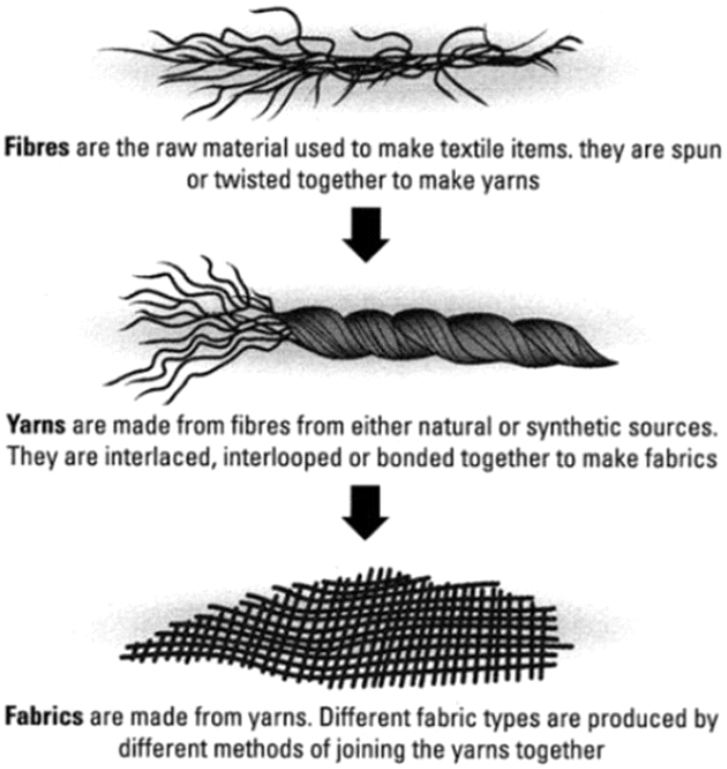


Figure 2.9 Fibre to Fabric

2.4.1. Fibre manufacturing: chemical (man-made) fibres

The fibres which are produced artificially are called man-made or synthetic fibres. According to the end-use, their chemical composition, structure, and properties are extensively modified during the production process. According to the raw materials used to make these, fibres are classified into three major categories: Regenerated, Synthetic, and In-organic fibres. Viscose, Tencel etc., are regenerated cellulosic fibres. Polyester, nylon, acrylic etc., are synthetic and Metallic fibres are Inorganic fibres.[7] The manufacturing of man-made fibres (Polyester) is only covered in this document. However, some preparation agents used in manufacturing may impact the emissions from subsequent fibre processing (pre-treatment). This is why some information about the manufacturing of man-made fibres is given in this section.

Man-made fibres are obtained by a manufacturing process, distinct from material that occurs naturally in

[7] *https://textileapex.blogspot.com/2020/02/fibre-vs-yarn-vs-fabric-find-differences.html*

fibrous form. The term man-made fibre refers to the method of fibre production and not to the origin of the polymer material. The chemical compounds from which man-made fibres are produced are known as polymers. Man-made fibres are classified into organic and inorganic fibres. Organic fibres include fibres obtained from naturally occurring polymers and synthetic polymers. These fibres' chemical composition, structure, and properties are significantly modified during the manufacturing process. Examples of man-made fibres include consumer products such as shirts, scarves, hosiery, home furnishings, etc., and industrial products such as cord, flame-proof linings, drive belts, etc.

2.4.1.1. Cellulosic polymers

2.4.1.1.1. Regenerated Cellulose

Viscose fibres

Viscose is defined as "a cellulose fibre obtained by the viscose process" by BISFA (International association of man-made fibre producers founded in 1928 under the French name of Bureau International pour la Standardization des Fibres Artificielles, hence the abbreviation BISFA) It is usually known as rayon. Viscose fibres are made from cellulose from wood pulp. The cellulose is ground and reacted with caustic soda. After a waiting period, the ripening process during which depolymerisation occurs, carbon disulphide is added. This forms a yellow crumb known as cellulose xanthate, easily dissolved in more caustic soda to give a viscous yellow solution. This solution is pumped through a spinneret, which may contain thousands of holes, into a dilute sulphuric acid bath where the cellulose is regenerated as fine filaments as the xanthate decomposes. The regenerated fibres are then cut to desired staple length, treated on after treatment machine, washing, bleaching, desulphurising, finishing, opening, drying and then baled

2.4.1.1.2. Cellulose ester

Cellulose acetate

The fibre produced from cellulose acetate is a chemical derivative of cellulose. Filaments are spun from an acetate acid ester of cellulose, coagulated or solidified from the spinning solution when pushed through a spinneret. It is fundamentally different in its chemical structure from natural cellulosic fibres and viscose, except that all contain cellulose. Its chemical properties differ from viscose in that it is sensitive to certain solvents, notably acetone, which dissolves it quickly.

The manufacturing process includes dissolving cellulose acetate in acetone, where acetone evaporates and leaves filaments and extrusion into heated air. The filaments are either gathered together like yarn or later cut into staples. It is a thermoplastic, which melts at 230 oC. However, fibre dries rapidly due to relatively low moisture absorption. It may soften and be damaged even at slightly lower temperatures. Dye affinity is different from viscose and cotton's as it can be dyed only with disperse dyes. Fabric made from cellulose acetate fibre is similar in external appearance to viscose fabric but not quite as strong or resistant to abrasion.

However, it is more resilient and has a more pleasing silky handle. It is crease-resistant, drapes well, and is not readily flammable. Exposed to a naked flame, it melts and drips as it burns. It does not conduct heat readily. In some instances, it is considered better artificial silk than viscose and comparatively less expensive. Though it is used as a clothing material, usage is mainly limited to rainwear, umbrellas, ties, etc. It is not suitable for such use, which needs quick absorbency.

Cellulose triacetate

It is thermoplastic and more resistant to heat than cellulose acetate, melting only at approximately 300 °C. It can be subjected to heat setting like synthetic fibre by subjecting it to about 195 °C[8]. The heat-set condition exhibits very low absorbancy and dip-dry properties like synthetic fibres. It is mainly used for pleated fabrics.

2.4.1.2. Non-cellulosic (synthetic) fibre

Synthetic fibres are classified as shown in Fig 2.3. Polyamides and Aramids are discussed in this section, and the remaining synthetic fibres are covered under other groups of chemicals.

2.4.1.2.1. Polyamide

Polyamide is a polymer containing monomers of amides joined by peptide bonds. Polyamides can occur naturally and artificially, examples being proteins, such as wool and silk. They can be made artificially through step-growth polymerization, examples being nylons, aramids, and sodium poly(aspartate). They are commonly used in textiles, automotive, carpet and sportswear due to their extreme durability and strength.

Linear polyamides, widely known as 'nylons', are the most common category of the family. Polyamides are chemically characterized by a macromolecular structure with the amide group (-NH-CO-). It is formed by the reaction of a carboxylic group with an amino group as a recurring functional unit that gives the specific chemical properties to the final products.

The most common use of the polyamides is for the production of yarns and fibres for different applications:

- Textile fibres, continuous fibres used in the textile sector
- Industrial fibres, continuous fibres used for technical applications
- Staple fibres, used for textile flooring and clothing
- Bulk continuous filament fibres (BCF fibres) for textile flooring

2.4.1.2.2. Aramid

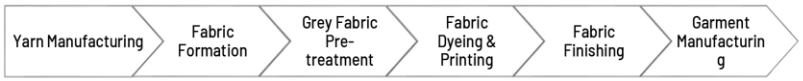
Aramid fibres are a class of heat-resistant and robust synthetic fibres. They are fibres in which the chain molecules are highly oriented along the fibre axis, so the strength of the chemical bond can be exploited. They are used in aerospace and military applications, for ballistic rated body armour fabric, bicycle tyres, and as an asbestos substitute. The name is a shortened form of "aromatic polyamide".

[8] *Marczak Daria, Lejcuś Krzysztof, Misiewicz Jakub, "Characteristics of biodegradable textiles used in environmental engineering: A comprehensive review", Journal of Cleaner Production, Volume 268, 2020.*

2.5. Production Process in Textile industry

The production processes in textile industries involve the following stages:

I) Manufacturing of yarn,
II) Fabric formation,
III) Pre-treatment of grey fabric
IV Dyeing & Printing
V) Finishing
VI) Manufacturing of garments from the processed fabric



2.5.1. Yarn Manufacturing

Textile processing begins with yarn manufacturing. Yarn is a strand of natural or man-made fibres or filaments that have been twisted or grouped for use in weaving, knitting or other textile fabric formation methods.

For manufacturing the yarn, succeeding steps are executed:

- Raw fibres are first processed and transformed into bales.
- Natural fibres are treated in the mill to remove dust and any foreign material. In contrast, man-made fibres are not required to undergo this process since factory operations manufacture them.
- Blending is the combining of different fibres to produce yarns for blended fabrics. Fibres are selected and blended in specific proportions so the fabric will retain the best characteristics of each fibre.
- The natural fibres are short in length, while man-made fibres are produced in continuous filaments.
- For yarn manufacturing, the filaments are first to cut into staple length.
- The staple fibres have to undergo various mixing/blending, opening, cleaning, drawing etc. It is then converted to yarns by first making a web in a carding machine. The webs are collected in the form of slivers containing parallelized short fibres held together by cohesion between the fibres. They are then subjected to drafting and twisting to yield yarns of desired thickness.

2.5.1.1. Yarn manufacturing processes for man-made fibres

I. Spinning

Spinning processes may be the same for some noncellulosic fibres and cellulosic fibres. The term spinning defines the extrusion process through bored devices (spinnerets) of fluid polymer masses, which can solidify in a continuous flow.

The spinning process used for a particular polymer is determined by the polymer's melting point, melt stability, and solubility in organic and/or inorganic (salt) solvents, as well as the end use of the fibres.

The three primary spinning methods are melt, dry solvent, and wet solvent, which are shown in Figure 2.10. A fourth and less commonly used method is reaction spinning. Wastes generated during spinning operations include VOC emissions and wastewater contaminated with solvents is shown in table 2.2.

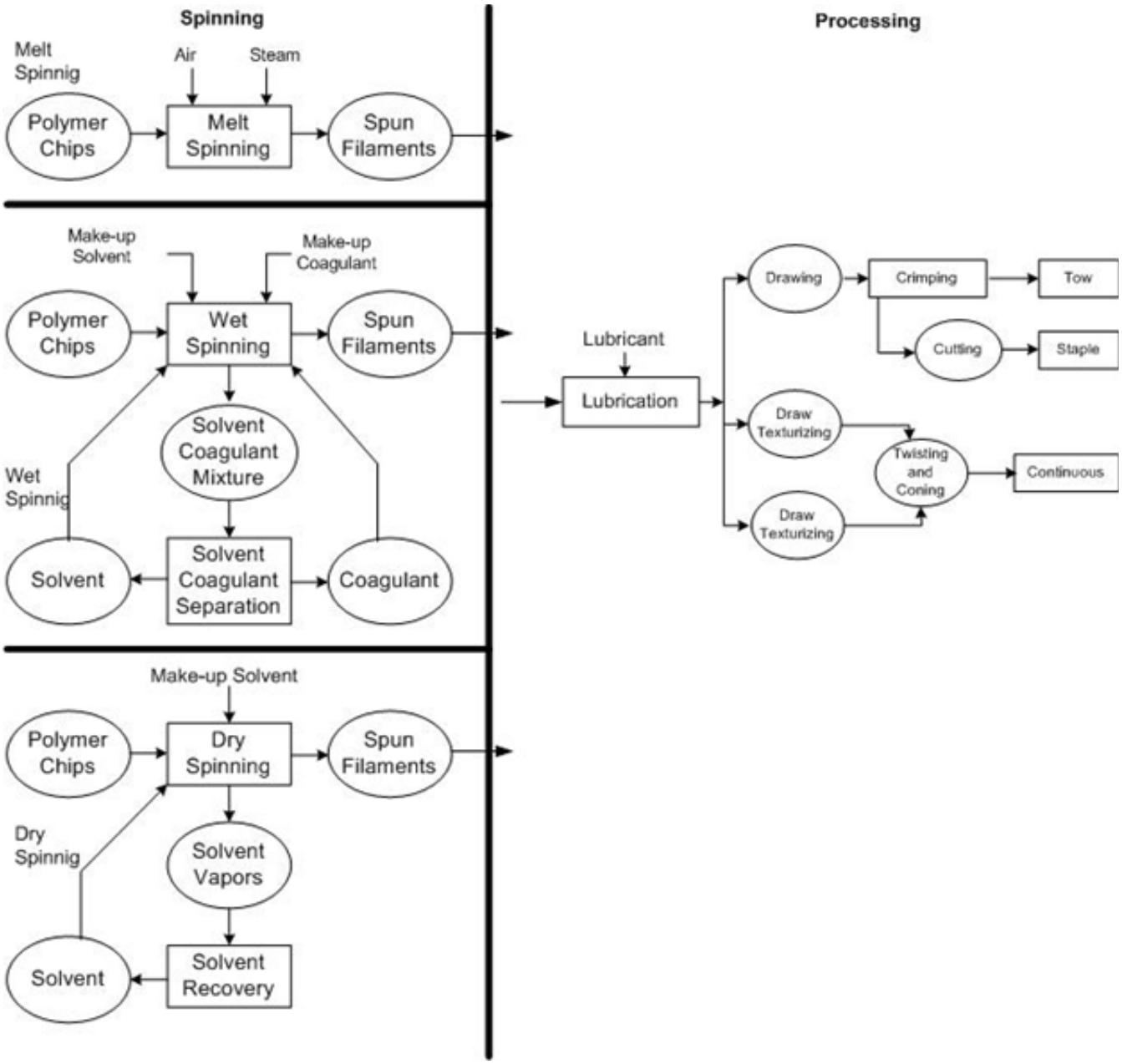


Figure 2.10 Process Diagram for Melt, Wet and Dry Spinning

Source: Technical Guidance Manual for Man-made Fibre Manufacturing Industry

Table 2.2: Typical Spinning Parameters for Selected Fibres

Spinning Method	Fibre Type	Solvents or Other Reactants
Melt Spinning	Nylon – 6 Nylon – 6,6 Polyester Polyolefin	N/A
Solvent Spinning	Acrylic/modacrylic cellulose acetate/ cellulose triacetate spandex acrylic/modacrylic	Dimethylacetamide Acetone or chlorinated hydrocarbon di-isocyanate, ethylenediamine, monoamine (stabilizer) dimethylacetamide
Dry solvent spinning		
Wet solvent spinning		
Reaction Spinning	Spandex Rayon (viscose process)	di-isocyanate, ethylenediamine, toluene, sodium hydroxide, carbon disulfide, sulfuric acid

a. Melt spinning

Melt spinning processes use heat to melt polymer, which can then be extruded through the spinneret. Spinning assemblies are fed by either electrically-heated screw extruders, which convert powdered or chipped polymer into a polymer melt or directly from a continuous melt polymerization process. Many nylon and polyester plants use continuous melt polymerization and send molten polymer directly to the spinning units from polymerisation units. Various additives may be incorporated during polymerisation or extrusion to impart unique properties to the fibres, such as heat stability, antistatic, and eased dyeing.

b. Dry Spinning

Dry spinning is typically used for easily dissolved polymers such as cellulose acetate, acrylics, and modacrylics. The polymer is first dissolved in an organic solvent in dry spinning processes. The solution (or spinning dope) is then blended with additives, filtered, and charged to a spin cell. The spin cell contains a feed vessel, a heat exchanger, a spinneret, and a quench cell. The solution is heated to a temperature above the solvent boiling point and is then extruded through the spinneret into a zone of heated gas. The solvent evaporates into the gas stream, leaving solidified filaments.

The heated gas stream is typically air, although inert gas, such as nitrogen and super-heated solvents, can also be used. Fibres are then passed through baths to wash residual solvent from the fibres. The wash water from these baths is typically recycled to reduce costs and pollution. These baths may be followed by activated carbon systems used to adsorb solvent from process air. Fibres produced by dry spinning contain less void space than those produced by melt spinning and therefore have higher densities and lower dyeability than those produced by other methods. Dry spinning operations have the most significant potential VOC emissions to the air of the three primary spinning methods.

c. Wet spinning

Wet spinning processes also use solvents, such as dimethylacetamide or aqueous inorganic salt solutions to prepare spinning dope. In wet spinning, the polymer is dissolved in the solvent in a solution vessel and is forced through a spinneret which is submerged in a coagulation bath. As the polymer solution emerges in the coagulating bath, the polymer is either precipitated or chemically regenerated. In precipitation, the fibre is formed when solvent diffuses out of the thread and coagulant diffuses into the thread. For some processes, a chemical reaction occurs during precipitation which generates fibres. Coagulated filaments pass over a guide to godets or drive rollers. Windup speeds are about 150 m/min. The yarn is then passed through additional baths for washing and residual solvent removal.

d. Reaction spinning

Reaction spinning methods are typically used to make spandex and rayon. The process begins with preparing a viscous spinning solution containing a dissolved low molecular weight polymer, such as polyester, in a suitable solvent and a reactant, such as di-isocyanate. The spinning solution is then forced through spinnerets into a diamine solution (similar to wet spinning) or combined with a third reactant and then dry spun. The primary distinguishing characteristic of reaction spinning processes is that the final cross-linking between the polymer molecule chains in the filament occurs after the fibres have been spun. The fibre is then transported from the bath to an oven, evaporating solvent.

The viscose process converts cellulose from one form (dissolved pulp) to another (rayon). Although the manufacturing process further purifies the cellulose, alters the physical form of the fibre, and modifies the molecular orientation within the fibre and its degree of polymerization, the product is essentially the same chemical as the raw material. Since the product retains the same chemical structure, all other chemicals used in the process and all by-products formed in the process must be removed. The viscose process is typically associated with a large volume of air emissions.

2.5.1.2. Fibre processing

In most cases, the extruded product from the melt, dry, wet, or reaction spinning is further processed to impart particular qualities to the fibres and facilitate downstream Processing. Fibres can be processed as filament yarn or as a staple.

After fibres have been formed, the spin finish is usually applied by collecting the extruded filaments on a grooved ceramic guide or rotating roller coated with a spin finish. The spin finish, including lubricants and finishing oils, facilitates further processing steps by reducing friction and static and improving mechanical processing. Mineral oils have historically been used as lubricants, and organic compounds have been used to reduce static. Spin finishes vary according to fibre type and are critical to the processing of fibres into yarns and fabrics. Insufficient lubrication of fibres can lead to strains in the fabric that may produce uneven dyeing, decreased strength, or unpleasing aesthetic qualities. These lubricants are removed during fabric pre-treatment process.

Wastes generated during fibre processing operations arise from the spin finish application and drying steps. Fibre finishes can be sources of volatile and hazardous air pollutants emitted into the air and wastewater during Processing.

I. Drawing

The polymer extruded by the spinnerets does not have the typical properties of textile fibre. The molecular chains need to be orientated (orientation phase) in the fibre axis direction and simultaneously /successively activate/increase the ordered arrangement of the intermolecular structure (crystallization phase). This process can be partly activated during spinning by increasing the ratio between the take-up speed and the extrusion speed (spinning ratio), but, except the case of high speed spinning of continuous filament yarns, the process needs to be completed by an additional operation of mechanical drawing.

The process entails winding the yarns on rollers or cylinders running at high speed. It can be carried out continuously on filaments from the spinning room (single phase process) or on filaments from a phase after spinning (two-phase process). The speed ratio between the delivery or drawing rollers and the feeding rollers is the draft ratio R. The mechanical configuration of the rotating devices and the filament path are designed to ensure the equivalence of fibre speed with the speed of contact organs.

2.5.2. Fabric formation

The next step in textile manufacturing is forming fabric from the yarns. Yarns can be converted into fabric by weaving or knitting. However, fabrics are generally made by the weaving method.

Two sets of yarns are used in the loom to make woven fabrics. One set of yarn is called warp yarn which is used length wise. And another set of yarn is called weft yarn which is used width wise. There are different woven fabric structures like plain weave, twill weave, satin weave, basket weave etc. Plain weave is used to make fabrics, usually used to make shirts. This weave is used to make fabrics, usually used to make jeans.

One set of yarn is used to make knitted fabrics by interloping. Due to their fabric structure, knitted fabrics have stretch properties. Lengthwise yarns are called wales, and widthwise yarns are called course. Usually, two knitted fabrics are weft knit and warp knit. Single jersey, Lacoste, Rib Knit, Interlock Knit, Pointelle, Fleece, Knitted Velour etc., are weft knit. Tricot, Raschel etc. are warp knit.

Non-woven fabrics are lighter and weaker than woven or knitted ones. Cotton, rayon, polyester etc. fibres are used to make non-woven fabrics. These are used to make surgical and industrial masks, bandages, wipes and towels. Sometimes non-woven fabrics are also used to make packing materials, roadbed stabilization sheeting, road-building materials, geotextiles, and roofing products.[9]

[9] *https://textileapex.blogspot.com/2020/02/fibre-vs-yarn-vs-fabric-find-differences.html*

Fabric formation industry	Weaving	Many parallel threads are arranged with the required length in weaving yarns production processes. They are wound on a beam, strengthened and smoothed by sizing and interlaced with weft threads on the loom to produce a woven fabric wound on another beam (cloth beam).
	Knitting	In circular and flat knitting yarns production processes, yarn packages are fed in the knitting machine, forming a fabric by interloping the threads together using knitting needles. However, many warp threads are arranged in parallel and wound on a beam to feed the knitting machine in warp knitting. The warp-knitting machine forms a fabric by inter looping the threads using knitting needles.  *Figure 2.11: Modern Power Loom*
	Non-woven	In the production line for needle punched non-woven fabric, artificial fibres are opened to form a fibre web with the required weight and then passed through the needle punching machine. The fibres are pushed depth-wise by barbed needles to get entangled to produce a felt-like fabric with high coherence and strength. Spraying fabric with a chemical adhesive strengthens the needle-punched non-woven and gives more bonding between fibres.
	Tufted Carpet	In the production processes of tufted carpet, the tufting machine is fed with a large number of threads, and a spun-bonded non-woven fabric, as the ground of the carpet. The needles of the tufting machine make tracks of parallel stitches through the ground fabric, creating a terry surface. The formed carpet is back coated with adhesive resin to bind the carpet pile to the ground fabric. The adhesive is covered with jute fabric as a back. Then, the carpet surface is sheared to improve the appearance and regulate it.

2.5.2.1. Woven Fabric

Weaving is the most commonly used manufacturing cloth out of yarn. It involves using a loom to interlace two yarns: the warp yarn (along horizontal direction) and the weft/filling yarn (along vertical direction) on a loom. Before commencing the weaving process, the warp yarns need to be assembled onto beams in a process called warping. This process is also known as beaming. A beam contains a large number of individual yarns parallel to each other. In order to lubricate and protect the warp yarn during weaving, sizing agents (in the form of water solutions or water dispersions) are applied after warping. With sizing, the strength & abrasion resistance of the yarn will improve, and the hairiness of yarn will decrease. A variety of substances can be used as sizing agents.

However, usually starch or starch derivatives, carboxymethylcellulose, poly-acrylic acid or polyvinyl alcohol are used. The type of sizing agent used varies according to the fibre to be processed. Now the yarn is ready to be woven into fabric.

In order to interlace the warp and weft yarn, every loom requires three primary operations as shown fig. 2.12.

- **Shedding:** The process of separating the warp yarn into two layers. One layer is raised, and the other is lowered.
- **Picking:** The process of inserting the weft/filling yarn across the warp end.
- **Beating-up:** The process of pushing the filling yarn across the warp end up to the cloth fell.

Different types of loom are available for weaving of the fabric, which are named after their filling insertion system. Based on the filling insertion system, the weaving machines can be classified as shuttle and shuttleless weaving machines.

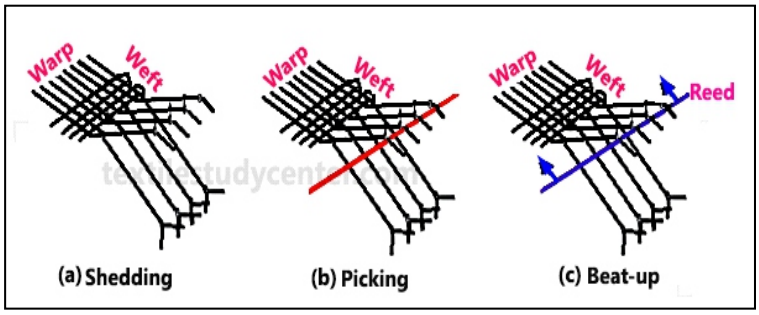


Figure 2.12 Primary operations during weaving



Figure 2.13 Shuttle for loom

Shuttle looms have been used for centuries to make woven fabrics. In this loom type, a shuttle carrying the filling yarn wound on a quill is transported from one side to the other and back.

There are mainly four types of shuttle looms:

- Handloom
- Non-automatic power looms
- Automatic power loom
- Circular loom

Although very practical and versatile, the shuttle looms are slow and noisy. Also, the shuttle sometimes leads to abrasion on the warp yarns and at other times causes thread breaks. As a result, the machine has to be stopped for tying the broken yarns.

Many kinds of shuttleless looms are used for weaving, such as Projectile Looms; Rapier Looms; Water Jet Looms, and Air Jet Looms.

Projectile Loom:

It is sometimes called missile loom as the picking action is done by a series of small bullet-like projectiles

holding the weft yarn and carrying it through the shed, returning empty. All the filling yarns are inserted from the same side of the loom. A unique tucking device holds the ends of the wefts in place at the edge of the cloth to form the selvedge. This loom needs smooth, uniform yarn that is appropriately sized to reduce friction. The projectile loom is less noisy than the shuttle loom.

Rapier Loom:

Rapier loom comes in many types. Early models used one long rapier device that traveled along the loom's width to carry the weft from one side to the other. Another type of rapier loom has two rapiers, one on each side. They may be rigid, flexible or telescopic. One rapier feeds the weft halfway through the sheds of warp yarns to the arm on the other side, which reaches in and carries it across the rest of the way. Rapier looms are very efficient. These looms can manufacture a variety of fabrics ranging from muslin fabric to drapery fabrics and even upholstery fabrics.

Water Jet Loom:

In it, a pre-measured length of weft yarn is carried across the loom by a jet of water. These looms are very fast and of low noise. Also, they do not exert much tension on the filling yarn. As the pick is tensionless, very high warp yarns are needed for efficient operation. Also, only yarns that are not readily absorbent can make fabrics on water-jet looms, such as filament yarn of acetate, nylon, polyester, and glass. However, it can produce high-quality fabrics with a great appearance and feel.

Air Jet Looms:

A jet of air is used to propel the weft yarn through the shed in the air jet weaving looms. Uniform weft yarns are needed to make fabrics on this loom. Also, heavier yarns are suitable for air-jet looms as the lighter fabrics are tough to control through the shed. However, too heavy yarns also can't be carried across the loom by air jet. Despite these limitations, air-jet loom can produce a wide variety of fabrics.

2.5.2.2. Knitted Fabric

Knitted fabrics are made using a series of needles to interlock loops of yarn. Like weaving, knitting is also a mechanical process that involves knotting yarn together with a series of needles. The yarn made for the knitting industry is lubricated or waxed (generally with paraffin wax) to allow knitting at higher speed and protect the yarn from mechanical stresses.

Knitting oil[10]:

Knitting machine needles must be lubricated with so-called knitting machine oils. Due to machine losses, these oils remain on the knitted fabric (about 4 – 8 % of the weight of the fibre). They are now based on synthetic oils, but mineral oil-based formulations are still standard practice. Lubricant in fabric leads to surfactant aids that must be added to the scouring bath to emulsify them.

[10] *Best Available Techniques (BAT) Reference Document for the Textiles Industry, Section 8.2.5 Knitting oils*



Figure 2.14: Circular Knitting Machine

There are two main types of knitting: **weft knitting and warp knitting. Weft knitting** produces a more extensible fabric and produces stockings, tights and socks. Weft knitting is when successive loops of a single yarn form a row running across the width of the fabric. Warp knitting is when successive loops of yarn run along the length of the fabric.

Knitting machines are either circular or flatbed. There are many types of **circular knitting machines.** A single jersey type utilizes one set of needles for knitting, disposed around the machine's circumference. Yarns are fed in multiple bobbins in creels at each side of the machine and delivered to the needles at various feeder points around the circumference. Cloth produced by this method is tubular and is collected on a cloth roller at the machine's base.



Figure 2.15: V shaped knitting Machine

Another type of knitting machine is the flat V-bed type which uses a single yarn supply that moves backwards and forwards on a carriage. The fabric produced by this machine is flat rather than tubular. It is usually employed for making heavier fabrics suitable for garment blanks for pullovers and cardigans.

2.5.3.Pre-treatment of Grey Fabric

The fabric obtained after weaving/knitting is called grey fabric. It does not have properties like absorbency softness. Grey fabric contains natural (dust, wax, pectin, etc.) and added impurities (size, oil, etc.) that are needed to be removed to make fabric suitable for dyeing & printing.

The fabric collected from various weaving setups cannot be used directly for manufacturing various textile products. Several impurities are present in the fabric, such as dust, dirt, oil stains, oil and waxes, starches or other sizing materials, seed particles, and natural colouring materials. These impurities can be classified as:

Natural Impurities: - Natural impurities are generally present in the natural fibres in oil, waxes, natural colour, vegetable matters (such as leaves particles, Seed particles, etc.), Dust particles. In the case of wool, sweat is also considered impurities deposited on the sheep's or goat's hair.

Added Impurities: - This type of impurities is manually added to the yarn or fibres during the manufacturing process to increase the efficiency of the weaving process such as. Sizing materials (including starches or polyvinyl alcohol) are applied on the yarn's surfaces to reduce yarn breakage during the weaving operation and increase the weaving efficacy.) This type of impurities is generally added to synthetic yarns, which contains Antistatic agents and Lubricants, reducing the static charge buildup and friction during the weaving operation. Spin finishes are another example of added impurities. These impurities make fabric hydrophobic and limit the fabric for further Processing.

These by-products together with the auxiliaries and chemicals used in pre-treatment cause a considerable ecological load in the wastewater as well as in the off-gas.

The main objectives of preparatory treatments of textile materials are,

- To remove all the impurities, both naturals and those added during production may interfere in subsequent dyeing or finishing processes.
- Improve the ability of the fibres to absorb water, dyes solutions and chemicals.
- Impart proper brightness or whiteness to fabrics according to need, especially when brilliant or pastel shades are desired.

All of these impurities cannot be removed by a single operation. It requires sequences of operations, which is called Processing. It is not necessary to use all the operations for all the fabrics. All the operations before the dyeing of fabrics are called Preparatory Process or Pretreatments.

Pre-treatment is a key factor for all downstream finishing steps. Poor pre-treatment generates quality problems and consequently re-works and therefore additional ecological loads in the downstream operations.

pre-treatment steps includes Mechanical, wet, and thermal treatment (Figure 2.16). The choice and sequence of processing steps is substrate specific (cotton, wool, man-made fibres, woven or knitted fabric, etc.), and depend also on the end-use resp. downstream processing steps of the textile and the installed equipment. Normally wet processes are carried out with water.

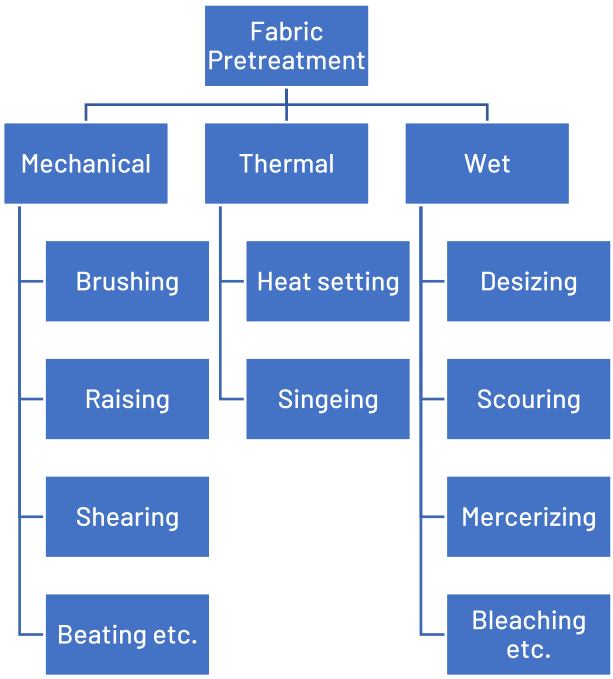


Figure 2.16: Main Pre-treatment processes

Source: Best Available Techniques in Textile Industry
by Dr. Harald Schönberger, Gottenheim and Dr. Thomas Schäfer EnviroTex GmbH, Augsburg

These pre-treatments include Singeing, Desizing, Scouring, Souring, Bleaching and Mercerizing. All of these operations have specific objectives.

It generally depends on the type of fabric, contains the fabric and the end uses of the fabric.

Pre-treatment is a fundamental process for all downstream finishing steps. Poor pre-treatment results in quality problems as a consequence of re-works. Therefore, additional loads are added to the downstream operations. Besides, the cleaning effect of pre-treatment has also an effect on the fibre properties:

- Absorption of dyes and textile auxiliary increases.
- Tensions in textiles are minimized; the dimensional stability is improved.
- The wettability of the material is improved.
- Mercerisation changes the cellulose's crystallinity; the lustre is improved.
- Bleaching increases, the whiteness of the substrates (important for undyed fabrics as well as for fabrics dyed in light shades or with a high brilliance)

Pre-treatment processes and techniques depend on:

- The type of fibre to be treated
- Form of the fibre (yarn, woven or knitted fabrics)
- The amount of material to be treated (for example, continuous methods are more efficient, but are economically viable only for large production capacities)

Typical pre treatment steps for Cotton, wool and man-made fabrics are summarized below.

2.5.3.1. Singeing

The objective of singeing is to remove protruding fibres, which give the fabric a fuzzy appearance. This process gives a smoother and cleaner appearance to the fabric's surface. Singeing is necessary:

- It improves the end-use and wearing properties of textiles.
- The burning-off of protruding fibres results in a clean surface that makes the fabric's structure clearer.
- Singeing reduces the fogginess caused by the differing reflection of light by the projecting fibre, and the dyed fabrics appear brighter.
- A closely singed fabric is essential for printing delicate, intricate patterns.
- Singeing facilitates and speeds up desizing if the fabric is impregnated with desizing liquor immediately after singeing.



Figure 2.17: Gas Flame Singeing of grey fabric

Mainly woven and knitted textiles made of cotton and cotton blends are treated on singeing machines. The machine with gas singeing mainly used in the industries is shown in figure 2.17. Synthetic materials are singed to reduce pilling effects. Sewing yarns are singed to improve their running characteristics. Singeing is often combined with a device to extinguish sparks and a padding device to impregnate the textile directly after singeing with the desizing liquor.

Types of machines used in the singeing process:

- Plate singeing M/C.
- Roller singeing M/C.
- Gas Flame singeing M/C

Table 2.3: Difference between Plate, Roller, and Gas singeing Processes

Plate Singeing Process	Roller Singeing Process	Gas Singeing Process
One side of the fabric can be singed.	One side of the fabric can be singed	Both sides of fabric can be singed
Uniform temperature cannot be maintained.	Uniform temperature cannot be maintained	Uniform temperature can be maintained
Extra lustre is produced due to friction between fabric and surface.	Extra lustre is produced due to friction between fabric and surface.	No Extra lustre is produced
Not suitable for dyeing and printing.	Not suitable for dyeing and printing.	Very suitable for dyeing and printing.
The brush is not used for proper singeing.	The brush is not used for proper singeing.	The brush is used for proper singeing.

2.5.3.2. Desizing

Desizing is a typical step in pre-treatment woven fabrics made of cotton and cotton blends. It is a process of removing the sizing agents on the warp yarns, applied in weaving mills for better weaving efficiency, before further Processing in textile finishing. Also, it is necessary for all grey synthetic materials containing sizes.

Size usually contains an adhesive (film former) and a lubricant. The film former is usually starch or a starch derivative for cotton fabrics. By their very nature, all starches are either water-insoluble or only sparingly soluble.

Desizing is done first in cotton pre-treatment or as a second step after singeing. Water-insoluble sizing agents have to be degraded during desizing; water-soluble sizes can be simply washed out.

The following methods are commonly used (depending on the size type):

- Enzymatic desizing processes; starch
- Oxidative desizing (e.g. persulfate); all size types
- Washing (with/without detergents); water-soluble sizing agents.

Desizing can be carried out in a continuous (pad-steam), semi-continuous process or batch-wise as shown in figure 2.18.

2.5.3.2.1. Enzymatic Desizing

The most effective way to remove starch from fabrics is using extracts containing appropriate enzymes. An outstanding feature of enzyme desizing is the specific nature of the enzyme action. Enzymes are biocatalysts; they differ from usual chemical catalysts because they are particular in their action. They are thermo-labile, have relatively low activation energies, and are usually active only over a narrow range of pH. They are classified based on substrate names that they decompose, e.g. amylases degrade amylose, proteases to proteins, and cellulases to cellulose.



Figure 2.18 Desizing Machine

Some properties of enzymes are as follow:

1) Enzymes are complex and high molecular weight protein molecules. Chemically enzymes are proteins of high molecular weight, e.g. molecular weight of the enzyme α-amylase is about 100,000.

The different preparations are applied under different conditions. 2) Enzymes are susceptible to high temperature and pH values outside their optimum ranges because they can be denatured. Still, most enzymes function best at or near the neutral point at temperatures between 40-60^{0}C;

above these temperatures, its effect is reduced. One exception is α-amylase from bacteria, which may be used at temperatures over this under some circumstances.

3) Enzymes react at specific parts of the substrate molecule because these are specific to their action.

Enzymatic desizing is the classical desizing process of degrading starch size on cotton fabrics using enzymes. The advantage of enzymes is that starches are decomposed without damaging cellulose fibre. A small quantity of enzyme can decompose a large quantity of the substance it acts upon. Effective enzymatic desizing requires strict control of pH, temperature, water hardness, electrolyte addition and choice of surfactant.

Amylases enzyme hydrolyses and reduces the molecular weight of amylose and amylopectin molecules in starch, rendering it water that is soluble enough to be washed off by the fabric.

2.5.3.2.2. Oxidative Desizing

In oxidative desizing, the size is removed by oxidative degradation. This technique is applicable not only for water-insoluble sizing agents but also for water-soluble sizing agents. A single-step process combining peroxide bleaching and oxidative desizing is possible. It has to be taken into account that oxidative desizing may attack cellulose if not well controlled. Following oxidizing agents are used in oxidative desizing:

- Hydrogen peroxide
- Sodium chlorite
- Persulphate
- Sodium bromite

2.5.3.2.3. Washing

Water-soluble sizes (polyvinyl alcohols, modified starch, modified cellulose, polyacrylates, polyesters) can be removed continuously or discontinuously (hot water with or without detergents).

2.5.3.3. Scouring

In the desizing process, only the added impurity of the sizing material on the yarn is eliminated. However, the fabric still retains natural impurities like fats, oils, minerals, pectin and waxes. These impurities interfere with dyeing and finishing, as they affect the fabric's absorbency to a greater extent.

Cotton fabrics and blends are treated discontinuously or continuously with hot alkali to extract sizing impurities. Besides alkaline (mainly sodium hydroxide) scouring agents, surfactants are used in the scouring liquor. The scouring process can be carried out as a separate pre-treatment step or in combination with bleaching or desizing.

The main processes in scouring are:

- Saponification of fats into water-soluble soap and water miscible glycerine on heating with NaOH.
- Emulsification and solubilisation of natural oils and waxes.
- Dissolution and extraction of mineral matter by boiling with water.
- Hydrolysis of proteins into water soluble degradation products.
- Dirt or dust removed is held in a stable suspension with the help of detergents present in the scouring bath.

The material after scouring is more absorbent, free from natural impurities and colouring matter.

2.5.3.4. Bleaching

Bleaching is a chemical treatment employed to remove natural colouring matter from the textile substrate The material appears whiter after the bleaching.



Figure 2.19: Continuous Bleaching Range of grey fabric

Natural fibres, i.e. Cotton, wool, linen etc. are off-white due to colour bodies present in the fibre. The degree of off-whiteness varies from batch to batch. Bleaching, therefore, can be defined as the destruction of these colour bodies. White is also a critical market colour, so the whitest white has commercial value. A consistent white base fabric has real value when dyeing light to medium shades. It is much easier to reproduce shade matches on a consistent white background than one that varies in yellow.

Objective of Bleaching

- It removes the natural colour from textile materials.
- It brings the textile materials permanent white.
- Improve the absorbency of the textile materials.
- Produce textile materials for the following process.
- Some fabrics are sold as bleached goods.

Bleaching may be the only preparatory process for industry, or it may be used in conjunction with other treatments, e.g. desizing, scouring and mercerizing. Combining such treatments for an individual situation will depend on the stringent preparation standard and economic factors within the various options. The fabric might not be bleached for dyeing the fabric in darker shades. Other chemicals will be used in addition to the bleaching agent. These serve various functions such as activating the bleaching system, stabilising or controlling the activation rate, giving wetting and detergent action, or sequestering metallic impurities.

Types of the Bleaching Process:

First of all, fibre type decides upon the choice of the bleaching process (half bleach or full bleach). Also, the bleaching process requires agents that are decided by several factors like concentration of chemicals, liquor ratio (L: R), pH of the chemical solution, and treatment time.

There are two chemically different bleaching processes:

Oxidative bleaching: There are two systems in this processes which are as follows:

(a) Peroxide systems–With hydrogen peroxide, sodium peroxide, sodium perborate, potassium permanganate, peracetic acids and other acids.

(b) Chlorine systems–Sodium hypochlorite, bleaching powder, lithium hypochlorite, sodium chlorite, chloramines, isocyanural trichloride.

Reductive bleaching: Bleaching with sodium hydrosulphite, stabilised hydrosulphite preparations and other sulphoxylates, sulphur dioxide, acidic sodium sulphite, sodium bisulphites.

The choice of chemicals depends on the required degree of whiteness, technological and ecological aspects, machinery, and economic aspects. Overdosing of the bleaching chemicals, insufficient temperature regulation, too long bleaching times, existence of catalysts, insufficient stabilising, etc. may lead to damaging of fibres and increase in effluent load.

Sodium Chlorite

AO_x generation through chlorination reactions with organic compounds has to be minimized through good process control and reduction of chlorite surplus after bleaching (adding of reducing agents, mostly sulfite). Bleaching with sodium chlorite is done under acidic conditions (pH 3 – 5) at temperatures between70 °C and 95 °C; buffers and sodium nitrate are added as a corrosion inhibitor. If the pH is not well controlled, highly toxic chlorine dioxide can be released in the process.

Advantages

- High brightness level (especially for acrylic fibres)

- Negligible degradation of fibres (Less weight loss for cellulosic fibres and no attack to the polymeric.
- Versatile bleaching agent for cellulosic, synthetics and blends, especially poly-cotton blends. It is also safe for those synthetic fibres which are sensitive to alkali.
- Non-sensitive to metal ions such as iron and Water hardness under acidic conditions.
- Provides permanent whiteness to the fabric because sodium chlorite has sufficient oxidizing.
- power to remove all the colouring matter without degrading the fibre quality. Thus can be used safely to produce better and permanent white without loss of tensile strength.
- Sodium chlorite can oxidize many naturally occurring waxes and pectin (in the cellulosic fibres).
- Hence, solubilize them to produce more even pieces of goods.
- Sodium Chlorite is not readily decomposed by acid or temperature. Thus the use of Sodium Chlorite is economical and highly effective in operation.
- The risk of forming oxycellulose is avoided by using lower pH instead of using an alkaline solution.
- The anhydrous salt is not hygroscopic, and samples can be kept for ten years with only negligible loss.

Disadvantages

- It is expensive as compared to hydrogen peroxide.
- It cannot be used for wool and silk.
- The acid solution of sodium chlorite generates Chlorine dioxide that is highly corrosive to metals and toxic. Thus it requires unique materials like glass, porcelain, earthenware or some selected plastic for sodium chlorite bleaching. Thus, it requires buffers and sodium nitrate as a corrosion inhibitor, increasing the bleaching process's cost.
- Fumes of chlorine dioxide are toxic and can cause sickness, lack of appetite, nausea. Hence effective air pollution control is essential.
- Bleaching in neutral and acidic pH damages cotton.
- An anti-chlorine treatment is necessary to reduce the chlorite surplus after bleaching.

Hydrogen peroxide

The fabric is treated in a solution containing hydrogen peroxide, caustic soda and hydrogen peroxide stabilizers at pH 10.5 – 12. The process of regulating or controlling per hydroxyl ion to prevent rapid decomposition of bleach and minimize fibre degradation is described as stabilization. Stabilizers for peroxide normally function by controlling the formation of free radicals. These are complex blends of a selection of materials serving many functions. They can be any of the following:

- Alkali, e.g. caustic soda/carbonate/silicate.
- Dispersant, e.g. acrylates/phosphonates.
- Sequestrants, e.g. EDTA/TPA/gluconates.
- Inorganics, e.g. magnesium salts.
- Colloid stabilisers, e.g. acrylic polymers.

The selection of alkali to be used in peroxide bleaching is dependent on the fibres or blends being bleached. Sodium silicate is the most conventional, readily available and widely used stabilizer.

This sodium silicate acts as a multifunctional agent:

- A stabilizer
- A sequestering agent keeps the metal ions away
- A buffer maintains the alkaline pH.

Sodium silicate does not itself act as a stabilizer. Instead, it reacts with $MgCl_2$ present in water, giving $MgSiO_2$, which acts as a stabilizer.

Other auxiliaries used in hydrogen peroxide bleaching are surfactants with emulsifying, dispersing and wetting properties. Surfactants employed are usually mixtures of anionic compounds (alkyl sulphonates and alkyl aryl sulphonates) with non-ionic compounds such as alkylphenol ethoxylates or the biologically degradable fatty alcohol ethoxylates.

Bleaching with hydrogen peroxide in neutral conditions (pH range of 6.5 – 8) is also possible in some cases (e.g. when treating cotton in blends with alkali-sensitive fibres). At these pH conditions, activators are required to carry out bleaching activities. Operating temperatures can vary over a wide range from ambient to high temperature. Nonetheless, a good bleaching action occurs when the process takes place around 60 – 90 ^{0}C.

A wide range of bleaching processes can be used, including cold pad-batch, bleaching under steaming conditions and bleaching processes in a long bath.

Advantages

- H_2O_2 does not react with residual protein of fibre. Hence, peroxide bleaching keeps the fibre quality intact.
- No need of antichlor treatment as there is no generation of chloramines.
- Permanent white cotton is obtained, and the bleached fabrics are highly hydrophobic. The waxes are solubilized and removed by a hot alkaline solution.
- Its reaction products are relatively non-toxic. It decomposes to oxygen, thus reducing the effluent pollution of the bleaching plant.
- Corrosion of stainless steel equipment does not occur.
- The weight of fabric after bleaching is higher than that of hypochlorite bleaching.
- Peroxide can carry out the scouring action simultaneously with the bleaching action. Thus, using hydrogen peroxide, a single-stage combined scour and bleach, or a continuous method.
- Due to stringent AO_X norm in effluent discharge from chlorine bleaching liquors, there is a shift to the peroxide process for bleaching cellulosic fibres.

Disadvantages

- It also causes a deleterious effect on the skin when used in a concentrated form.
- A stabilizer should be used in order to hold the strength of H_2O_2.
- Higher energy is needed to bleach the fabric.
- H_2O_2 bleaching is expensive.

Sodium hypochlorite

The high reactivity of this bleaching agent imposes softer operative conditions than hydrogen peroxide (pH 9 - 11 and temperatures not above 30 °C). An anti-chlorine treatment follows the bleaching stage to eliminate the hypochlorite and decompose the chloramines generated.

Bleaching with sodium hypochlorite can be carried out in batch (e.g. overflow, jet, jigger, and winch beck), semi-continuous (pad-batch) or continuous mode. A two-stage process is also used in which hypochlorite and hydrogen peroxide are used.

Advantages of hypochlorite bleaching

- Hypochlorite bleaching is the cheapest because its high reactivity leads to milder operative conditions. Thus can save energy.
- Large batches of fabric can be processed.

Advantages of hypochlorite bleaching

- Hypochlorite bleaching is the cheapest because its high reactivity leads to milder operative conditions. Thus can save energy.
- Large batches of fabric can be processed.

Disadvantage

- The process is slow, carried out at a low temperature, and is challenging to integrate into rapid continuous operation.
- The relatively high salt loads in the process are undesirable for ecological reasons.
- When either calcium hypochlorite or sodium hypochlorite acts upon cotton fibres, oxycellulose is formed. This degraded ion product is objectionable to the yarn or cloth because it can lead to the development of yellowish and brownish stains on storage. There is a risk of damage to the cellulosic fibres.
- An anti-chlorine treatment is necessary to eliminate the hypochlorite and decompose the chloramines generated during bleaching.

Optical bleaching

Certain organic compounds possess the property of fluorescence which means that they can absorb shorter wave-length light and re-emit it at longer wave-lengths. A substance can adsorb invisible ultra-violet rays and re-emit them within the visible spectrum. Therefore a surface containing a fluorescent compound can emit more than the total amount of daylight that falls on it, giving an intensely brilliant white. Compounds that possess these properties are called Optical Brighteners or OBA's. The effect is only operative when the incident light has a significant proportion of ultraviolet rays such as sunlight. When OBA's are exposed to UV fluorescing light bulbs, "black light", the objects glow in the dark, a sure fire way of identifying fibers that are treated with optical brighteners. .

There are several classes of chemical compounds whose structure serve the purpose. These structures have dye-like properties and in essence are colorless dyes, they can exhaust onto various fibers. Anionic OBA's will exhaust onto cotton, wool and silk. Cationic ones exhaust onto acrylics and certain polyesters.

Non-ionic ones exhaust onto all synthetics.

OBA's are not a substitute for bleaching. They are used to obtain brilliant market whites. These "white" whites can be obtained without over bleaching and damaging the fibre. On cellulose, they have poor wash fastness but most commercial laundry detergents contain OBA's so they are constantly replenished. Some OBAs have poor wash fastness - some non-ionic types have excellent light fastness. Fibre producers can include OBA,s in their spinning process. These can have excellent durability to both light and washing.

Optical brighteners can be regarded as invisible direct dyes. Application of it is possible in a single step or during bleaching. Optical brightening can also be carried out during finishing. The water toxicity and relatively low degree of bio-elimination of the fluorescent agents are often considered; however, the amount of brighteners in the effluent is on a low level.

2.5.3.5. Mercerizing

Mercerization is a finishing treatment for the cotton fabric to improve lustre, tensile strength and dye uptake. Mercerizing (cotton and cotton blends with strong alkali under tension) improves dye absorption and increases tensile strength. This process achieves a good handle, better dimensional stability, and a resistant lustre. Mercerizing leads to a change in the crystalline structure of the cellulosic molecules and the fibres' swelling. The machine usually used for mercerizing is as shown in figure 2.20.



Figure 2.20: Mercerizing machine

Mercerization is possible

- On grey goods
- After desizing
- After desizing and scouring
- After bleaching
- After dyeing.

Woven fabrics are mercerized in full width, whereas knitted fabrics in full width or rope form

2.5.3.6. Washing/Scouring (synthetic fabrics)

synthetic materials are washed with water and detergents to remove preparation agents (such as spin finishes, coning, warping oils, twisting oils etc. and other impurities). The efficiency depends on dwell time, water throughout and the appropriate conditions concerning temperature and detergents. A high COD load is observed in washing /scouring. The effluent is not readily biodegradable if preparation agents based on mineral oils are used.

The intense exchange of information in the textile chain is vital to adjust the appropriate washing conditions (kind and quantity of surfactants, pH, temperature, dwell time, liquor exchange etc.) to achieve good quality and minimize effluent load.

2.5.3.7. Weight Reduction

Weight reduction aims to produce finer fibres in the handle and a fabric's visual properties. Polyester

fabric is treated with sodium hydroxide to give a smooth surface texture with decreased fibre diameter.

The chemistry is based on the saponification of the glycol and terephthalate at the surface of fibres with lye, whereby the terephthalic acid formed neutralizes sodium hydroxide solution, leading to a steady fall in the pH of the treatment bath. The rate of weight reduction increases with liquor concentration and temperature. The process temperature lies in the range 80 – 120 °C and treatment time depending on liquor concentration and temperature from 1-4 hours.

Relevant results are achieved by monitoring the concentration of alkali, time and temperature of the process without any significant deterioration in the crucial characteristics of the fibre. The higher temperature in processes with strong liquor and consequent relatively long dwelling time leads to an unnecessary loss of strength.

2.5.3.8. Raw wool scouring

The number of impurities, especially the wool grease, may be so high that it may hinder wool processing. The transfer of wool grease from fibres to metallic machine parts may lead to dirt/oil accumulation on processing equipment. Therefore, wool is generally scoured at the fibre stage. Scouring involves treatment with aqueous scouring liquors containing mainly surfactants. Due to scales' presence on the wool fibre surface tends to shrink.

2.5.3.9. Carbonizing

Sometimes scoured wool contains vegetable impurities that mechanical operations cannot altogether remove. Sulphuric acid is used for destroying these vegetable particles. This process is called carbonizing. The following steps are involved in this process:

- Contact with carbonizing liquor (sulphuric acid up to 7%)
- Centrifugation or squeezing
- Drying
- Burning (up to 140 °C)
- Mechanical treatment and
- Neutralisation.

2.5.3.10. Heat Setting

Heat setting is a heat treatment by which shape retention, crease resistance, resilience and elasticity are imparted to the fibers. It also brings changes in strength, stretchability, softness, dyeability and sometimes on the color of the material. Different heat setting methods also help get a flat fabric with required weight and standard width. All these changes are connected with the structural and chemical modifications occurring in the fiber. Normally heat setting done for synthetic fabric.[11]

In order to achieve good shape retention and to prevent the marking of running creases during wet processing, polyester fibres must be stabilized; in other words, tensions within the individual fibres and in the fabric are levelled out by relaxation. Heat setting step is to achieve the dimensional stability of a yarn or fabric containing thermoplastic fibres. The fibres are extended during drawing, spinning, weaving, or knitting and finishing processes. Twisting and bending forces exert significant stress on the fibres. As a result, any subsequent heat treatment or washing leads to stress reduction that shows as shrinkage or

[11] *Methods of Heat Setting in Textile Industry (https://textilelearner.net/methods-of-heat-setting-in-textile-industry/)*

change of shape. Therefore, the objective of the heat setting process is to achieve desired stress-free fibres to make a textile product.

Setting is carried out at high temperature, usually with hot water, steam, or dry heat. The selection of the setting method depends on the textile material itself and the desired setting effect, and very often, of course, on the equipment available. Relaxation of tensions within the textile material results in shrinkage. Excessive shrinkage is liable to cause trouble in subsequent finishing. After setting, the material should not undergo any further shrinkage during wet processing; this is particularly important in cases where the material is dyed or finished in the batched state.

The Pin Stenter is an ideal fabric setting machine, as it completely controls the width and length. The heating time to achieve a setting temperature of 200^{0}C depends on the fabric thickness and air velocity, generally it is 20 seconds minimum. If the fabric is dried and heat set in one run, the Stenter speed will be low, and the fabric temperature will not rise until drying is almost complete. However, the time required toreach the set temperature is very short. In the case of blends with natural fibres, the temperature set will usually be limited to 150°C (wool) or 180°C (cotton & cotton blends). This is to control the damage and yellowing to the extent possible.

The sequence of the heat setting process depends on the fabric structure, its cleanliness and the dyeing method. Setting after scouring is recommended when a fabric is heavily oil-stained. Setting after dyeing may significantly alter the colour.

2.5.3.11. Environmental issues related to pre-treatment

Water pollution is the leading environmental issue associated with textile pre-treatment/wet processing. Minor air pollution by chemicals and lint is also associated with this process.

Even for a constant product type, no two textile mills use precisely the same production methods. Those steps taken after forming fabric are primarily the most water consuming and energy-intensive and, hence, potentially the highest waste-generating part of the textile industry. The characteristics of the emissions vary concerning several factors: the make-up (yarn or fabric), the sequence adopted, combining of steps to carry out the process in a single go etc. The most relevant issues related to the various operations involved in pretreatment have been highlighted below.

Singeing

Singeing is essential when a smooth surface is of interest (esp. as pre-treatment step before printing processes). Of ecological interest are dust and volatile organic carbon (VOC). Also a relative strong odour emission can be observed during singeing.

Singeing is often combined with a device to extinguish sparks and a padding device to impregnate the textile directly after singeing with the desizing liquor.

Sizing

Size is a mixture of primary and auxiliary chemicals. Three main types of size are currently used.

- Natural products (starch)
- Entirely synthetic products (PVA, PVAc, PAA, Pes).
- Semi-synthetic products (blends) (modified starch, starch ether, starch ester, carboxy methyl cellulose (CMC), hydroxy ethyl cellulose (HEC), carboxy methyl starch (CMS).

Auxiliaries used in sizing mixture include:

- Adhesives and binders, Antistatic agents, Anti-sticking agents, Biocides, Defoamers, Deliquescent, Emulsifier, dispersants and surfactants, Humectants, Lubricants and Softeners, Thinning agents, Tints.

These additives present in the size mixture will later be removed in wet processing. Thus, these materials will appear in waste streams from de-sizing operations. Most of these additives impart very high BOD values.

Artificial fibres are generally sized with water-soluble sizes easily removed by a hot water wash or in the scouring process. On the other hand, natural fibres such as cotton are most often sized with water-insoluble starches or a mixture of starch and other size materials. Enzymes are used to break these starches into water-soluble sugars.

Bacteria in wastewater treatment can quickly attack the water-soluble sugars, which are highly degradable and have high BOD. The washing water from desizing may contain up to 70 % of the total COD load in the final effluent. Neither enzymatic nor oxidative desizing allows size recovery. In contrast, size recovery is technically feasible for some synthetic sizing agents but practically difficult.

Desizing

It is to be mentioned that the desizing liquors contribute to the main part of the COD-load of a finishing mill (up to 70% in mills finishing woven fabrics). Depending on the desizing technique, COD concentrations range from 3000 to 80000 mg /lit, observed in the desizing liquors.[12]

The major ecological impact in scouring is caused by non-readily biodegradable surfactants and complexing agents and a high COD-load of the organic impurities removed from the fibres. COD-concentrations from 2000 to 6000 mg /lit are typical.[13]

In man-made fabric scouring, synthetic materials are washed with water and detergents to remove preparation agents as spin finishes, coning, warping, twisting oils, etc., and other impurities. The efficiency depends on dwell time, water througput and the appropriate conditions concerning temperature and detergents. A high COD-load is observed in washing /scouring. If preparation agents based on mineral oils are used, the effluent is not readily biodegradable.

Bleaching

The most common bleaching agents include hydrogen peroxide.

The strong alkali causes main ecological impact to wastewater, complexing agents (phosphonates, polycarboxylic acids), wetting agents, stabilizing agents (esp. sodium silicate), and by-products removed from the cellulose. COD- content in the effluent is in a range between 3000-10000 mg O_2/l.

Bleaching with sodium chlorite is done under acidic conditions (pH 3 – 5) at temperatures between 70 °C and 95 °C; buffers and sodium nitrate as a corrosion inhibitor are added.

Highly toxic chlorine dioxide can be released in the process, if the pH is not well controlled. AOX generation through chlorination reactions with organic compounds has to be minimized by means of a good process control and reduction of chlorite surplus after bleaching (adding of reducing agents; mostly sulfite).[14]

[12] *Best Available Techniques in Textile Industry by Dr. Harald Schönberger, Gottenheim and Dr. Thomas Schäfer EnviroTex GmbH, Augsburg, pg 46*
[13] *Best Available Techniques in Textile Industry by Dr. Harald Schönberger, Gottenheim and Dr. Thomas Schäfer EnviroTex GmbH, Augsburg, pg 46*
[14] *Best Available Techniques in Textile Industry by Dr. Harald Schönberger, Gottenheim and Dr. Thomas Schäfer EnviroTex GmbH, Augsburg, pg 47*

Mercerising

The sodium hydroxide concentration varies from 20% - 30%. And, the main ecological impact in mercerising is the high concentrated residual lye.

Heat setting

heat setting of grey fabrics or insufficient pre-washed textiles can lead to a considerable ecological impact to the off-gas depending on the amount and type of preparation agents and other fibre inherent ecological loads (residual fibre solvents, residual fibre monomers). In case of direct heated stenters Organic-C-load and formaldehyde content in the off-gas due to incomplete burning out of the gases (methane or propane/butane) is to be considered.

2.5.4. Dyeing

Dyeing is a colouring method of textile material. A dye is applied to the fibre, yarn or fabric uniformly to obtain an exact shade with performance and fastness appropriate to its final use. Dyestuffs may be dissolved or dispersed in a liquid and thickened with a suitable thickening agent, applied to the fabric and then fixed on the fabric by steaming or other means. In dyeing, a small amount of dye will colour a large amount of fabric because it absorbs or exhausts the dye from the distributed liquid.

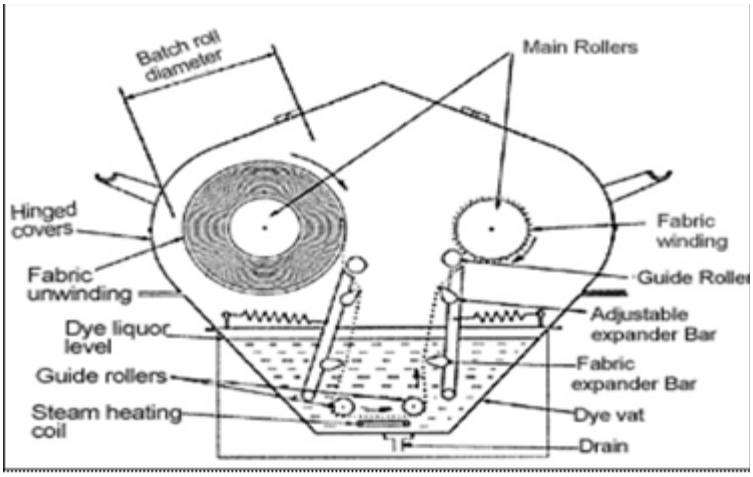


Figure 2.21: Overview of Jigger Dyeing Machine (b) real machine

The factors which influence the dyeing are:

I) The fibre to be dyed,
ii) Dyestuff to be used and
iii) Medium in which dyeing is done.

The type of dyestuff used is determined by the property of fibre to be dyed. These factors are closely interdependent. For example, the fibre to be dyed may be natural or synthetic. If the fibre/fabric is not absorbent, it will be difficult to obtain complete penetration of dyes.

Dyeing can be carried out in batch or continuous/semi-continuous mode.

The choice between the two modes depends on the type of makeup, the chosen class of dye, the available equipment, and the cost involved.

Both continuous and batch dyeing involves the following steps:

- Preparation of the dye liquor
- Dyeing
- Dye Fixation
- Washing and drying

Batch Dyeing:

The batch dyeing process is the most popular and common method used for dyeing textile materials. It is also referred to as exhaust or discontinuous dyeing. A certain amount of textile material is loaded into a dyeing machine and brought to equilibrium with a solution containing the dye along with addition of the auxiliaries over a period ranging from minutes to hours. The dye gets slowly transferred from a comparatively large volume dye bath to the fibre, yarn, or fabric to be dyed.

The dyeing process starts with the absorption of colourant onto the external surface, followed by diffusion and migration through the fibre. Before initiation of batch dyeing, the steps to be accomplished are to fill the machine with water, load the fabric, and ensure it is thoroughly wetted. Primarily needed chemicals are added to the system, followed by establishing the initial dyeing temperature and later on adding dyes (either all one time, in several portions, or sequentially, depending on the type of dyeing machine).

The dyeing process is temperature-sensitive. Different fabrics need a changed range of temperature for appropriate dyeing. Some batch dyeing machines operate at temperatures below 100°C which can dye cotton, rayon, nylon, wool, and other fibres. However, polyester and a few other synthetic fibres require a temperature higher than 130°C for dyeing. Closed type dyeing machines are a boon to such fabrics. Due to a pressurized system, it can be operated at a temperature above 100°C.

When the dyeing is judged to be the right shade, the spent dye bath is drained and the textile material is washed to remove unfixed dyes and chemicals. Washing is usually carried out in the same equipment. The use of chemicals and controlled temperatures accelerates and optimises the dye's exhaustion and fixation(rate/level).

An essential parameter in batch dyeing is the liquor ratio of the equipment. It is defined as the weight ratio between the total dry material and liquor. For example, a liquor ratio of 1:10 means 10 litres of water on 1 kg textile material. This parameter influences the amount of water and energy consumed in the dyeing process and plays an essential role in the level of exhaustion of the dye and the consumption of both chemicals & auxiliaries.

A few vital batch dyeing machines are the Jigger dyeing machine, Jet dyeing machine, Winch dyeing machine, soft flow dyeing machine.

- Continuous and Semi-Continuous Dyeing:

In continuous and semi-continuous dyeing, the dye liquor is applied to the textile by impregnation and fixation.

The fabric passes through a small bath containing the dye solution in continuous impregnation methods. Then two rubber-covered rollers squeeze out the excess solution. This process is called padding. After padding, the dyes must diffuse into the fibres. This step is called fixation, which is achieved using either chemical or heat (steam or dry heat). The final operation is washing, usually carried out in washing machinery at the end of the same line. Continuous dyeing is most suitable for woven fabrics. Mainly continuous dye ranges are designed for dyeing blends of polyester and cotton. Some of the continuous



Figure 2.22 : Dis-continuous Dyeing Machine (Softflow machine)

dyeing process methods are Pad-steam, Wet-steam, and thermosol dyeing. In semi-continuous dyeing, the fabric is first impregnated with the dye liquor in a padding machine. Then it is subjected to batch-wise treatment in a jigger. This step helps in the fixation of the dyes onto the fibre. After this fixation process, the material in full width is thoroughly cleansed and rinsed in continuous washing machines. Alternatively, it can also be stored with a slow rotation for many hours. One of the widely used techniques for the semi-continuous dyeing process is the Pad Batch Dyeing.

There is only one point of difference between the continuous and semi-continuous dyeing process. In semi-continuous dyeing, the dye is applied continuously by padding, while fixation and washing remain discontinuous. In continuous and semi-continuous processes, the liquor ratio is not of practical importance. It is not used as a parameter. In these processes, the factor to be taken into account is the wet pick-up % (grams of liquor picked up by 100 grams of substrate) and the concentration of the dye.

Selection of Dye:

A dyestuff is a molecule that contains a chromophoric group (conjugated system) capable of interacting with light, thus giving the impression of colour. Textile dyeing involves using several different chemicals and auxiliaries to assist the dyeing process. Some of them are process-specific, while others are used in other operations also. Some auxiliaries (e.g. dispersing agents) are present in the dyestuff formulation. However, more commonly, auxiliary agents are added later to the dye liquor.

Table 2.4 Classification of dyes according to usage

Dye class	Cellulose (cotton, viscose, rayon)	Protein (woo/, silk)	Polyester	Nylons	Acrylics
Direct	**	*	-	*	-
Reactive	**	**	-	*	-
Sulphur	**	-	-	-	-
Vat	**	-	-	-	-
Disperse	-	-	**	*	**
Acid	-	**	-	**	-
Basic	-	-	-	-	**

** The most important dye applied in dyeing and printing.
* Less important dye applied in dyeing and printing.
- No practical application.

Source: Process control in dyeing of textiles, pg 301

Table 2.5 The key issues concerned for dye selection

Parameter	**Requirement**
Dyeing behaviour	Shade consistency
	Evenness
	Exhaust and fixation rate
	Colour fastness
	Reproducibility
	Compatibility
Production cost	Dye price
	liquor ratio
	Auxiliary agents required
	Dyeing temperature and time
	Washing effectiveness
	Short dyeing process
	Right-first-time
Others	Environmental friendly

Source: Process control in dyeing of textiles, pg 308

The above-mentioned table 2.5 lists the majority of considerations in dye selection. The type of dyestuff used is determined by the nature of fibre being dyed and the desired fastness properties. All classes of dyestuffs are chemically diverse and applicable for dissimilar fibres with different application methods as shown in table 2.4. The nine major classes of dyestuff commonly used in textile industry are Direct dyes, Vat dyes, Reactive dyes, Azoic dyes, Sulphur dyes, Disperse dyes, Acid dyes, Metal complex dyes and Pigments.

1. Vat Dyes

Vat dyes are insoluble organic compounds, and they do not have any substantivity to cellulose. These dyes are widely used for cellulose, protein, and nylon fibres. They produce good colour range. Bright green is more popular in this class. A large amount of dye is required to attain deeper shade.

Application

Since these dyes are insoluble in water, they cannot be applied directly to the fabrics. First, these dyes are converted into water-soluble form (by reducing them with the help of caustic soda and sodium

hydrosulphate). They can then be applied to the fabric. After the application, these dyes are again converted into water-insoluble form by oxidation process (with hydrogen peroxide and acetic acid or simply by air oxidation).

These dyes are most difficult to process and require a skilled person to dye the fabric. Vat dyes have excellent fastness to crocking, perspiration, chlorine bleaching, oxidizing agents and high-temperature treatments.

Vat dyes are used on the best quality of fabrics where all-around fastness is required. This is a costly dyeing process. The high initial cost of dye and chemicals prevents it from being used in regular fabrics dyeing. Indigo is the first known class of Natural Vat dye.

2. Azoic/Naphthol Dyes

Azoic Dyes are derived from aryl amides organic compounds. These chemical compounds cannot be used directly as dyes. However, the dyes are formed inside the fibre by the reaction of primary Amines with Napthols under controlled conditions. Hence, these dyes are also called ingrain dyes. The azo group is generally present in this dyes class, also called Azo dyes.

These dyes are also insoluble in water and primarily used for cellulose fibres. Sometimes these are used with triacetate to produce black shades.

These dyes produce a full range of red, orange, brilliant yellow colours and maroons, scarlet, deep black, and burgundies. Azoic dyes lack green and bright blue colours.

Application

These dyes are applied in two stages; the first stage is called Naptholation of the fabric. In the second stage, the fabric is treated with soluble salt of primary amines, at cold conditions, generally 0°C – 5°C. Hence these dyes are also called Ice colours. Owing to this, these dyes are the first choice of the dyers for Batik printing. They have good colour fastness to washing, dry cleaning and poor to good fastness to light. Dark colours have poor fastness to crocking. The Azoic Dyeing process is complex and time-consuming.

3. Direct Dyes

These dyes are derived from a formulation of Benzedrine salts. These are water-soluble dyes and the least expensive ones. These dyes are easy to apply and can be applied directly to the fabric without any pre-treatment. Dye fixing agents are not required to fix this category of dye. These dyes are widely used on cellulosic fibres.

Direct dyes have a wide range of colours and shades. The fabric dyed with the direct dyes generally does not have bright colours. Only bright green is available among the bright colours, but it is more expensive than any other colour.

Application

These are water-soluble dyes; hence, they can be directly applied to the fabric. These dyes have good colour fastness to perspiration and dry cleaning. The light fastness of these dyes varies widely from poor to very good.

Some direct dyes are metalized with copper to increase their lightfastness. In other cases, copper salts are applied after treatment to improve light and wash fastness. These dyes have poor fastness to washing and crocking. The majority of the direct dyes are used as a background colour for discharge printing.

4. Sulfur Dyes

These dyes are derived from the formulation of compounds containing sulfur. These are water-insoluble dyes and are applied by the exhaust dyeing method. Sulfur dyes are widely used for cellulosic fibres for darker shades

Application

These are water-insoluble dyes and cannot be applied to fabric directly. Sulfur dyes are water-soluble and are made by reducing with Sodium Sulphite and sodium hydroxide. If dye is still insoluble, then small amount of Sodium Hydro Sulphite is added with warm water. Once the dye becomes water-soluble, it is applied by the exhaust dyeing method.

After dyeing, Sulfur dyes are again converted into water-insoluble by the oxidation process. These dyes are generally used for darker shades, especially Navy-blue, Jet black, Brown, and Khakhi. These dyes are not having full spectrum of colors; true yellow color is not available in this dye category.

5. Reactive Dyes

Reactive dyes are water-soluble anionic dyes. These dyes can be classified as hot brand reactive dyes and cold brand dyes. Since these types of dyes react with fibres and make covalent type of bond with the fibre, they are called Reactive dyes.

These dyes are primarily used for cotton and other cellulose fibre at an alkaline pH of 9-12. However, these dyes can also be used for wool, silk and polyamide fibres in weak acidic dye baths.

Application

The exhaust and pad batch methods can apply reactive dyes and are available in complete range of colors. They are very bright in colour.

These dyes are having very some properties like

- Good fastness to washing,
- Good to excellent fastness to light,
- Good fastness to dry cleaning, perspiration, crocking and
- Poor fastness to chlorine bleaching.

It is elementary to obtain level dyeing using reactive dyes. These dyes have high flexibility in the choice of application of dyeing. These dyes take excessive time for the dyeing process. The cost of reactive dyeing is high because of the loss of dyes during application and extensive washing.

6. Disperse Dyes

These dyes were initially developed for the dyeing of cellulose acetate. However, they are used to dye nylon, cellulose triacetate, and acrylic fibres. These dyes were used mainly for the dyeing of polyester material. Disperse dyes are Non-ionic aromatic compounds with relatively low molecular weight and extremely low solubility in water.

These dyes are available in powder, granules, liquid or paste. These dyes can be sublimated at a higher temperature. This sublimation property of Disperse dyes at high temperature is used in the transfer printing and rapid dyeing process.

Polyester dyeing is generally carried out at a high temperature and high pressure. These dyes are also used for heat transfer printing. Disperse dyes produces an excellent range of shades except for dark blue and black. These dyes have good -excellent fastness to perspiration, crocking, dry cleaning, and Fair-Good fastness to light and washing. When these dyes are used on acetate, they exhibit poor fastness to light and are subject to gas fading.

7. Basic Dyes

These are water-soluble dyes and contain cationic groups derived from salts of triphenylmethane derivatives. These dyes are mainly used for dyeing acrylic and mod acrylics materials. Apart from these, basic dyes can also be used effectively for dyeing nylon with good fastness but wool and silk with poor fastness properties.

Some variety of polyester can also be dyed with the Basic class of dyes. A basic dye produces a complete range of bright colours with Good colour fastness to light, washing, perspiration and crocking for acrylic and modacrylic. However, it exhibits very poor fastness to washing and light on wool and silk.

8. Acid Dyes

These dyes are sodium salt of sulphonic acid that has an excellent affinity to wool and silk fibre under an acidic medium.

- These dyes are available in the form of salts and are water-soluble.
- These dyes are applied in an acid medium by the exhaust method.
- Acid dyes are mainly used for the dyeing of wool and silk. However, Acrylic, nylon and spandex can also be dyed with acid dyes with excellent fastness properties.

An acid dye produces a complete range of colours except for bright red and greenish-blue. However, some bright colours tend to bleed while others have good color fastness to light, dry cleaning, and crocking. A few of the Acid dyes have poor fastness to washing.

9. Chrome / Mordant / Metallic Dyes

In this class of dyes, Metallic salt of cobalt's, aluminium or copper are added to dye molecules to improve the dyes' fastness properties. These water-soluble dyes can be applied in an acidic medium on fibre, yarn or fabric form are generally and are applied. Mordant dyes take more time compared to other classes of dyes.

Metallic dyes are effectively used for dyeing of wool & silk, where maximum wet fastness is required. However, Acrylic, nylon, and spandex can also be dyed with mordent dyes. Mordant dyes have excellent fastness to perspiration and washing. Good fastness to light and dry cleaning and very good fastness to crocking.

Table 2.6: Application of dyes on Various Fibres

Dye	Application
Acid	Wool, silk, synthetic fibres, leather
Azoic	Printing inks and pigments
Basic	Silk, wool, cotton
Direct	Cotton, cellulosic and blended fibres
Disperse dyes	Synthetic fibres
Reactive	Cellulosic fibres and fabric
Organic pigment	Cotton, cellulosic, blended fabric and paper
Sulphur	Cotton and cellulosic fibres
Vat dyes	Cotton, cellulosic and blended fibres

Dye preparation:

The preparation of the solution or dispersion of the dyes is necessarily not as simple as it might seem. Most dyes are easy to dissolve, but the less soluble types require care.

Firstly, water-soluble dyes must be completely dissolved in solution. The undissolved particles may cause deeply coloured spots on the fabric surface.

Dye powders usually are pasted with warm water. A wetting agent or some chemical agents often helps wet the powder. Then, cold, warm or boiling water is poured onto the paste, and the mixture is stirred well. Gradually, granules formed can be dispersed in water and dissolved by stirring. Boiling will usually dissolve all the dyes if the concentration is high or has limited solubility.

The concentrated dye stock solution is added to the bath through a fine sieve to ensure the removal of undissolved particles. The same techniques are also used to prepare dispersions of insoluble dyes such as vat and disperse dyes.

In some cases, soluble dyes may be placed directly into the water already in the dye bath before the fabric is loaded.

Various chemicals and auxiliaries used additionally with dyestuffs are given in the table 2.7.

Table 2.7 List of Chemicals & Auxiliaries used in dyeing

Chemicals & Auxiliaries	Function
Solublizing Agent	Increase the solubility of dyes. Controls the sublimation at high temperature.
Reduction Inhibitor	Mild oxidizing agent controls the reduction of dyes at high temperature or during steaming.
Alkali	Controls the rate of reaction between dyes and cellulose or in other words it is used for fixation of Reactive Dyes.
Binding Agent	Used as an adhesive to fix the pigment dyes on cotton fibre at high temperature.
Wetting Agent	To increase the wettability of fabric and penetration of dyes in the fibre.
Dispersing Agent	Used for dispersing of disperse and vat dyes.
Antifoaming Agent	Used to prevent formation of foam during stirring or during dyeing in one bath.
Electrolyte	Decreases solubility of dyes in liquor. Increases affinity between dyes and fibre under moist condition.

Dyeing is often one of the final processes in textile processing. Many types of dyeing faults, such as colour blotches and spots, colour shading from side-to-side, end-to-end or face-to-face of the fabric, watermarks, and crack or crease marks, are often a consequence of poor preparation, dye selection, or dyeing technique. For uniform dyeing, the fabric's absorbency must be uniform. Pre-treatment may not remove all the natural and synthetic chemicals present in the grey material. However, care should be taken that residues should be minimal and uniformly distributed.

Methods of Dyeing

Textiles may be dyed as fibre, yarn, fabric, and garments, depending upon the type of fabric or garment produced. Colour is applied to the fabric by different methods, for different fibre types and at different stages of the textile production process. Dyeing can be done during any stage in the textile manufacturing process.

Dyeing methods include:

- Direct dyeing;
- Stock dyeing;
- Top dyeing;
- Yarn dyeing;
- Piece dyeing;
- Garment dyeing
- Solution pigmenting or dope dyeing etc.

Direct dyeing and Yarn Dyeing methods are the most popular ones.

1. Direct Dyeing

When a dye is applied directly to the fabric without the aid of an affixing agent, it is called direct dyeing. In this method, the dyestuff is either fermented (for natural dye) or chemically reduced (for synthetic vat and sulfur dyes) before being applied. The direct dyes, used mainly for dyeing cotton, are water-soluble and can be applied directly to the fibre from an aqueous solution. Most of the synthetic dyes, other than vat and sulfur dyes, are also applied in this way.

2. Stock Dyeing

Stock dyeing refers to the dyeing of the fibres or stock before it is spun into yarn. It is done by putting loose, unspun fibres into large vats containing the dye bath, then heated to the temperature required for the dye application and dyeing process.

This type is usually suitable for woollen materials when heather like colour effects are desired. Wool fibre dyed black, for example, might be blended and spun with un-dyed (white) wool fibre to produce a soft heather shade of grey yarn.

Tweed fabrics with heather like colour effects such as Harris Tweed are examples of stock dyed material. Other examples include heather like colours in covert and woollen cheviot.

3. Top Dyeing

Top dyeing is also the dyeing of the before the fibre is spun into yarn It serves the same purpose as stock dyeing – producing soft, heather-like colour effects. The term top refers to the fibres of wool from which the short fibres have been removed. The top thus selects long fibres that are used to spin worsted yarn. The top in the form of sliver is dyed and then blended with other colours of dyed top to produce desired heather shades.

4. Yarn Dyeing

Yarn dyeing is the dyeing of the yarns before they have been woven or knitted into fabrics. In yarn dyeing, dyestuff penetrates the fibres in the yarn's core. Yarn dyeing is used to create exciting checks, stripes and plaids with different-coloured yarns in the weaving process.

There are many forms of yarn dyeing:

A. Skein (Hank) Dyeing

Skein dyeing consists of immersing large, loosely wound hanks (skeins) of yarn into dye vats specially designed for this purpose. Soft, lofty yarns, such as hand-knitted yarns, are usually skein dyed. Skein dyeing is the costliest yarn-dyeing method.

B. Package Dyeing

The yarn is wound on a small perforated spool or tube called a package in package dyeing. The flow of the dye bath alternates from the centre to the outside, and then from the outside to the centre of the package. Many spools fit into the dyeing machine. Package dyed yarns do not retain the softness and loftiness of skein-dyed yarns. However, they are satisfactory and very widely used for most types of yarns found in knitted and woven fabrics.

C. Warp Beam Dyeing

Beam dyeing is the much larger version of package dyeing. An entire warp beam is wound onto a perforated cylinder then placed in the beam dyeing machine. Beam dyeing is more economical than a skein or package dyeing. However, it is only used in woven fabrics where an entire warp beam is dyed. Knitted fabrics, which are mainly produced from the cones of the yarn, are not adaptable to beam dyeing.

5. Piece Dyeing

Piece dyeing is the dyeing of cloth after it is woven or knitted. It is the most common method of dyeing. The various methods used for this dyeing include jet dyeing, Jig dyeing, pad dyeing and beam dyeing.

6. Garment Dyeing

Garment dyeing is the dyeing of the completed garments. The types of apparel that can be dyed are mostly non-tailored and simpler forms, such as sweaters, sweatshirts, T-shirts, hosiery, and pantyhose. Before dyeing, the effect on sizing, thread, zippers, trims, and snaps must be considered. Customized items, such as suits or dresses, cannot be dyed as garments because the shrinkage difference of the various components and linings distort and misshape the article.

Garment dyeing is done by placing a suitable number of garments (usually about 24 sweaters or the equivalent, depending on the weight) into a large nylon net bag. The garments are loosely packed. From 10 to 50 of the bags are placed in large tubs containing the dye bath, which is kept agitated by a motor-driven paddle in the dye tub. The machine is appropriately called a paddle dryer.

2.5.4.1. Environmental issues related to Dyeing

Potential sources and types of emissions associated with dyeing processes are emissions to water during colour kitchen operation, i.e. dye & auxiliaries' preparation and batch/continuous dyeing.

Water polluting substances in the process may originate from dyes, auxiliaries, basic chemicals and contaminants present on fibre. Owing to the low vapour pressure of the substances in the dye bath, emissions to air are generally not significant. They can be regarded more as problems related to the workplace atmosphere.

Pollutant impacts are also associated with chemicals used during dyeing, equipment maintenance and cleaning. Dyeing contributes most of the metals and essential salts and colour in effluent from textiles operations. These may originate from the dyes themselves. These are priority areas for pollution prevention. Certain reports are stating that dyeing consumes 7% of the water and contributes 5% of the BOD in a typical cotton finishing operation.[15] The table 2.8 gives the detail of the pollutants associated with various dyes.

Table 2.8 - : Pollution associated with Dyes

Dye Class	Type of Pollution
Direct dyes	Salt, after treatment with water toxic cationic agents
Reactive dyes	Partially low fixation degree, AOX source, low adsorption tendency of dyestuff hydrolysates in activated sludge treatment, high amount of salts (sodium chloride, sodium sulfate)
Vat dye	Reducing agents (sulfur compounds), partially halogene containing oxidizing agents
Sulphur dyes	Sulfur containing dyestuffs and reducing agents, partially halogene containing oxidizing agents
Chrome dyes	Chrome
Metal Complex dyes	Heavy metal content in dyestuffs
Basic (cationic)	Retarder in dyeing PAC (quaternary ammonium compounds)
Disperse dyes	Carriers, reductive aftertreatment (sulfur compounds)

Source: Best Available Techniques in Textile Industry by Dr. Harald Schönberger, Gottenheim and Dr. Thomas Schäfer EnviroTex GmbH, Augsburg, pg 41

Spent dye baths, residual dye liquors and water from washing operations always contain a certain percentage of unfixed dye. The rates of fixation vary considerably among the different classes of dyes.

The degree of fixation of an individual dye varies according to fibre, shade and dyeing parameters. Therefore, fixation rate values can be given only as approximations. However, they help explain the amount of unfixed dyes found in wastewater. The table[16] 2.9 below gives the information about the number of unfixed dyes from various processes.

[16] *Water and Chemical use in the Textile Dyeing and Finishing Industry (GG62 Guide) (http://www.envirowise.gov.uk/uk.html)*

Table 2.9: Fixation percentage of dyes

Fabric	Dye type	Unfixed dye (percentage)
Wool and Nylon	Acid dyes/reactive dyes for wool	7 – 20
	Pre-metalized dyes	2 – 7
	After chromes	1 – 2
Cotton and viscose	Azoic dyes	5 – 10
	Reactive dyes	20 – 50
	Direct dyes	5 – 20
	Pigment	1
	Vat dyes	5 – 20
	Sulphur dyes	30 – 40
Polyester	Disperse	8 – 20
Acrylic	Modified basic	2 – 3
Polypropylene	Spun dyed	N/A

Source: Textile Dyeing by N.N. Mahapatra, pg 3

Another factor to be taken into consideration is the colourant's colour strength. For example, with reactive dyestuffs, less amount of colourant is needed to achieve a given shade compared to other classes of dyes (e.g. direct, vat and sulphur dyes). So less dyestuff alone will have to be removed from the wastewater.

Dyestuffs that are poorly bio-degradable (unless they are submitted to destructive treatment techniques) will pass through a biological wastewater treatment plant and will ultimately end up in the discharged effluent. This results in objectionable coloured water. This is the first noticeable trait of the receiving water is the colour. High doses of colour cause aesthetic impact and can also impede photosynthesis, thus affecting aquatic life.

Other effects are related to the organic content of the colourant (generally expressed as COD and BOD, but could be better expressed as organic carbon, using the TOC parameter). Its aquatic toxicity and the molecule of metals or halogens can give rise to AO_x emissions. Vat, disperse, and reactive dyes are more likely to contain halogens in their molecule.

Different additives are present in the dye formulations depending on the dye class and the application method employed (e.g. batch or continuous dyeing, printing). Typical additives used are: Salts, dispersants, thickening agents, binders and buffers. Since these substances are not absorbed/ fixed by the fibres, they are completely discharged into the wastewater stream. These additives are not toxic to aquatic life; they are poorly biodegradable and not readily bio-eliminable.

2.5.5. Printing

Printing (like dyeing) is applying colour to a substrate. However, instead of colouring the whole substrate (cloth, carpet or yarn) as in dyeing, print colour is applied only to defined areas to obtain the desired pattern. It involves different techniques and different machinery with respect to dyeing. Nevertheless, the physical and chemical processes between the dye and the fibre are analogous to dyeing.

A typical printing process involves the following steps[17]:

- **Colour paste preparation:** The dye or pigment is not in an aqueous liquor when printing textiles. Instead, it is finely dispersed in a printing paste, in high concentration
- **Printing:** the dye or pigment paste is applied to the substrate using different techniques
- Fixation: immediately after printing, the fabric is dried, and then the prints are fixed mainly with steam or hot air (for pigments)
- **After treatment:** the final operation is washing and drying the fabric (these operations are not carried out during pigment printing or with other techniques such as transfer printing).

Pigment and **dye** printing are both direct printing methods. Two other crucial indirect printing methods are discharge and resist printing, giving coloured designs.[18]

In **discharge printing,** a uniformly dyed fabric is printed with a paste containing chemicals that destroy the colour leaving a white pattern. If the paste contains other dyes, stable to the chemical that discharges the ground colour. In that case, they can dye the treated area. In this way, multi-colour effects are also possible.

Whereas in **resist printing,** the fabric is dyed after printing. The printed areas resist dye absorption so that these design areas are retained. After removing the resist agent, the design may be white or coloured if other dyes and appropriate chemicals were present in the original paste.

2.5.5.1. Printing with Pigments

The most widely used printing method today is pigment printing. Pigments can be used on almost all types of textile substrates. With the increased performance of modern auxiliaries, it is now possible to obtain high-quality printing using this technique.

This involves printing the coloured pattern onto the fabric surface and curing the printed areas by heating air. The print paste contains coloured pigments, a thickening agent, a binder and, if necessary, other auxiliaries such as fixing agents, plasticizers, defoamers, etc. White spirit-based emulsions, used in the past as thickening systems, are used only occasionally today (mainly half-emulsion thickeners).

On curing in hot air, the binder forms a solid film of transparent polymer that holds the pigments in place on the fabric surfaces. The great advantage of pigment printing is that the fabric does not require washing after the fixation process.

[17] *http://textileengg.blogspot.com/2015/12/printing.html*
[18] *https://ctnbee.com/blog/en/fabric-printing-methods-printing-technology-choose/*

2.5.5.2. Printing with Dyes

Soluble dyes used in printing fabric are the same types as those commonly used to dye it solid. Apart from this in pigment printing, the usual sequence of operations is printing, drying, steaming and washing. Dyes for printing must have high solubility because there is only a limited amount of water in a thickened print paste. After drying, the dyes must re-dissolve in a limited amount of condensed steam. The paste must dissolve the dyes to allow their diffusion into the fibres. It will also contain all the required chemicals for fibre wetting and dye fixation.

The final washing removes the thickening agent, unfixed dyes and other auxiliary chemicals from the printed surface. The dyes removed must not stain any white background or other printed areas during washing. Thus the dyes used for printing often have relatively low molecular weights so that their substantivity is not very high. When a manufacturer sells the same dye for both dyeing and printing, the two product formulations will invariably be different.

Printing paste preparation

The process traditionally starts with the preparation of the paste. Compared to pigment printing, the composition of the pastes is more complex and variable because it is being determined not by the dye used but by the printing technique, the substrate, the application and the fixation methods applied.

Apart from the dye, printing pastes contain a thickening agent and various auxiliaries. All the necessary ingredients are mixed in the required proportion according to their function as follows:

- Oxidizing agents (e.g. m-nitrobenzene sulphonate, sodium chlorate, hydrogen peroxide)
- Reducing agents (e.g. sodium dithionite, formaldehyde sulphoxylates, thiourea dioxide, tin(II) chloride)
- Discharging agents for discharge printing (e.g. anthraquinone)
- Substances with a hydrotropic effect, like urea
- Dye solubilisers are polar organic solvents like glycerine, ethylene glycol, butyl glycol, thiodiglycol, etc.
- Resists for reactive resist printing (e.g. sulfonated alkanes)
- Defoamers (e.g. silicon compounds, organic and inorganic esters, aliphatic esters, etc.)

It is common practice in many printing houses to filter the printing pastes before application, using filter cloth or other filter media. This operation is essential for thickeners to prevent free particles from blocking the openings of the screens.

Printing (paste application)[19]

After preparation, the paste is applied to specific areas of the textile using one of the following techniques:

- Direct printing (which also includes digital and transfer printing)
- Discharge printing
- Resist printing

[19] *Boruah, Sunita & Kalita, Binita. (2016). Utilization of natural printing paste for textile application. ASIAN JOURNAL OF HOME SCIENCE. 11. 136-141. 10.15740/HAS/AJHS/11.1/136-141.*

In the case of **direct printing**, the dye is applied to specific areas of a pretreated textile substrate, which can be white or pre-dyed (in light colours).

In **discharge printing**, if the etched (discharge), previously dyed area becomes white, then the process is called white discharge. If, on the contrary, a coloured pattern has to be obtained in the etched area after the destruction of the previously applied dye, then the process is called coloured discharge. In this case, the printing paste must contain a reduction-resistant dye and the chemicals needed to destroy the previous one. The dye, resistant to reduction, takes its place. As a result, the pre-dyed background is destroyed according to a pattern.

In the case of physical resist, the material is printed with a difficult-to-wet resin that inhibits the penetration of a dye applied in a second stage. In the case of resist printing, a special printing paste (called resist) is printed onto some regions of the fabric to prevent dye fixation. On the other hand, with a chemical resist, dye fixation is prevented by a chemical reaction.

Fixation

The subsequent fixation process aims to transfer as much dye as possible, retained by the thickener, into the fibres. A substantial part of the colour is removed if a typical textile print is washed soon after printing and drying. An appropriate fixation step is therefore necessary. Complete fixation can rarely be achieved. However, removing unfixed dye, thickening and auxiliary chemicals in a subsequent washing process are usually required. The processes efficiency of fixation and washing is vitally important to both the prints' quality and cost.

Printed dyes are usually fixed by steaming processes. The steam providing the moisture and rapid heating brings about the transfer of dye molecules from the thickener film to the fibre within a reasonable time.

The time and conditions for fixation by steam vary with the properties of the dyes and fibres used. The time ranges from 10 seconds to 60 minutes, and the steam temperature is between 150 to 200^{0}C. Technical and economic factors have encouraged higher temperatures and shorter times and the change from batch-wise to continuous processes.[20]

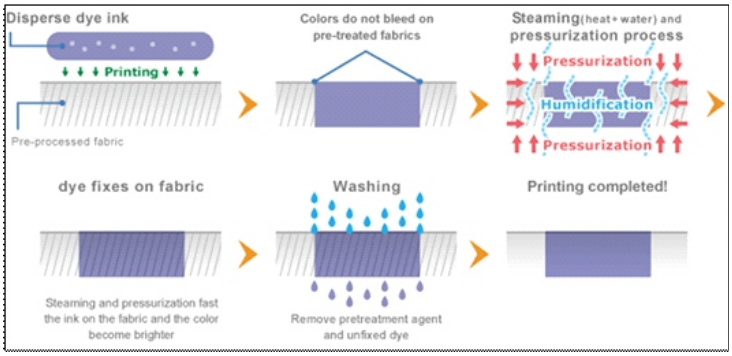


Figure 2.23: Mechanism of dye fixation on grey fabric

Water vapour condenses on the printed material, swells up the thickener, heats the print and provides the necessary transfer medium for the diffusion of the dye. This process is also called the ageing of fabric. The distribution of the dye between fibre and thickener is an essential factor in determining the fixation degree of the dye, which is called the "retaining power" of the thickener. Fixation is carried out in Loop agers. Here the fabric is suspended.

[20] *Lin L, Zhu W, Zhang C, et al. Combination of wet fixation and drying treatments to improve dye fixation onto spray-dyed cotton fabric. Sci Rep. 2021;11(1):15403. Published 2021 Jul 28. doi:10.1038/s41598-021-94885-z*

After Treatment

The last step of the printing process consists of washing and drying the fabric. In this case, after an initial rinsing with cold water, the printed material is treated with hydrogen peroxide. The process is completed with a soap treatment with sodium carbonate at the boiling point.

2.5.5.3. Ancillary operations

Various cleaning operations are carried out at the end of each batch and at each colour change. The rubber belt (to which the fabric is glued during printing) is cleaned continuously with water to remove excess adhesive and printing paste. The printing gears responsible for feeding and applying the paste to the fabric are cleaned by removing the paste residues as much as possible first and then rinsing them with water. In some companies, the paste residues are directed back to the appropriate printing paste batch containers for re-use.

2.5.5.4. Environmental issues related to Printing

Textile printing also generates varying amounts and types of pollutants. Emission sources typical of printing processes are:

- Printing paste residues
- Wastewater from wash-off and cleaning operations
- Volatile organic compounds from drying and fixing.

Presented in table 2.10 [21] below are the primary pollutants associated with printing and their sources:

Table 2.10 Pollutants Associated with Textile Printing and Sources

Pollutant	Typical Sources
Suspended solids	Discarded print paste and clear (Pigment printing)
Formaldehyde	From binder
Urea	Print waste (Wet printing)
Air emissions	Drying / Curing oven emissions (Solvents and Acetic acid)
Solvents	Non-aqueous oil / water thickeners, Machine cleaning, Screen cleaning
Aquatic toxicity	Surfactants, Solvents
Colour	Discarded print waste, Colour kitchen operations, cleaning
Metals	Discarded print waste, Photo operations, Reducing agents in discharge printing, Screen making, Engraving operations
Water (and Heat)	Washing of printed cloth, Desizing operations
BOD	Back-coating operations (Carpet printing)

[21] Impact of Textile in Environmental Issues and Environmental Legislation (Part I), By: Karthik T. and Gopalakrishnan D.

Wastewater in printing processes is generated primarily from final washing of the fabric, cleaning application systems in the printing machines, cleaning of kitchen equipment, and cleaning of belts. Wastewater from cleaning-up operations accounts for a large share of the total pollution load. In a typical print plant, printing contributes only 6% of the BOD of the total pollutant load. It accounts for 7% of water consumption. On the other hand, print washing uses more than one-quarter of the total water in the mill but produces only 1% of the total BOD load.[22]

Emission loads to water are mainly attributable to dyestuff printing processes because of pigment printing. Pigments are entirely fixed on the fibre, leaving no need for washing-off. However, considerable amounts of wastewater arise from cleaning operations.

2.5.6. Finishing

The term "finishing" covers all those treatments that serve to give the textile the desired end-use properties. These are properties related to visual effect, handle and unique characteristics such as waterproofing and non-flammability. Finishing may involve mechanical/physical and chemical treatments. Moreover, among chemical treatments, one can further distinguish between treatments involving a chemical reaction of the finishing agent with the fibre and chemical treatments where this is unnecessary (e.g. softening treatments).[23]

Some finishing treatments are more typical for certain fibre types, e.g. calendaring & sanforizing for cotton, antistatic treatment for synthetic fibres etc. Other finishes have more general applications e.g. softening.

Finishing processes have been described below:

2.5.6.1. Mechanical Finishing

Mechanical finishing involves the application of physical phenomena such as friction, temperature, pressure, tension and many others.

A. Calendaring

A process of passing cloth between rollers (or "calendars"), usually under carefully controlled heat and pressure, produces various surface textures or effects in fabric such as compact, smooth, supple, flat, and glazed.

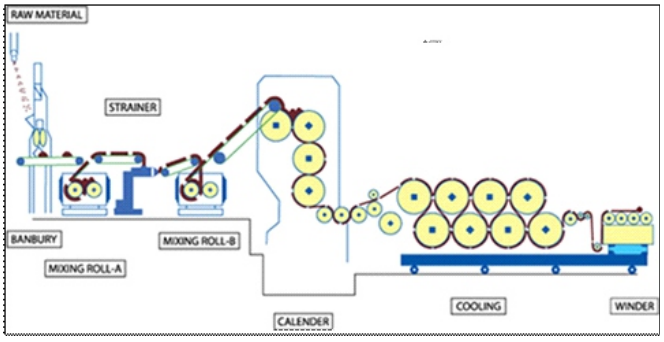


Figure 2.24: Calendering Process

As shown in figure 2.24, The process involves passing the fabric through a calendar in which a highly polished, usually heated, steel bowl rotates at a higher surface speed than the softer (e.g. cotton or paper packed) bowl against which it works, thus producing a glaze on the face of the fabric that is in contact with the steel bowl. The friction ratio is the ratio of the peripheral speed of the faster steel bowl to that of the slower bowl. It is generally in the range of 1.5 to 3.0.

[22] *https://www.fibre2fashion.com/industry-article/3406/water-efficiency-in-textile-processe*
[23] *W.D. Schindler, P.J. Hauser, "Finishes to improve colour fastness", Chemical Finishing of Textiles (2004)*

The normal woven fabric surface is not flat, particularly in ordinary plain weave fabrics, because of the round shape of the yarns and interlacing of warp and weft at right angles to each other. In such fabrics, it is more often seen that it is not flat even when the fabric is more often seen that it is not flat even when the fabric is quite regular.

During calendering, fabric yarns are squashed into a flattened elliptical shape; the intersections are made to close up between the yarns. The calender machines may have several rollers, some of which can be heated and varied in speed, so that in addition to pressure a polishing action can be exerted to increase lustre. It causes the fabric surface to become flat and compact. The improved planeness of the surface improves the glaze of the fabric.

B. Compacting

Durable finish imparted on man-made fibres and knitted fabrics by employing heat and pressure to shrink them to produce a crêpey and bulky texture.

C. Embossing

This particular calendaring process allows engraving a simple pattern on the fabric. To produce a pattern in relief by passing the fabric through a calendar, a heated metal bowl engraved with the pattern works against a relatively soft bowl built up of compressed paper or cotton on a metal centre.

D. Sueding

This process is carried out using a roller coated with abrasive material. The fabric has a much softer hand and an improved insulating effect thanks to the fibre end pulled out of the fabric surface.

E. Raising or Napping

The raising of the fibre on the face of the goods utilizing teasels or rollers covered with card clothing (steel wires) that is about one inch in height. Action by either method raises the protruding fibres and causes the finished fabric to provide more warmth, makes the cloth more compact, causes the fabric to become softer in hand or smoother in feel, increases durability and covers the minute areas between the inter-lacings of the warp and the filling. Napped fabrics include blankets, flannel, unfinished worsted, several coatings, and some dress goods. Other names for napping are Gigging, Genapping, Teaseled, Raised.

F. Decatizing

Decatizing is applied to fabrics to set the material, enhance the lustre and improve the hand. Fabric wound onto a perforated roller is immersed in hot water or has steam blown through it.

G. Sanforizing

Sanforizing is a mechanical finishing process of textile fabrics to prevent the typical dimensional alternation of fabric. It is a process of treatment used for cotton fabrics mainly and most of the textiles made from natural or chemical fibres. It is also called the anti-shrinkage finishing process.

In this method the fabric is passed between the heavy rollers for stretching, shrinking and fixing the fabric in both length and width, before cutting to reduce the shrinkage which would otherwise occur after wash.

2.5.6.2. Chemical Finishing

The finishes applied through chemicals of different origins enable fabric to receive properties otherwise impossible to obtain with mechanical means.

A. Easy-care treatments

Easy-care finishing is applied to cellulose-containing fibres to impart characteristics such as easy washing, creasing resistance during wash, and wear and no ironing or minimum ironing. These properties are now required for cellulose fibres to compete with synthetic fibres such as polyamide and polyester.

Easy-care recipes consist of various ingredients:

- Cross-linking agent
- Catalyst
- Additives (softeners, hand builder most commonly, but also water-repellents, hydrophilizing agent,etc.)
- Surfactants as a wetting agent.

In the easy-care process, after being padded, the fabric is dried in open-width in a stenter frame and is finally cured. The most common curing method is the dry cross-linking process, in which the fabric is cured in a dry state in a curing apparatus or on the stenter immediately after drying.

B. Anti-Pilling

Fabrics with pills have an unsightly appearance and an unpleasant handle. Pilling is masses of tangled fibres that appear on fabric surfaces during wear or laundering and is a phenomenon in fabrics formed from spun yarns (yarns made from staple fibres). Loose fibres are pulled from yarns and are formed into spherical balls by the frictional forces of abrasion. These balls of tangled fibres are held to the fabric surface by longer fibres called anchor fibres. Anti-pilling finish reduces the forming of pills on fabrics. Knitted products made from yarns with synthetic-fibre content are inclined to pilling by their considerable strength, flexibility and resistance to impact. The anti-pilling finish is based on the use of chemical treatments that aim to suppress fibres' ability to slacken and reduce the mechanical resistance of synthetic fibre.

C. Water-Repellent Finishes

Water-repellent finishes resist wetting. If the fabric becomes very wet, water will eventually pass through. This method is applied to fabrics found in raincoats, all-weather coats, hats, caps, umbrellas and shower curtains.

D. Absorbent Finishes

They increase moisture holding power of fibres. Such finishes are being applied to towels, cloth diapers, underwear, sports shirts and other items where moisture absorption is important.

E. Anti-Static Finish

The process consists of treating the fabric with hygroscopic substances (antistatic agents) which increases the electrical conductivity of the fibre, thus avoiding the accumulation of electrostatic charge. These finishing treatments are widespread for synthetic fibres.

2.5.6.3. Environmental issues related to Finishing

The finishing operation generates solid and liquid wastes as well as atmospheric pollutants. Pollutant categories include:

- **Solid wastes:** Fabric scraps and trimmings from salvages and seams; fibre dust and fragments from napping, shearing and related operation, additionally paper tubes and empty chemical drums.
- **Liquid:** Discarded finishing mixes and rinses water from finishing implements and equipment and facility clean up.
- **Vapours:** Exhaust gases from drying and curing.

Apart from the above pollutants from various processes, the hazardous chemicals can cause health risks to workers.

2.5.7. Drying

2.5.7.1. Hydro-extraction by squeezing

The fabric is squeezed using a padding machine through two or three rollers covered with rubber. This process cannot be applied to the delicate fabric.

2.5.7.2. Stenter



This machine is used for complete drying of the fabric. The fabric is conveyed through the machine in open width. A hot current of air is blown across the fabric, thereby evaporating the water.

The fabric is sustained and moved by two parallels endless chains. The fabric is hooked, undulating and not taut to allow its shrinking during drying.

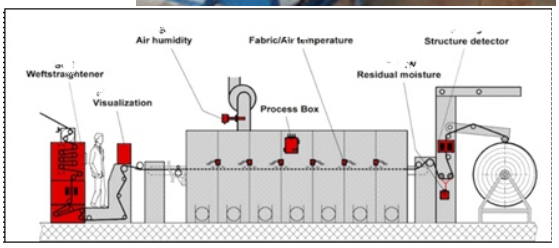


Figure 2.25: Stenter Machine
(a) Real picture (b) Sketch of the machine

The most common stenter designs are horizontal and multi-layer, but many new designs exist. In the horizontal stenter machine, the fabric enters wet from one side and exits dried from the other while, in the multi-layer type, it enters and leaves from the same side. In the first one, the fabric moves horizontally without direction changes. Whereas, in the second direction, the fabric deviates many times, making this equipment unsuitable for delicate fabrics. Horizontal stenter frames occupy more space and are less efficient (higher energy consumption).

The most common drying technique found in the textile industries in Gujarat is drying in the Stenter machine, in which, along with drying, finishing of the fabric is also done.

2.5.7.3. Contact dryer (heated cylinder)

The fabric is longitudinally stretched on the surface of a set of metallic cylinders. The cylinders are heated internally by means of steam or direct flame. In this type of machinery, the fabric is dried by direct contact with a hot surface.

2.6. Cotton Textile Processing

The manufacturing of cotton textile, beginning from raw cotton fibre processing for yarn making, fabric formation, dyeing, printing and finishing, will be described in detail in this section.

As described above, textile processing begins with fibre processing for yarn manufacturing. Cotton fibres are first separated from the seeds and cleaned to remove the foreign particles by mixing and breaking the fibre into small pieces (Staple). This is called ginning. The fibres are then compressed in bale form and taken to the mill for processing into yarns.

Spinning is the process by which the staple fibres are transformed into yarn. The natural fibres contain dirt and other impurities that must be removed first. The staple fibres have to undergo various mixing/blending, opening, cleaning, drawing etc., before the final yarn of desired thickness is obtained. Mechanical spinning is carried out mainly for cotton wool and blends with other fibres like polyesters.

The cotton fibre has to pass through the following stages during its spinning.

Opening: The cotton arrives in the mill in large bales weighing about 180 kg each, from where it is brought to the blow room. The compressed mass of raw fibre in the bales is removed, and then it is mixed, opened and cleaned.

Mixing is necessary to obtain uniformity of fibre quality. The opening is required to loosen hard lumps of fibre and disentangle them. Cleaning is required to remove trash- such as dirt, leaves, burrs and any remaining seeds. These functions are carried out through a continuous series of machines in the blow room.

Carding: The cotton laps from the blow room are then fed to the carding machine. The lap passes between two cylinders covered with specially bent wires in this machine. The remaining impurities (trash) are removed, and the cotton is opened into individual fibres. Here the individual fibres are straightened and made somewhat parallel. This cleaning and opening of the cotton into individual fibres is known as "Carding". The fibres emerge like a thin, uniform web drawn in a funnel-shaped device from the carding roll. It gathers into a soft mass of a rope of fibres, about ¾ inch in diameter. It is called "sliver". The sliver is collected into containers called cans. Card slivers are used for coarse and medium count yarns.

Combing: This is an optional process. The carded sliver is fed through the ' Comber' when the fibre is intended for fine or superfine yarns. Here fibres are combed by the fine-toothed combs. The fibres are thus made perfectly parallel and entirely straightened. The short fibres are removed. These combed fibres are formed into slivers called "combed slivers" and collected in cans.

The combed sliver, made of the longest fibres, produces a smoother and more even yarn of fine and superfine quality. Combing is an expensive process and adds considerably to the cost of the fabric. Combed fibres lead to the formation of better fabric because of better fineness, strength, uniformity, smoothness and lustre.

Drawing: In the drawing operation, several slivers are fed into the drawing rollers simultaneously. The drawing frame consists of four steps of rolls each, of which successive set travels at a faster speed than the previous set of rollers. Speed difference causes elongation of the sliver and draws it into a new sliver without any twist. This makes the sliver even and the fibres become fully parallel and straightened.

Roving: After the single or several stages of drawing (for combed sliver), the sliver is taken to a "slubber" where it is drawn out further to the desired shape, twisted. It is wound on bobbins and placed on the intermediate frame, where additional drawing and twisting occur. In the case of fine and superfine cotton,

the yarn passes through a roving frame and is then placed onto jack frames. The operations of intermediate and jack frames are identical, but each machine yields a more refined product. At this point, up to roving, fibres are only partially twisted and have low tensile strength. They may break with a slight pull.

Spinning: Next, the yarn is placed on the ring-spinning frame, where it passes through several sets of rollers running at successively higher speeds. It is finally drawn out or drafted by introducing twist and winding operations.

The yarn passes through the traveller to the spindle that revolves and puts in the specified number of twists as the yarn is wound up on the desired bobbin. The ring spinning frame completes the manufacture of yarn by drawing out, inserting, twisting and winding the yarn, all in one stretch.

The majority of cotton fabric formation is done by weaving. Further, cotton fabric formation is done by weaving or knitting the yarns into fabric. As described earlier, sizing is done on yarn for lubricating yarns for weaving. The sizing agent used for cotton is starch or starch derivatives. This sizing agent must be removed from the fabric before its dyeing. The yarns are then either weaved or knitted into fabric, depending on the yarn type and the end-use.

2.6.1. Woven Cotton Pre-treatment

Pre-treatment of cotton involves:

- Singeing
- Desizing
- Scouring
- Bleaching
- Mercerization

As shown in Fig. 2.26, some of these treatments are obligatory steps only for specific make-ups (e.g. desizing is carried out only on woven fabric). It should be noted that the application of treatment techniques is not necessarily the same as mentioned above. The steps may vary based on the fabric quality& even a few steps may be omitted.

The pre-treatment processes have been described in detail in section 2.3.3.

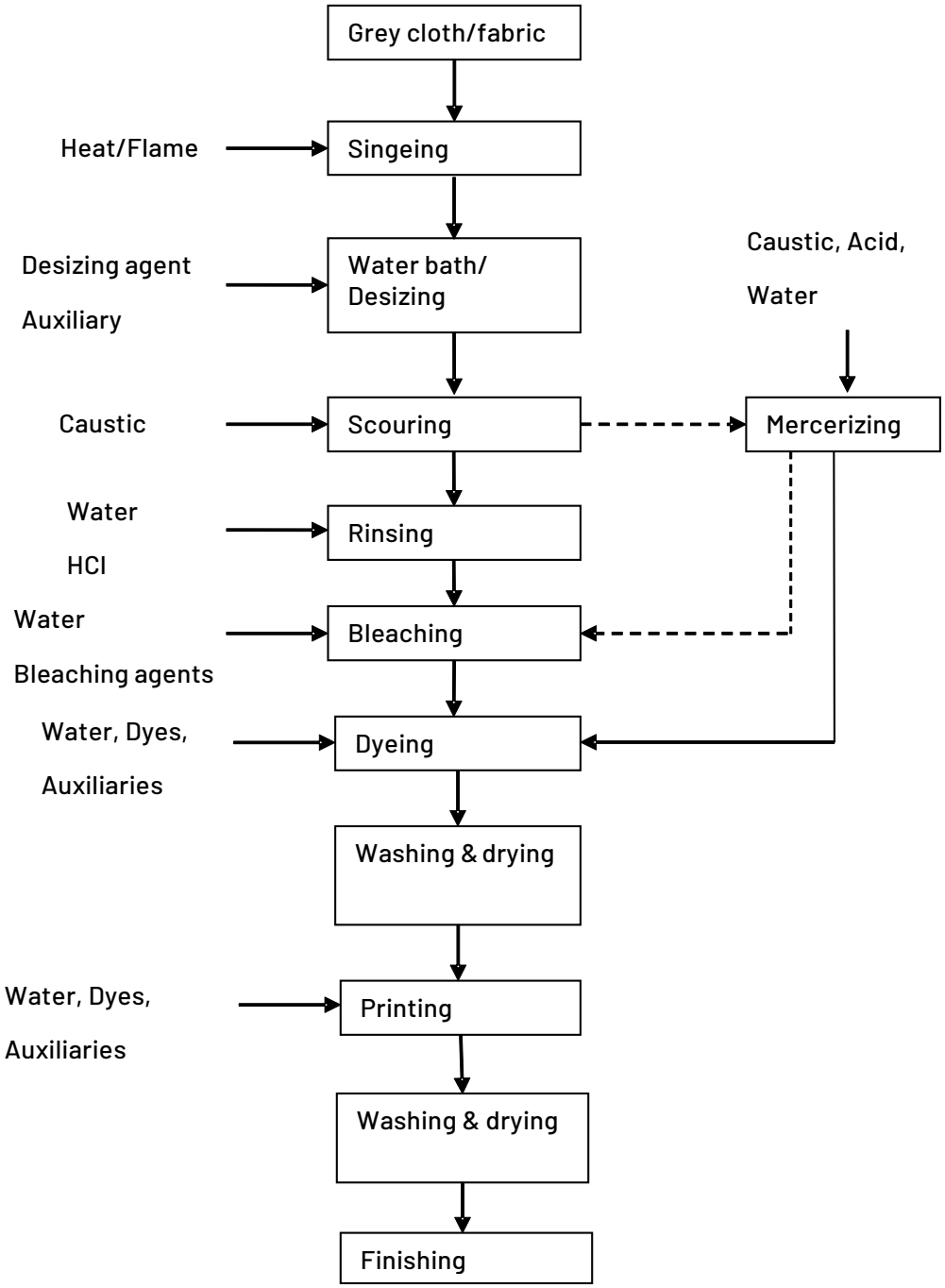


Figure 2.26 Process Flow Diagram for Cotton Woven Fabric Processing

2.6.2. Dyeing

Cotton can be dyed in either yarn or fabric form. Mostly cotton is dyed in the fabric form according to the end user's demand. Yarn dyeing is employed only when the fibre is used for manufacturing denim.

Cotton can be dyed with a wide range of dyestuffs, namely:

- Reactive dye
- Direct dye
- Vat dye
- Sulphur dye
- Azoic dye

The most commonly used dye for cotton dyeing is reactive dyes. Reactive dyes react chemically in the presence of alkali with the cotton fibre, which forms the covalent bond between the dye and fibre.

Since cotton needs to be dyed in open-width, a jigger dyeing machine is used. As shown in Fig. 2.27, the machine consists of a bath tub and two rolls on which it is alternatively wound. During rotation of rollers the dye in the bath penetrates and diffuses into the fabric. The cycle continues till the required shade is achieved.

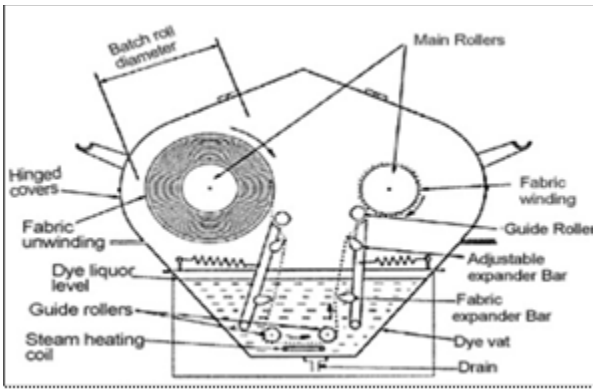


Figure 2.27: Overview of Jigger Dyeing Machine (b) real machine

After dyeing, the liquor is drained. The material is rinsed and then washed off with auxiliaries for better fixation of dyes on the fabric surface. Auxiliaries like alkali (sodium carbonate, bicarbonate & caustic soda) and salt are generally used for this fabric. Later on, the material is always carefully washed off in open width or in a rope form to remove altogether the hydrolyzed colourant followed by drying on the stenter.

For more information on dyeing please refer to section 2.5.4.

2.6.3. Printing

Fabric Printing can be carried on a flat-bed or rotary machine, depending on the number of designs to be printed. Many table printing units are also found in the Ahmedabad & Jetpur region for cotton. Post – COVID 19, due to stiff market competition, many table printing units have shifted towards flat bed printing.

For cotton printing, reactive dyes are generally used. The printing paste is prepared with water and gum powder. The dye-stuff is later added to this thick gum paste as per the desired shades. The printing paste is taken in the screen perforation. It penetrates the screen perforation and imprints the design on the fabric surface. The printed fabric is then steamed and washed for removing unfixed dye and any other chemicals remaining unfixed on the fabric surface. Then the printed fabric is dried. Small table printing units generally send the fabric to washing ghats for washing and drying.

For more information on dyeing please refer to section 2.5.5.

2.6.4. Finishing

After washing, the fabric is dried on Stenter. Whereas, Calendaring & Sanforizing are the finishing processes generally applied for cotton fabric (See section 2.5.6).

2.7. Polyester Textile Processing

Polyester is a man-made fibre formed by chemical reaction between acid or its esters and alcohol. When acid and alcohol are reacted in vacuum at high temperature, condensation polymerisation takes place.

Today over 70 to 75% of polyester is produced by continuous polymerization process using PTA (purified Terephthalic Acid) and MEG. PTA which is a white powder is fed by a screw conveyor into hot MEG to dissolve it.

Polymerisation is carried out at high temperature (290 to 300 °C) and in almost total vacuum. Monomer gets polymerised into the final product, PET (Poly ethylene Terephthalate). This is in the form of thick viscous liquid. This liquid is then pumped in to spinning machines to melt. Spin finishes are added at melt. As presented in Fig. 2.28, Draw machine provides static protection, cohesion and certain frictional properties to the fibre to enable it to get processed through these machines. Polymer comes out of each hole of the spinneret and is instantly solidified by the flow of cool dry air. This process is called quenching. The filaments from each spinneret are collected together to form a small ribbon, which passes over a wheel that rotates in a bath of spin finish. This ribbon is then mixed with ribbons coming from other spinning positions, this combined ribbon is a tow and is coiled in cans.

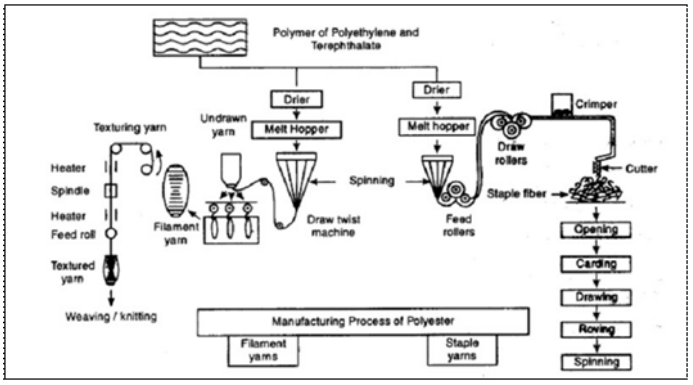


Figure 2.28: Process Flow diagram for Man-made Fibre processing

The fibres are then stretched up to five times their original length and wound on cones as filament and then cut into staple.

2.7.1. Polyester Pre-treatment

The polyester manufactured through chemical process consists of lesser impurities. Process flow diagram for polyester fabric is displayed in Fig. 2.29 below.



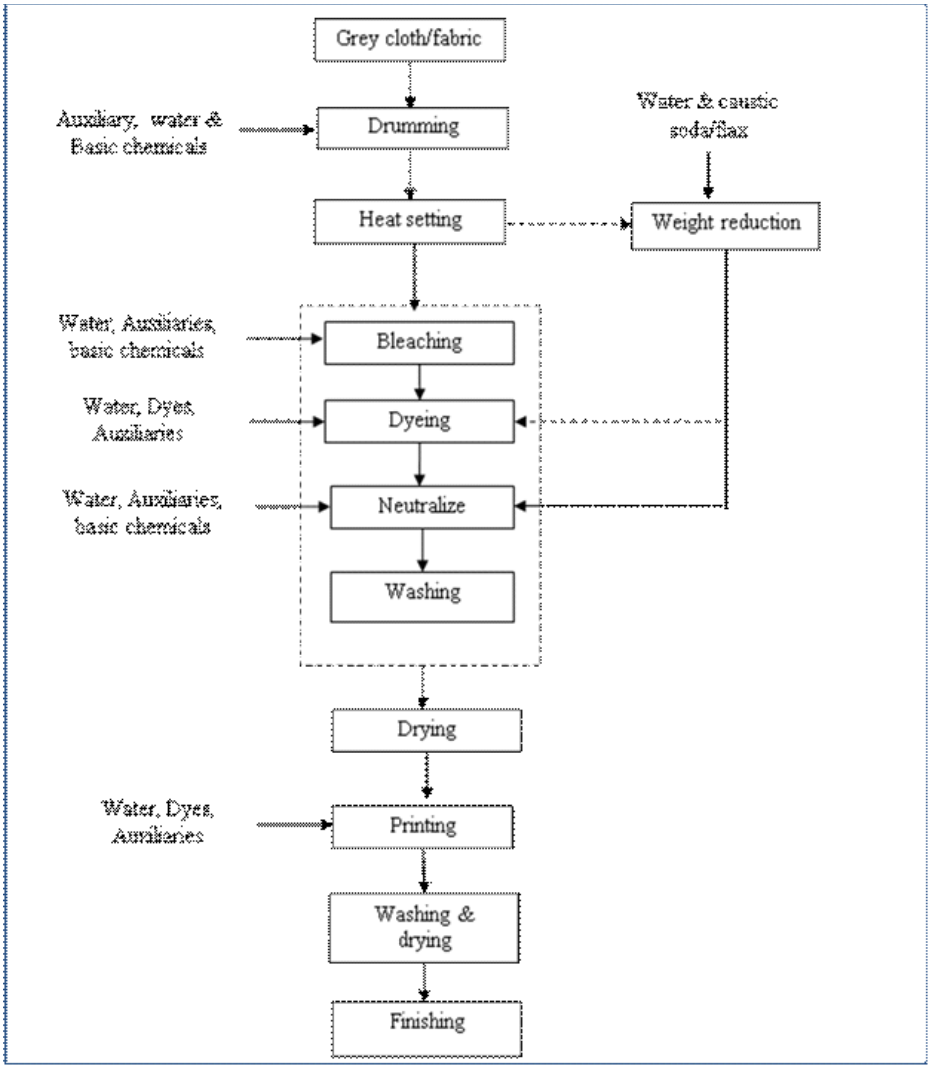


Figure 2.29: Pre Treatment of polyestrer

2.7.1.1. Desizing[24]

Desizing of Synthetic Fibre Fabrics and Their Blends with Cellulose The most common sizing agents used for nylon are based upon PVA, gelatin, casein or variety of vegetable and mineral oils. Desizing of regenerated celluloses depends on nature of size that must be removed. Desizing is difficult as rayon swells in water to a great extent. This leads to poor penetration of enzyme. When water soluble PVA is used as sizing agent in weaving, no desizing of synthetic fibre fabrics is necessary. Light scouring with non-ionic surfactant (3-5 g/l) at 95^{0}C-100^{0}C~ for 20-30 min is enough to remove the sizing material. However, high molecular weight PVA above 1,00,000 are found to be quite difficult to remove from the fabric during desizing and results in uneven desizing. Polyester sizing agents are not removed by simple washing treatment. Suitable detergents for removing polyester size are the efficient anionic or non-ionic types or blends containing both types. The grey fabric is treated with a solution containing non-ionic surfactant, 2-3 g/l; sodium hydroxide or soda-ash, 1-2 g/1at 80^0-95^0~ for 20-30 min. Alternatively, treatment with sodium tripolyphosphate (1-2g/l) in presence of soda-ash or sodium hydroxide (1-2 g/l) and non-ionic surfactant (2-3g/l) at 80^{0}C-90^{0}C~ for 20-30 min can be used. It is recommended to use soft water during washing as metal ions may interfere with removal of size. Alternatively, suitable sequestering agents are added.

[24] *Chemical Technology in the Pre-treatment Processes of Textiles by S.R. Karmakar*

2.7.1.2. Scouring[25]

Synthetic fibres generally do not contain naturally ccuring impurities like natural fibres i.e. cotton and wool. However, spin finishes, processing and coning oils and antistatic agents are added to improve the physical and mechanical properties during spinning, weaving and knitting. Other impurities are dirt and sighting colours (to distinguish one kind of fibre from the other). The objective of scouring synthetic fibre fabrics is to remove the dirt, size, processing lubricants and sighting colours, achievement of relaxation in the case of texturised and knitted fabrics and production of special effects.

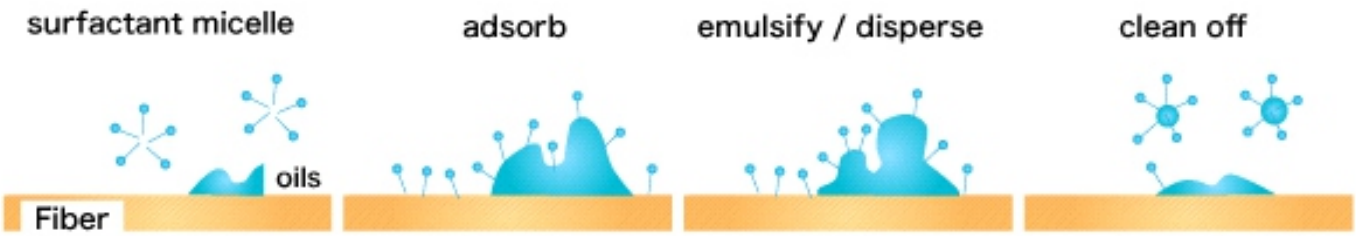


Figure 2.30: Scouring agent Mechanism[26]

2.7.1.3. Drumming

The polyester fabric undergoes drumming process for bulkiness and to develop consistent grain effect on the fabric. Drumming process is carried out at $90^0 - 100^\circ C$ temperature in Drum machine. The fabric is first washed to remove the dirt. Then basic chemicals like caustic and soda ash are added for swelling of fabric. Along with these, chemicals auxiliaries like leveling agent and/or wetting agent are also added.

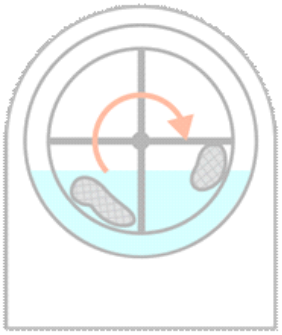


Figure 2.31: Drum Machine cross-sectional view

2.7.1.4. Bleaching

Following to the drumming process, bleaching is carried out to whiten the fabric. Bleaching becomes necessary if the fabric is to be dyed for bright and light to medium shades. On the contrary, if the fabric is to be dyed with a dark shade bleaching can be omitted. Bleaching of polyester is carried out with hydrogen peroxide & soda ash in Jet machine.

[25] *Chemical Technology in the Pre-treatment Processes of Textiles by S.R. Karmakar*
[26] *https://nctexchem.com/product/process/preparation/scouring/*

2.7.1.5. Weight reduction[27]

Weight reduction is generally carried out in Jet machine. Many a times, when weight reduction more than 25% is required, the process is carried out in Softlina machine.

When polyester fibres are given an alkaline treatment with caustic soda in a hot medium (hydrolytic action) the surface of the fibre is peeled off. The desired handle modification which results is silk-like. A pleasant effect of deweighted goods is their improved absorbency. Although the deweighting of PES fibres produces a loss in weight (finer titre) which can be controlled by the amount of alkali, temperature and treatment time, it also results in loss of strength which must be taken into consideration. It is therefore necessary to make a compromise and produce a fibre which is as silky soft as possible without losing too much of its strength. The attainable deweighting effect depends to a large extent on the type of PES fibre. It is therefore advisable to carry out tests in the lab in each case to determine the acceptable degree of deweighting, weight and strength losses.

A. Discontinuous deweighting

In most cases deweighting is carried out on the relevant dyeing machine (winch, overflow, HT beam, etc.). To accelerate alkalisation, treatment can be carried out under HT conditions or a cationic accelerator can be applied, which permits a drastic reduction in the caustic concentration. At the end of treatment an anionic surfactant is added to the liquor to stop the peeling process and to disperse the peeled fibre residues.

B. Semi continuous and Continuous deweighting

Interesting alternatives are the continuous methods. Apart from the treatment on pad-steam ranges, cold causticising by the pad batch method is particularly suitable for deweighting 100% polyester articles.

2.7.1.6. Heat setting

Fabrics produced from synthetic fibres or from blends containing large proportion of such fibres are normally heat-set to stabilise them. Heat-setting is a heat treatment by which shape retention, crease resistance, resilience and elasticity are imparted to the fibres. It also brings changes in strength, stretchability, softness, dyeability and sometimes on the colour of the material. All these changes are connected with the structural and chemical modifications occuring in the fibre. An unset polyester filament yam shrinks about 7% when allowed to relax in boiling water. This shrinkage is about 10% in the presence of carrier at boil. It is, therefore, necessary to confer on fabric some degree of dimensional stability in order that the yarns or fabrics retain their shape during subsequent processing, washing and ironing.

A. Stages of Heat Setting

Heat-setting can be carried out at three different stages in a processing sequence i.e. in grey condition; after scouring; and after dyeing. The stage of heat-setting depends on extent of contaminations and types of fibres or yams present in the fabric.If heat-setting is carried out in the loom state, mineral oils and non-ionic emulsifiers can modify the fibre structure and rubbing and perspiration fastness may be reduced due to the solubility of disperse dye in the coning oil. PVA size above 135~ loses its Tg which is followed by becoming crystallized and melts.

[27] *Pretreatment of Textile Substrates by Mathews Kolanjikombil*

The H-bonds, therefore, can no longer be broken with the result that PVA becomes difficult to remove from the fabric. However, grey heat-setting is useful in the warp knitting industry for materials that can carry only small amount of lubricants and for goods that are to be scoured and dyed on beam machines. The other advantages of grey heat-setting are: yellow colour due to heat-setting can be removed by bleaching, fabric is less sensitive to crease formation during subsequent processing etc. Heat-setting can be carried out after scouring if it is suspected that the goods will shrink or for the cloth in which 'stretch' or other properties are developed during a carefully controlled scouring process. However, this stage requires drying the cloth twice. Heat-setting can be carried out after dyeing also. Post set fabrics show considerable resistance to stripping compared with the same dyeing on unset fabric. The disadvantages of post setting are: yellow colour developed cannot be removed any more by bleaching, handle of the cloth may get altered and there is a risk of colours or optical brighteners be faded somewhat.

B. Methods of Heat-Setting

Contact method

In this method the fabric is run in contact with a heated metal surface. Some machines are composed of metal rollers having gas fired cores and are filled with a liquid known as diatherm to uniformly distribute the heat. Sometimes enclosed rollers are heated with high temperature steam. This method is mainly used for heat-setting of polyester/cotton blended fibre fabrics. Though heat is used efficiently in this method, the width of the fabrics cannot be controlled while fabrics run fiat against the roller surfaces, apart from variation in degree of setting caused by variation in tension.

Steam-setting method

Short staple polyester yarns including polyester/cotton blends are normally set by relaxation in saturated steam. The most effective means of stabilising these materials are to steam at 107~^{0}C on the ring spinners tube and soft dyeing packages under minimum tension. Steaming is carried out in an autoclave fitted with vacuum pump, e.g. two times 15 min at 125^{0}C-135^{0}C~ with intermediate evacution or alternatively, for 60 min with saturated steam. Sewing threads receive special setting treatments, designed to confer stability whilst preserving their high tensile properties. Polyester garments, garment lengths and hosiery are also stabilised by steaming in much the same way as for yams.

Nylon can be set in saturated steam at temperatures above 100°C in an autoclave by batchwise process. Nylon yam is wound on to a collapsible paper tube or cross wound in cheese form to a spring core and is treated in steam for 30 min cycles, vacuum/steam 5 to 20 lb/in^{2}/vacuum and rewound on to the spring in the case of paper tube. For textured nylon yam similar packages can be used but the package density is very much lower. Woven or warp knitted nylon fabrics are batched in open-width on to a perforated roller and setting cycle commences by a vacuum exhaustion down to a pressure of 28 inches of Hg. Saturated steam is then injected at the desired temperature and treatment continued for 10 min. This is followed by a further vacuum exhaustion and prolonged steaming cycle of 20 min at selected temperature. A final vacuum exhaustion completes the process. In the case of hose and half-hose, the goods are framed onto metal formers on which the goods are shrunk during steaming operation. Typical steam setting conditions are 115°C (lb/in^{2}) to 130°C (25 lb/in^{2}) for nylon 6,6 and 108°C (5 lb/in^{2}) to 121°C (15 lb/in^{2}) for nylon 6. Steam setting increases the build up of acid dyes and unlevel dyeing will result if the temperature varies throughout the batch.

Hydro-setting method

The hydro-setting or aqueous heat-setting of polyester is done with hot water in a high temperature liquor circulating machine at about 130°C. A typical cycle may require 30 min. Water (or steam) promote swelling of fibre and may cause some hydrolysis in the ester groups in polyester chain. This causes partial destruction of intermolecular bonds and depolymerisation of fibre with a result in loss in tenacity. However, the hydro setting temperature can be lowered by adding some selected organic or inorganic substances causing swelling of polyester, but such conditions have not yet found industrial application.

Nylon fabric can be hydro-set in hot water since the swelling action assists in weakening or breaking intermolecular bonds. The fabric in flat form is batched onto a perforated metal cylinder and immersed in hot or boiling water for a short period of time. Hydro setting at boil is roughly equivalent to dry setting at 185°C.

The texturised and tubular knitted fabrics are suitable as the fabric quality depends greatly on the methods of application. After setting in boiling water polyester is further shrunk by 11-12% on exposure to hot air at 200°C. Unlike polyester, nylon fabrics if set (relaxed) with boiling water shrinks only 3-4% on subsequent exposure to hot air at 200°C.

Heat-setting using Stenter frame

Stenters are widely used for stretching, drying, heat-setting and finishing of fabrics. Woven and knitted fabrics of polyester and nylon fibres and their blends are normally heat-set on pin-stenter in hot air. An alternative to the pin stenter is the clip machine. The fabric is held into the chains either by pins mounted

into a base plate or by clips in which the fabric edge is clamped between two smooth surfaces. Stenters that are used for setting only have a light pin chains whereas stenters used for both drying and setting (finishing) are provided with a heavy combined pin and clip chain. For knit goods vertically running pin stenter chains are particularly suitable. In order to be suitable for drying and setting purposes, the stenter rails are divided into three sections and can be moved laterally about the centre line. The entry section consists feeding in, with padding mangle, selvedge uncurler (for knitted goods), shrinkage apparatus (up to 30%), selvedge feeler for automatic correction of width and instrument panel with all switches.

This section is usually about 5 m long for woven fabrics and 7 m for warp knits. The centre section is as long as oven, which may have from 3 to 8 heating chambers (sections), each about 3 m long. There should be at least two setting fields. The delivery section is about 4-5 m long to permit sufficient cooling to take place before the fabric is stripped off the pins by a roller and either rolled or plaited. On some machines an air blower is fitted after the heating sections to force cool air

2.7.2. Dyeing

The dyeing of hydrophobic fibres like polyester fibres with disperse dyes may be considered as a process of dye transfer from liquid solvent (water) to a solid organic solvent (fibre). Disperse dyes are added to water with a surface active agent to form an aqueous dispersion. The insolubility of disperse dyes enables them to leave the dye liquor as they are more substantive to the organic fibre than to the inorganic dye liquor. The application of heat to the dye liquor increases the energy of dye molecules and accelerates the dyeing of textile fibres.

Heating of dye liquor swells the fibre to some extent and assists the dye to penetrate the fibre polymer system. Thus the dye molecule takes its place in the amorphous regions of the fibre. Once penetrated in to the fibre polymer system, the dye molecules are held by hydrogen bonds and Van Der Waals' force.

The fabric is subjected to dyeing, with the dyes and auxiliaries at 120°C to 130°C in jet dyeing machine along with water and heat transfer through steam. Initially, a paste of dye and dispersing agent is prepared and then water is added to it. Dye bath is kept at 60°C temperature and all the chemicals along with the material are added to it. Then the bath is kept for 15 min without raising the temperature. pH of bath is controlled by acetic acid at 4-5.5.

Then temperature is lowered to 60°C. Additionally, resist and reduction clearing is done if required. Reduction clearing is done only to improve the wash fastness. Material is rinsed well after reduction clearing and then dried.

2.7.3. Printing

Polyester can be printed with the following class of dyestuffs: Indigo sol colors, Pigment dyes, Disperse dyes.

Disperse printing of polyester make use following chemicals:

- Thickener (esp. acid stable)
- Disperse dyes
- An acid donor or catalyst
- An auxiliary to enhance the dye uptake as and when required

Thickening agent is the most important component of the printing paste and it should be cost- effective. The fact is that since the printing paste is acidic, the thickener should have very good stability in the pH range of 2-5 for long time. Thus, the most recommended thickener is guar gum.

The fabric is then printed on flat-bed or rotary printing machine. After printing, for fixation, the fabric is aged in loop ager at 170°C temperature. Later the fabric is washed for removal of superficial colour, if any, and then dried.

2.7.4. Finishing

At finishing, fabric is dried in stenter, where along with drying width setting of the fabric is also achieved. The fabric is first dipped in liquor to give special finish properties like softness, stiffness, etc. as per the end user requirement.

2.8. Blends -Processing

Blending is the combining of different fibres together ultimately to achieve a desired product characteristic. Blending is done to produce a fabric, which is economical by combining the aesthetic comfort properties of the natural fibres with the easy care and strength properties of synthetic fibres.\

Firstly, man-made fibres are manufactured in the form of continuous filaments. The long continuous filament fibres can't be used for blending because they are too long to handle easily. Also, natural fibres, such as wool and cotton, with which many manufactured fibres are blended, are very short. Therefore,

before blending man-made fibres, they are first cut into short fibres, called staple fibres. The staple fibres can more easily be twisted with the shorter natural fibres, or with staple fibres of another manufactured fibre.

Moreover, staple fibres are created by extruding many continuous filaments of specific denier from the spinneret and collecting them in a large bundle called a "tow". A tow may contain over a million continuous filaments. The tow bundle is then crimped and mechanically cut into staple fibres, usually ranging in length from 1 to 6-1/2 inches, depending on the fact that how they are to be used.

Also fibres are selected and blended in such a proportions that the fabric will retain the best characteristics of each fibre. Blending can be done with either natural or manufactured fibres, but is usually done using various combinations of manufactured fibres or manufactured and natural fibres.

For example, polyester is the most blended manufactured fibre. Polyester fibre is strong, it resists shrinkage, stretching and wrinkles, it is also abrasion resistant easily washable. Blends of 50 to 65% polyester with cotton provides a minimum care fabric used in a variety of shirts, slacks, dresses, blouses, sportswear and many home fashion items. A 50/50 polyester/acrylic blend is used for slacks, sportswear and dresses. Blends of polyester (45 to 55%) and worsted wool create a fabric which retains the beautiful drape and feel of 100% wool as the polyester adds durability as well as resistance to wrinkles.

2.8.1. Polyester/Cotton Blends

Polyester fibre blended with cellulosic fibre in the ratios of 65/35 and 50/50 is the common production. PC blends follow processing as that for Polyester fabric.[28] The weaved PC fabric is received in industries and processed as per the requirement.

Bleaching treatments of such blends are normally required to remove the natural colour of cotton, sighting colour, i.e. yellowing of polyester portion at the time of heat-setting operation. Chlorine bleaching, peroxide bleaching and hypochlorite bleaching are employed widely. If the polyester portion requires bleaching, then chlorine bleaching is used, as this bleaching agent bleaches both polyester and cellulose. If the polyester portion does not need bleaching, then peroxide bleaching is advisable. As alkaline hydrogen peroxide bleaching is the most preferred method for polyester/cotton blends.

Additionally, for dyeing the PC blends, dyeing of cotton with reactive dyes takes place first which is done on jigger and later on jet dyeing machine. The polyester part of fabric is dyed using disperse dyes. Many a time instead of separate dyeing, the fabric is dyed in jet dyeing machine only for medium to dark shade.

2.8.2. Polyester/Wool Blends

Poly-wool blends are used for manufacturing suiting fabrics. It is observed that unlike Polyester-Cotton Blends, Polyester and wool are blended at fibre stage. Wool being a natural fibre needs to be cleaned first Wool is scoured for removal of greasy material present in it. Wool scoring may be carried out in a series of bowls where the wool fibre mass is transported from one bowl to another with gentle stirring. Non-ionic surfactants are primarily used for contaminant removal. Sodium carbonate may be used as builder sometimes to facilitate contaminant removal when immersion time is short. As wool gets cleaned progressively, the composition of treatment bowls keeps changing. The most important auxiliary used for wool scouring is a detergent. After scouring, the woolen fibres are rinsed with water at a temperature of 46°C to 50°C to remove the residual chemicals and remaining dirt. Clean wool fibres from several different

[28] *https://textilelearner.net/bleaching-of-blended-fibre-fabrics/*

batches are often blended or mixed mechanically. Blending helps in uniforming the slightly-different basic colors of raw wool. It also standardizes staple length and diameter for uniform quality.

The fibre are then carded and combed into slivers of defined thickness.

2.9. Denims

Denim is a durable cotton twill textile in which the weft passes under two or more warp threads. It is typically used to make jeans, overalls, and other clothing. Denim was traditionally colored blue with indigo dye to make blue "jeans". Denim is made from a vat dye, the Indigo dye, which is applied to cotton fabric in loosely held form in layers. As far as manufacturing process of denim is concerned, it is similar to that of Grey fabric up to the process of weaving. The only difference in case of Denim Fabric is, it is dyed at the stage of sizing where as in case of Grey Fabric, the decision regarding dyeing depends upon the finished product.

The initial stage of denim production is Opening and Blending. Opening begins with the separation of baled cotton fibre into small tufts. A blend of cotton fibres is made on each opening line. Cotton is delivered by air suction from the Opening and Blending lines, through additional cleaning and blending machines, to the Cards. The major functions of Carding are to remove foreign matter and short fibres and form the cotton into a web and convert the web into a rope-like form known as a sliver.

The drawing process produces a single, uniform sliver from six card slivers. The additional blending, paralleling of fibres and cleaning in this process produce a sliver for Open End and Ring Spinning. For Ring Spinning, however, the sliver must pass through an additional process called Roving.

Denim Fabrics woven of 100% cotton would be very strong and durable. The look and quality of the Denim Fabric shall improve after dyeing, which differs from plant to plant. Normally the process of dyeing dictates the technology of Denim manufacturing.

2.9.1. Spinning

Manufacturing Staple Fibre Currently, it is possible to obtain different types of thread in the denim yarn market, according to the manufacturing system used:

- Rotor or Open-End (OE) System
- Ring System
- Compact System

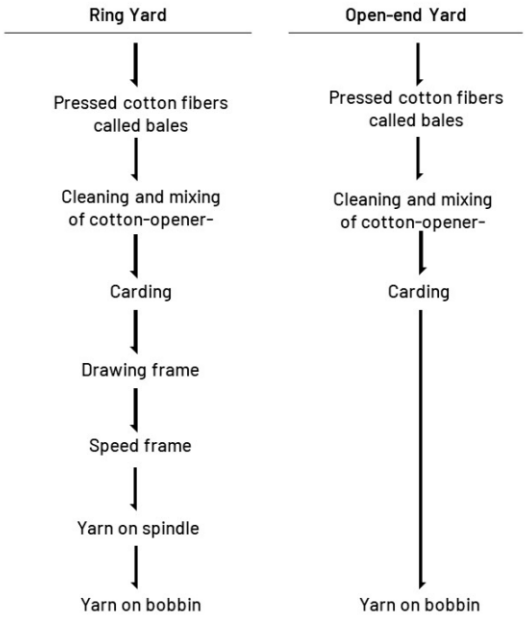


Figure 2.32: Production phases of the two most important types of thread

2.9.1.1. Rotor or Open-End (OE) System

This type of spinning was historically the most frequently used for the manufacturing of denim items. In the OE system differences in length of fibres when they are grouped together are accepted, thus making it possible to work with medium or low quality cotton. Furthermore, fibres in the final yarn can be arranged irregularly.

The manufacturing process includes the following operations:

Cleaning: a process during which impurities and cotton seeds are eliminated.

Mixing: cotton from different origins is mixed and finally emerges in the form of fleece. This process is also called the opening of cotton, as it arrives in the form of bales. The machine used for this initial operation is known as the opener. With this operation it is possible to achieve a high degree of regularity in the final yarn.

Carding: an operation that involves the elimination of fibres which are too short, their orientation and the formation of tufts (ropes) using fibres of adequate length. In addition to carding, the threads might be also combed. In this case, the fibres laid parallel, superior in smoothness to carded yarn.

Passage through the spinning machine: an operation during which the final degree of thread twist is determined, as well as thickness, regularity and weight. The thread is formed by passing the tuft through a spinneret where a combination of tension and air finishes the process of production. The resulting thread is then placed on the bobbins.

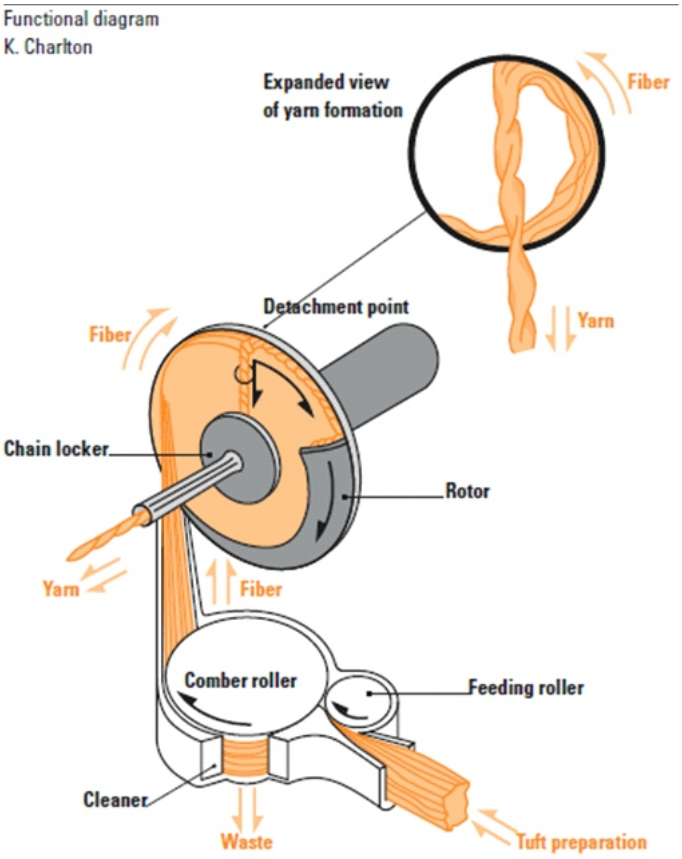


Figure 2.33: Operating diagram of a rotor spinning

2.9.1.2. Ring System

At present the majority of yarn destined for denim is manufactured using this system. Rotor or OE system is gradually losing ground to the ring system. The main characteristics of ring yarn include: greater volume, softness, elasticity and resistance than that of yarn produced through the OE system. The ring thread has fibres of greater length and regularity than those of the open-end yarn. The production of the ring thread includes more operations within the global process of spinning than those needed for the manufacturing of open-end yarn. Apart from the operations of cleaning, mixing, carding and the passage through a continuous spinning machine, the production of ring yarn also includes the following steps:

Drawing frame step, during which a more intimate blend is produced from cotton of different origins, the fibres stay more parallel and the tuft is thinner.

Speed frames or drawing frames step, during which the tuft is drawn apart. A certain number of fibres are eliminated in order to obtain the final desired thickness. These fibres come out completely parallel to each other.

Spinning machine step, during which the final yarn is not formed by passing through a spinneret, but by passing the tuft through a drawing and rotation system by means of a ring, at very high velocities. Then the yarn passes on to spindles and finally to the bobbins

This way the ring system ensures that cotton fibre length is more regular, which implies better cotton quality and therefore higher costs, because of additional operations as mentioned earlier.

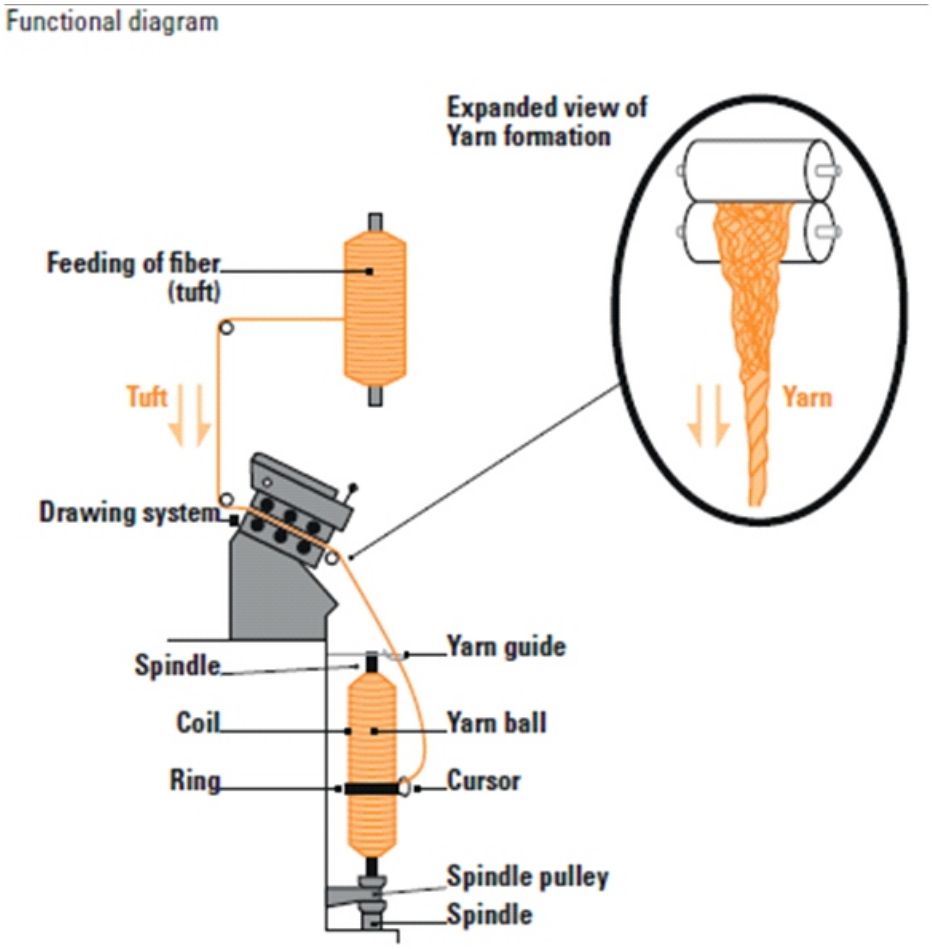


Figure 2.34: Operating diagram of ring spinning

2.9.1.3. Compact System

Currently a new type of spinning system is gaining importance. It is called the compact system and does not differ much from the ring system as regards the quality of the obtained thread. In this case, a special system of fibre orientation exists which gets the thread at considerably higher velocities than through the ring system, but with a similar efficiency as that attained by using the open-end system. Other notable characteristics of compact spinning are considerable less fluffiness of threads manufactured by this system, compared with those produced through the ring or OE systems. Thanks to this property, denim fabrics produced through a manufacturing system using compact-type thread, usually have a cleaner surface than fabrics with ring threads. Handle, volume, absorption capacity, capillarity and softness are other characteristics that differentiate one type of spinning from the other.

Characteristics of Different Types of Yarn

Yarn destined for warp dyeing should present certain physical properties which make them suitable for their application in the phases of preparation, dyeing and subsequent operations. Yarn is characterized according to the following criteria:

- Type of fibres
- Thickness or diameter
- Degree and direction of thread twist
- Strength
- Elasticity
- Regularity
- Absorption capacity

The type of fibres forming the thread (in respect of length, thickness and form) is determined by the origin of cotton.

Thickness or diameter, called the count or number of the thread, are the numbers which describe

characteristics of a thread and are preceded by the system symbol which was used to name them. In general, two types of systems can be distinguished:

Direct systems: they determine how much a certain length of thread weighs, for example the Tex system, which refers to the weight in grams of 1000 meters of thread. It is used mostly for continuous type nylon filaments, PES or Rayon.

Inverse systems: the most common systems for cotton warp yarn destined for denim fabrics. They are based on calculations of the length of a certain weight of thread and are called inverse, because the higher the number, the thinner the thread.

Various inverse systems are known:

- Metric number: indicates the length in meters of 1 gram of thread, indicating also how many ends the thread has. Example: Nm16.79/1. It means that 1 gram of this thread is 16.79 meters long and that in this case a single end thread was used.
- English number: indicates the number of hanks of 840 yards – equivalent of 768,08 meters – which weigh 1 lb (451,59g). The way of expressing the value is the same as in the case of Nm.
- Catalan number: similar to the English number, indicates the number of hanks of 777,5 m, which weigh 440 grams.

The thread twist's degree and direction is the number of turns given to the thread per unit of length. The purpose of the twist is to increase the cohesion of fibres in order to better preserve their position in the yarn. The direction of the thread twist can be either Z (left twist) or S (right twist) (Figure 2.35).

The twist influences thread resistance: the greater the twist, the higher the resistance, but less elasticity – which is the degree of thread recuperation, after it is stretched.

In warp threads the twist is usually greater because it has to endure more tension in the dyeing machine as well as later, in the loom.



Figure 2.35: Z & S twist directions

Strength, which should be greater than the tensions that the thread has to endure during different phases of the textile process.

Elasticity is the degree of extension of the thread after it recovers its initial length. Depending on the type of thread, elasticity will be greater, such as in the case of the ring or compact yarn, and less in the case of open-end.

Regularity of the thread is determined by the presence or lack of:

- Knots: loops formed by fibres.
- Flames or slubs: thick parts of the yarn. The flame effect is an accumulation of fibres in alternate areas of the thread. These accumulations appear due to consecutive stretching and overfeeding of material. Each of these accumulations is called slub. When the number of slubs in yarn is very high, it is called multiflamé. The final appearance of a fabric with this type of thread is very uneven, with thicker and thinner areas, therefore washing the garment will eventually show special uneven effects. This is the case of 'controlled unevenness'.
- Multicount: this type of thread irregularity is produced by alternating threads with different numbers, in such a way that areas of thinner thread (26/1c) pass on to areas of thicker thread (22/1c). Changes in periodicity, length and thread number can be controlled 'on-line', which results in 'controlled irregularities.' Depending on the available type of spinning, the same effects could be obtained in openend type spinning as well as in ring or compact, by following pre-established spinning computer programs.
- Neps: entangling of fibres. Depending on what effect is supposed to appear in the final garment, more or less irregularities are created.

Absorption capacity of a thread in a dye bath is determined by the quality of cotton and by the orientation of fibres in the thread. The greater the orientation in the same direction, the lower the absorption capacity.

Influence of the Type of Yarn on Dying

During warp dyeing the quality of the yarn, as well as its type, is an important factor when it comes to enduring tensions with which the ranges work. Generally, open-end type yarn have a good absorption capacity in short periods of bath-material contact in dye vats. Ring type yarn also has a good absorption capacity, although lower than that of open-end yarn. If the ring yarn is additionally combed (with greater orientation of fibres in the same direction), absorption capacity is even lower, although yarn quality is the best.

Influence of the Type of Yarn on the Finish: Effects

The type of yarn used in the construction of a fabric and later in garment production decidedly influences the latter's final appearance. Among the different existing possibilities, already commented,

when it comes to type of yarn, ring or open-end, we can find differences as regards the regularity/irregularity, which influence decidedly the final appearance of the garment.

The use of yarn that display certain irregularities is related to the current tendency to produce final garments with worn-out or 'old' appearance. Attempts are also made to manufacture jeans using methods that were used in the past, when the operation of weaving was craftwork and the irregularities were produced accidentlly or by chance.

2.9.2. Dyeing Ranges

At present there are three different types of preparation and dyeing systems for warp yarn denim which are carried out by the following ranges:

- Rope dyeing range
- Slasher dyeing range
- Loop dyeing range

The first system used for denim was rope, while slasher and loop were incorporated later. Historically, you could observe a clear differentiation between geographical areas, which gradually disappeared.

Before entering the dyeing range the yarn has to be prepared in the form of big cylindrical structures called beams where the threads are wound in optimal conditions of pressure and regularity. This process, which is begun by spinning cones is called warping as shown in figure 2.36. Depending on the type of dyeing range, beams are constituted from yarn set parallel, flat and open in the case of slasher and loop, or arranged in small groups forming ropes, as in the case of rope range.

To conclude, the different types of existing machinery are made up of a certain amount of vats or boxes destined primarily for preparing the material and dyeing and also vats or boxes for cleaning or final rinsing.

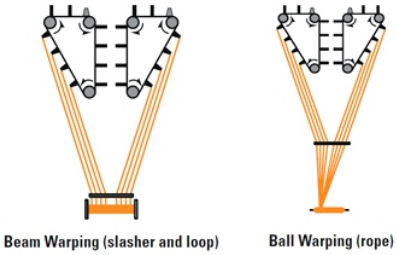


Figure 2.36: Types of warp yarn preparation

2.9.2.1. Rope Dyeing Range

In this type of denim range warp threads are extended along the range in the form of a rope. Yarn groups are composed of 300 and 400 ends forming ropes or cables.

The total width of rope ranges is taken up by a number of ropes ranging between 12 and 48, depending on the width of the machine. The total number of ends, depending on the number of ropes, can range between 3600 and 19200.

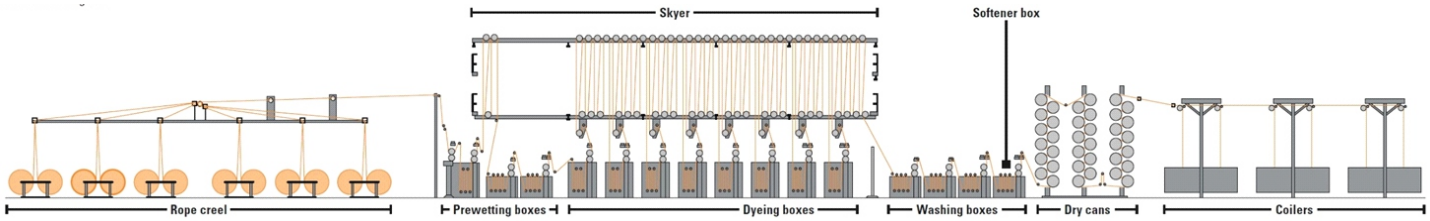


Figure 2.37: Rope Dyeing Range

2.9.2.2. Loop Dye Range

The system of preparation of beams as well as the way of circulating yarn in the loop range is the same as in slasher range, which means that parallel threads enter and circulate in one layer.

In loop range, as opposed to slasher, yarn does not circulate along a machine composed of various boxes. After the impregnation with a solution of dyestuff and squeeze, the yarn pass through a closed circuit to enter again into the single vat.

This lap of yarn passes as many times as required through the single dyestuff impregnation vat.

The number of times the lap passes through the same indigo vat is determined by various factors: the type of yarn used, the number of this yarn, the number of yarn forming the warp, as well as the desired color intensity.

It is necessary to maintain precise control during squeezing, since during each pass, threads from different layers are being accumulated and all of them have to be squeezed out in an absolutely regular and homogeneous way in the squeezing mangle.

Once the warp sheet has passed through the dye vat, the latter turns to the final skying time to oxidize the indigo dyestuff, then washing, drying and sizing , in the form of a single layer (like in the slasher).

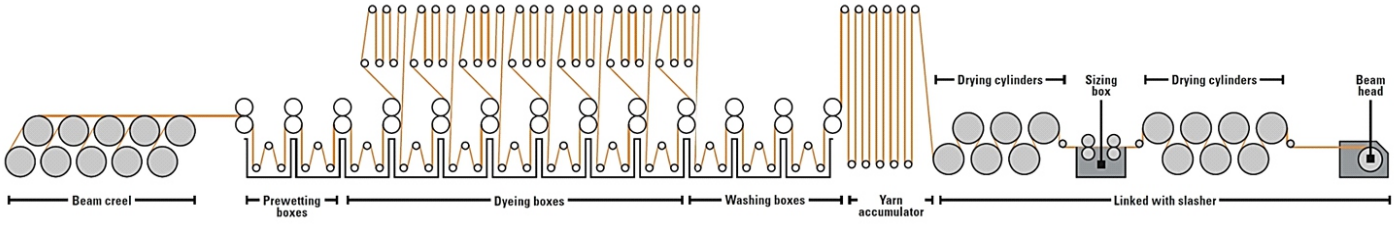


Figure 2.38: Slasher Range

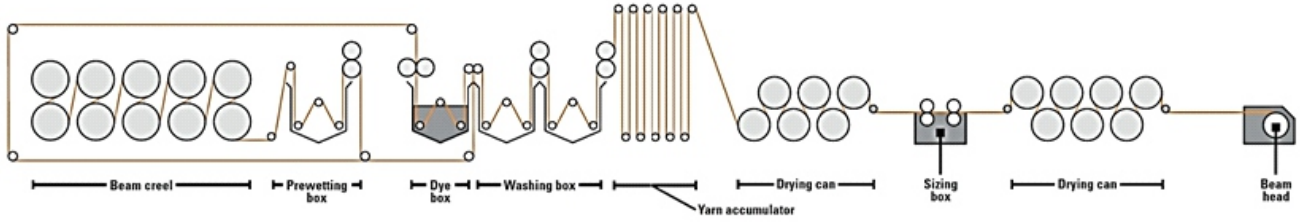


Figure 2.39: Loop Range

2.9.3. Pre-treatment for Denim

2.9.3.1. Pre-wetting

The quickness of pre-wetting is the most important quality parameter of the warp yarn wetting agent. It is because there is a time limitation in the contact between the fibre and the bath in normal application conditions. The pre-wetting of the yarn should be uniform and constant. If this condition is not fulfilled, differences in the degree of penetration of the dyestuff could appear subsequently, and as a consequence, different intensities will be visible.

The wetting agent of anionic nature is usually applied at room temperature with at least one post-rinsing, it is to prevent possible problems with stability when the yarn enters successive dye vats. It is also recommended to use a dispersing agent; capable of maintaining dispersed those oils and impurities which are removed during pre-wetting.

2.9.4. Dyeing & Sizing

The dyeing for Denim Fabric happens at the sizing stage. Indigo has been used as the main dyestuff in the production of standard blue denim cotton fabrics. In order to widen the jeans color range, sulfur dyestuffs are started being used individually, not combined with indigo. Black has always been the second most commonly used dyestuff after indigo blue. Other colors, such as brown, olive, burgundy etc. are being incorporated as well.

Commercial forms in which indigo is offered are diverse. However, powder or granulate is the most common form in the market, in relation to liquid or dispersed forms. From the chemical point of view indigo is based on an oxidation-reduction principle, similar to sulfur dyestuffs. Indigo is an insoluble pigment, without affinity for cellulose in oxidized state. For application the dyestuff should be in reduced leucoalkaline, soluble state. In order to maintain the reduced condition ns of Indigo, a particular concentration of alkali is used (usually caustic soda) as well as strong reducing agent, the sodium hydrosulfite, auxiliaries like dispersing or wetting agents etc. Indigo dye bath should be controlled by means of chemical parameters such as pH and reduction.

The indigo is applied to the yarn by means of repeated impregnations, and then passed through the skyer to become gradually oxidized. Contrary to sulfur dyes, Indigo is characterized by a low affinity and a quick oxidation tendency. Owing to these two factors the dye needs several impregnations in order to reach medium-high intensities (from 4-6 to 10-12 impregnations). After impregnation and squeezing in the squeezing mangle, the yarn should spend some time in the air duct, where the indigo dye is gradually oxidized. It becomes insoluble and gets fixed on the yarn by means of weak bonds (Eg Vander Waals bonds). This way the indigo is deposited on the yarn in as many layers, as there are impregnations. In any case the final effect of indigo on the yarn is superficial because of low diffusion of the dye.

This characteristic implies certain limitations as far as fastness is concerned, especially when high intensity colors are required. So it is necessary to control certain chemical parameters, such as:

- Alkalinity (pH)
- Reduction (mV)
- Temperature
- Concentration of indigo in the dye bath
- Impregnation time of the yarn in dye box

The usual **pH values** move between 11.5-13. Values lower than this range could trigger inconsistency in shade after dyeing.[29] This is owing to the fact that indigo presents a chemical form called acid vat, insoluble and without affinity. Generally, at higher pH values the shade is more reddish, dye diffusion is greater and the intensity is lower.

Reduction is measured as the function of the concentration of free sodium hydrosulfite for an optimum state of indigo reduction. Generally, the ideal concentration of this reducing agent is that the presence of sodium hydrosulfite should not lead to reaction that means very quick oxidation which causes low washing fastness has to be prevented. The usual values of free sodium hydrosulfite vary depending on the type of range used (rope or slasher). The general rule is that the values range from a minimum of 0.2 g/liter to more extreme values of 7-8 g/liter.

The application is done at room temperature. Substantial differences in temperature at the same workplace cause variations in the degree of indigo oxidation and also in the consumption of hydrosulfite. The higher the temperature, the more the degree of oxidation and consumption of sodium hydrosulfite.

The **concentration of indigo** in the bath can be measured by conducting a titration reaction at a laboratory or by using a spectrophotometer taking a sample from the indigo bath.

The **impregnation time** of the dye in the dye vat is directly related to the speed at which the yarn passes through the denim range.

Sulfur dyestuffs evolved in commercial powder forms have higher content of sodium sulphide compared to the liquid forms available. These molecules are often long and they contain few solubilizing groups. In fact, just as in the case of indigo, sulfur dyestuffs are insoluble in their"pigmentary" form which is their oxidated state. Sulfur dyestuffs require a much more energetic oxidation in order to develop completely the final color. Contrary to indigo, which becomes completely oxidized while passing several times through air passage skying, the sulfur dye needs a chemical oxidation through the impregnation of the yarn in a solution with any oxidizing agent. Most commonly used oxidizing agents for sulfur dyeing are: sodium bromate at acidic pH, hydrogen peroxide at both alkaline and acidic pH and sodium chlorite.

Generally, there are two most popular methods of dyeing Denim Fabric. They are: Rope Dyeing and Sheet Dyeing. In order to obtain deep blue indigo dyed yarns, the color must be built in layers. The dye is layered by passing of the rope of yarn, required number of times ,into the soluble dye and then exposing it to the air for oxidation. This multiple passing of yarn into dye is called dips. Normally, this process is repeated from three to twelve times to build up a deep indigo blue color. The number of dips is limited to the number of dye boxes on the dye range. If the concentration of indigo dye in the dye boxes is doubled, this will result in slightly darker denim. This acts as a multiplier when labeling the denim.

A double concentration of dye in nine dye boxes makes it 18-dip denim. Tripling the concentration makes it 27-dip denim. When even darker shades are desired, a sulfur black or blue dye can be applied to the yarn before indigo dyeing. This is known as a sulfur bottom. If the sulfur dye is applied after the yarn has been indigo dyed, it is known as sulfur top.

After dyeing, the dyed yarn is washed with fresh water for two-three times and finally squeezed before allowing it to pass through drying cylinders. The dyed yarn enters the starching device and sizing is done.

[29] *https://www.fsw.cc/ph-monitoring-improve-reactive-dyeing/*

2.9.5. Sizing

Neither classical weaving nor modern high speed weaving can be carried out without sizing agents. They adhere the individual fibres in the yarn to each other and form a protective film on the fibre surface which enables the yarn to survive the extreme mechanical stress during weaving. Only the warp yarn has to be sized due to its function as skeleton of the fabric.

In the denim production sizing process can be carried out continuously linked to the dyeing process on sheet or slasher dyeing machine or by using the rope dying machine after the warping of the ropes in a separate sizing machine. The sizing process is necessary to achieve highest weaving efficiency on the looms.

Today a large number of classes of chemical substances are used as sizing agents. They can be classified in two main groups: a. Natural or semi-synthetic b. Synthetic polymers. For sizing of cotton yarns, starch is widely used along with other auxiliaries such as binders.

Sizing agents are applied to the warp threads from aqueous liquors. The threads pass from the warp beams through the sizing trough where they dip in the sizing liquor and impregnate with it. The surplus liquor is then squeezed off in the immersion roller which allows a liquor pick-up of 50- 150 %, depending on the physical warp characteristics, machine settings and sizing liquor parameters. The sized warp threads are dried in the cylinder drier, separated in the dry splitting field and wound onto the weaving beam. After the weaving process the task of the sizing agent is complete. It must then be totally removed in the pretreatment process.

2.9.6. Weaving

Denim fabric is distinguished by a colored warp and a raw or uncolored weft. The weaving process is carried out by using looms, which are weaving devices, that maintain the warp tension in order to facilitate the inter weaving of the weft.

The weaving process interlaces the warp, which are the length-wise indigo dyed yarn and the filling, which are the natural-colored cross-wise yarn. The warp thread is in the form of sheet. The weft thread is inserted between two layers of warp sheets by means of a suitable carrier, such as Shuttle, Projectile, Rapier, Air current, Water current, etc.

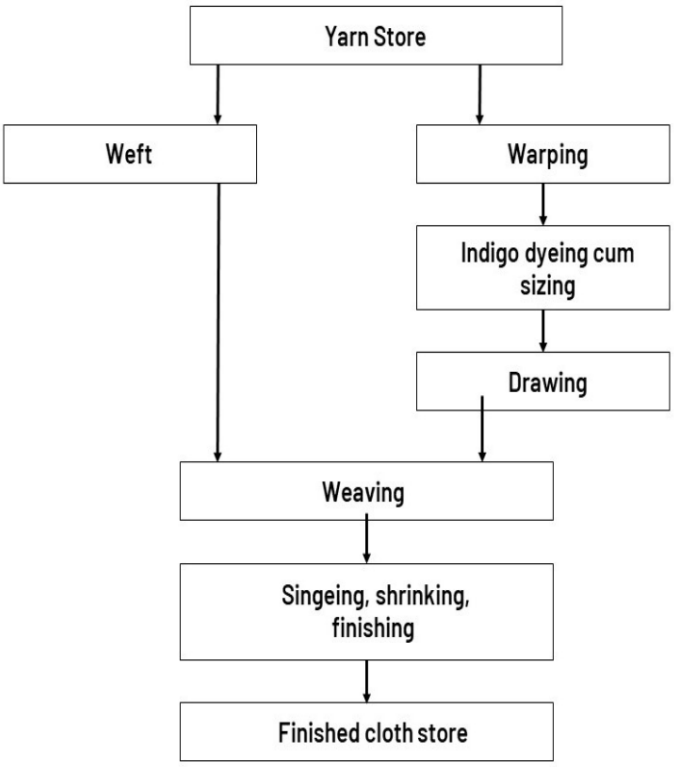


Figure 2.40: Flowchart of Weaving Process

Basic operations are always carried out on the denim fabric just after the weaving process. They are required for the correct physical behavior of the fabric. After weaving, the woven Denim Fabrics goes for various finishing processes consisting of brushing, singeing, washing, impregnation for dressing and drying.

2.9.7 Finishing of Denim

Finishing methods for denim fabrics have been developed a lot over the past few years. Apart from conventional ones that assure standard quality, there are also special finishing treatments which improve the performance of the fabric and the final effect on the garment. Now-a-days, finishing is an element of differentiation in the denim market. Fabrics need to be subjected to finishing before the manufacturing of the garment. It is necessary to obtain the correct physical behavior and stability of the garment during home laundering. On the other hand, the finishing treatments of the denim garments are based on fashion trends and effects. In this case physical and chemical treatments are used (dry and wet garment processing).

Brushing and singeing are consecutive operations, which eliminates superficial fibres which give the fabric a fluffy look. During that process the fabric is subject to a superficial combustion of the fibres with a gas flame at elevated speed (specially adjusted so that the fabric does not suffer any deterioration or damage). After singeing a posterior washing is carried out in order to clean the fabric.

Sanforizing is a physical treatment carried out on the denim fabric. It is technically called control of shrinkage due to compression. It is carried out in a cylinder with a rubber tape or mat stuck to it which exerts pressure on another cylinder. It can be observed in the picture. There is a pressure area between the cylinder and the rubber where the shrinkage of the fabric takes place. The warp thread is joined there and shrunk evenly.

2.10. Textile Industry Categories

The textile sector is fragmented and heterogeneous. Earlier in this chapter, the fundamental unit processes in the textiles have been described in detail. The information has been structured by fibre type and this helps in determining the issues related to the physico-chemical behavior of fibre.

There are established pattern of activities for mills tending to concentrate on particular kinds of end-product e.g. yarn, woven fabric, finished fabric, printed fabric, etc.

The industry processes wide variety of fibres, even if one type is dominant in a particular industry (e.g. cotton, polyester, etc).

Looking at the textile clusters that are in the scope of this document, the textile industries are classified in three major groups:

- Cotton Process House
- Polyester Process House
- Denim Processing

Further, these industrial categories will be described based on the scale (scale of industry is defined based on the capital investment & scale of operation) of industry i.e. micro, small, medium & large.

Depending on the quality of end-product required by the customer, many parameters vary namely, production varies from 2,00,000 m/month to 75,00,000 m/month. Also significant difference is observed in the processing conditions. The working pattern also varies ranging from operating hours from 24 hours/day all week to industries working 6 days' week for 15-16 hours.

2.10.1. Cotton Process House:

As described earlier in section 2.6 the cotton textile processing follows the sequence as shown in the chart. The sequence as well as the number of stages in the processing may vary in the units depending on the demand of the end user.

Majority of textile industries perform job work. The fabric is received from vendors and processed as per their requirement and hence the processing sequence is varied.

Among the selected cluster in Gujarat for BREF, cotton is mainly processed at Ahmedabad & Jetpur. The scale of units varies from small to large scale (classification based on the investment in plant & machinery). A few micro scale units having hand printing operation also exist in these regions. The fabric is processed as per the demand of domestic as well as foreign market. The water and chemical consumption varies depending on the weight of the fabric. It also varies based on the machinery used and the type of process adopted.

Taking this into consideration, cotton textile industries are categorized as:

- Mills processing the fabric
- Mills finishing fabric with significant dyeing & printing
- Table printing units

A. Mills processing fabric

Process sequence for wet processing of the cotton fabric is shown in fig. 2.41.

The process can be carried out on semi-continuous/continuous or in batch mode mainly depending on the size of the lot. Also processes like desizing, scouring & bleaching can be combined as one.

B. Mills finishing fabric with significant dyeing & printing

Typical process sequence for cotton finishing mill is shown in fig. 2.41.

Pretreatment operations such as desizing, scouring and bleaching are very often combined in one single step in continuous lines. The processes can be carried out in Batch or continuous mode. Cotton is processed

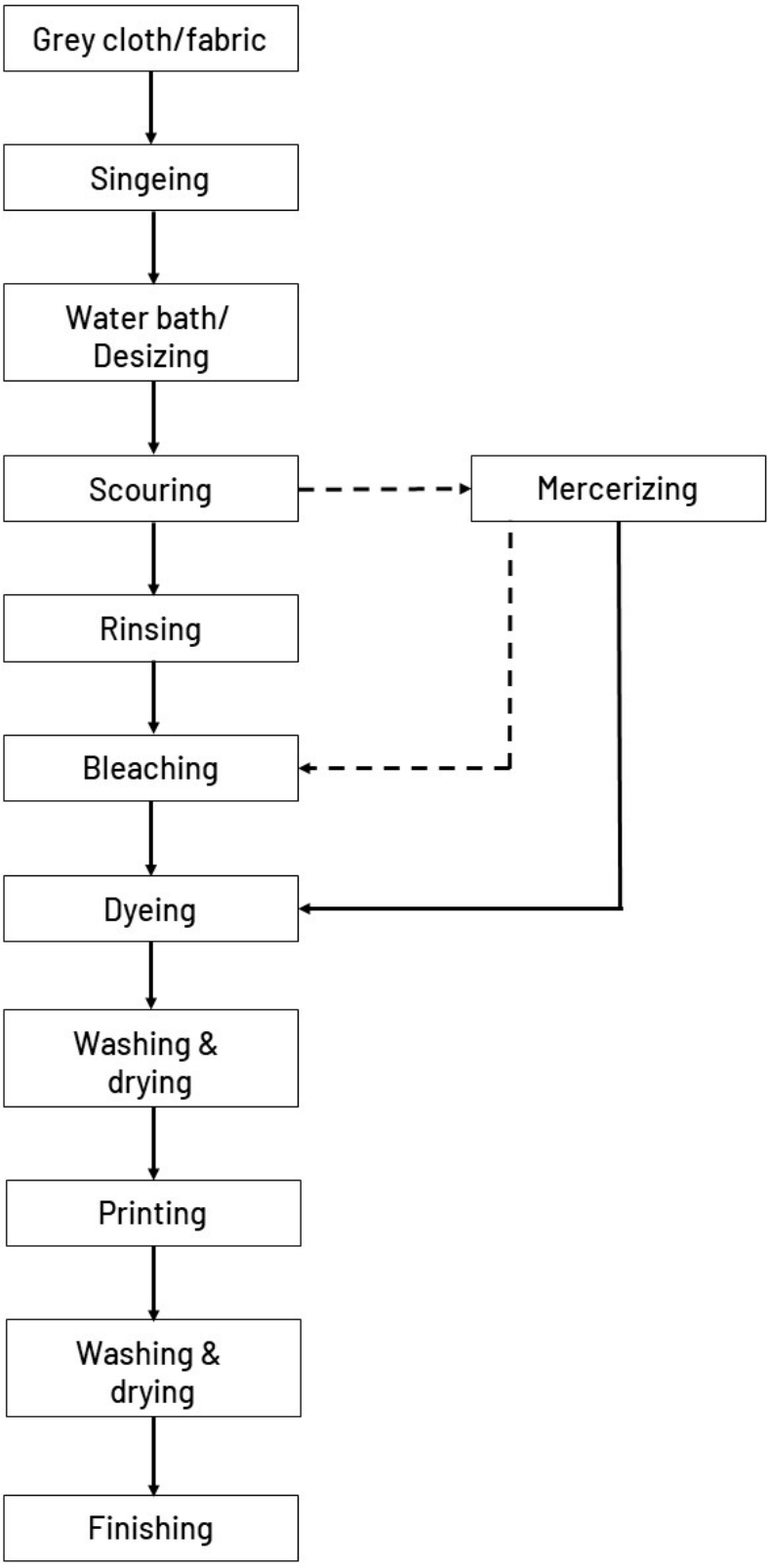


Figure 2.41: Typical process sequence for cotton finishing mills

mainly on Jigger since cotton requires to be processed in open width.

Cotton fabric can be dyed with different classes of dyestuffs such as reactive, direct, sulphur and vat. Out of all, Reactive dyestuffs are the most commonly used.

C. Table printing units

This category of industry is defined separately as only manual printing on table is carried out in these industries. These industries operate at micro level and do not have any machinery for cloth washing or drying. Cloth is further sent to the washing-ghats for washing.

2.10.2. Polyester Process House:

The textile cluster at Surat processes mainly the art silk, which is polyester fabric. Basic polyester processing is as described in section 2.7.

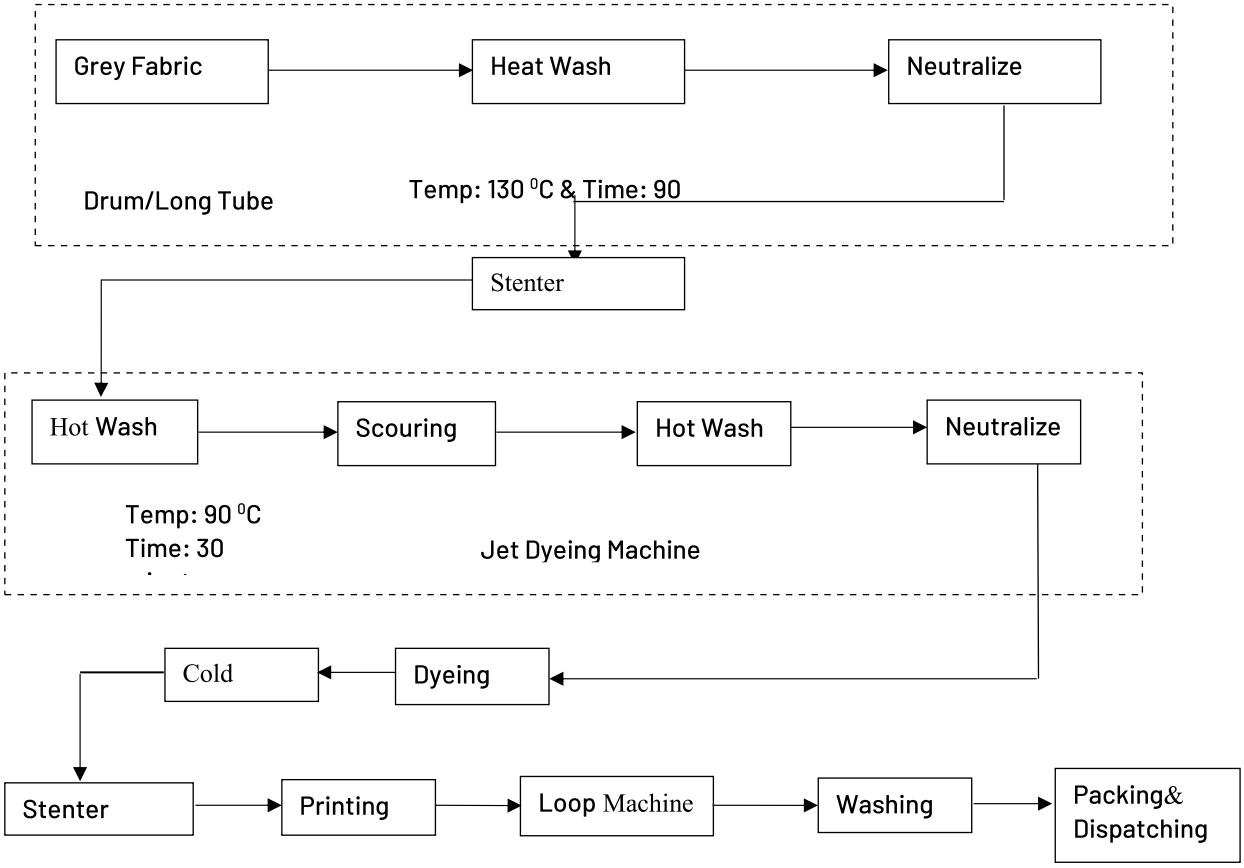


Figure 2.42 Typical process sequence in the polyester textile industries

2.11. Boilers

2.11.1 Introduction

Steam is used for direct heating and hot water generation. It plays an integral role at several stages of the textile manufacturing process. These include the following operations:

- Textile pre-treatment processes such as scouring, bleaching, and mercerization
- Dyeing (exhaust and continuous)
- All hot washing processes with hot water (batch and continuous)
- Stenter operation

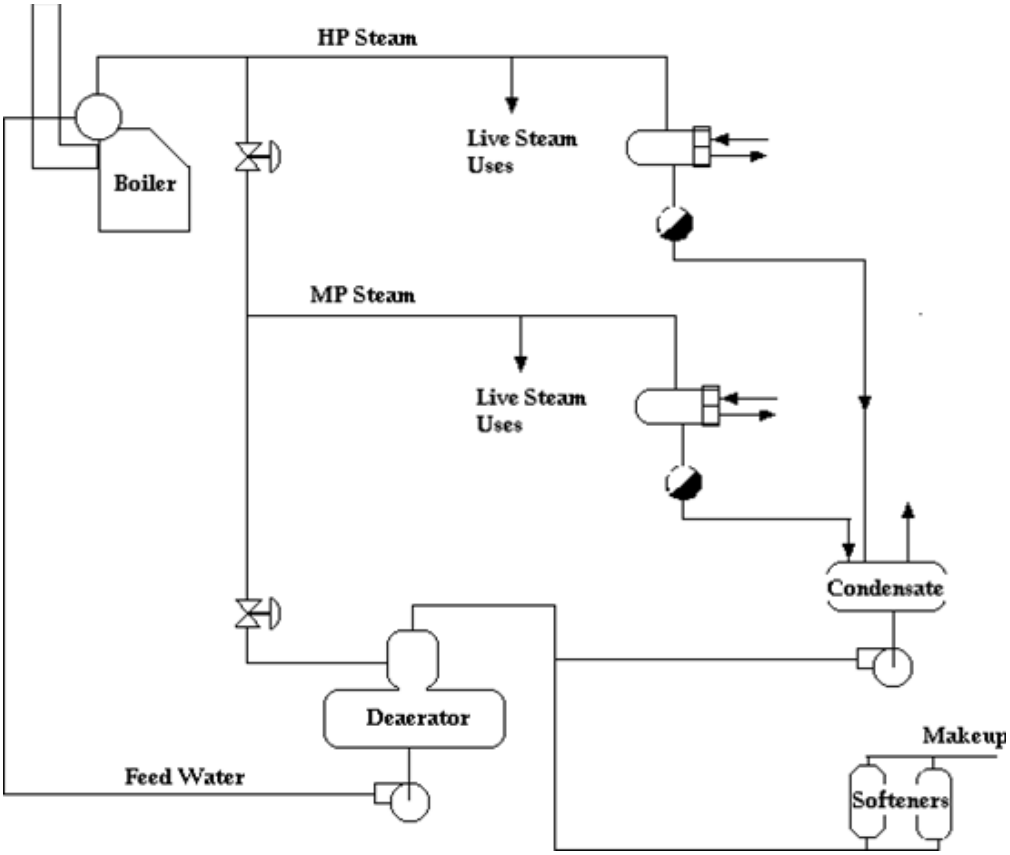


Figure 2.43 Steam System

As illustrated in Figure 2.43, Steam system components includes:

- Boiler & Boiler auxiliaries
- Fuel storage and handling equipment
- Steam piping & Steam traps
- Feed Water treatment equipment
- Turbines (if co-generation)
- Heat exchangers
- Pressure reducing stations
- Condensate recovery and return system
- Air pollution control devices

2.11.2 Types of Boilers

2.11.2.1 Fire Tube Boiler

It is generally used when relatively small steam capacities (12,000 kg/r) and low to medium steam pressures (18 kg/cm^2) is required.

2.11.2.2 Water Tube Boiler

In a water tube boiler, boiler feed water flows through the tubes and enters the boiler drum. The circulated water is heated by the combustion gases and converted into steam at the vapour space in the drum. These boilers are selected when the steam demand as well as steam pressure requirements are high as in the case of process cum power boiler / power boilers.

Most modern water boiler tube designs are within the capacity range 4,500 – 120,000 kg/hour of steam, at very high pressures. Many water tube boilers are of "packaged" construction if oil and /or gas are to be used as fuel. Solid fuel fired water tube designs are available but packaged designs are less common.

The features of water tube boilers are:

Boiler & Boiler auxiliaries

- Forced, induced and balanced draft provisions help to improve combustion efficiency.
- Less tolerance for water quality requires process water treatment (softening)
- Higher thermal efficiency levels are possible.

2.11.2.3 Packaged Boiler

The packaged boiler is so called because it comes as a complete package. Once delivered to a site, it requires only the steam, water pipe work, fuel supply and electrical connections to be made to become operational.

Package boilers are generally of a shell type with a fire tube design so as to achieve high heat transfer rates by both radiation and convection.

The features of packaged boilers are:

- Small combustion space and high heat release rate resulting in faster evaporation.
- Large number of small diameter tubes leading to good convective heat transfer.
- Forced or induced draft systems resulting in good combustion efficiency.
- Number of passes resulting in better overall heat transfer.
- Higher thermal efficiency levels compared with other boilers.

These boilers are classified based on the number of passes - the number of times the hot combustion gases pass through the boiler.

2.11.2.4 Fluidized Bed (FBC) Boiler

When an evenly distributed air or gas is passed upward through a finely divided bed of solid particles such as sand supported on a fine mesh, the particles are undisturbed at low velocity. As air velocity is gradually increased, a stage is reached when the individual particles are suspended in the air stream – the bed is called "fluidized". With further increase in air velocity, there is bubble formation, vigorous turbulence, rapid mixing and formation of dense defined bed surface. The bed of solid particles exhibits the properties of a boiling liquid and assumes the appearance of a fluid – "bubbling fluidized bed".

- The fuels burnt in these boilers include coal, washery rejects, rice husk, bagasse & other agricultural wastes.
- The fluidized bed boilers have a wide capacity range - 0.5 T/hr to over 100 T/hr.
- The fluidized bed combustion (FBC) takes place at about 840°C to 950°C.

Fluidized bed combustion (FBC) has emerged as a viable alternative and has significant advantages over a conventional firing system and offers multiple benefits – compact boiler design, fuel flexibility, higher combustion efficiency and reduced emission of noxious pollutants such as NOx. Compared to other combustion systems, the reduction of SO_x is much easier to realize with the use of calcium-based additives.

Three types of FBC boilers are explained below:

a. **Atmospheric Fluidized Bed Combustion (AFBC) Boiler** - Most operational boiler of this type is of the Atmospheric Fluidized Bed Combustion. (AFBC). In this boiler, atmospheric air, which acts as both the fluidization and combustion air, is delivered at a pressure, after being preheated by the exhaust fuel gases

b. **Pressurized Fluidized Bed Combustion (PFBC) Boiler** - a compressor supplies the Forced Draft (FD) air and the combustor is a pressure vessel. A deep bed is used to extract large amounts of heat. This will improve the combustion efficiency and sulphur dioxide absorption in the bed. The steam is generated in the two tube bundles, one in the bed and one above it. Hot flue gases drive a power generating gas t urbine. The PFBC system can be used for cogeneration (steam and electricity) or combined cycle power generation.

c. **Atmospheric Circulating Fluidized Bed Combustion (CFBC) Boiler** -. In a circulating system the bed parameters are maintained to promote solids elutriation from the bed. They are lifted in a relatively dilute phase in a solids riser, and a down-comer with a cyclone provides a return path for the solids.

There are no steam generation tubes immersed in the bed. Generation and super heating of steam takes place in the convection section, water walls, at the exit of the riser.

Benefits:

i. CFBC boilers are generally more economical than AFBC boilers for industrial application requiring more than 75 – 100 T/hr of steam.

ii. For large units, the taller furnace characteristics of CFBC boilers offers better space utilization, greater fuel particle and sorbent residence time for efficient combustion and SO_2 capture, and easier application of staged combustion techniques for NOx control than AFBC steam generators..

2.11.2.5 Stoker Fired Boiler

Stoker fired boilers are classified according to the method of feeding fuel to the furnace and by the type of grate. The main classifications of stokers are "spreader stoker" and "chain-grate or traveling-grate stoker".

a. **Spreader stokers**

Spreader stokers utilize a combination of suspension burning and grate burning. The coal is continually fed into the furnace above a burning bed of coal. The coal fines are burned in suspension; the larger particles fall to the grate, where they are burned in a thin, fast-burning coal bed.

This method of firing provides good flexibility to meet load fluctuations, since ignition is almost instantaneous when the firing rate is increased. Due to this, the spreader stoker is favored over other types of stokers in many industrial applications.

b. **Chain-grate or traveling-grate stoker**

Coal is fed onto one end of a moving steel grate. As the grate moves along the length of the furnace, the coal burns before dropping off at the end as ash.

The coal-feed hopper runs along the entire coal-feed end of the furnace. A coal gate is used to control the rate at which coal is fed into the furnace by controlling the thickness of the fuel bed.

Coal must be uniform in size as large lumps will not burn out completely by the time they reach the end of the grate.

2.11.2.6 Pulverized Fuel Boiler

The coal is pulverized to a fine powder until less than 2% of the coal is +300 micro meter and 70-75% is below 75 microns for bituminous coal. The pulverized coal is then blown with part of the combustion air into the boiler plant through a series of burner nozzles.

The combustion takes place at temperatures ranging between 1300-1700 degrees Celsius depending mainly on the coal grade. The particle residence time in the boiler is typically 2 to 5 seconds and the particles have to be small enough to be completely combusted during this time period. This system has many advantages such as ability to fire varying quality of coal, quick responses to changes in load, use of high pre-heat air temperatures etc.

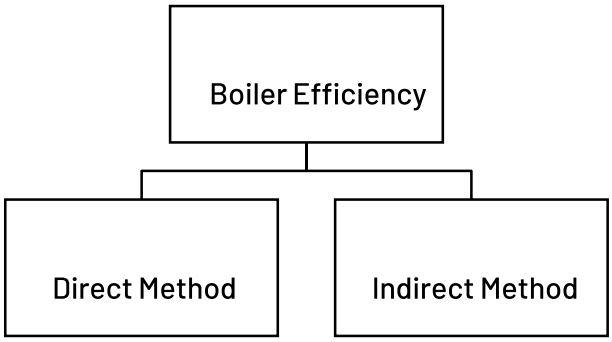
2.11.2.7 Waste Heat Boiler

A waste heat boiler can be economically installed wherever waste heat can be available at medium or high temperatures.

Wherever the steam demand is more than the steam generated by waste heat boiler, auxiliary fuel burners are also used. If there is no direct use of steam, the steam may be let down in a steam turbine- generator set and power produced from it. It is widely used in the heat recovery from exhaust gases from gas turbines and diesel engines.

2.11.3 Steam System Efficiency

2.11.3.1 Boiler Efficiency



Thermal efficiency of a boiler is defined as the percentage of heat energy input that is effectively useful in the generated steam.

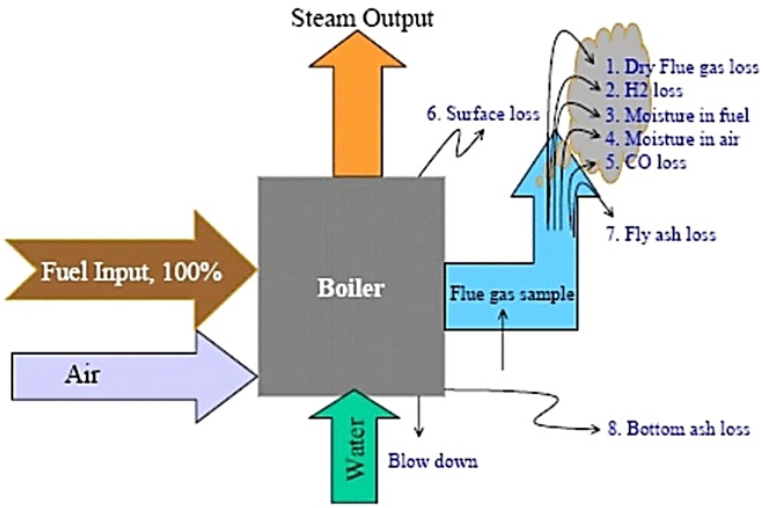


Figure 2.44 - Boiler Heat losses
Source: Bureau of Energy Efficiency

There are two different methods to assess boiler efficiency. They are direct and indirect method.

- In the direct method, the energy gain of the working fluid, that is the water and steam, is compared to the energy content of the boiler fuel.

$$Direct\ Boiler\ efficiency\ (\eta) = \frac{Heat\ Input}{Heat\ Output} \times 100 = \frac{Q \times (hg - hf)}{Q \times GCV} \times 100$$

,

where,

hg -the enthalpy of saturated steam in kcal/kg of steam

hf -the enthalpy of feed water in kcal/kg of water Parameters:

Quantity of steam generated per hour (Q) in kg/hr

Quantity of fuel used per hour (q) in kg/hr

The working pressure (in kg/cm^2(g)) and superheat temperature (°C), if any

The temperature of feed water (°C)

Type of fuel and gross calorific value of the fuel (GCV) in kcal/kg of fuel

- In the indirect method, the efficiency is calculated as the difference between the losses and energy input

Indirect boiler efficiency (n) = 100 - (I + ii + iii + iv + v + vi + vii)

Principle losses:

I) Dry flue gas

ii) Evaporation of water formed due to H_2 in fuel

iii) Evaporation of moisture in fuel

iv) Moisture present in combustion air

v) Unburnt fuel in fly ash

vi) Unburnt fuel in bottom ash

vii) Radiation and other unaccounted losses

The data that is required to calculate boiler efficiency according to the indirect method include: Ultimate analysis of fuel in terms of H_2, O_2, S, C, moisture content and ash content. Percentage of oxygen or CO_2 in the flue gas; flue gas temperature; ambient temperature and humidity of air; as well as GCV of fuel. In case of solid fuels, the percentage combustible in ash and GCV of ash.

Heat balance is an attempt to balance the total energy that enters a boiler against the energy that leaves it Figure 2.44 illustrates the different typical losses that occurs while generating steam.

Loss due to dry flue gas - The temperature of the flue gas is one of the main sources of energy losses during boiler operation. Flue gases carry heat with them and release it into the environment because their temperature is higher than the ambient temperature. The loss will be greater the higher the flue gas temperature.

Loss due to moisture in fuel - Coal, briquettes, and husk are examples of solid fuel that are particularly effective at absorbing moisture from the air. The fuel's calorific value and combustion efficiency are both decreased by this moisture. When this moist fuel is burned in the furnace, water vapor is produced in the flue gases, which lowers the stack temperature.

Loss due to excess air - Despite the fact that air is necessary for complete fuel combustion, utilizing more air than is required could be costly since excess air is cooler than required and absorbs heat from the fuel flame. It further causes the heat transfer to the boiler to be reduced. This air, along with waste flue gases, carries this heat away. As a result, boiler systems waste energy when there is too much air. For every 10% reduction in excess air, boiler efficiency increases by 0.5%.

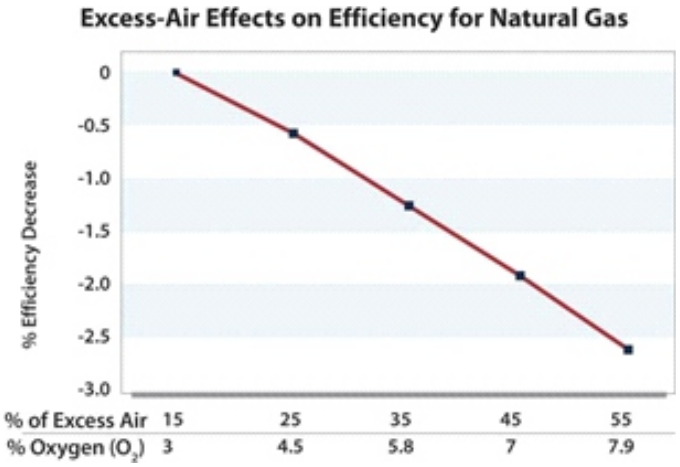


Figure 2.45 - Loss due to excess air

Heat loss due to incomplete combustion - The supply of air provides the oxygen needed for continuous and complete fuel burning. In total combustion, carbon and oxygen react to form carbon dioxide, while hydrogen and carbon dioxide react to form water. When there is insufficient air, carbon is oxidized, producing CO instead, which produces less heat and results in incomplete combustion.

Bottom ash loss - It can be determined using the temperature and carbon content of the ash and is dependent on the properties of the coal. The carbon in the ash is what truly matters, not its temperature, which only has a modest impact on ash loss.

2.11.3.1.1 Boiler Feed Water Treatment

The water must be treated to control steam purity, deposits, and corrosion in order to generate quality steam. Selecting and controlling the supply water used in a boiler directly affects the boiler's performance, efficiency, and longevity.

When feed water enters the furnace, the high temperatures and pressures alter the behaviour of the water components, including dissolved salts. The majority of components in feed water are soluble. Under heat and pressure, however, most soluble components leave the solution as particulate solids, sometimes crystallized and sometimes amorphous. When the solubility of a specific component in water is exceeded, scale or deposits form. The boiler water must be sufficiently free of particles that form deposits to allow for rapid and efficient heat transfer, and it must not be corrosive to the boiler metal.

Hence, feed water needs to be treated with the below mentioned two methods:

External - treatment prior to entering the furnace

Internal - treatment within the boiler.

The above-mentioned treatment is elaborated upon in a later section, but the section below explains why it is necessary to treat the feed water.

Water Impurities

Salts of calcium and magnesium, also known as hardness salts, are the most significant substances in water that contribute to the formation of deposits in boilers.

Calcium and magnesium bicarbonate dissolve in water to form an alkaline solution, which is alkaline

solution, which is alkaline hardness. Upon heating, they decompose, releasing carbon dioxide and producing a soft sludge that settles. This is called as temporary hardness, which can be eradicated by boiling.

Calcium and magnesium sulphates, chlorides, nitrates, etc., when dissolved in water, are chemically neutral and are known as non-alkaline hardness. These are known as permanent hardness and form difficult-to-remove scales on furnace surfaces.

Non-alkalinity hardness chemicals leave the solution due to decreased solubility as the temperature increases, concentration caused by evaporation within the boiler, or chemical transformation to a less soluble compound.

Water Hardness

Hardness contamination of feed water and corrosive substances from the condensate and feed water system can cause deposits in boilers.

Depositions and corrosion cause efficiency losses and can lead to boiler tube failures and the inability to generate steam. Deposits function as insulators and reduce heat transfer.

Large deposits throughout the boiler could impede heat transfer and significantly reduce the boiler's efficiency. Different types of deposits have varying effects on boiler efficacy. Thus, it may be beneficial to examine the characteristics of the deposits. The insulating effect of deposits causes the boiler metal temperature to rise and may lead to tube failure by overheating.

Water Treatment

External

The treatment removes suspended solids, dissolved solids (especially calcium and magnesium ions, which significantly cause scale formation), and dissolved gases (oxygen and carbon dioxide).

The water treatment techniques include

- Ion Exchange,
- Demineralization,
- Reverse Osmosis and
- Deaeration.

Before using any of these, removing suspended solids and colour from the unfiltered water is necessary, as they can foul the resins used in subsequent treatment sections.

Simple sedimentation in settling containers or settling in clarifiers with the aid of coagulants and flocculants are pre-treatment techniques. Metal ions can be removed from bore well water by using pressure sand filters with spray aeration to remove carbon dioxide and iron.

Internal

Chemicals are added to the boiler to prevent scale formation by converting scale-forming compounds into free-flowing sludges that can be blown away. This method is applied as a post-external treatment inside boilers where the feed water is low in hardness ions, to low pressures where a high TDS content in boiler water can be tolerated, and when only a small quantity of water requires treatment. If these conditions are not met, excessive rates of blowdown are required for sludge disposal.

They become uneconomical because of heat and water loss.

Different waters necessitate unique chemical treatments. For this purpose, sodium carbonate, sodium aluminate, sodium phosphate, sodium sulphite, as well as compounds of vegetable or inorganic origin, are used.

There are specialized chemicals available for varying water conditions. The expert must be consulted in order to determine the most appropriate chemicals for each situation. Internal water treatment alone is not advised.

2.11.3.1.2 Steam Generation

Radiation and Convection Losses - Shell Losses

Radiation and convection losses are typically less than 1.0% of the energy input in the fuel for water tube boilers. They are typically less than 0.5% of input energy for fire tube boilers and the percentage increases as boiler load decreases because shell loss magnitude is essentially constant.

Troubleshoot

- Search for "hot spots" (areas with the surface temperature greater than the surrounding areas)
- Measure boiler surface temperatures (infrared)
- Typical surface temperature should range between 120°F and 180°F
- Repair refractory
- Monitor surface cladding integrity
- Reduced boiler load can present an opportunity
    - But combustion efficiency impact must be considered

Blowdown Losses

Boiler blowdown is the removal of liquid water from the boiler to maintain proper water chemistry. Feed water contains dissolved solids that are insoluble in steam; therefore, as steam is produced the concentration of these chemicals increase in the boiler water.

Blowdown is required to reduce the concentration of dissolved solids in the boiler water to keep them in solution.

If boiler water chemistry is not properly maintained scale and sludge can form

- Scale impedes heat transfer resulting in tube failures and increased flue gas losses
- Sludge impedes circulation resulting in tube failures and increased flue gas losses

Hardness precipitates as a solid scale or solid sludge

- Scale is a continuous layer of material deposited on the water side of the boiler tubes
    - This layer acts as an insulating material and a barrier to heat transfer
- Sludge is a general term applied to loose solid material found in boiler water
    - Sludge contributes to tube plugging and is removed by blowdown

Since, heat is the driving force in the reaction to form scale it is usually found in areas of high heat flux. Boiler blowdown takes several forms

- Continuous

- Intermittent
- Surface
- Bottom

Troubleshoot

- Blowdown amount is dependent on:
  - Water quality
  - Boiler operating pressure
- Blowdown management typically takes two forms
  - Water quality improvement
  - Heat recovery

High quality water systems may have less than 1% blowdown while Low quality water systems may have as much as 10% blowdown.

- Blowdown Energy Recovery - Recovering energy from blowdown can dramatically reduce blowdown losses

The blowdown stream presents a significant fouling potential (even in a cooling environment). The capability of cleaning the heat transfer surfaces of blowdown heat exchangers must be provided

- Straight tube with blowdown on the tube side
- Plate and frame

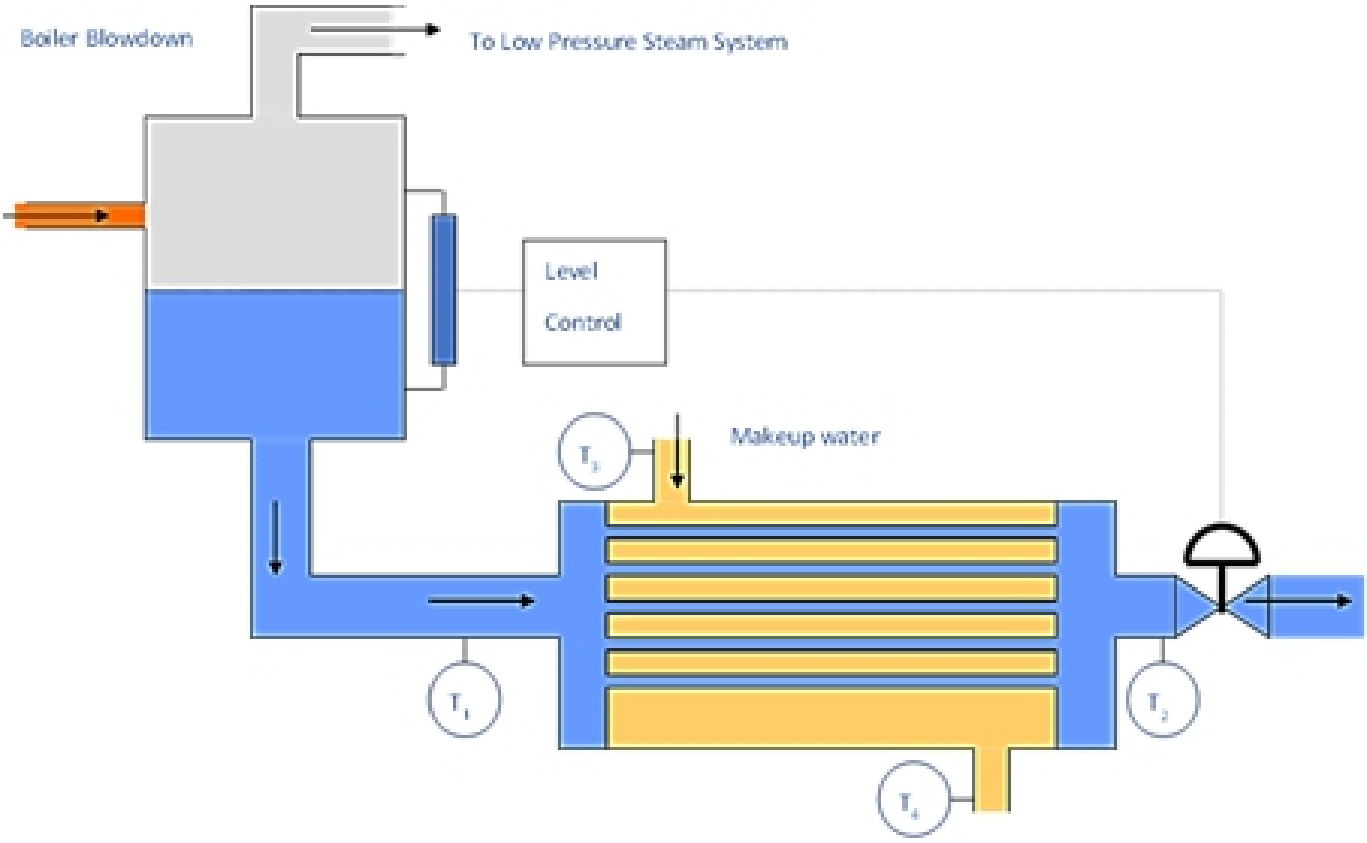


Figure 2.46 - Blowdown Energy Recovery

- Measure blowdown flow (chemical analysis)
- Control blowdown flow (conductivity)
- Control water chemistry
- Improve feedwater quality
  - Softening
  - Dealkalization
  - Demineralization
  - Reverse osmosis
- Recover flash steam to low pressure systems and preheat inlet streams

Stack Losses

Stack losses are typically categorized as

- Temperature losses
- Combustion losses

Combustion efficiency is the method generally used to determine stack losses. It is generally determined by a chemical analysis of the flue gas and a flue gas temperature measurement

Temperature losses

A significant amount of energy resides in the flue gas, the temperature of the flue gas indicates the energy content. And, below mentioned typical factors influences the flue gas temperature:

- Boiler design
- Boiler load
- Failed flue gas path component
- Water side fouling
- Fire side fouling

Energy Recovery from temperature losses

- A feedwater economizer recovers energy from the flue gas to the boiler feedwater through a heat exchanger
- A combustion air preheater recovers energy from the flue gas to the combustion air
  - Solid fuel boilers are more likely to have these components to aid in combustion by pre- drying the fuel

Troubleshoot

- Monitor and record flue gas temperature with respect to
  - Boiler load
  - Ambient temperature

- Flue gas oxygen content
- Compare flue gas temperature to previous, similar operating conditions
- Maintain appropriate fire side cleaning
- Maintain appropriate water chemistry
- Evaluate heat recovery component savings potential Combustion losses

Theoretically, air and fuel would mix completely and complete combustion would occur, i.e. each fuel molecule would find exactly the correct amount of oxygen for the combustion reaction to occur. This is referred to as stoichiometric combustion as shown below.

$C(s)+O_2(g)\rightarrow CO_2(g)$

However, for the majority of combustion processes, air is used as the source of oxygen. As a result, more air is added to the combustion process than is theoretically required to ensure that all fuel is completely reacted.

Hence, Upper and lower oxygen limits must be established and maintained to ensure the complete combustion of fuel.

Troubleshoot

Below mentioned factors influence the combustion efficiency

- Fuel
- Control method
- Boiler load
- Sensing location
- Burner condition

2.11.3.2 Steam Distribution System Efficiency

2.11.3.2.1 Steam Leaks

Steam leakage is a visible indicator of waste and must be avoided. It has been estimated that a 1 mm diameter hole on a pipeline carrying 3 kg/cm^2 steam would waste 1.6 kg/hr steam amounting to Rs 5 lakhs per year.

Steam leaks on high-pressure mains are prohibitively costlier than on low pressure mains. Any steam leakage must be quickly attended to. In fact, the plant should consider a regular surveillance programme for identifying leaks at pipelines, valves, flanges and joints. Indeed, by plugging all leakages, one may be surprised at the extent of fuel savings, which may reach up to 5% of the steam consumption in a small or medium scale industry or even higher in installations having several process departments.

2.11.3.2.2 Steam Traps

The purpose of installing the steam traps is to obtain fast heating of the product and equipment by keeping the steam lines and equipment free of condensate, air and non-condensable gases. Asteam trap is a valve device that discharges condensate and air from the line or piece of equipment without discharging the steam.

Functions of Steam Traps

The three important functions of steam traps are:

- To discharge condensate as soon as it is formed.
- Not to allow steam to escape.
- To be capable of discharging air and other incondensable gases.

Actual energy efficiency can be achieved only when selection, installation and maintenance of steam traps meet the requirements for the purpose it is installed. In most cases, trapping problems are caused by bad installation rather than by the choice of the wrong type or faulty manufacture.

To ensure a trouble-free installation, careful consideration should be given to the drain point, pipe sizing, air venting, steam locking, group trapping vs. individual trapping, dirt, water hammer, lifting of the condensate, etc.

There are three basic types of steam trap into which all variations fall, all three are classified by International Standard ISO 6704:1982.

1. Thermostatic (operated by changes in fluid temperature) - The temperature of saturated steam is determined by its pressure. In the steam space, steam gives up its enthalpy of evaporation (heat), producing condensate at steam temperature. As a result of any further heat loss, the temperature of the condensate will fall. A thermostatic trap will pass condensate when this lower temperature is sensed. As steam reaches the trap, the temperature increases and the trap closes.

2. Mechanical (operated by changes in fluid density) - This range of steam traps operates by sensing the difference in density between steam and condensate. These steam traps include 'ball float traps' and 'inverted bucket traps'. In the 'ball float trap', the ball rises in the presence of condensate, opening a valve which passes the denser condensate. With the 'inverted bucket trap', the inverted bucket floats when steam reaches the trap and rises to shut the valve. Both are essentially 'mechanical' in their method of operation.

3. Thermodynamic (operated by changes in fluid dynamics) - Thermodynamic steam traps rely partly on the formation of flash steam from condensate. This group includes 'thermodynamic', 'disc', 'impulse' and 'labyrinth' steam traps.

Table 2.11 - Selection of steam trap

Application	Feature	Suitable trap
Steam mains	Open to atmosphere, small capacity – Frequent change in pressure – Low pressure - high pressure	Thermodynamic type
Equipment Reboiler Heater Dryer Heat exchanger etc.	Large capacity– Variation in pressure and temperature is undesirable– Efficiency of the equipment is a problem	Mechanical trap, Bucket, Inverted bucket, float
Tracer line Instrumentation	Reliability with no over heating	Thermodynamic & Bimetallic

2.11.3.2.3 Condensate Recovery

The steam condenses after giving off its latent heat in the heating coil or the jacket of the process equipment. A sizable portion (about 25%) of the total heat in the steam leaves the process equipment as hot water.. The percentage of energy in condensate to that in steam can vary from 18% at 1 bar g to 30% at 14 bar g; clearly the liquid condensate is worth reclaiming. If this water is returned to the boiler house, it will reduce the fuel requirements of the boiler. For every 60°C rise in the feed water temperature, there will be approximately 1% saving of fuel in the boiler.

Benefits of condensate recovery:

- Water charges are reduced.
- Effluent charges and possible cooling costs are reduced.
- Fuel costs are reduced.
- More steam can be produced from the boiler.
- Boiler blowdown is reduced - less energy is lost from the boiler.
- Chemical treatment of raw make-up water is reduced.

2.11.3.2.4 Heat Transfer Loss Through Insulation

Heat can be lost due to radiation from steam pipes. As an example, while lagging steam pipes, it is common to see leaving flanges uncovered. An uncovered flange is equivalent to leaving 0.6 metre of pipe line unlagged. If a 0.15 m steam pipe diameter has 5 uncovered flanges, there would be a loss of heat equivalent to wasting 5 tons of coal or 3000 litres of oil a year. This is usually done to facilitate checking the condition of flange but at the cost of considerable heat loss. The remedy is to provide easily detachable insulation covers, which can be easily removed when necessary.

The various insulating materials used are cork, Glass wool, and Rock wool.

Table 2.12 - Quantity of heat lost at different temperatures

Difference in temperature between ambient & surface (°C)	**Heat loss (kCal/m^2/h)**
50	500
100	1350
200	3790
400	13640

This is based on 35°C ambient temperature, 0.9 emissivity factor and still wind conditions. The effective insulation of a steam system can bring down the heat losses to less than 75 kCal/m^2/h

2.11.1.4 Energy Saving Opportunities

2.11.4.1 Monitoring Steam Traps

For testing a steam trap, there should be an isolating valve provided in the downstream of the trap and a test valve shall be provided in the trap discharge. When the test valve is opened, the following points have to be observed:

Condensate discharge –- Inverted bucket and thermodynamic disc traps should have intermittent condensate discharge. Float and thermostatic traps should have a continuous condensate discharge. Thermostatic traps can have either continuous or intermittent discharge depending upon the load. If inverted bucket traps are used for extremely small load, it will have a continuous condensate discharge. **Flash steam** –- This shall not be mistaken for a steam leak through the trap. The users sometimes get confused between a flash steam and leaking steam. The flash steam and the leaking steam can be approximately identified as follows:

- If steam blows out continuously in a blue stream, it is a leaking steam.
- If a steam floats out intermittently in a whitish cloud, it is a flash steam.

2.11.4.2 Continuous steam blow and no flow indicate, there is a problem in the trap

Whenever a trap fails to operate and the reasons are not readily apparent, the discharge from the trap should be observed. A step-by-step analysis has to be carried out mainly with reference to lack of discharge from the trap, steam loss, continuous flow, sluggish heating, to find out whether it is a system problem or the mechanical problem in the steam trap.

2.11.4.3 Avoiding Steam Leakages

Steam leakage is a visible indicator of waste and must be avoided. Steam leakage is a visible indicator of waste and must be avoided.

2.11.4.4 Providing Dry Steam for Process

The best steam for industrial process heating is the dry saturated steam. Wet steam reduces total heat in the steam. Also, water forms a wet film on heat transfer and overloads traps and condensate equipment. Super-heated steam is not desirable for process heating because it gives up heat at a rate slower than the condensation heat transfer of saturated steam.

Since dry saturated steam is required for process equipment, due attention must be paid to the boiler operation and lagging of the pipelines.

The steam produced in a boiler designed to generate saturated steam is inherently wet. Although the dryness fraction will vary according to the type of boiler, most shell type steam boilers will produce steam with a dryness fraction of between 95 and 98%.

Wet steam can reduce plant productivity and product quality, and can cause damage to most items of plant and equipment. Whilst careful drainage and trapping can remove most of the water, it will not deal with the water droplets suspended in the steam. To remove these suspended water droplets, separators are installed in steam pipelines.

A steam separator may be installed on the steam main as well as on the branch lines to reduce wetness in steam and improve the quality of the steam going to the units. By change of direction of steam, steam seperators causes the entrained water particles to be separated out and delivered to a point where they can be drained away as condensate through a conventional steam trap.

2.11.4.5 Utilizing Steam at the Lowest Acceptable Pressure for the Process

A study of the steam tables would indicate that the latent heat in steam reduces as the steam pressure increases. It is only the latent heat of steam, which takes part in the heating process when applied to an indirect heating system. Thus, it is important that its value be kept as high as possible. This can only be achieved if we go in for lower steam pressures. As a guide, the steam should always be generated and distributed at the highest possible pressure, but utilized at as low a pressure as possible since it then has higher latent heat. However, it may also be seen from the steam tables that the lower the steam pressure, the lower will be its temperature. Since temperature is the driving force for the transfer of heat at lower steam pressures, the rate of heat transfer will be slower and the processing time greater. In equipment where fixed losses are high (e.g. big drying cylinders), there may even be an increase in steam consumption at lower pressures due to increased processing time. There are, however, several equipment in certain industries where one can profitably go in for lower pressures and realize economy in steam consumption without materially affecting production time.

Therefore, there is a limit to the reduction of steam pressure. Depending on the equipment design, the lowest possible steam pressure with which the equipment can work should be selected without sacrificing either on production time or on steam consumption.

2.11.4.6 Proper Utilization of Directly Injected Steam

The heating of a liquid by direct injection of steam is often desirable. The equipment required is relatively simple, cheap and easy to maintain. No condensate recovery system is necessary. The heating is quick, and the sensible heat of the steam is also used up along with the latent heat, making the process thermally efficient. In processes where dilution is not a problem, heating is done by blowing steam into the liquid (i.e.) direct steam injection is applied. If the dilution of the tank contents and agitation are not acceptable in the process (i.e.) direct steam agitation are not acceptable, indirect steam heating is the only answer.

Ideally, the injected steam should be condensed completely as the bubbles rise through the liquid. This is possible only if the inlet steam pressures are kept very low-around 0.5 kg/cm^2 and certainly not exceeding 1 kg/cm^2. If pressures are high, the velocity of the steam bubbles will also be high and they will not get sufficient time to condense before they reach the surface. shows a recommended arrangement for direct injection of steam.

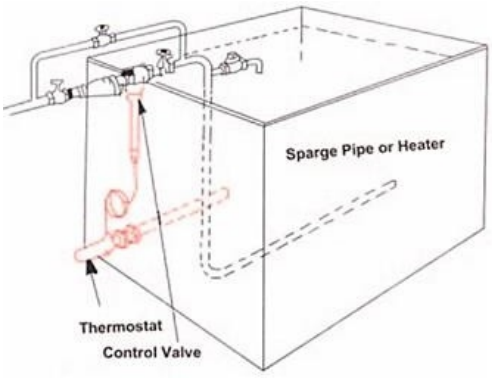


Figure 2.47 - Recommended Arrangement for Directly Injected Steam

A large number of small diameter holes (2 to 5 mm), facing downwards, should be drilled on the separate pipe. This will help in dissipating the velocity of bubbles in the liquid. A thermostatic control of steam admitted is highly desirable.

2.11.4.7 Minimizing Heat Transfer Barriers

The metal wall may not be the only barrier in a heat transfer process. There is likely to be a film of air, condensate and scale on the steam side. On the product side there may also be baked-on product or scale, and a stagnant film of product. Agitation of the product may eliminate the effect of the stagnant film, whilst regular cleaning on the product side should reduce the scale.

Regular cleaning of the surface on the steam side may also increase the rate of heat transfer by reducing the thickness of any layer of scale, however, this may not always be possible. This layer may also be reduced by careful attention to the correct operation of the boiler, and the removal of water droplets carrying impurities from the boiler.

2.11.4.8 Proper Air Venting

When steam is first admitted to a pipe after a period of shutdown, the pipe is full of air. Further amounts of air and other non-condensable gases will enter with the steam, although the proportions of these gases are normally very small compared with the steam. When the steam condenses, these gases will accumulate in pipes and heat exchangers. Precautions should be taken to discharge them. The consequence of not removing air is a lengthy warming up period, and a reduction in plant efficiency and process performance.

Automatic air vents for steam systems (which operate on the same principle as thermostatic steam traps) should be fitted above the condensate level so that only air or steam/air mixtures can reach them. The best location for them is at the end of the steam mains as shown in .

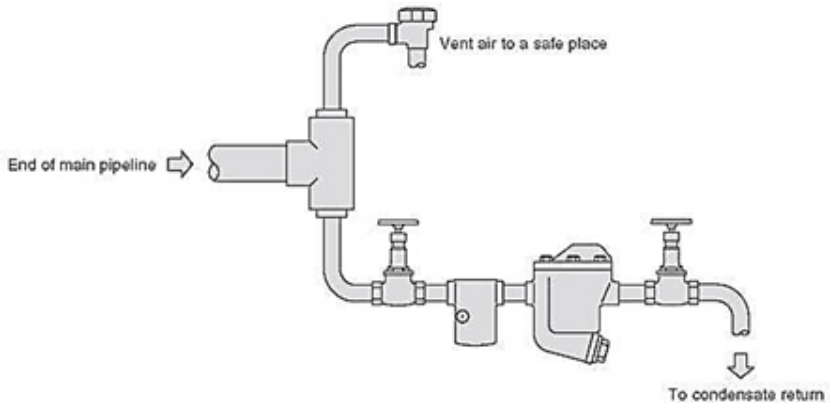


Figure 2.48 - Draining and Venting at the End of a Steam Main

2.11.4.9 Condensate Recovery & Piping Insulation

As described above in Steam System efficiency section, use of condensate will reduce the fuel requirements of the boiler and effective insulation of a steam system can bring down the heat losses.

2.11.4.10 Flash Steam Recovery

Flash steam is produced when condensate at a high pressure is released to a lower pressure and can be used for low pressure heating. The higher the steam pressure and lower the flash steam pressure the greater the quantity of flash steam that can be generated.

In many cases, flash steam from high pressure equipment is made use of directly on the low-pressure equipment to reduce use of steam through pressure reducing valves.

2.11.5 Air Pollution control equipment

A variety of constituents found in the products of combustion have been targeted for post-combustion control by national and state pollution control board. Primary among these are sulfur dioxide (SO_2), oxides of nitrogen (NOx appearing mainly as NO), and particulate matter (PM).

The type of emissions control technology employed for a specific application depends upon the regulatory requirements as well as upon the post-combustion emission levels. Emissions are highly site specific depending upon the fuel being burned and the combustion system.

A variety of post-combustion technologies provide significant control which typically include filtration, condensation, absorption, adsorption, and various chemical reactions. Therefore, the key issues for selecting specific technologies include

- Meeting the emissions requirements at an acceptable minimum cost (capital, operations, and maintenance)
- Achieving reliable long-term operation.

The different technologies are listed below.

- **Cyclone separator –** it uses centrifugal force to separate the dust particles from the flue gas.
- **Electro-static precipitator –** it is a pollution control device that uses static electricity to remove particulate matter such as soot and ash from the flue gas.
- **Bag Filter -** It helps to remove particulate matter in the flue gas. They can remove particles as small as 0.3 microns, which is much smaller than the particles that can be removed by other types of air pollutioncontrol devices, such as cyclones and scrubbers.
- **Wet bath scrubber -** It is ideal to remove fly ash and gases (SO_x and NO_x) from the exhaust gas.

2.11.5.1 Online Emission Monitoring

The Central Pollution Control Board (CPCB) (vide its letter No. B-29016/04/06PCI-1/5401 dated 05.02.2014) has directed the 17 categories of highly polluting industries Common Effluent Treatment Plants (CETP), Sewage Treatment Plants (STPs), Common Bio-Medical Waste and Common Hazardous Waste Incinerators to install online effluent quality and emission monitoring systems. In addition to above, G.S.R. 96(E) January 29, 2018 Notified by MoEF&CC under Environment (Protection) Act, 1986 mandates installation of CEMS with the Boilers used in the Industries namely Sugar, Cotton Textile, Composite Woolen Mills, Synthetic Rubber, Pulp & Paper, Distilleries, Leather Industries, Calcium Carbide, Carbon Black, Natural Rubber, Asbestos, Caustic Soda, Small Boilers, Aluminium Plants, Tanneries, Inorganic Chemicals & other such industries using boilers.

Parameters required to be monitored in the stack emissions using the Continuous Emission Monitoring System (CEMS), are industry specific and are specified below: -

a. PM (Particulate Matter)
b. HF (as Total Fluoride)
c. NH_3 (as Ammonia)
d. SO_2 (Sulphur Dioxide)
e. NOx (Oxides of Nitrogen as NO_2)
f. Cl_2 (Chlorine)
g. HCl (Hydrochloric acid) and HF (Hydro Fluoric Acid)
h. TOC (Total Organic Carbon) / THC (Total Hydro Carbon) / VOC (Volatile Organic Carbon) - CnHm
I. Hg (Gaseous mercury)
j. Process parameters (Mandatory) to be monitored at each stack at sampling point/plane:
    i. Temperature
    ii. Flow (applicable wherever load-based standards prescribed and DC Tribo system installed for monitoring of PM)
k. Diluents gas CO_2 or O_2 as prescribed in the emission standards of respective processes /industries
l. Carbon Monoxide as prescribed in the emission standards of respective processes / industries i.e. Incinerators, etc.;
m. The emission values should be corrected for Moisture Content (For In-situ and Hot extractive analyzers real-time moisture monitoring values of inbuilt measurements can be used). Moisture content value recorded during manual monitoring conducted by empaneled labs, at the time of

verification/calibration can be considered for correction.

n. The absolute pressure must be monitored in the sampling plane to normalize emission values. The value recorded during manual monitoring can be used for normalization.
o. Real-time moisture monitoring is incinerator stack.

The Continuous Emission Monitoring (CEM) System consists of all the necessary equipment for determining the concentration of gaseous emission and/or particulate matter and/or emission rate using analytical measurements and a computer programme that provides results in units of the applicable emission limits or standards.

The generated data is sent via analogue outputs to a recording system or directly to a DAS (Data Acquisition System) for storage and transmission.

The Data Acquisition System consists of specialized devices for validating data and transmitting it to SPCB/CPCB's Central servers via a cloud server.

2.11.5.1.1 Sampling Technology

The sampling location substantially affects the representativeness and accuracy of collected samples. Suitable measurement sites and sections are essential for reliable and comparable emission measurement results.

During plant design, measurement sections and sites must be selected appropriately.

The measurement site and measurement section for CEMS is based on EN 15259 criteria for the selection of measuring point/ port locations. It depends upon the following conditions (For details, refer to EN15259 Standards):

a. Whether to monitor concentration alone or gas flow also;
b. Whether the system requires periodic calibration using a standard method or whether the CEMS can be calibrated by other means.

The Central Pollution Control Board (CPCB) has issued guidelines for continuous emission monitoring systems (CEMS). These guidelines specify the sampling technologies that can be used for CEMS.

The sampling technologies mentioned under CPCB guidelines are:

In-situ systems:

These systems are installed directly in the stack or duct. They are the most common type of sampling systems used for CEMS. The analyzer is placed directly in the stack or duct and measures the pollutants without extracting a sample.
It has the advantage of having a fast response time and eliminating the need for a sample transport and conditioning system. It also directly measures the pollutants in the stack without any interference or

dilution. However, it has the disadvantage of requiring a robust and reliable analyzer that can withstand the harsh conditions in the stack. It may also have limited options for measuring multiple pollutants and require frequent maintenance and calibration.

In-situ systems are relatively simple to operate and maintain and are typically less expensive than extractive systems. However, in-situ systems can be susceptible to interference from other pollutants in the flue gas. It may be unable to collect a representative flue gas sample if the pollutant concentration is very low.

Extractive systems:

Extractive methods are used when the concentration of pollutants in the flue gas is too low for in-situ systems to measure accurately. These systems draw the flue gas from the stack or duct through a probe and into a sampling train. The sampling train is a series of devices that clean and condition the sample before it is analyzed. This method requires a representative sample and a reliable transport system. Extractive systems are more complex and expensive than in-situ systems, but they can accurately represent the flue gas.

It has the advantage of allowing the use of various analyzers that can measure multiple pollutants with high accuracy and sensitivity. It also avoids exposing the analyzer to harsh conditions such as high temperature, pressure, moisture and dust. However, it has the disadvantage of requiring a complex and costly sample transport and conditioning system that may introduce errors or losses in the sample. It also has a longer response time and may not represent the spatial variation of the pollutants in the stack.

Measurement Technology		Technology	Stack Diameter (m)	Concentration (mg/m³)		Filter Type	Self-checks		Dry	Humid	Wet	Type of dust		Velocity Dependant
				Min	Max		Sensor contamination check	Zero & span				Same	Changing	
Probe Electrification	Charge Induction (AC)	ElectroDynamic	0.2-4	0.05	1000	Bag,Cyclone, Drier,Scrubber[5], None[5]	✓ (7)	✓ (7)	✓	✓	x	✓	x	No [10]
	Contact Charge Transfer (DC)	DC Triboelectric	0.2-2	1	1000	Bag,Cyclone, None[6],ESP[10]	x	x	✓	x	x	✓	x	Yes
	Combination AC & DC	Combination AC & DC/ Tribo	0.2-2	1	1000	Bag,Cyclone, None[6]	x	✓ (7)	✓	x	x	✓	x	Yes
Transmissometry	Ratiometric Opacity	Dynamic Opacity	1-15[1][2][7]	10[5]	1000	Bag[2],Cyclone,EP,None	✓	✓ (7)	✓	x	x	✓	x	No
		Dyanamic Detection Principle	1-10[1][2]	20	1000	Bag[2],Cyclone,EP,None	✓	x	✓	x	x	✓	x	No
	Opacity	Opacity	2-10[1][2]	30[4]	1000	EP,None	✓	✓	✓	x	x	✓	x	No
		Non Comliance Transmittance	2-10[1][2]	30[4]	1000	EP,None	x	x	✓	x	x	✓	x	No
Scattered Light	Light Scattering	Forward Scatter	1-3[2]	0.1	200	Bag,Cyclone,EP,None	✓	✓	✓	✓	✓[9]	✓	X	No
	Light Scattering	Backward / Side Scatter	1-4[1][2]	25	500	Bag[2],Cyclone,EP,None	✓	✓	✓	x	x	✓	X	No

Notes: (1) Concentration dependent
(2) Representative Flow dependent
(3) Application specific
(4) Stack diameter dependent
(5) No water droplets
(6) No filter-not advised
(7) Model specific
(8) Varying velocity range 8-20 m/sec
(9) Using extractive wet stack monitoring system
(10) Advised with Faraday Shield/edge

There are a number of Opacity instruments with TUV approvals for particulate measurement. The certification ranges for opacity monitor are dependent on path length. The measuring range of 0-1000mg/m3 is suggested for a path length of 0.5 to 15 mt. However, low range i.e. 0 to 10 mg/Nm3 can be monitored in stack with minimum 5m path length.

This information is meant as a guide and reflects the majority of technology limitations of instruments currently commercially available, however specific models may offer decreased or increased capability the actual stack conditions will dictate instrument suitability

Figure 2.49: PM CEMS Technology Applications and Limitations

Source: Revised Guidelines for Continuous Emission Monitoring Systems, August 2018

Table 2.13 Overview of Technical Selection & Suitability for Gaseous CEMS Technology

Industries/ Facilities	Units of Operation	Parameters Prescribed	Emission Limits	Options available for CEMS
Cotton Textile, Composite Woolen Mills	Boiler (Other fuels)	SO_2	600 mg/NM3 at 6% dry O_2, for solid fuel and 3% dry O_2 for liquid fuel	In-situ NDIR / IR GFC/UVDOAS
				Extractive NDUV / FTIR / NDIR / IR-GFC / IR-CFM
				Dilution extractive UVFluorescence
		NOX	600 mg/NM3 at 6% dry O_2, for solid fuel and 3% dry O_2 for liquid fuel	In-situ UV-DOAS, NDIR, IR GFC
				Extractive – NDUV / FTIR, NDIR GFC, NDIR-CFM
				Dilution Extractive – Chemiluminescence

Source: Revised Guidelines for Continuous Emission Monitoring Systems, August 2018

Note:

- Temperature measurement and reporting are compulsory for all installations.
- CO_2 and/or O_2 as prescribed in notified standards for respective sectors and processes to be monitored.
- All the data has to be corrected to mass/volume at STP (760mm Hg Pressure and 25^0C temperature in dry condition).
- All In-situ and Dilution extractive and Hot Wet Extractive systems shall monitor and report moisture to correct the results in dry condition. Waste incineration plants including Hazardous waste incinerators and Waste to Energy plants requires continuous moisture monitoring.
- Installations using dilution techniques must inform CPCB and SPCBs/PCCs in case of any change in dilution ratio.
- NDIR based NOx analyzer ideally converts all NOx to NO for measurement purpose. 5% of total converted NO represents NO_2. NDIR based In-situ Analyzers without converters are measuring NO and considering upto 5% of NO values as NO_2 resulting under reporting of NOx. Hence, in order to correct the data special calculation as given below will be applied. Reported NO values will be multiplied by 1.05 and then 95% of the product will be considered as NO and 5% of the product will be considered as NO_2. Final reporting shall follow the equation NOx = NO + NO_2 = NO X 1.53+ NO_2= NOx as NO_2 In other cases, NOx values are required to be reported as NO_2mg/NM3: NOx = NO + NO2 = Nox 1.53+ NO_2= NOx as NO_2 For the IR based instrument without converter the reported NO values will be multiplied by 1.05 and then 95% of the product will be considered as NO and 5% of the product will be considered as NO_2. Final reporting shall follow the equation NOx = NO + NO_2 = NO X 1.53+ NO_2= NOx as NO_2.

In other cases NOx values are required to be reported as NO_2mg/NM3: NOx = NO + NO_2 = NO X 1.53+ NO_2= NOx as NO_2

- Recommended to go for NO + NO_2 measurement for correct reporting as NO_2.
- Hg CEMS requirement is applicable for thermal power plants only in case such condition is specified in Environmental Clearance granted by MoEF&CC / SEIAA

2.11.6. Ash Control

Ash Collection and Transportation

Fly ash is collected in dry form from the ESP hopper and disposed of either in dry form or through the wet slurry form. While bottom ash is collected at the bottom of the boiler and is disposed in wet slurry form in the ash ponds.

Following technologies are conventionally used for handling & disposal of fly ash and bottom ash collected from ESPs hoppers and boiler bottom, respectively, within the plant or up to the ash pond area:

i. Dry Pneumatic conveying
ii. Dry (moist) Conveying system through belt conveyor/tube belt conveyor
iii. High-concentration slurry disposal system
iv. Medium concentration slurry disposal system
v. Lean concentration slurry disposal system

Amongst the above technologies, Dry Pneumatic conveying, Medium concentration slurry disposal system, High concentration slurry disposal system, and Dry (moist) Conveying system through belt conveyor/tube belt conveyor are preferable as compared to Lean concentration slurry disposal system.

Storage

Installation of Bag Filters with dry fly ash collection and storage in Silos at loading and unloading points are standard practices at both locations i.e. loading at the power plant site and the unloading point at the site. The following are suggestions for further enhancing existing practices:

I. Current practice of loading fly ash in Bulkers/Tankers requires improvement at the stage of loading of fly ash in Tankers. The opening of telescopic chutes at the loading end should be airtight and confined to avoid fugitive dust emission.
ii. The pollution control equipment/cascade filters attached to the fly ash loading chute should be periodically cleaned along with regularly scheduled maintenance of the bag filter to avoid choking and its malfunctioning. It would mitigate dust emissions during the loading of fly ash.
iii. With regular maintenance, level sensors malfunctioning can be avoided to prevent overfilling of fly ash in tankers.
iv. The Weigh Bridge is to be installed under the fly ash loading chute to fill just the required quantity of fly ash in tankers so that overflow/spillage of fly ash in open areas is avoided, otherwise resulting in heavy fugitive emission all around.
v. The tanker's opening needs to be locked appropriately during the transportation of fly ash. An automatic opening/closing system needs to be installed without fail.

vi. Pneumatically transferring fly ash from a tanker to a storage container is relatively efficient. Still, it should be noted that the number of curves should be reduced. Otherwise, the bends and joints of the transport channel will leak fly ash. The abrasive nature of fly ash causes damage to the bends and joints. Fly ash should therefore be transported through PVC-coated pipelines to prevent abrasion; failure to do so may result in fly ash leakage. A mechanical offloading system should be considered to prevent high-pressure and dust leakage from unloading pipelines.
vii. The storage silo for fly ash should be constructed of or coated with anti-abrasive or anti-corrosive material. A concrete silo or hopper is preferable to prevent leaks.
viii. Ensure proper operation of all level sensors of the Storage Hopper to prevent any possible overflow from the Hopper opening.
ix. Dumping of ash in the Ash Pond should be done mechanically in moist conditions so that ash does not get airborne and pose a fugitive dust problem.
x. The bottom ash discharged from the boiler bed may be transported pneumatically in dry form/slurry form to the ash pond

Utilization

The Central Pollution Control Board (CPCB) of India has issued a notification on the utilization of fly ash. The notification number is S.O. 5481(E) dated 31.12.2021.

The notification sets out the guidelines for the utilization of fly ash. These guidelines aim to promote the safe and environmentally sound utilization of fly ash and to reduce the environmental impact of coal-fired power plants.

The notification allows for the utilization of fly ash in a variety of applications, including:

I. Concrete: Fly ash can be used as a partial replacement for cement in concrete. It can help to reduce the cost of concrete and improve its performance.
ii. Bricks: Fly ash can be used to make bricks. It can help to reduce the demand for clay bricks and conserve natural resources.
iii. Soil stabilization: Fly ash can be used to stabilize the soil. It can help improve the soil's strength and durability and make it more resistant to erosion.
iv. Land reclamation: Fly ash can be used to reclaim land damaged by mining or other industrial activities. It can help to restore the land to its original condition and improve its environmental quality.
v. Filling materials: Fly ash can be used as a filling material in various applications, such as road construction and embankments. It can help reduce the construction cost and improve the structure's stability.
vi. Fillers: Fly ash can be used as a filler in various products, such as paints, plastics, and adhesives. It can help improve these products' properties and reduce their cost.
vii. Sealants: Fly ash can be used to make sealants. It can help to protect surfaces from water, moisture, and other elements.

The notification also sets standards for the quality of fly ash that can be utilized. These standards ensure that fly ash is safe and environmentally sound to use.

Textile finishing is associated with the generation of considerable quantities of wastewater.. The effluent contains many chemical compounds. They depend on several factors, mainly on the make-up (woven fabric, knitwear, yarn, loose material), the textile substrate (cotton, polyester, viscose, polyamide, wool, silk, etc.), the type of finishing processes (continuous, semi-continuous or discontinuous, with or without printing), the type of dyestuffs used and application of chemicals for final finishing.

Table compiles ranges of analytical results from more than 100 textile finishing industries

Table 2.14: Ranges of analytical results of textile wastewater for conventional parameters

Parameter	Unit	Concentration	Remarks
Suspended solids (textile fibres)	mg/l	200 - 950	The higher values are for cotton woven fabric, whereas the lower values are for knitwear.
pH		5 – 13	Usually, textile wastewater is alkaline. High values occur in case of cotton mainly due to scouring and mercerization. In case of very high values (around pH 13), caustic soda recovery for mercerization is missing or insufficient. The low value is exceptional and may happen in case of dyeing polyamide with acid dyestuffs.
Conductivity	µS/cm	300 – 9000	Directly correlates with the content of neutral salts, especially sodium chloride and sulphate.
COD	mg O_2/l	400 – 4000	The lower value is for significantly diluted wastewater, whereas the higher value is for water-efficient finishing of woven fabric with a high add-on of sizing agents.
TOC	mg C/l	150 – 1500	see the remarks for COD.
BOD5	mg O_2/l	80 – 1200	see the remarks for COD (in case of high BOD_5, the sizing agents are easily biodegradable).
COD/BOD5		2.3 – 7	The COD/BOD_5 ratio is a rough indication of the biodegradability of wastewater, but there are exemptions (compounds that are biodegradable under certain conditions (low F/M, adaptation)).
AOX	mg Cl/l	0.05 – 6	High values in case of hypochlorite bleaching and use of certain dyestuffs containing chlorine or bromine (other compounds which can contribute to AOX: by-products from chlorite beaching, certain biocides and flame retardants etc.).
Mineral oil	mg/l	< 0.1 – 30	High values in case of knitwear consisting of synthetic fibres (mainly PES and PA) and, possibly, also from scouring of cotton woven fabric.
Anionic surfactants	mg/l	2 – 24	-
Non-ionic surfactants	mg/l	5 – 50	-
Free active chlorine	mg/l	< 0.1 - 1	Higher values in case of bleaching with hypochlorite.

Trichloromethane	µg/l	<0.1-170	High values in case of bleaching with hypochlorite.
Kjeldahl Nitrogen	mg/l	6-110	Very high values in case of high consumption of urea for printing.
Ammonium/ammonia	mg/l	<0.1-110	Very high values in case of high consumption of urea for printing and conversion of urea to ammonium during analysis.
Sulphide	mg/l	<0.5-90	High values in case of dyeing with sulphur dyes which are not sulphide free.
Total copper	mg/l	<0.001-2	High values in case of application of dyes with copper phthalocyanine as chromophoric group.
Total chromium	mg/l	< 0.005 - 2 (13)	High values in case of application of chromium complex dyes, extremely high values (in brackets) in case of discharge of insufficiently treated chromic acid for stripping screens for printing or of oxidizing sulphur dyes with dichromate (no more in Europe).
Total zinc	mg/l	0.02-0.7	Higher values in case of zinc compounds used for final finishing.

Abbreviations:

pH: potential of hydrogen; COD: chemical oxygen demand; TOC: total organic carbon, BOD_5: biochemical oxygen demand during 5 days; AO_X: adsorbable organic halogens; F/M: food-to-microorganism ratio; PES: polyester; PA: polyamide

The ranges are quite wide-ranging and can only be comprehended by studying in more detail. For instance, the range for COD is between 400 and 4000 mg/L (one order of magnitude). The low value may occur if an industry only performs after-washing of woven or knitted fabric, with likely high water consumption. In contrast, a high value is attained if industries process woven fabrics with a high content of sizing agents while consuming less water. Table 2.14 contains details of the value measures.

A closer look is required into the chemical composition of textile wastewater. In principle, the chemical compounds present in textile wastewater derive from the following two different sources:

- Chemicals present on the textile substrate when it enters the textile finishing
- Chemical products used for textile finishing.

Both sources are of high environmental relevance. As an example, sizing agents are mentioned here as they are most important from the point of quantity. However, they are only relevant for woven fabrics because they are applied to warp yarns to protect them during weaving. During textile pre-treatment, they must be removed entirely to enable proper and even dyeing and printing. The specific COD and BOD_5 values of the most important sizing agents are compiled in Table 2.15.

Table 2.15: Specific COD and BOD_5 values for the most common sizing agents

Type of sizing agent	Specific COD-value [mg O_2/g]	Specific BOD_5-value [mg O_2/g]
Starch	900 – 1000 *1	500 – 600
Carboxymethylcellulose (CMC)	800 – 1000 *1	50 – 90
Polyvinyl alcohols (PVA)	ca. 1700 *1	30 – 80 *2
Polyacrylates	900 – 1650	< 50
Galactomannans	1000 – 1150 *1	400
PES-dispersions	1450 – 1700	< 50
Protein sizing agents	1200	700 – 800

[1] Considering the usual moisture content of commodity
[2] For non-adapted "inocula"

With these values, the contribution of sizing agents to the overall COD load can be estimated. An example is given in the textbox below.

Example for estimating the COD concentration and load derived from sizing agents.
Assumptions:
A woven fabric contains a mixture of starch and PVA. The add-ons of starch is 8 weight-% and of PVA 2 weight-%.
A water-efficient finisher of woven fabric has a specific water consumption between 50 and 100 L/kg
Estimations:
The COD contribution of starch is 80 g/kg (1000 mg/g x 80 g/kg) and those of PVA is 34 g/kg (1700 mg/g x 20 g/kg). So, the specific COD emission is 114 g/kg. With the assumed specific water consumption, the range of the contribution of sizing agents to the COD concentration is between 1140 and 2280 mg/l. it is considerable. It is known that the contribution of sizing agents to the overall COD load of a woven fabric finisher can be in the order of 50 %. The exact contribution of sizing agents to the overall COD load can be estimated using the aforementioned annual mass stream overview or the wastewater template.

Concerning the BOD_5 values given in Table 2.16, it must be stressed that the COD/BOD_5 ratio is an indicator for biodegradability but additional information must be taken into account. For instance, PVA has a low BOD_5 value but can be fully biodegraded under certain conditions in biological wastewater treatment plants (temperature above 15 °C and lower than 37°C, low F/M ratio and adaptation (which can be achieved if PVA is regularly discharged to the wastewater treatment plant concerned).

As already indicated, the second principle contribution of chemical compounds in textile wastewater derives from using chemical products for textile finishing. They can be divided into nine groups as follows:

- Auxiliaries and finishing agents for fibres and yarns
- Pre-treatment agents

- Textile auxiliaries for dyeing and printing
- Finishing assistants
- Technical auxiliaries for multipurpose use in the textile industry
- Textile auxiliaries, not mentioned in the TEGEWA Textile Auxiliaries Buyer's Guide
- Basic chemicals (all inorganic compounds, all aliphatic organic acids, all organic reducing and oxidizing agents, urea)
- Dyestuffs and pigments

All chemicals present on yarns, knitwear and woven fabric will end up in wastewater during pre-treatment of wet processing. From the point of quantity, as described above, sizing agents are most important. All the chemicals used for textile pre-treatment reach wastewater. The same is true for almost all auxiliaries used for dyeing and printing, except pigment printing. During dyeing and printing, except for pigment printing, only dyestuffs mainly remain on textiles but, due to fixation rates between 60 and 95 %, a considerable percentage appears in wastewater. The chemicals for final finishing usually remain on textiles, unless they are after-washed. Then only the exhausted finishing baths or residual padding liquors enter the wastewater.

	Oxygen consumption in biological WWTP — not relevant + moderate ++ high	Bioeliminability in biological WWTP e easily m medium h heavily	Specific notes and problems
Fibres	—	e	Removal prior to WWTP required in order to avoid clogging of devices
Fatty acids and derivatives	+	e	no specific problems if the concentration is on the usual level
Vegetable oils, fats and waxes	+	e	no specific problems if the concentration is on the usual level
Starch and easily biodegradable starch derivatives	++	e	Could cause aggregates in primary treatment, high oxygen consumption
Soap and biodegradable surfactants (fatty alcohol sulfates, polyglycol ether, fatty alcohol polyglycol ether)	++	e	The surfactants can cause foam issues which may require reduction measures
Enzymes	+	e	no specific problems if the concentration is on the usual level
Alginates (thickener for reactive printing)	++	e	easily biodegradable; thus, it can contribute to high oxygen consumption
Acetic acid, formic acid, oxalic acid	++	e	no specific problems if the pH is well adjusted (optimum range: 6.5 - 9)
Hydroxmethane sulfinic acid	+	e	no specific problems if the concentration is on the usual level
Sodium chloride	—	h	usually no issue unless there is low dilution capacity in the receiving water
Sodium sulphate	—	h	in case of concentrations higher than 500 mg/l, corrosion of concrete can occur
Magnesium chloride	—	h	no specific problems if the concentration is on the usual level
Sodium carbonate (soda)	—	h	no specific problems if the concentration is on the usual level
Sulphuric acid, hydrochloric acid, caustic soda, potash	—		no specific problems if the pH is well adjusted (optimum range: 6.5 - 9)
Hydrogen peroxide	—	e	bleaching agent without impact on aquatic life
Sulphites, hydrogen sulphites, thiosulphite	++	e	up to about 10 mg SO_3^{2-}/l, there are no problems; high quantities can lead to high oxygen consumption; thiosulphate can inhibit nitrification
Sodium silicate (water glass)	—	h	can lead to scaling of devices of the WWTP
Phosphates	—	h	requires specific measure in order to precipitate phosphates
Active chlorine (from hyochlorite)	—	e	can have an adverse impact on biological treatment at concentrations higher than 10 mg Cl/l
Formaldehyde	—	e	biodegradable but can cause inhibiting effect at elevated concentration

Table 2.16: Chemical compounds in textile wastewater which usually do not have an adverse impact on wastewater treatment

In contrast to the chemical compounds in Table 2.16, the ones in Table 2.17 are heavily or non-biodegradable but may adsorb to activated sludge to a certain extent. Of course, this compilation is not exhaustive but all the compounds mentioned are relevant in practice.

It is important to note that biological wastewater treatment plants have three elimination mechanisms:

- Biodegradation,
- Adsorption to biomass (activated sludge),
- Stripping to air.

Biodegradation and adsorption are most important whereas stripping to air is rarely an issue for textile wastewater.

Table 2.17: Chemical compounds in textile wastewater which are heavily or non-biodegradable but may adsorb to activated sludge to a certain extent

	Oxygen consumption in biological WWTP – not relevant + moderate ++ high	Bioeliminability in biological WWTP e easily m medium h/n heavily or non-bioeliminable	Specific notes and problems
Textile pre-treatment			
Sizing agents on the basis of starch ether and esters	+	m	No specific problems if the concentration is on the usual level
Polyvinyl alcohol (PVA) (sizing agent)	+	h/n	PVA is biodegradable but only under certain conditions (temperature higher than 15°C and lower than 35°C, low F/M ratio, adaptation is required, i.e. PVA must be regularly discharged to the WWTP)
Polyacrylates (sizing agents)	–	h/n	some polyacrylates do adsorb to activated sludge to a high extend
Carboxymethylcellulose (sizing agent)	–	h/n	Non- biodegradable and adsorption to activated sludge is low
Polyester (sizing agent)	–	h/n	Non- biodegradable but adsorption to activated sludge is high
Mineral oil (knitting oil or oil in fibre preparations)	+	h/n (m)	No specific problems at low quantities as it will adsorb to activated sludge; it can contribute to scum.
Polyethylene glycol/polypropylene glycol (in preparations for texturising)	–	h/n	
Polycarboxylates	–	h/n	
Wool fat	+	m	Should be removed within the textile industry as far as possible as it forms aggregates and cloggs devices
Textile pre-treatment and dyeing			
By-products in linear alkylbenzene sulfonates (LAS)	–	h/n	Technical products of LAS contain non-biodegradable by-products (few weight-%)
Alkylphenol polyethoxylates (APEO)	–	h/n	APEO are still used as dispersing agents in dyestuffs. They are biodegradable but toxic metabolites are formed.
Low-molecular polyacrylates	–	h/n	
Phosphonates (complexing agents)	–	h/n	Phosphonates do adsorb to activated sludge to a low extend
Nitrilotriacetate (NTA)	+	h/n	NTA is biodegradable but only under certain conditions (low F/M ratio and adaptation)
Polyethoxylated tallow amines	–	h/n	Surfactant with low biodegradability
Phosphoric acid ester	–	h/n	Wetting agent with low biodegradability
Silicon compounds	–	h/n	Silicon compounds are used as defoamer and do adsorb to activated sludge

	Oxygen consumption in biological WWTP	Bioeliminability in biological WWTP	Specific notes and problems
	— not relevant	e easily	
	+ moderate	m medium	
	++ high	h/n heavily or non-bioeliminable	
Dyeing			
Dyestuffs	—	n	Under aerobic conditions non-biodegradable. Under anaerobic conditions, the azo group of many azo dyestuffs is cleaved but the resulting naphthalene derivatives are non-biodegradable. Water-insoluble dyestuffs such as disperse, vat or sulphur dyestuffs do adsorb to activated sludge to a high extend which is not the case for water soluble direct and reactive dyestuffs.
Dispersing agents for water-insoluble dyestuffs	—	h/n	Lignin sulfonates and condensation products of naphthalene sulfonates and formaldehyde are mainyl used. They are non-biodegradable but do adsorb to activated sludge, however not to a high extend
Quinoline	—	h/n	Quinoline is an impurity contained in naphthalene-based dispersing agents in concentrations up to several thousands milligrams
N-alkylphthalimides, methylnaphthalene derivatives, o-phenylphenol derivatives	—	h/n	These dyeing accelerators are substitutes of the much more hazardous trichloro benzenes
Printing			
Dyestuffs	—	n	See the note concerning dyestuffs under dyeing above
Aromatic (naphthalene) amines formed during etch printing (reducive cleavage of azo groups)	—	n	The naphthalene derivatives are water soluble and are neither biodegradable nor adsorbable to activated sludge
m-Nitrobenzene sulfonate	—	h/n	Mainly used as reducing agent for printing. It is biodegradable under certain conditions (low F/M ratio and adaptation)
Dichlorotoluene	—	h/n	Used as biocide for printing pastes. Practically, it is non-biodegaradable.
Isothiazolinones	—	h/n	Used as biocides for printing pastes. They are non-biodegaradable.
Cross-linked polyacrylates	—	n	Synthetic thickeners for pigment printing; non-biodegradable but do adsorb to activated sludge
Copolymers of ethyl acrylate and butyl acrylate with acrylonitrile, styrene and others	—	n	Non-biodegradable but do adsorb to activated sludge
Finishing			
Optical brightheners	—	h/n	Optical brightheners (mainly stilbene disulphonic acid derivatives) that do adsorp to activated sludge but extend is variable
Ethylene urea derivatives	—	h/n	Applied for non-iron treatment
Organophosphorous compounds	—	h/n	Applied as flame retardant, non biodegradable and should not be discharged with wastewater
Polyfluorinated compounds	—	n	Applied as water and oil repellent; it is non-biodegradable and should not be discharged with wastewater
Polysiloxanes	—	n	Non-biodegradable but do adsorb to activated sludge to a high extend

Many of the coumpounds mentioned above can be removed with the help of an effective effluent treatment plant (ETP). The "treated" water can then be discharged into the environment, or, with additional treatment steps, can be recycled.

Effluent from textile dyeing industries must meet the effluent discharge quality standards set by the CPCB, and may also need to meet additional standards set by international textile buyers. Consequently, any ETP/CETP must be designed and operated in such a way that it treats the wastewater to these standards.

Table 2.18: Standards for discharge of effluents from the textile industry

Sr. No.	Industry	Parameter	Standard (applicable for all mode of disposal*)
1	2	3	4
*6	All integrated textile units. Units of colon/ woollen/ carpet/ polyester, units. Having printing / dyeing/ bleaching process or manufacturing and garmet units.	Treated effluents	Maximum concentration values on mg/l except for pH, colour and SAR
		pH	6.5 to 8.5
		Suspended solids	100
		Color, P.C.U (Platinum Cobalt unit)	150
		Bio-chemical Oxygen Demand (3 days at 270C) (BOD3)	30
		Oil and Grease	10
		Chemical Oxygen Demand (COD)	250
		Total Cromium as (Cr)	2
		Sulphide as (S)	2
		Phenolic Compound as (C6H5OH)	1
		Total Dissolved Solids Inorganic (TDS)	2100**
		Sodium Absorption Ration (SAR)	26**
		Ammonium Nitrogen (as N)	50

NOTES:

1. *In case of direct disposal into rivers and lakes, the Central Pollution Control Board (CPCB) or State Pollution Control Boards / Pollution Control Committees (SPCBs / PCCs) may specify more stringent standards depending upon the quality of the recipient system.
2. **Standards for TDS and SAR shall not be applicable in case of marine disposal through proper marine outfall.
3. The treated effluent shall be allowed to be discharged in the ambient environment only after exhausting options for reuse in industrial process / irrigation in order to minimize freshwater usage.
4. Any textile unit attached with the Common Effluent Treatment Plant (CETP) shall achieve the inlet and treated effluent quality standards as specified in serial number 55 of Schedule-I to the Environment (Protection) Rules, 1986 and shall also be jointly and severally responsible for ensuring compliance.

5. The standalone Micro, Small and Medium Enterprises (MSMEs) as per the MSME Development Act, 2006 shall meet the values specified above.
6. The standalone large scale units shall meet the values specified above; however, CPCB or SPCBs / PCCs with the approval of CPCB, may mandate Zero Liquid Discharge in Large scale units in environmentally sensitive / critical areas.
7. The TDS value with respect to treated effluent shall be 2100 milligrams per litre; however, in case where TDS in intake water is above 1100 milligrams per litre, a maximum contribution up to 1000 milligrams per litre shall be permitted provided the maximum value of 3100 milligrams per litre is not exceeded in the treated effluent.".

Some of the main parameters listed in the above effluent discharge standards are briefly discussed below to give a working knowledge of their importance.

pH - pH measures the concentration of hydrogen ions in the wastewater and indicates how acidic or alkaline the wastewater is. This parameter is important because aquatic life such as most fish can only survive in a narrow pH range between pH 6-9.

Oil and Grease - This includes all oils, fats and waxes, such as kerosene and lubricating oils. Oil and grease cause unpleasant films on open water bodies and negatively affect aquatic life. They can also interfere with biological treatment processes and cause maintenance problems as they coat the surfaces of components of ETP/CETP. However, in very few cases, oil and grease are relevant for textile wastewater.

Colour - It is caused by the dyestuffs applied for dyeing or printing. In contrast to most other chemicals, dyestuffs are visible. Reducing colour is therefore important for the public perception of a factory.

BOD and COD - Measurement of the oxidizable organic matter in wastewater is usually achieved by determining the 5-day biological oxygen demand (BOD_5), which determines the concentration of easily biodegradable organic compounds, and the chemical oxygen demand (COD) and total organic carbon (TOC) which determine all organic compounds.

TDS and TSS - Wastewater can be analyzed for total suspended solids (TSS) and total dissolved solids (TDS) after removing coarse solids such as rags and grit. A sample of wastewater is filtered through a standard filter, and the residue's mass is used to calculate TSS. Total solids (TS) is found by evaporating the water at a specified temperature. TDS is then calculated by subtracting TSS from TS.

Sulphide –. For the application of sulphur dyes, sodium sulphide can be used and is present in the dyestuff itself. This is a problem because of the unpleasant smell of rotten eggs and the presence of sulphides in effluents can interfere with biological treatment processes.

Phosphorus, Total Nitrogen, Nitrate and Ammonia - These parameters are all used to measure the nutrients present in the wastewater, as the high nutrient content of discharged wastewater can result in eutrophication in receiving water bodies

2.12.1 Treatment Levels

Treatment of textile wastewater consists of a sequence of techniques. They can be grouped as indicated in Figure 2.50.

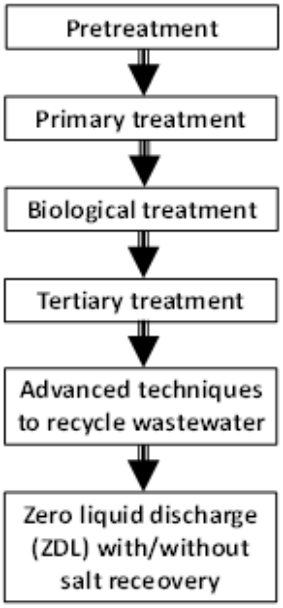


Figure 2.50: Grouping the different techniques for treating textile wastewater

The pre-treatment of textile wastewater consists of heat recovery, fluff/fibre removal, neutralization and equalization. First, the temperature issue has to be solved. The reduction of wastewater temperature is best if a combination of heat recovery directly at machines (see Figure 2.51) and central heat recovery (heat exchanger for composite wastewater) is applied.

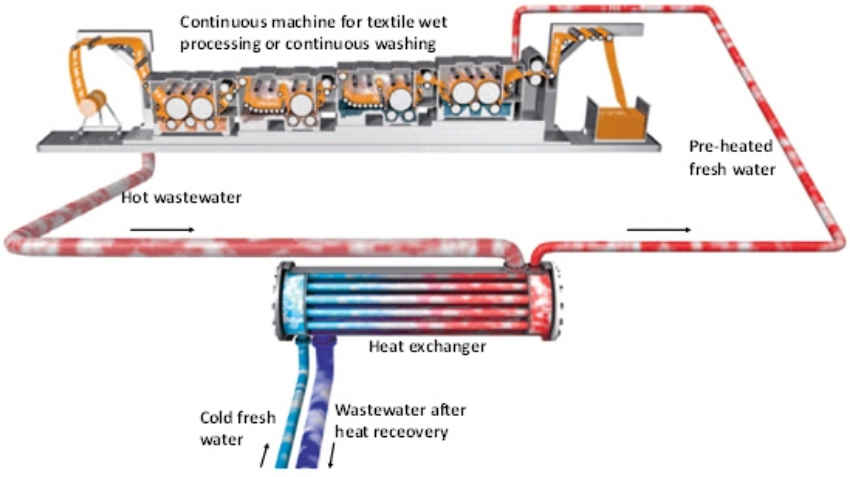


Figure 2.51: Heat exchange of hot wastewater with cold freshwater directly at a finishing machine

If highly efficient heat exchangers are applied, such as plate heat exchangers, efficient fluff/fibre removal and a very careful maintenance of them must be in place. Different efficient devices are available for fluff/fibre removal but are not described here in detail. The width of the openings can be down to 100 – 200 µm. So, even very small fibres can be removed.

Whenever possible, neutralization should be carried out by means of flue gas. For this purpose, flue gas is counter-currently injected into wastewater. The CO_2 and possible SO_2 of the flue gas is neutralizing caustic soda. This technique has been commonly applied in Europe for several decades, but it is not common in India.

Biological treatment requires a constant composition and concentration of inorganic and organic substrates as far as possible. As the composition of textile wastewater can considerably vary during the day and week, at least, a one-day-equalization should be achieved.

Often, clari-flocculation, also called precipitation/flocculation is used as the primary treatment for textile effluent. During treatment, iron(III) salts (iron(III) chloride or iron chloride sulphate) or aluminium salts ($AlCl_3$ or poly aluminium chloride) are typically used along with an organic polyelectrolyte to produce larger flocs for enhanced separation by sedimentation or flotation. The COD removal efficiency for composite textile wastewater generally is between 25 and 50 percent, depending on the composition, the flocculant's type & amount, and the method used to separate the precipitate. The process of clari-flocculation is shifting the load from wastewater to solid waste which needs to be disposed of. Consequently, clari-flocculation should be avoided if emissions limit values can be reached without it. However, certain individual wastewater streams which cause problems in biological treatment can be pre-treated by clari-flocculation such as wastewater from pigment printing.

It has to be considered that a precipitation/flocculation stage before biological treatment will reduce the removal efficiency of the biological stage as the compounds adsorbing to activated sludge have already been removed. As already indicated, it has to be stressed that precipitation/flocculation is associated with significant amounts for sludge which are difficult to dispose of. Against this background, it is usually not recommended.

Biological treatment is the major stage to reduce organic compounds, both by adsorption and biodegradation, oxidize ammonium (called nitrification), and denitrify nitrate to molecular nitrogen (called denitrification). The most common biological wastewater treatment technique is the activated sludge system. As a consequence, the focus is laid on this system. In addition, phosphorous can be reduced by simultaneous precipitation, i.e. phosphorous removal is combined with activated sludge treatment. The design of activated sludge systems is important. The most critical design parameter is the food-to-microorganism ratio (F/M) which tells the quantity of food (measured as BOD5) which is offered to micro-organisms (quantified as mixed liquor suspended solids (MLSS)) per day; the unit is kg BOD_5/kg MLSS x d. At low F/M, i.e. lower than 0.15 – 0.2 kg BOD_5/kg MLSS x d, also heavily biodegradable chemical compounds, used for textile finishing can be biodegraded, such as polyvinyl alcohol, m-nitrobenzene sulphonate or nitrilotriacetate. In addition, at such a low level, ammonium can be practically fully biochemically oxidized, i.e. the residual ammonium concentration is lower than 0.5 mg/L. However, non-biodegradable compounds that do not adsorb to the biomass (activated sludge) will remain in the water phase and be measured as residual COD concentration. In the case of well-performing plants, a COD reduction of 90 % can be observed. In exemplary cases (biological membrane reactor with optimum performance and a high percentage of easily biodegradable compounds, especially starch), removal efficiency of up to 96 % can be achieved.

After biological treatment, tertiary treatment may be applied to reduce organic compounds which have passed biological treatment. Visible compounds are dyestuffs, especially reactive dyestuffs as they are non-biodegradable and adsorb to activated sludge only to a low extent. Adsorption to activated carbon and ozonation are commonly applied for tertiary treatment and de-colourization. For the latter, reductive cleavage of the azo groups of reactive dyestuffs using Fe(II) salts (usually Fe(II) sulphate) at pH 10 has also been applied but due to the formation of non-biodegradable aromatic amines, this method is not recommended.

As shown above, textile wastewater treatment consists of various techniques. Thus, textile wastewater treatment plants at an industrial scale are relatively complex. In the following, more details are provided for the different treatment steps.

2.12.1.1 Flow Equalization

The flow of wastewater entering a common effluent wastewater treatment plant varies over the course of a 24-hr day, with above-average flows occurring during mid-morning and late afternoon, and low flows occurring at night (11 pm to 5 am). The flow variation also occurs due to wet weather conditions, infiltration, and inflow, which may significantly increase the concentration of suspended solids and organic loading (BOD_5).

Flow equalization is a method of damping the variations in flow rates so that the unit processes receive nearly constant flow rates. Flow equalization improves the performance of the downstream processes and reduces the size and cost of downstream treatment facilities.

The principal benefits that are cited as deriving from the application of flow equalization are:

- Biological treatment is enhanced because shock loadings are eliminated or can be minimized, inhibiting substances can be diluted, and pH can be stabilized;
- The effluent quality and thickening performance of secondary sedimentation tanks following biological treatment is improved through improved consistency in solids loading.
- Effluent filtration surface area requirements are reduced, filter performance is improved, and more uniform filter-backwash cycles are possible by lower hydraulic loading; and
- In chemical treatment, damping of mass loading improves chemical feed control and process reliability. Apart from improving the performance of most treatment operations and processes, flow equalization is an attractive option for upgrading the performance of overloaded treatment plants.

Disadvantages of flow equalization includes:

- Relatively large land areas or sites are needed,
- Equalization facilities may have to be covered for odor control near residential areas,
- Additional operation and maintenance is required, and
- Capital cost is increased

Mixing is usually provided to ensure adequate equalization and prevent settling ablesettleable solids from depositing in the basin. In addition, the oxidation of reduced compounds in the waste stream or the reduction of BOD by air stripping may be achieved through mixing and aeration.

Methods that have been used for mixing include:

- Distribution of inlet flow and baffling
- Turbine mixing
- Diffused air aeration
- Mechanical aeration
- Submerged mixers

2.12.1.1 Neutralization

Many industrial wastes contain acidic or alkaline materials that require neutralization prior to discharge to receiving waters or before chemical or biological treatment. For biological treatment, a pH in the biological system should be maintained between 6.5 and 8.5 to ensure optimum biological activity. The biological process provides neutralization and a buffer capacity due to the production of CO_2, which reacts with alkaline substances. The degree of pre-neutralization depends on the ratio of BOD removed and the causticity or acidity present in the waste.

Types of Process

- Mixing Acidic and Alkaline Waste streams
- Acid Wastes Neutralization through Limestone Beds
- Mixing Acid Wastes with Lime Slurries
- Basic (Alkaline) Wastes
- Neutralization with flue gas

Neutralization factors for common alkaline and acid reagents

Chemical	Formula	Equivalent weight	To neutralize 1 mg/l acidity or alkalinity (expressed as CaCO3) requires n mg/l	Neutralization factor, assuming 100% purity for all compounds
				Basicity
Calcium carbonate	$CaCO_3$	50	1.000	1.000/0.56 = 1.786
Calcium oxide	CaO	28	0.560	0.560/0.56 = 1.000
Calcium hydroxide	$Ca(OH)_2$	37	0.740	0.740/0.56 = 1.321
Magnesium oxide	MgO	20	0.403	0.403/0.56 = 0.720
Magnesium hydroxide	$Mg(OH)_2$	29	0.583	0.583/0.56 = 1.041
Dolomitic quicklime	$(CaO)_{0.6}(MgO)_{0.4}$	24.8	0.497	0.497/0.56 = 0.888
Dolomitic hydrate lime	[Ca(OH)2]0.6 [Mg(OH)2]0.4	33.8	0.677	0.677/33.8 = 1.209
Sodium hydroxide	NaOH	40	0.799	0.799/40 = 1.427
Sodium carbonate	Na_2CO_3	53	1.059	1.059/0.56 = 1.891
Sodium bicarbonate	NaHCO3	84	1.680	1.680/0.56 = 3.00
				Acidity
Sulfuric acid	H_2SO_4	49	0.980	0.980/0.56 = 1.750
Hydrochloric acid	HCl	36	0.720	0.720/0.56 = 1.285
Nitric acid	HNO_3	62	1.260	1.260/0.56 = 2.250
Carbonic acid	H_2CO_3	31	0.620	0.620/0.56 = 1.107

2.12.1.3 Biological Treatment

Biological treatment is still also called secondary treatment. The objectives of biological treatment are to breakdown organic compounds measured as e BOD and COD or TOC to acceptable levels. In some cases, nutrient removal may also be an objective. Depending on discharge limits, the biologically treated effluent may be discharged to surface waters after disinfection, or proceed to tertiary treatment.

Two major categories of biological treatment processes are:

(I) Activated sludge process
(ii) Attached growth process (biofilm process)

Activated sludge process

In an activated sludge process, the microorganisms are suspended in a biological reactor using a suitable mixing technique, preferably by fine-bubble aeration from the bottom. Micro-organisms use organic matter as food and convert them to carbon dioxide, water, ammonium, phosphate, and new biological cells (biomass also called sludge). The formed biomass has to be de-watered and properly disposed of. As shown, textile wastewater contains various organic compounds. As a result, a large variety of microorganisms or a mixed culture is required for complete treatment. Each type of microorganism in the mixed culture uses the most suitable food, i.e. organic compounds, for its metabolism (Peavy et al., 1985). The larger species, in turn, feed on the smaller species. For example, the rotifers and crustaceans feed on the protozoa, while the protozoa feed on the bacteria, and so on.

The micro-organisms used in the biological treatment processes are essentially the same as those found in surface waters, performing degradation of organic compounds during natural purification processes. Natural purification processes take place over an extended period, ranging from days to weeks, depending on the strength of the wastewater and the availability of a suitable microbial population.A thorough understanding of microbial growth kinetics, substrate utilization, principles of mass balance, reactor kinetics, and operational parameters is necessary to design biological treatment processes.

Design and operational parameters

The following are definitions of basic design parameters for biological treatment reactors.

MLSS – mixed liquor suspended solids concentration in the biological reactor. It is measured as volatile suspended solids (VSS) or total suspended solids (TSS) concentration in the reactor, expressed as mg/L or kg/m3. MLVSS represents the active biomass concentration in the reactor. The concentration of active biomass plus the inert solids is called MLSS. Usually, the term MLSS is used for both, with the units of measurement (VSS or TSS) indicating the difference.

SRT – solids retention time of the reactor. It is also called sludge age, or mean cell residence time. It is the time spent by a unit mass of activated sludge in the reactor. It is defined as the ratio of the mass of solids in the reactor, to the mass of solids wasted per day. It is given by the equation below.

$$\theta_c = \frac{\text{Mass of solids in reactor}}{\text{Mass of solids wasted per day}}$$

SRT is an important design and operating parameter, affecting process performance, aeration tank volume, sludge production, and oxygen requirements.

For BOD removal, an SRT of 3 d may be used at temperatures ranging from 18°C to 25°C. At 10°C, SRT values of 5–6 d ays r required (Metcalf and Eddy et al., 2013).

F/M Ratio – the ratio of food, i.e. organic compounds, to the mass of micro-organisms in the reactor. It is calculated as the daily load of BOD_5 charged to the reactor, divided by the total mass of micro-organisms. The unit is kg BOD_5/kg MLSS x d.

Conventional activated sludge processes are operated at F/M ratios from 0.2 to 0.4 kg BOD_5/kg MLSS x d. The F/M appliued also depends on the temperature. At higher temperature, the microorganisms are more active and thus a higher F/M can be applied to achieve the same removal efficiency copmpared to lower temperature. In the past years, activated slude systems with extended aeration have been established and operated. In this case, the F/M is less then 0.1 kg BOD_5/kg MLSS x d. Then, the formation of excess sludge is minimized, can be almost nill, as the microorganisms are in the maintenance or endogenous respiration mode. The use of SRT and F/M ratio in design allows for a trade-off between reactor volume and MLSS concentration in the reactor.

HRT – hydraulic retention time of the reactor. It is the time a fluid particle spends in the reactor before discharge. The HRT is expressed as

where,

$$\theta = \frac{V}{Q}$$

- θ = hydraulic retention time, d
- V = volume of the reactor, m^3
- Q = volumetric flow rate, m^3/d

The HRT in conventional activated sludge reactors ranges from 3 to 8 h. It can be reduced in high-rate processes.

Types of Suspended Growth Processes (activated sludge process)

- Conventional activated sludge
- Step aeration or step feed process
- Tapered aeration process
- Contact stabilization process
- Staged activated sludge process
- Extended aeration process
- Oxidation ditch
- Sequencing batch reactor (SBR)

- Membrane biological reactor (MBR)

Conventional activated sludge system

The basic activated sludge process consists of three components, as illustrated in 2.52 . They are,

- A biological reactor where the micro-organisms are kept in suspension and aerated,
- A sedimentation tank, also called clarifier, and
- A recycling system for returning settled biomass from the clarifier to the aeration tank (bio reactor).

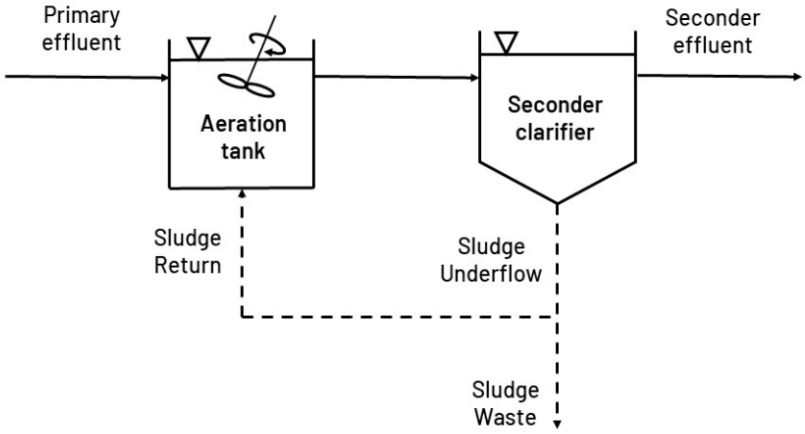


Figure 2.52 - Activated sludge process

Wastewater flows continuously into the aeration tank also called biological reactor. Air is introduced to mix the wastewater with the micro-organisms and to provide the oxygen necessary to maintain aerobic conditions, at least a dissolved oxygen content of 1.5 mg O_2/L. The micro-organisms degrade the organic compounds in wastewater and convert them to carbon dioxide, water, ammonium and biomass. Due to the biomass, non-biodegradable organic compounds with limited water solubility as well as heavy metals adsorb to it. Both, the biological degradation and the adsorption are called ioleminination bioelimination.

The mixture then goes to the clarifier, where sedimentation of the biomass (suspended solids) and some thickening of settled solids takes place. The clarified effluent is discharged for further treatment or disposal.

The sedimented solids are returned to the aeration tank called return activated sludge (RAS). A portion of it is diverted as so-called excess sludge also called waste activated sludge (WAS).

Many variations of the activated sludge process have been developed and are currently used. The biological reactor may be operated as a continuous-flow stirred tank reactor (CSTR) or plug-flow reactor (PFR). Recently, activated sludge processes have been used more frequently for BOD removal in conjunction with removing nitrogen and/or phosphorus.

Typical design values for completely mixed systems are (Peavy et al., 1985) HRT 3–5 hr, F/M 0.1–0.4 kg BOD_5/kg MLSS x days, SRT 4–15 days, VL 0.8–2.0 kg BOD_5/m^3/day, with BOD_5 removal efficiency of 85–98%.

In the case of extended aeration, the F/M is below 0.1 kg BOD_5/kg MLSS x day. Then, the BOD_5 removal efficiency is 98 – 99 %.

In plug flow systems, there is a strong gradient of organic compounds (measured as BOD_5, COD or TOC) along the reactor. The plug flow system is more efficient than the completely mixed systems.

Step aeration or step feed process

A long and narrow aeration tank is used for plug flow configuration. The influent (wastewater) enters the aeration tank at several locations along the length. This helps to reduce the oxygen demand at the head inlet point. At the same time, compressed air is injected into the tank at several locations along the length. This helps provide uniform aerobic conditions throughout the tank.

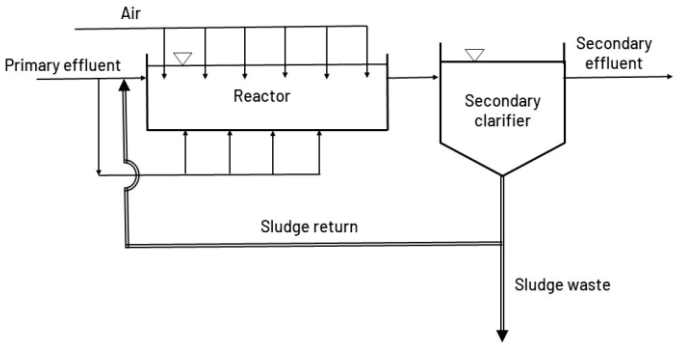


Figure 2.53 - Step feed process

This is illustrated in Figure 2.53. The typical design values are HRT 3–5 hr, F/M 0.1–0.4 kg BOD5/kg MLSS x day, SRT 4– 15 days, VL 0.6–1.0 kg BOD_5/m^3/day, with BOD_5 removal efficiency 85–98%.

Tapered aeration process

Plug flow configuration is used, with the wastewater entering the aeration tank at one end. The airflow is tapered with the higher flow toward the inlet, gradually tapering to low airflow toward the outlet. Air and maximum oxygen are provided at the highest organic load inlet. As the wastewater flows through the tank, the substrate is degraded and the oxygen demand is lower toward the outlet. This results in efficient use of the oxygen where it is needed most.

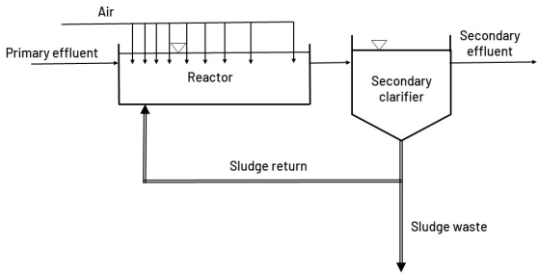


Figure 2.54 - Tapered aeration process

The tapered aeration process is illustrated in Typical design values are HRT 4–8 h, F/M 0.1–0.4 kg BOD_5/kg

MLSS x day, SRT 5–15 days, VL 0.3–0.6 kg BOD_5/m^3/day, with BOD_5 removal efficiency 85–98%.

Contact stabilization process

The contact stabilization process is presented in This process uses two separate tanks to treat wastewater and stabilize activated sludge. The process consists of a contact tank with a short HRT of 30–60 min, followed by a clarifier. The readily biodegradable soluble organic compounds are oxidized or stored, while particulate matter is adsorbed on the biomass at the same time. The treated wastewater is separated from the biomass in the clarifier. The settled biomass with the adsorbed organic matter is then transported to a stabilization tank (HRT 1–2 hr), where the stored and adsorbed organics are degraded. The biomass is then returned to the contact tank as activated sludge.

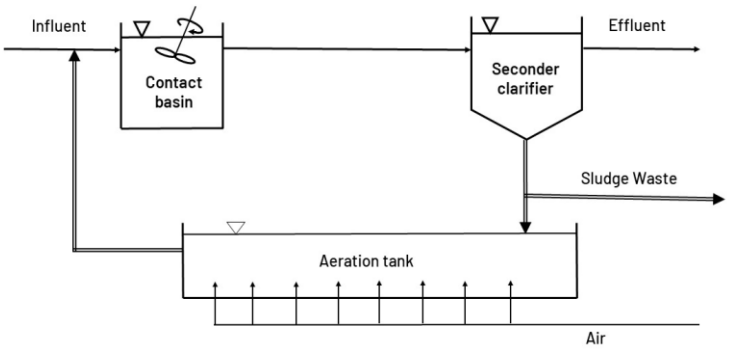


Figure 2.55 - Contact stabilization process

The advantage of this system is the reduction in overall tank volume. The overall BOD_5 removal efficiency is 80–90%. Since the MLSS is very high in the stabilization tank, this results in a lower tank volume.

Staged activated sludge process

Several completely mixed reactors are placed in series followed by a final clarifier. The return-activated sludge comes back to the first tank. it is illustrated in figure 2.56.

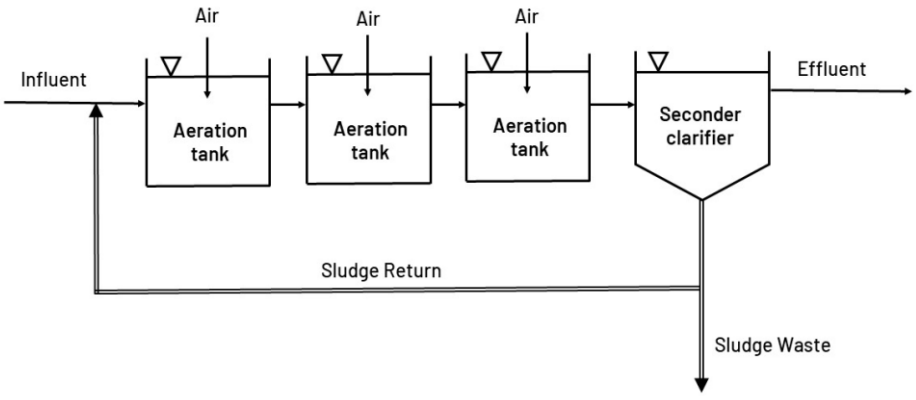


Figure 2.56 - Staged activated sludge process

Three or more reactors in series approximate a plug flow system. The process can handle high organic

loads with high BOD_5 removal efficiencies.

Extended aeration process

This process treats wastewater from small communities that generate low volumes of fairly uniform characteristics. A completely mixed activated sludge process configuration is used Typical design values are HRT 18–24 hr, F/M 0.05–0.1 kg BOD_5/kg MLSS x day, SRT 20–30 days, VL 0.16–0.4 kg BOD_5/m^3/day, with BOD_5 removal efficiency of 98 - 99%. The reactor is operated in the maintenance or endogenous respiratrion mode which is associated with a very low formation of excess sludge.

Oxidation ditch

This old process consists of an oval-shaped aeration channel, where the wastewater flows in one direction, followed by a secondary clarifier. Brush-type mechanical aerators provide aeration and mixing, keeping the water flowing in the desired direction. The influent enters the channel and is mixed with the return-activated sludge. The flow in the channel dilutes the incoming wastewater by a factor of 20–30 process kinetics approach that of a complete mix reactor, but with plug flow along the channels. The oxidation ditch is illustrated in Figure 2.57.

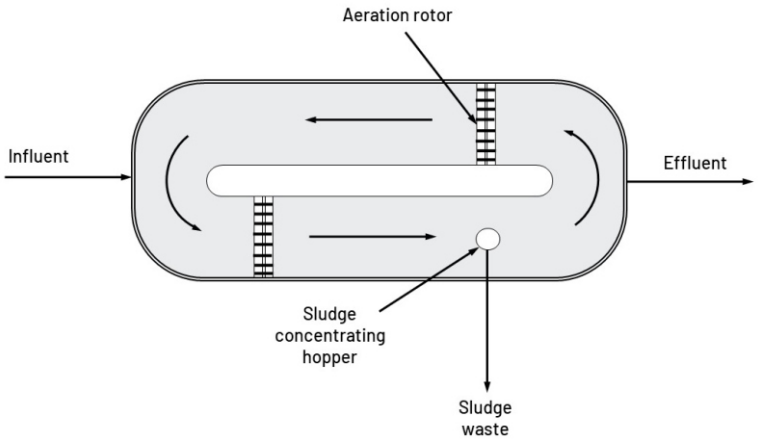


Figure 2.57 - Oxidation ditch.

This process is suitable for use in small rural communities with large land areas. The oxidation ditch can be designed and operated to achieve BOD_5 and nitrogen removal.

Sequencing batch reactor (SBR)

The SBR is a fill-and-draw-type system where aeration, biodegradation, and settling occur in the same reactor. The reactor sequences through a number of steps in one cycle. The reactor can go through 2–4 cycles per day. A typical cycle consists of the following steps:

- Fill – where the substrate is added;
- React – mixing and aeration is provided;
- Settle – for clarification of effluent;

- Decant – for withdrawal of effluent.

An idle step may also be included to provide flexibility at high flows. Aeration is accomplished by jet aerators or coarse bubble diffusers with submerged mixers.

Palsana Enviro Protection Ltd. (PEPL), is performing this type of activated sludge process to recycle 50 MLD wastewater for the member industries.

Membrane biological reactor (MBR)

The MBR process uses a biological reactor with suspended biomass. The biomass is not separated by sedimentation but by organic ultrafiltration membranes. The bioreactors may be aerobic or anaerobic. The content of suspended solids is very low which is a prerequisite for subsequent wastewater recycling by means of reverse osmosis. Further, the MLSS content is much higher than in conventional activated sludge systems (up to 11 g MLSS/kg).. MBRs have been used to treat municipal and industrial wastewater and reuse water.

Recent research has focused on the use of nanomaterials which are applied as a coating on the membranes to improve the hydrophilicity, selectivity, conductivity, fouling resistance, and anti-viral properties of membranes (Su et al., 2012; Kim and van der Bruggen, 2010; Lu et al., 2009; Zodrow et al., 2007; Bae and Tak, 2005).

Membrane bioreactor systems have two basic configurations. They are

- Integrated bioreactor that has a membrane module immersed in the reactor and.
- Recirculated MBR where the membrane module is separately mounted outside the reactor.

Immersed membranes use hollow fibre or flat sheet membranes mounted in modules. They operate at lower pressures and are used in activated sludge bioreactors. The separate systems use pressure-driven, in-pipe cartridge membranes. They are used more for industrial wastewater.

Attached growth and combined processes

Attached growth systems are characterized by a high degree of liquid recirculation (100–300%) to the biological reactor. The micro-organisms are attached to an inert medium in attached growth systems, forming a biofilm. As the wastewater comes in contact with and flows over the biofilm, the micro-organisms remove and degrade the organic compounds. A secondary clarifier is used, but sludge recirculation to the biological reactor is unnecessary. The settled sludge of sloughed biofilm is usually recirculated back to the wet well or primary clarifier. The media is usually an inert material with high porosity and surface area, formerly rock or gravel, but nowadays as plastic materials. The system can be operated as an aerobic or anaerobic process. The media can be wholly or partially submerged in the wastewater. Common attached growth processes include trickling filters, bio-towers, and rotating biological contactors (RBC). The attached growth processes are rarely applied to textile wastewater.
Solids generated from primary, secondary, and advanced wastewater treatment processes are called

sludge. Sludge is usually liquid or semisolid, typically containing from 0.25% to 12% solids by weight. It is classified into the following categories:

- Primary sludge – it consists of settable solids carried in the raw wastewater;
- Secondary sludge – it consists of biological solids and additional settleable solids.
- Tertiary sludge (produced in the advanced treatment process)

The first step in sludge handling is usually thickening. The purpose of thickening is to reduce sludge volume before further treatment. The main thickening methods used are gravity thickening, floatation thickening, centrifugation, gravity-belt thickening, and rotary-drum thickening (Metcalf and Eddy et al., 2013).

The second step is mechanical sludge de-watering by means of a centrifuge, belt press or chamber filter press. The highest solid content can be achieved with a chamber filter press
The final disposal methods for sludge are

- Landfilling,
- Co-processing

Figure 2.58. illustrates the sludge treatment and disposal flow diagram.

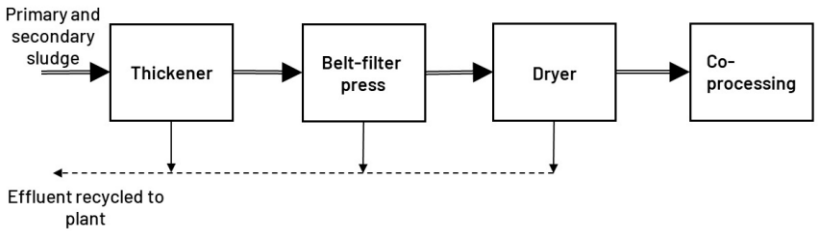


Figure 2.58 - Flow diagram for sludge treatment and disposal

The above illustrated route is generally followed by the Ahmedabad and Surat Cluster (including Sachin, Kadodara and Pandesara) CETPs.

2.12.3.3. Hybrid Treatment of textile wastewater

Biological treatment methods can address both biodegradable and non-biodegradable substances that adsorb to biomass (MLSS). However, water-soluble compounds that are not biodegradable (see Table 4) persist in the water phase. Especially reactive dyestuff are apparent examples.

In the textile industry, it is difficult to treat certain dye molecules and other water-soluble substrates using only biological methods at various wet processing phases. Chemical treatment procedures cannot always eliminate all dye molecules from textile effluent water. In addition to requiring additional energy, such as UV radiation and chemical reagents, such as Fe^{3+}, H_2O_2, and oxidizers, the technology may be expensive [91]. Biological treatment methods as a pre-treatment and chemical oxidation as a post-treatment, or vice versa, are the alternative methods for complete removal. Depending on the

constituents of textile effluent wastewater, the pre-treatment method is employed for the partial oxidation of non-biodegradable contaminants, such as dye molecules and other noxious substances, in order to generate biodegradable substrates. Processing must minimiseminimize the use of chemicals, energy, and operating expenses. In the literature, various combinations of biological and chemical oxidation remediation strategies have been reported. To remove COD and TOC from textile effluent wastewater, biological and chemical treatment methods can be combined.

Ultimately, the goal of integrating chemical and biological treatment techniques as pre- or post-treatment is to reduce investment costs and increase output quality. The total investment cost for a biological process effluent treatment plant (ETP) combined with chemical oxidation is 70–80 percent lower.

Figure 2.59 depicts the various processing stages that must be adhered to for a potential selection of chemical and biological integrated treatment methods for textile effluent wastewater. As a pre-treatment, the biological method was used to remove biodegradable pollutants from textiles in wastewater effluents. In the posttreatment, the advanced oxidation process (AOP) was utilisedutilized to eliminate non-biodegradable pollutants.

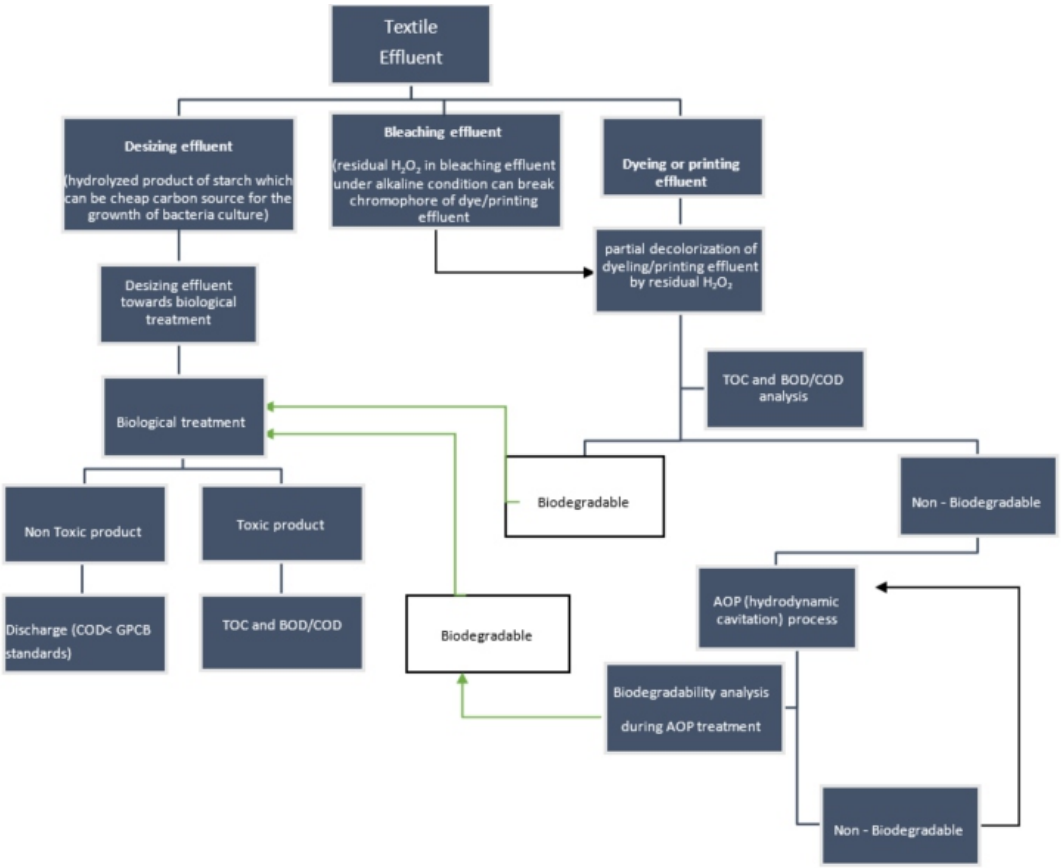


Figure 2.59 - System for integrating chemical oxidation with biological process for wastewater treatment from textile effluent
Source: Textile Industry Effluent Treatment Techniques, Journal of Chemistry · July 2021

This section provides information on textile-specific CETPs in Gujarat.

2.12.3.4. CETPs across Gujarat

Narol Textile Infrastructure & Enviro Management (NTIEM)

2.12.3.4.1. Ahmedabad

NTIEM was incorporated on 25th March 2010 as a company. The company predominantly provides wastewater treatment services to its member industries, all textile processing units, through a common effluent treatment plant (CETP) of 100 MLD capacity. This CETP caters to as many as 127 individual textile processing units which are processing cotton and blended fabrics, denims, and synthetic textiles. NTIEM provides its services to the textile processing units that are spread over an area of about 500 hectares in and around Narol, Shahwadi, Ranipur, Isanpur and Piplaj areas of Ahmedabad district in the state of Gujarat. The layout of the plant can be seen from Figure 2.60.



Figure 2.60 Layout of the NTIEM CETP

The basic scheme of the CETP is presented in Figure 2.61.

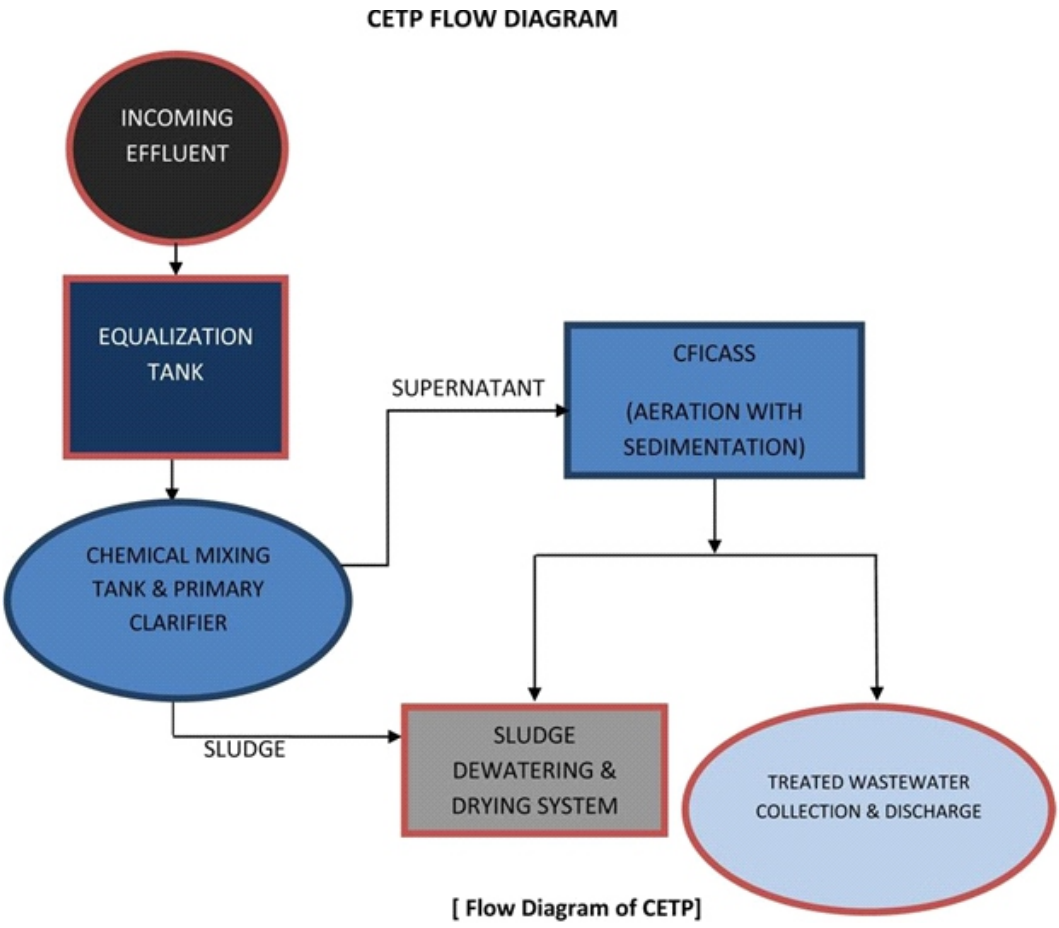


Figure 2.61 NTIEM CETP flow diagramTreatment Process

Treatment Process

- **Coarse Screening**

Wastewater flows via gravity into an inlet chamber and then through the manual coarse screens in the screen chambers. Screened wastewater flows into the wet well which has an effective capacity of 2,470 m^3 and a total retention capacity of around 30 minutes.

- **Equalization**

The pre-screened wastewater is pumped to the equalization tanks to dampen and equalize process water concentration variations in the still effluent.

- **Primary Treatment**

This treatment includes different units such as coagulation, flocculation and gravity settling to remove residual suspended and colloid solids (i.e., colour compounds and organics). A polymer addition system is provided for adding polymer to the flocculator zone as needed.

- **Neutralization**

The pH is adjusted using product PAC and two hydrofoil post clarifier pH adjustment agitators with 7.5 hp motor size.

- **Secondary treatment**

The biological treatment approach is a continuous flow integral clarifier activated sludge system (CFICASS) with secondary clarifiers (i.e., integral clarifiers) within the aeration tanks. CFICASS can sustain higher biomass than conventional activated sludge treatment and has no moving parts that come into contact with the wastewater.

- **Sludge Dewatering System and Solar Sludge Dryer**

The equipment for dewatering consists of four volute press with a total capacity of 105 m^3/hour. it dries the sludge moisture from 80% to less than 10%. The dewatered cake is to be stored and dried in the sludge storage shed before the final disposal.

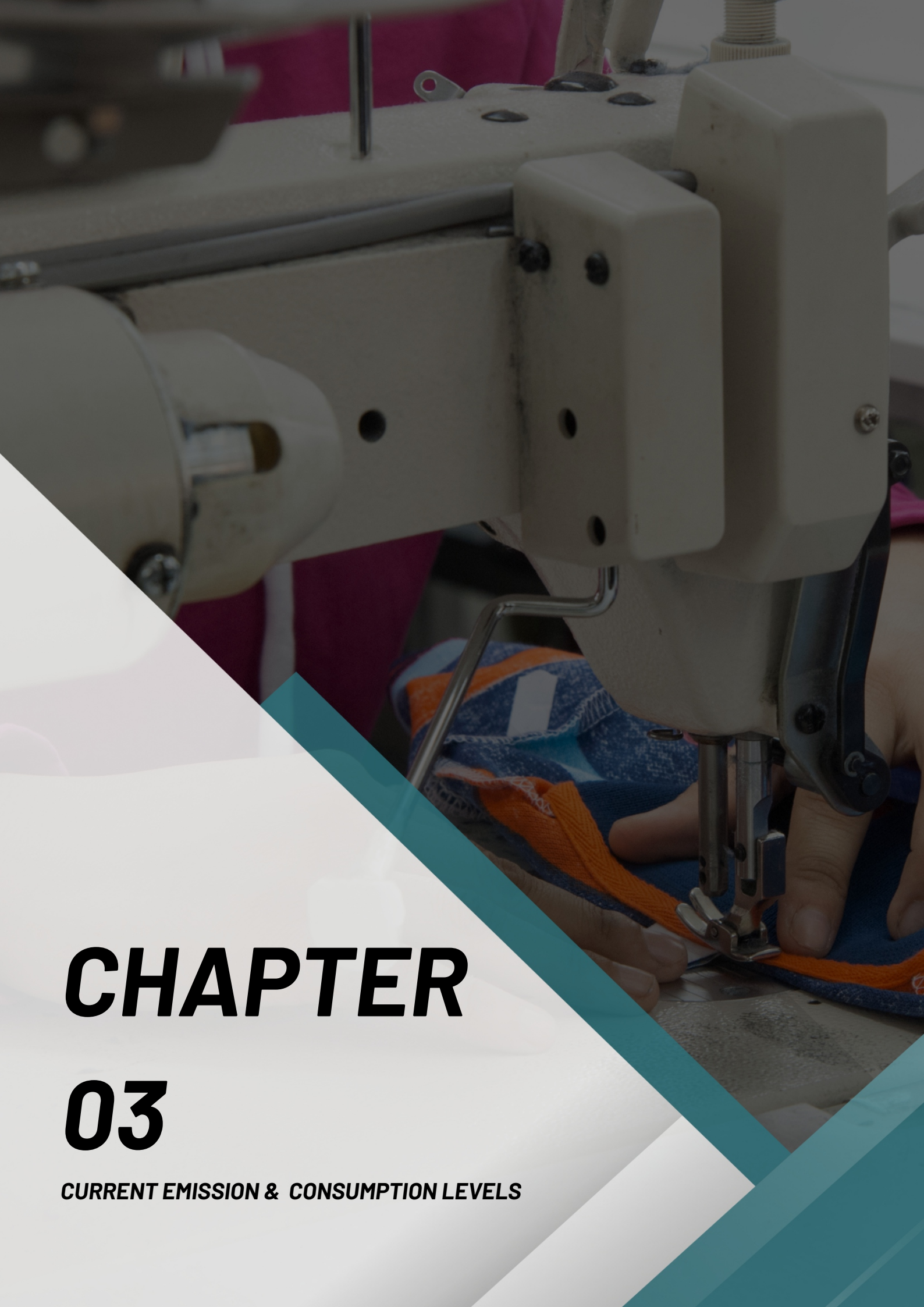
Final Discharge Point: The treated effluent as per GPCB norms from Ahmedabad CETP is discharged into the river Sabarmati downstream at Pirana, as per the directions of the Hon'ble Gujarat High Court, and as specified by GPCB in its CC&A.

2.12.3.4.2. Surat

Palsana Enviro Protection Limited (PEPL)

Palsana Enviro Protection Limited (PEPL) located in Surat, Gujarat, is a company promoted by the cluster of textile processing industries (member industries) for setting up of common effluent treatment plant (CETP) for conveyance, treatment and disposal of wastewater generated from the member industries. These industries are located in an area of approximately 100 sq km area. PEPL started its operational activities in 2008 with a treatment capacity of 50 MLD; as of today, its capacity is 150 MLD with a recycling facility of 50 MLD. PEPL started recycling its treated water to its member units to use it in their process activities.

PEPL is the first private entity that initiated recycling the treated wastewater in such a huge quantity to member units for reuse in non-potable activity. In connection with the Waste to Wealth (W2W) concept PEPL installed India's first solar sludge drying system to eliminate the moisture content from sludge generated in CETP and reuse the dried sludge as a fuel in boiler and cement Industries in fertilizer, bricks manufacturing etc.



CHAPTER 03

CURRENT EMISSION & CONSUMPTION LEVELS

3: Current Emission and Consumption Levels

In textile finishing CPH, typically, wastewater emissions are of the highest environmental relevance. Quantity and composition of waste water strongly depend on the end product, kind of textile substrate (cotton, polyester etc.), applied processes, and chemicals, respectively.

A sizable portion of the pollutant load that results from various textile operations can be attributed to the removal of raw material impurities including oil, dirt, lignin, and other contaminants from natural fibres. Additionally, leftover chemicals from the wet processing or those released during textiles washing operation are considered possible sources of pollution. Due to the range of chemicals used, the composition of the effluent stream may also vary considerably. Thus, the consumption and emission levels are to be monitored judiciously for the betterment of the environment.

As mentioned in Section 2.5, steps taken in fabric wet processing are the most water and energy-intensive. They are also potentially the highest waste-generating part of the textile mill. This chapter comprises of the analysis done by the author on consumption and emission pattern based on observation of collected data which may vary owing to a complex combination of factors, including:

- Types of fibres involved
- Types of end products processed
- Techniques applied
- Types of chemicals and auxiliaries used in the process.

The data presented further down has different ranges because the production varies widely during a year (because of seasonal changes, end user demand and fashion) and even over a single day (according to the production programme). Since the availability of process-specific data is very inadequate for various reasons, the optimum strategy used is a systematic examination of every process.

Moreover, it was also observed that resource-consumption records at each stage of process are not measured, making data assortment challenging for further records. The information collected is based on the author's interaction with the concerned personnel in CPH, although relevant assumptions were also made during a few statistical derivations.

The emission and consumption levels of CPH are presented in three different sections as mentioned below:

Emission and Consumption

- Section 1 - Woven Cotton Processing House (CPH)
- Section 2 - Polyester Fabric Processing House (PPH)
- Section 3 - Denim Processing House (DPH)

Table 3.1 shows the list of coding systems used to name the units for the following sections:

Table 3.1 - Industry Coding System

Code	Description
CPHS	Cotton Processing House (Small)
CPHM	Cotton Processing House (Medium)
CPHL	Cotton Processing House (Large)
PPHS	Polyester Processing House (Small)
PPHM	Polyester Processing House (Medium)
PPHL	Polyester Processing House (Large)
DPHM	Denim Processing House (Medium)
DPHL	Denim Processing House (Large)

3.1. Woven Cotton Processing House (CPH)

The emission and consumption levels presented in this section are based on data collected from CPH across Ahmedabad and Jetpur. Table 3.2 shows no. of the CPH considered for the in-depth resource consumption and emission study.

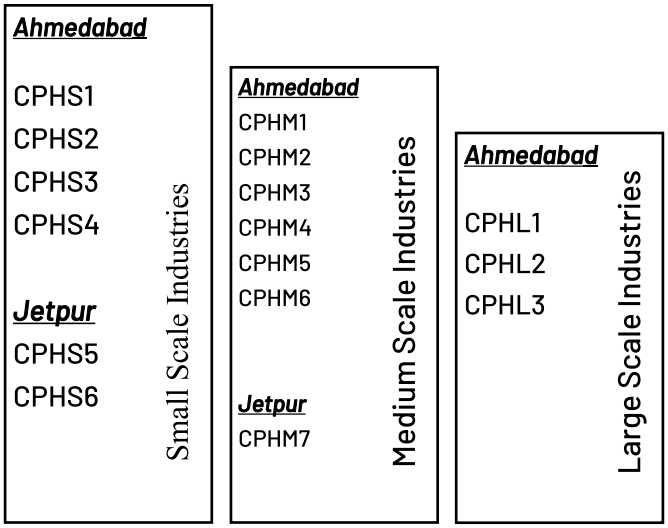
Table 3.2 : Cluster wise no of CPH

Cluster	Scale of Industry	Total number of CPH
Ahmedabad	Small	4
	Medium	6
	Large	3
Jetpur	Small	2
	Medium	1
	Large	-
Total CPH		16

*Jetpur consist of majorly MSME export-oriented CPH.

As shown in Table 3.3.3 shows a reference code assigned to the participating CPH and used throughout the document to refer to the specific industry easily.

Table 3.3 Industry-wise reference code



As mentioned earlier that the majorly woven cotton processing house (CPH) are operating on job work basis, the author has tried to capture the consumption and emission data of major fabric quality processed in the specific industry. Based on the interaction with the participating CPH, as shown in Table 3.4 data regarding the fabric dimensions and end application were obtained. That can further help to derive the resource consumption and emission during various processes.

Table 3.4 Industry wise End Product Application

Industry code	GSM	Width (in inch)	GLM	Mtr per kg	End product
CPHS1	140	58	206.25	4.85	Shirting & Suiting
CPHS2	150	44	167.64	5.97	Ladies Dress Fabric
CPHS3	115	58	169.42	5.90	Bedsheet/Quilt Cover
CPHS4	135	58	198.88	5.03	Ladies Dress Fabric
CPHS5	-	48	190	5.26	African Dress Fabric
CPHS6	-	48	190	5.26	African Dress Fabric
CPHM1	150	58	220.98	4.53	Shirting & Suiting
CPHM2	141.5	58	208.46	4.80	Shirting & Suiting
CPHM3	150	58	220.98	4.53	Shirting & Suiting
CPHM4	165	58	243.08	4.11	Indonesian Dress Fabric
CPHM5	150	44	167.64	5.97	Shirting & Suiting
CPHM6	150	58	220.98	4.53	Shirting & Suiting
CPHM7	-	48	195	5.13	African Dress Fabric
CPHL1	180	58	265.18	3.77	Shirting & Suiting
CPHL2	200	58	294.64	3.39	Bottoms
CPHL3	135	58	198.88	5.03	Shirting & Suiting

The following sections are based on the scale of industry (refer to Table No. 3.5), the investment in machinery varies widely across the different scale of industry which affect the overall resource consumption and emission factor as higher investment will attract more sophisticated and efficient machineries and equipment.

Table 3.5 - Definition of MSME

Classification	Micro	Small	Medium
Manufacturing Enterprises	Investment in Plant and Machinery or Equipment: Not more than Rs.1 crore	Investment in Plant and Machinery or Equipment: Not more than Rs.10 crore	Investment in Plant and Machinery or Equipment: Not more than Rs.50 crore

Source: msme.gov.in

3.1.1. CPH specific resource consumption

3.1.1.1. Small Scale CPH

CPH in both Clusters follows different process routes as the end product application is in different market. Hence, the data derived and observation made are put-up separately for both Clusters.

3.1.1.1.1. Ahmedabad Cluster

The typical process sequence for finishing woven cotton fabric is the same in all scale of CPH of Ahmedabad Cluster,as shown in figure 3.1.

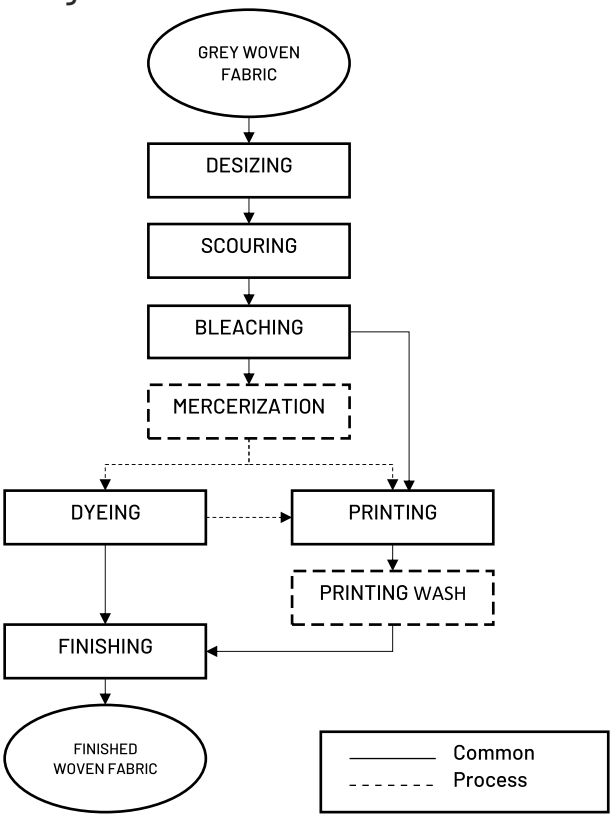


Figure 3.1 - Process route of woven cotton CPH in Ahmedabad Cluster

As mentioned in Table 3.6, of the Jigger machine is primarily used for all pre-treatment and dyeing processes in small scale CPH of the Ahmedabad cluster.

Table 3.6 - Process-wise Machines used in Small Scale CPH of Ahmedaad Cluster

Industry Code	Desizing	Scouring	Bleaching	Mercerization	Dyeing	Printing	Washing
CPHS1	Jigger	Jigger	Jigger	Mercerizer	Jigger	Flat Bed	Not Performing
CPHS2	Padding	Jigger	Jigger	Mercerizer	Jigger	Not Performing	Not Performing
CPHS3	Jigger	Jigger	Jigger	Not Performing	Not Performing	Flat Bed	Not Performing
CPHS4	Jigger	Jigger	Jigger	Not Performing	Jigger	Not Performing	Not Performing

Table 3.7. - List of Chemicals added per process in Small Scale CPH

Chemical Consumption

Industry Code	Desizing	Scouring	Bleaching	Mercerization	Dyeing	Printing
CPHS1	1. Enzyme 2. Wetting Agent 3. Acetic Acid	1. Caustic Soda 2. Wetting Agent	1. Hydrogen Peroxide 2. Stabilizer 3. Sodium Hypochlorite 4. Soda Ash	1. Caustic Soda	1. Dyes 2. Salt 3. Soda Ash	1. Pigment 2. Binder 3. Thickener
CPHS2	1. Enzyme 2. Salt	1. Caustic Soda 2. Wetting Agent	1. Hydrogen Peroxide 2. Stabilizer 3. Sodium Hypochlorite	1. Caustic Soda	1. Dyes 2. Salt 3. Caustic Soda	Not Performing
CPHS3	1. Enzyme	1. Caustic Soda 2. Wetting Agent 3. Soda Ash	1. Sodium Hypochlorite	Not Performing	Not Performing	1. Pigment 2. Binder 3. Thickener
CPHS4	1. Enzyme 2. Wetting Agent 3. Acetic Acid	1. Caustic Soda 2. Wetting Agent 3. Soda Ash	1. Hydrogen Peroxide 2. Stabilizer 3. Sodium Hypochlorite 4. Soda Ash	Not Performing	1. Dyes 2. Dyes Fixing Agent 3. Salt 4. Soda Ash	Not Performing

a. Desizing

As shown in Table 3.7, these CPHs are performing enzymatic desizing method. Where, CPHS1 & CPHS4 are using wetting agent as auxiliary while CPHS2 & CPHS3 are using auxiliary rarely. As per conversation with CPHS2, they are adding salt to the liquor to increase the swelling of fabric for better penetration of enzyme in fabric as per their conception. But in fact, adding NaCl salt decreases the activity of enzyme.

b. Scouring

All 4 CPHs are performing scouring process in Jigger machine where fabric is processed under caustic solution and wetting agent. CPHS3 & CPHS4 are adding soda ash to maintain the pH of liquor.

c. Bleaching

Due to cost factor, grey fabric sourced is of lower quality having higher cotton seed husk tangled with fabric. Due to which the CPHS1 & CPHS4 are using Hypochlorite along with H_2O_2 as bleaching agent. CPHS3 is using Hypochlorite to get proper whiteness index at lower cost.

d. Mercerization

As mentioned in Table 3.4, CPHS3 & CPHS4 are involved in low quality end products that doesn't require dyeing. Hence, to save costs, both CPH rarely perform mercerization on customer demand.

e. Dyeing

CPHS2 uses caustic to create uses caustic to create an alkali medium while the rest use soda ash to attain alkali medium.

f. Printing

These CPHs are majorly involved in pigment printing; hence, printed fabric doesn't need to be washed after printing.

Water Consumption

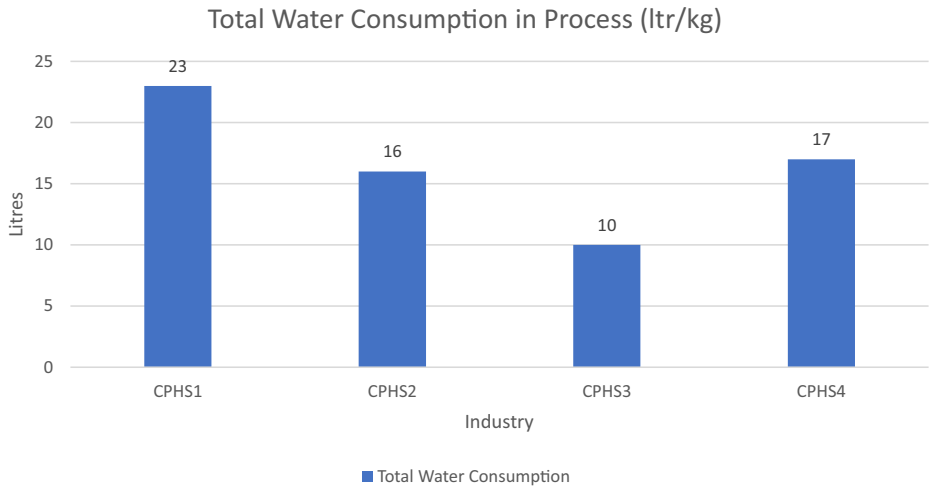


Figure 3.2 : Overall Water Consumption in Small Scale CPH of Ahmedabad Cluster

Figure 3.2 shows the range of total water consumption in process in small-scale CPH is between 10 and 23 ltr/kg. As, water monitoring is not available in these small scale CPH. The total water consumption was determined by assessing process-by-process water consumption (refer to Table 3.8) based on interactions with CPH and by determining the quantity based on the number of steps, batch size, and tank volume.

Although CPHS3 uses the least quantity of water, this does not necessarily mean that it is the most efficient. The key reason for the low consumption is that dyeing, a significant water-intensive process step, is not performed. Additionally, the unit has reduced the number of post-processes washing steps to save resources like steam and water based on the quality of the finished product processed (shown in Table 3.4).

Table 3.8 Process wise Water Consumption in Small Scale CPH of Ahmedabad Cluster

Industry Code	Desizing	Scouring	Bleaching	Mercerization	Dyeing	Printing	Washing	Total Water Consumption
CPHS 1	3	3	3	3	8	3	Not Perfroming	23
CPHS2	1	2	3	4	6	Not Perfroming	Not Perfroming	16
CPHS3	1	2	4	Not Perfroming	Not Perfroming	3	Not Perfroming	10
CPHS2	2	5	4	Not Perfroming	6	Not Perfroming	Not Perfroming	17

Values are in Ltr/kg

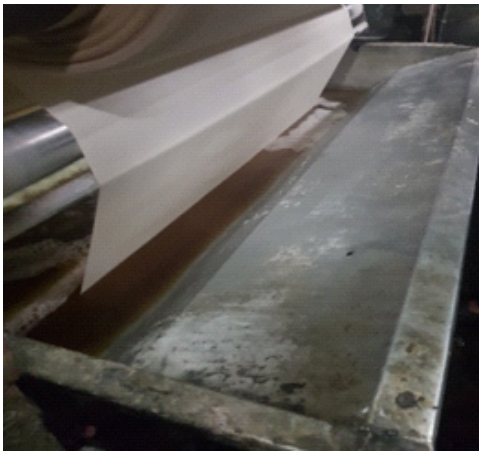


Figure 3.3 Low Liquor ration maintained in Jigger Machine

Water consumption in CPHS4 during scouring is on higher side due to provision of running water wash. It should also be noted that being small scale CPH, values mentioned don't include leakages due to poor equipment maintenance, condensate formed where direct steam is supplied for heating and other losses like manpower errors etc.

To reduce the water consumption, all CPH are maintaining a very low liquor ratio in Jigger machine as shown in Figure 3.3, which also results in reduced chemical consumption.

Utilities

Third-party walk-through Energy Audit were carried out by BEE certified Energy Auditor at all small scale CPHs selected for study.

Steam Utilised (kg/kg of fabric)				
Machine	CPHS1	CPHS2	CPHS3	CPHS4
Jigger	1.9	2.23	1.51	2.07
Mercerizer	-	0.772	-	0.79
Drying Range	2.48	-	1.62	
Loop Ager	3.85	-	4.41	4.41
Sanforization	0.52	-	0.331	0.3

Thermic Oil Utilised (kcal/kg of fabric)				
Machine	CPHS1	CPHS2	CPHS3	CPHS4
Flat Bed	740.7		703.4	
Stenter	1083.3	826.55	773.9	802.4

CPHS1 was found very inefficient in terms of maintenance. It was observed that the CPHS1 uses firewood as boiler fuel. And is using an inefficient steam distribution system that is resulting in energy loss.

Sr.No	**Schemes**	**Remarks**
1.	Steam controller in Jigar Dying	No
2.	Condensate recovery from Drying Range	No
3.	Temperature controller in chambers of Flatbed machine	No
4.	Zero -Zero machine Circulation water reuse	No

Also, in fabric processing section, many instances were found where BAT mentioned in Chapter 4 can be implemented.

Energy Survey		
Sr.No	**Description**	**Remarks**
1	Condensate Recovery system	Not Proper
2	Optimization of steam distribution	Not Proper
3	Steam Traps	Leakage
4	Insulation Condition	Not Proper

The CPHS1 has also implemented various BATs which are referred in Chapter 4.

CPHS2

Energy survey		
Sr.no	**Description**	**Remarks**
1	Condensate Recovery system	Yes
2	Optimization of steam distribution	Yes
3	Steam Traps	Leakage
4	Insualtion Condition	Not proper

Sr.No	**Schemes**	**Remarks**
1	Steam controller in Jigar Dying	No
3	Condensate recovery from Drying Range	Yes
4	Temperature controller in chambers of Flatbed machine	Yes
6	VFD installation in ID FAN	Yes
7	zero -zero machine circulation water reuse	No
8	Leakages in Drying Range	Yes

CPHS3

Energy Survey		
Sr.No	**Description**	**Remarks**
1	Condensate Recovery system	Yes
2	Optimization of steam distribution	No
3	Steam Traps	Leakage
4	Insulation Condition	Not proper

SR No.	**Schemes**	**Remarks**
1	Steam controller in Jigar Dying	No
3	Condensate recovery from Drying Range	Yes
4	Temperature controller in chambers of Flatbed machine	Yes
6	VFD installation in ID FAN	Yes
7	zero -zero machine circulation water reuse	No
8	Leakages in Drying Range	Yes
9	Energy efficient bore well	No
10	Re use of ETP water for blanket cleaning of flat belt	Yes

CPHS4

Energy Savings Scheme Survey		
Sr.No	**Description**	**Remarks**
1	Condensate Recovery system	No
2	Optimization of steam distribution	No
3	Steam Traps	Leakage
4	Insulation Condition	Not Proper

Sr.No	**Schemes**	**Remarks**
1	Steam controller in Jigar Dying	No
3	Re use of cooling water in Jet Dying	No
4	Condensate recovery from Drying Range	Yes
5	Temperature controller in chambers of Flatbed machine	Yes
6	VFD installation in the jet dying Pump	Yes
7	VFD installation in ID FAN	Yes
8	zero-zero machine circulation water reuse	No
9	Leakages in Drying Range	Yes
10	Energy efficient bore well	No
11	Re use of ETP water for blanket cleaning of flat belt	Yes

3.1.1.1.2. Jetpur Cluster

As shown in Figure 3.4, all CPH in Jetpur follow this unconventional approach in processing woven cotton. Discussion with CPH revealed that they are taking this approach in order to cut processing time and costs

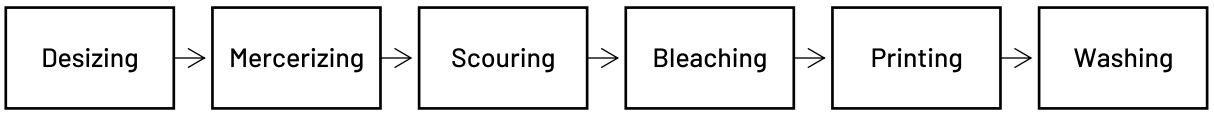


Figure 3.4 - Process sequence for wet processes for the finishing of woven fabric in Jetpur Cluster

From Table 3.9, it can be inferred that the machines used for processes in Jetpur Cluster is quite different from the Ahmedabad Cluster (refer As mentioned in Table 3.6, Jigger machine is primarily used for all pre-treatment and deying process in small scale CPH of Ahmedabad cluster).

Table 3.9 : Process wise Machines used in Small Scale CPH of Jetpur Cluster

Industry Code	Desizing	Mercerization	Scouring	Bleaching	Dyeing	Printing	Washing
CPHS5	Padder + J Box	Mercerizer	J Box	Kundi	Not Performing	Flat bed	Sent to Washing Ghat
CPHS6	Padder + J Box	Mercerizer	J Box	Kundi	Not Performing	Flat bed	Sent to Washing Ghat

All CPH in Jetpur Cluster perform wet processing operations in similar sequences and machines.

Chemical Consumption

Table 3.10 - List of Chemicals added per process in Small Scale CPH of Jetpur cluster

Industry Code	Desizing	Mercerization	Scouring	Bleaching	Printing
CPHS5	Enzyme Wetting Agent	Caustic Soda Soln (ml/kg)	No Chemicals added	1. Peroxide 2. Stabilizer 3. HCl 4. Soda Ash 5. Sodium Hypochlorite 6. OBA	1. Reactive dye 2. Synthetic Gum
CPHS6	Enzyme Wetting Agent	Caustic Soda Solution (ml/kg)	No Chemicals added	1. Peroxide 2. Stabilizer 3. HCl 4. Soda Ash 5. Sodium Hypochlorite 6. OBA	1. Reactive dye 2. Synthetic Gum

1. Desizing

CPHS5 & CPHS6 are performing enzymatic desizing using padder, and washing is done in J Box.

2. Mercerization

As mentioned in Table 3.4 , CPHS5 & CPHS6 are involved in African countries export oriented products. To save costs, both CPH are performing causticization (semi-mercerization) post-desizing. Depending on the batch size, it is kept on roller for 6 -12 hrs. The washing operation is performed post process, but the last tank still consists of weak caustic liquor soaked into fabric.

3. Scouring

Since caustic has been used in previous process and fabric is already wet with caustic, no further caustic is added and only hot treatment with steam is carried out.

4. Bleaching

Cascading tanks are built for bleaching operation. Due to cost factor, grey fabric sourced is of lower quality with higher cotton seed husk tangled with fabric. Due to which all CPH are using Hypochlorite along with H_2O_2 as bleaching agent to get proper whiteness index at lower cost.

5. Printing

These CPHs are involved majorly in reactive printing. Post printing wash is not done in the CPH premises; they are sent to washing ghats.

Water Consumption

Table 3.11 shows that the range of total water consumption in process in small-scale CPH of Jetpur area is between 4 and 9 ltr/kg. As the CPH in Jetpur cluster do not have effluent pipe discharge system, they are sending through tankers to CETP for treating wastewater.

Table 3.11 - Process wise Water Consumption in Small Scale CPH of Jetpur Cluster

Industry Code	Desizing	Mercerization	Scouring	Bleaching	Dyeing	Printing	Washing	Total Water
CPHS5	3	0.7	0.7	1.8	Not Performing	1	Sent to Washing Ghat	4.2
CPHS6	3	1.2	1.8	5	Not Performing	1	Sent to Washing Ghat	9

The total water consumption was determined based on the daily tankers required, no of batches per day and avg. batch quantity. The author has tried to assess process-by-process water consumption (refer Table 3.11) based on interactions with CPH and by determining the quantity based on the number of steps, batch size, and tank volume.

Overall water consumption is less in CPHS5 because they only replace water in the mercerization and scouring process bath once a day instead of discharging it.

3.1.1.2. Medium Scale CPH

3.1.1.2.1.Ahmedabad Cluster

The process sequence for the finishing of woven cotton fabric processed in Medium Scale CPH of Ahmedabad Cluster is similar to shown in Table 3.12.

Table 3.12: Process-wise Machines used in Medium Scale CPH of Ahmedabad Cluster

Industry Code	Desizing	Scouring	Bleaching	Mercerization	Dyeing	Printing	Washing
CPHM1	Desizer	CBR		Mercerizer	Jigger	Rotary	Washer
CPHM2	Desizer	CBR		Mercerizer	Jigger	Not Performing	Not Performing
CPHM3	Desizer	CBR		Mercerizer	Jigger	Not Performing	Not Performing
CPHM4	Not Performing	Maxi	Maxi	Batch Mercerizer	Not Performing	Rotary	Washer
CPHM5	Desizer	Maxi	Maxi	Mercerizer	Jigger	Rotary	Not Performing
CPHM6	Desizer	Jigger	Jigger	Mercerizer	Jigger	Not Performing	Not Performing



Figure 3.5 - Maxi Jigger

Compared to CPHS, CPHM are using more efficient and sophisticated machines as shown in table 3.12. CPHM1, CPHM2 and CPHM3 are using Continuous Bleaching Range (CBR) that drastically reduce the water and chemical consumption observed in Table 3.14.Meanwhile, CPHM4 & CPHM5 are using Maxi Jigger (Closed) as shown in Figure 3.5 that attribute to saving energy and process time. Also, CPHM performing printing are using rotary printing machine instead of flatbed machine which is more efficient and provide higher printing productivity.

Chemical Consumption

Table 3.13 - List of Chemicals added per process in Medium Scale CPH of Ahmedabad Cluster

Industry Code	Desizing	Scouring	Bleaching	Mercerization	Dyeing	Printing
CPHM1	1. Enzyme 2.Wetting Agent	1.Caustic Soda 2.Chelating Agent 3.Wetting Age	1.Hydrogen Peroxide 2.Stabilizer	1. Caustic Soda 2. Wetting agent	1. Salt 2. soda ash 3.Soaping 4. Acetic acid 5. Reactive dyes	1. Reactive dye 2. Synthetic Gum 3. Soda Bicarbonate 4. Resistive salt 5. Ammonia 6. Urea
CPHM2	1. Enzyme 2. Wetting Agent 3.Chelating Agent	1. Caustic Soda 2. Chelating Agent 3. Wetting Agent	1. Hydrogen Peroxide 2. Stabilizer 3. Chelating Agent 4. Wetting Agent	1.Caustic Soda	1. Salt 2. soda ash 3. Soaping 4. Reactive dyes	Not Performing
CPHM3	1. Enzyme 2. Wetting Agent 3. Chelating Agent	1. Caustic Soda 2. Chelating Agent 3. Wetting Agent	1. Hydrogen Peroxide 2. Stabilizer 3.Chelating Agent 4. Wetting Agent	1. Caustic Soda 2. Wetting agent	1. Salt 2. soda ash 3. Soaping 4. Reactive dyes	Not Performing
CPHM4	Not Performing	No Chemicals added	1. Hydrogen Peroxide 2. Stabilizer 3. EDTA 4. Sodium Percarbonate 5. OBA	1. Caustic Soda 2. Wetting agent	Not Performing	1. Reactive dye 2. Synthetic Gum 3. Soda Bicarbonate 4.Resistive salt
CPHM5	1. Enzyme 2. Wetting Agent	1. Caustic Soda 2. Wetting Agent	1. Hydrogen Peroxide 2. Stabilizer 3. Chelating Agent 4.Wetting Agent	1. Caustic Soda 2.Wetting agent	1. Salt 2. Caustic 3. Soaping 4. Dye fixing agent 5. Reactive dyes	1. Binder 2. Thickener 3. Pigment
CPHM6	1. Enzyme 2.Wetting Agent	1. Caustic Soda	1. Hydrogen Peroxide 2. Stabilizer 3. Chelating Agent 4. Wetting Agent	1. Caustic Soda	1. Salt 2. Caustic 3. Dye fixing agent 4. Reactive dyes	Not Performing

1. Desizing

All medium scale CPH except CPHM4 perform enzymatic desizing using padding machine as shown in Figure 3.6. Only CPHM4 is performing the causticizing process to remove starch from the fabric. Depending on the batch size, it is kept on roller for 6 -12 hrs.

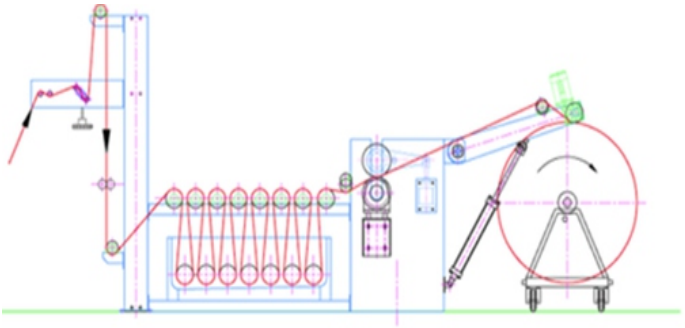


Figure 3.6 - Schematic of Desizing Machine

Also, as per discussion with CPHM4, it was found that they are buying their own fabric from weaved by Air Jet Looms due to which amount of sizing is already less on fabric.

2. Scouring & Bleaching

CPHM1, CPHM2 and CPHM3 use Continuous Bleaching Range (CBR) to carry out scouring and bleaching operations. While, CPHM4 & CPHM5 are using Maxi jigger to carry out the combined operation. CPHM6 only is following conventional route i.e. through jigger.

All CPH use chelating and wetting agents as auxiliaries.

CPHM4 uses the caustic soaked on fabric during the causticizing process for scouring operation. The unit uses EDTA as a chelating agent and Sodium Percarbonate as an oxidizing agent. They are also using Optical Brightening Agents to increase the whiteness index.

3. Mercerization

All CPHs except CPHM4 are performing mercerization process.

4. Dyeing

All CPHs are performing the dyeing process. CPHM4 is involved in discharge printing CPHM1, CPHM5 & CPHM6 are performing dyeing with Cold Brand ("M") Dyes that require dyeing at room temperature, hence saving energy. More details on these dyes are given in the annexure.

5. Printing

CPHM1 is majorly involved in reactive printing. CPHM2, CPHM3 and CPHM6 are processing majorly dyed fabric and, hence are only printing on specific customer demand. CPHM4 is performing reactive discharge printing.

Water Consumption

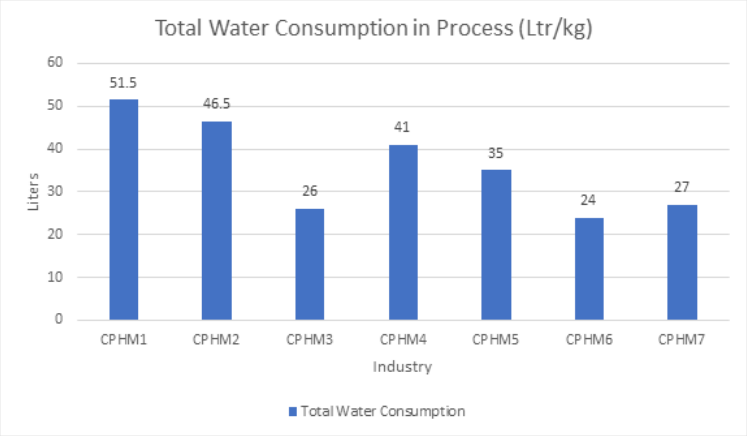


Figure 3.7 : Total water consumption in process in Medium Scale CPH of Ahmedabad Cluster

Figure 3.7 shows the range of total water consumption in process in medium-scale CPH is between 24 and 51.5 ltr/kg. As, water monitoring is accurate for some processes as they have PLC. The total water consumption was determined by assessing process-by-process water consumption (refer to Table 3.14) based on interactions with CPH and by determining the quantity based on the number of steps, batch size, and tank volume.

Table 3.14 - Process wise water consumption in Medium Scale CPH of Ahmedabad Cluster

Industry Code	Desizing	Scouring	Bleaching	Mercerization	Dyeing	Printing	Washing	Total Water Consumption
CPHM1	2	2	2.5	5	14	3	23	51.5
CPHM2	1	2	3.5	4	33	3	Not Performing	46.5
CPHM3	1	8	12	4	16	Not Performing	Not Performing	41
CPHM4	Not Performing	4.5	4.5	1	Not Performing	4	21	35
CPHM5	2	2.5	2.5	4	11	2	Not Performing	24
CPHM6	1	6	5	4	11	Not Performing	Not Performing	27

The CPH have associated their water consumption with the fabric cost factor. So, CPHM5 & CPHM6 have lower water consumption values due to processing of locally demanded fabric quality. Additionally, the unit has reduced the number of post-processes washing steps to save resources like steam and water based on the quality of the finished product processed (shown in Table 3.4).

CPHM4, being export oriented unit also has lower water consumption as the unit has recreated more efficient approach towards whole cotton textile wet processing. The unit mercerizes fabric without any post washes and provides dwell time to caustic on fabric. Further, the unit performs scouring and bleaching in automated Maxi Jigger for maximum efficiency. The unit approach is unique and does not follow the conventional pre-treatment sequence i.e., desizing, scouring, bleaching and mercerizing. Also, the coloured printed fabrics are directly printed instead of conventional dyeing and then printing to save resources and time.

Utilities

Steam Utilised (kg/kg of fabric)				
Machine	CPHM1	CPHM3	CPHM4	CPHM6
Jigger	1.31	1.25	-	1.8
CBR	3.3	2.19	-	-
Maxi	-	-	1.49	-
Mercerizer	0.46	0.411	-	0.53
Drying Range	1.16	0.42	1.536	1.73
Loop Ager	2.41	-	1.75	3.24
Sanforization	0.194	-	-	0.25
Print Washer	0.41	-	-	0.85

Thermic Oil Utilised (kcal/kg of fabric)				
Machine	CPHM1	CPHM3	CPHM4	CPHM6
Flat Bed	588	-	-	942
Rotary	625	-	601	-
Stenter	537	467.2	583.3	802

CPHM1

Energy Savings Scheme Survey		
Sr.No	**Description**	**Remarks**
1	Condensate Recovery system	Yes
2	Optimization of steam distribution	Yes
3	Steam Traps	Ok
4	Insualtion Condition	Ok
5	Low Pressure Turbine Installation	Yes

Sr.No	Schemes	Remarks
1	Steam controller in Jigar Dying	No
3	Condensate recovery from Drying Range	No
4	Temperature controller in chambers of Flatbed machine	No
5	VFD installation in the jet dying Pump	No
6	VFD installation in ID FAN	Yes
7	zero -zero machine circulation water reuse	No
8	Leakages in Drying Range	Yes
9	Re use of ETP water for blanket cleaning of flat belt	Yes

CPHM3

Energy Savings Scheme Survey		
Sr.No	**Description**	**Remarks**
1	Condensate Recovery system	Yes
2	Optimization of steam distribution	No
3	Steam Traps	Ok
4	Insulation Condition	Ok

Sr.No	Schemes	Remarks
1	Steam controller in Jigger Dying	yes
2	Low pressure system in Jigger Dying	No
3	Re use of cooling water in Jet Dying	No
4	Condensate recovery from Drying Range	Yes
6	VFD installation in the jet dying Pump	No
7	VFD installation in ID FAN	Yes
8	zero -zero machine circulation water reuse	No
9	Leakages in Drying Range	No

CPHM4

Energy Savings Scheme Survey		
Sr.No	Description	Value
1	Condensate Recovery system	Yes
2	Optimization of steam distribution	Yes
3	Steam Traps	Ok
4	Insulation Condition	Ok

Sr.No	Schemes	Remarks
1	Re use of cooling water in Jet Dying	Yes
2	Condensate recovery from Drying Range	Yes
3	Temperature controller in chambers of Flatbed machine	Yes
4	VFD installation in the jet dying Pump	No
5	VFD installation in ID FAN	Yes
6	Leakages in Drying Range	No
7	Energy efficient bore well	Yes
8	Re use of ETP water for blanket cleaning of flat belt	Yes

3.1.1.2.2. Jetpur Cluster

All CPHs in Jetpur follow unique steps apart from the general steps in woven cotton wet processing. During discussion with CPH, it was observed that to reduce the processing time and cost. They are following this unique route.

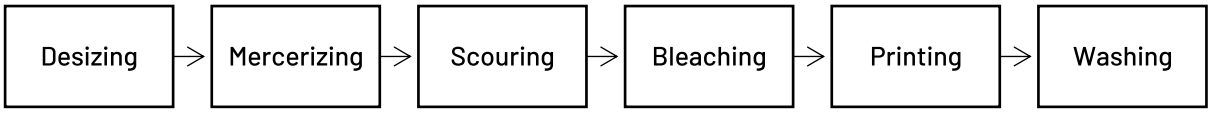


Table 3.15 : Process-wise Machines used in Medium Scale CPH of Jetpur Cluster

Industry Code	Desizing	Mercerization	Scouring	Bleaching	Dyeing	Printing	Washing
CPHM8	Desizer	Mercerizer	J Box	Kundi	Not Performing	Rotary	Kundi

Chemical Consumption

Table 3.16 - List of Chemicals added per process in Medium Scale CPH of Jetpur Cluster

Industry Code	Desizing	Mercerization	Scouring	Bleaching	Printing
CPHM7	1. Hydrogen Peroxide 2. Wetting Agent 3. Soda Ash	1.Caustic Soda	No Chemicals added	1. Peroxide 2. Stabilizer 3. Soda Ash 4. Sodium Hypochlorite 5. OBA	1. Reactive dye 2. Discharging Agent 3. Resist Salt 4. Urea 5. Synthetic Gum

CPHM7 is performing a similar operation as CPHs of the Jetpur cluster. The only difference is that it is performing discharge printing instead of reactive printing.

Water Consumption

Table 3.17 : Process-wise Water Consumption in Medium Scale CPH of Jetpur Cluster

Industry Code	Desizing	Scouring	Bleaching	Mercerization	Dyeing	Printing	Washing	Total Water Consumption
CPHM8	1.8	0	1.2	4	Not Performing	2	4	13

CPHM8 is a ZLD unit. Considering the scale of operation, the unit has installed water monitoring practice to avoid water wastage.

3.1.1.3. Large Scale CPH

The process sequence for the finishing of woven cotton fabric processed in Large Scale CPH of Ahmedabad Cluster is similar to shown in table 3.18. The major difference is the use of machineries.

Table 3.18 : Process-wise Machines used in Medium Scale CPH of Jetpur Cluster

Industry Code	Desizing	Scouring	Bleaching	Mercerization	Dyeing	Printing	Washing
CPHL1	Desizer	CBR		Mercerizer	CDR	Rotary	Washer
CPHL2	Desizer	CBR		Mercerizer	CPB/PDPS	Rotary	Drum Washer
CPHL3	Desizer	CBR		Mercerizer	Jigger	Rotary	Washer

3.1.1.3.1. Chemical Consumption

Table 3.19 - List of Chemicals added per process in Large Scale CPH

Industry Code	Desizing	Scouring	Bleaching	Mercerization	Dyeing	Printing
CPHL1	1. Enzyme 2. Wetting Agent 3. Chelating Agent	1. Caustic Soda	1. Peroxide 2. Stabilizer 3. Chelating Agent 4. Wetting Agent	1. Caustic Soda	CDR 1. soda ash 2. Caustic 3. Reactive dyes	1. Reactive dye 2. Synthetic Gum 3. Soda Bicarbonate 4. Resistive salt
CPHL2	1. Peroxide 2. Caustic 3. Stabilizer 4. Wetting Agent 5. Sequestering Agent	1. Caustic Soda 2. Chelating Agent 3. Wetting Agent	1. Peroxide (gm/kg) 2. Stabilizer (gm/kg)	1. Caustic Soda	CPB 1. Silicate 2. Reactive Dyes PDPS 3. Salt 4. Soda ash 5. Caustic 6. Anti-Migrating Agent 7. Reactive dyes	1. Reactive dye 2. Synthetic Gum 3. Soda Ash 4. Soda Bicarbonate 5. Urea
CPHL3	1. Enzyme Wetting Agent 2.Chelating Agent	1. Caustic Soda	1. Peroxide 2. Stabilizer 3. Chelating Agent 4. Wetting Agent	1. Caustic Soda 2. Mercerizing Agent	1. Salt 2. soda ash 3. Caustic 4. Reactive dyes	1. Pigment 2. Binder 3. Thickener 4. Fixer 5. Softener 6. Emulsifier

1. Desizing

CPHL1 & CPHL3 perform enzymatic desizing using a padding machine as shown in Figure 3.6. CPHL2 has very old facility and old machineries, so as to avoid pin hole formation due to excessive oxidation of fabric, they perform oxidative desizing to remove starch from the fabric. In this manner, they control the usage of hydrogen peroxide by adding it in small quantities in different processes.

2. Scouring & Bleaching

All large-scale CPHs use Continuous Bleaching Range (CBR) to carry out scouring and bleaching operations.

Chelating and wetting agents are majorly used as auxiliaries.

3. Mercerization

All CPHs perform the mercerization process and have their own Caustic Recovery Plant.

4. Dyeing

All CPHs perform the dyeing process. CPHL1 performs dyeing in the Continuous Dyeing Range while CPHL2 performs Cold Pad Batch (CPB) dyeing and Pad-Dry-Pad-Steam (PDPS) dyeing. CPHL3 is performing a conventional dyeing process in jigger machine.

As shown in Table 3.19, major benefit can be seen in the CPB process, where no salt is required during the process, hence reducing the TDS in the wastewater.

5. Printing

All CPHs perform the printing process. We've gathered the CPHL1 & CPHL2 data for reactive printing.

3.1.1.3.2. Water Consumption

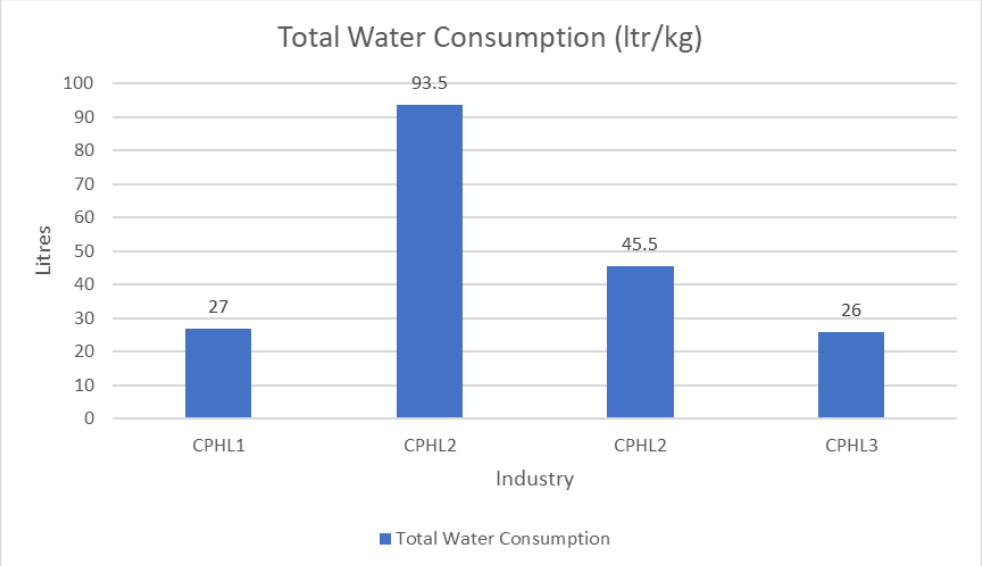


Figure 3.8 : Overall Water Consumption in Large Scale CPH of Ahmedabad Cluster

Figure 3.8 shows that the total water consumption in large-scale CPH is between 27 and 93.5 ltr/kg, as water monitoring is accurate for some processes as they have PLC. The total water consumption was determined by assessing process-by-process water consumption (refer to Table 3.20) based on interactions with CPH and by determining the quantity based on the number of steps, batch size, and tank volume.

CPHL1 have implemented many BAT techniques that are further elaborated in Chapter 4. That has helped the CPHL1 in becoming one of the most efficient CPHs.

Table 3.20 - Process wise Water Consumption in Large Scale CPH of Ahmedabad Cluster

Industry Code	Desizing	Scouring	Bleaching	Mercerization	Dyeing	Printing	Washing	Total Water Consumption
CPHL1	1	1.5	1.5	4	9	1	9	27
CPHL2	4	4	4	5	11.5	2	63*	93.5
CPHL2	4	4	4	5	11.5	2	15**	45.5
CPHL3	1	2	4	5	11	3	Not Performing	26

*Reactive Printing Wash **Discharge Printing Wash

CPHL1 is reusing post wash water of CBR into pre wash tanks and hence, is reducing overall water consumption in CBR.



Figure 3.9 Continuos Rotary Drum Washer

CPHL2 has installed a continuous rotary drum washer (as shown in Figure 3.9) which is different from the continuous washing range installed in other large scale CPHs.

CPHL2 claims the machine has better washing efficiency than the regular continuous washing range.

It was found that for reactive printing washing, the unit consumes 63 ltr/kg which is very high compared to others.

3.2. Woven Polyester Processing House (PPH)

The emission and consumption levels presented in this section are based on data collected from PPH across Surat. Table 3.21 shows no. of the PPH considered for the in-depth resource consumption and emission study.

Table 3.21 : Cluster-wise no of PPH

Cluster	Scale of Industry	Total no of PPH
Surat	*Small*	5
	Medium	7
	Large	5
Total PPH		*17*

As shown in table 3.22, a reference code is assigned to the participating PPH and used throughout the document for easy reference to the specific industry.

Table 3.22 Industry-wise reference code

PPHS1 PPHS2 PPHS3 PPHS4 PPHS5	PPHM1 PPHM2 PPHM3 PPHM4 PPHM5 PPHM6 PPHM7	PPHL1 PPHL2 PPHL3 PPHL4 PPHL5
Small Scale Industries	Medium Scale Industries	Large Scale Industries

As mentioned earlier, the majorly woven polyester processing house (PPH) operates on a Job work basis. The author has tried to capture the consumption and emission data of major fabric quality processed in a specific industry. Based on the interaction with the participating PPH, the author observed that fabric processes are based on the weight of the fabric and end application. The PPH defines the fabric weight based on the local term "TAKA."

1 Taka = 100 mtr

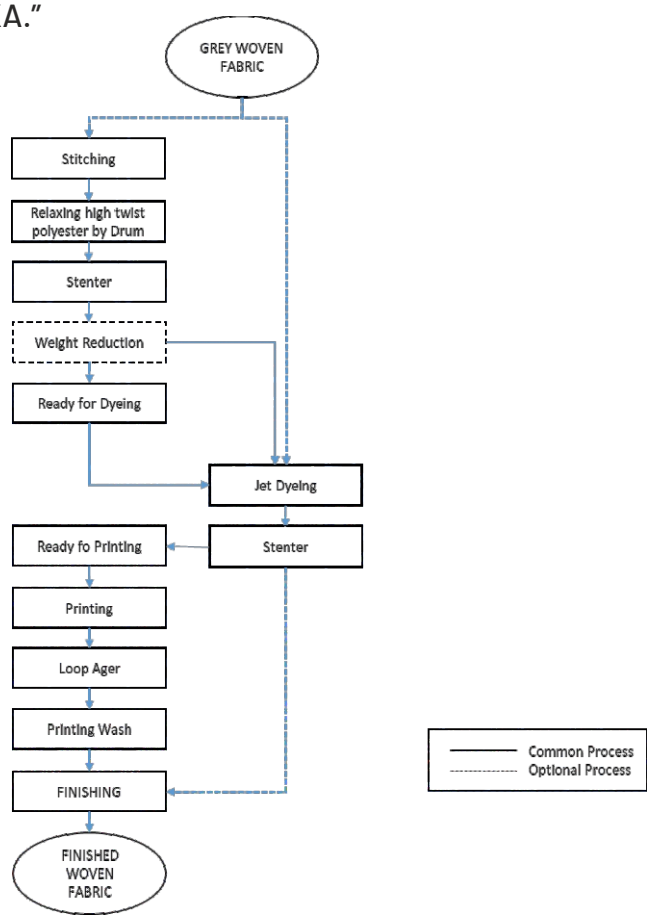


Figure 3.10 - Process route of woven PPH in Surat Cluster

The PPHs are taking this term in mind while considering the consumption pattern. Even though the end product is ladies' garments i.e. Dresses and Sarees, various garments are produced as per market demand, season and other factors.

The typical process sequence for finishing woven polyester fabric is the same in all scales of PPH of Surat Cluster, as shown in Figure 3.10.

Even though the end product is a ladies' garment, wide varieties are produced, leading to minor changes in the process route. The dyed fabric follows shorter route post dyeing. It passes through the stenter and directly goes to the finishing department. Fabric printed with disperse dyes in the printing area after the width setting in the stenter moves to the finishing section after the subsequent steps.

For example, woven polyester garment with a high twist is processed in relax rotary drum machine. It relaxes the yarn twist thereby giving grainy effect to the fabric.

Woven polyester garment with crepe/chiffon effect is obtained by processing fabric in a long tube jet.

Using the drum machine, softleena, and jet dyeing machine together is also possible in some varieties of garments. However, this combination is rarely seen due to the very high cost of processing.

The flow diagram in Figure 3.10 covers possible PPH routes taken by the PPHs.

PPHs' use of machinery is very different from CPHs. As you can see in the CPH section, machines vary based on the scale of operation, but the same is not the case with PPHs. As shown in the table, small scale to large-scale PPH uses similar machines (refer to Table 3.23).

Table 3.23 : Process wise Machines used in Polyester Processing House

Scouring	Weigh Reduction	Heat Setting	Dyeing	Printing	Print Fixation	Print Wash
Drum/Jet	Sofleena/jet	Stenter	Jet	Flatbed/Rotary	Loop Ager	Washing Range (Open/Closed)

Chemical Consumption

Table 3.24- Overall Mahine wise Chemical Consumption in PPHs of Surat Cluster

Machines				
Drum	Sofleena	Jet Dyeing	Flatbed/Rotary Bed	Washing Range (Open/Closed)
List of Process carried out per machine				
Drumming, Scouring, Whitening	Wt. Reduction	Scouring, Whitening, Dyeing, Wt. Reduction	Printing	Print Washing
Chemical	Chemical	Chemical	Chemical	Chemical
Stain Remover Swelling Agent Water Softener Caustic Soda Soda Ash Sodium dithionite (Hydrosulphite) Scouring Agent Desizing Agent Optical Brightening Agent Hydrochloric Acid Acetic Acid Wetting Agent Chelating Agent Oxalic Acid ... And So On	Caustic Soda Soda Ash Water Softener Wetting Agent Weight Reducing Agent Acetic Acid Oxalic Acid	Acetic Acid Oxalic Acid Levelling Agent Dye Detergent Scouring Agent Stabiliser Chelating Agent Dispersing Agent Bleaching Agent White R (Optical Brightening Agent) Defoamer Swelling Agent HCl Caustic Soda Sodium dithionite (Hydrosulphite)	Gum All In One Chemical Dispersing Agent Dyes Levelling Agent Tartaric Acid Citric Acid Oxalic Acid Auxiliary Agent Loop Accelerator Buffer Reserving Agent Defoamer	Acetic Acid Sodium Hydrosulphite Caustic Detergent/Soap Auxiliary Agent Anti-Tinting Agent Wetting Agent Dispersing Agent

Unlike CPH, where machines are defined for pre-treatment and dyeing processes of woven cotton fabric. The same is not the case with polyester fabric; PPHs do not follow any process-wise chemical consumption pattern, as it can be seen from the above table that multiple processes are carried out in sequence in different machines. The selection of machines for any process depends on the Dyeing master and the type of fabric to be processed.

Pre-treatment

Preparation agents applied during fibre processing, spinning and fabric formation cause the main ecological charges in the pre-treatment of textiles made of man-made fibres. A series of preparatory cleaning operations are carried out to remove knitting oils, waxes, and other contaminants.

Anionic and/or Non-Ionic scouring agents which are generally surfactants and stain remover are added to remove these impurities.

Drumming Process

The majority of woven or knit crepe fabrics are made by highly twisting polyester filament yarns, relaxing the resulting fabric in hot water to release the temporarily locked untwisting torque, creating the "pebble" appearance on the fabric's surface. During this process, swelling agents are added to impart grains on polyester fabric.

The table shows that every process across various PPH uses acids like HCl, acetic acid, oxalic acid, tartaric acid etc.

Weight reduction

The weight reduction process is discussed in Chapter 2. The quantity of caustic soda requirement is more for low temperature weight reduction than high temperature weight reduction. Usually, the PPH stores and reuse the caustic used during process in an overhead tank of the machine.

Theoretically, NaOH can completely hydrolyze an ester monomer when applied in a ratio of 2:1.

$$Weight\ Reduction\ \% = \frac{192\ \text{x}\ \%\ \text{solid NaoH applied}\ \ \text{O.W.F.}}{2\ \times 40}$$

where 192 is Mole wt. of ester Monomer and 40 is Molecular wt. of NaOH and since 2 moles are required, it is multiplied with 2.

Weight reduction depends on fabric quality, twist, denier, time and temperature, heating gradient at which it treated with caustic soda.

With 1% caustic soda solution, polyester loses 2.4% of its weight.

$$Weight\ Reduction\ \% = \frac{192\ \text{x}\ 1}{2\ \times 40}$$

$$Weight\ Reduction\ \% = 2.4\%$$

Alkaline hydrolysis treatment affects the surface fibres of the polyester

Dyeing

Usually, high temperature and high pressure are used for dyeing polyester fabric. Since disperse dyes are insoluble in water, Levelling and dispersing agents are used to keep a uniform build-up of disperse dyes. They are added to the dye bath to regulate the dyeing process to obtain uniform shade throughout the substrate.

Apart from Ready for Printing fabric, majorly only whitening of fabric is done with the help of Optical brightening agents.

The BAT for the dyeing process to conserve water and energy is elaborated in Chapter 4.

Print Washing

After dyeing polyester fibres with disperse dyes, the excess dye on the fibre surface is reductively degraded to remove the dye that affects dyeing fastness. Generally, drainage is performed after dyeing, and reduction clearing is performed under alkaline conditions. Sodium dithionite (Hydrosulphite) and thiourea dioxide are used as reducing agents under alkaline conditions. In addition, after alkaline reduction clearing, the neutralisation process using acid is necessary.

One of the reference units uses an anti-tinting washing-off agent, which helps neutralise the bleeded colour and prevent its redeposition on the fabric.

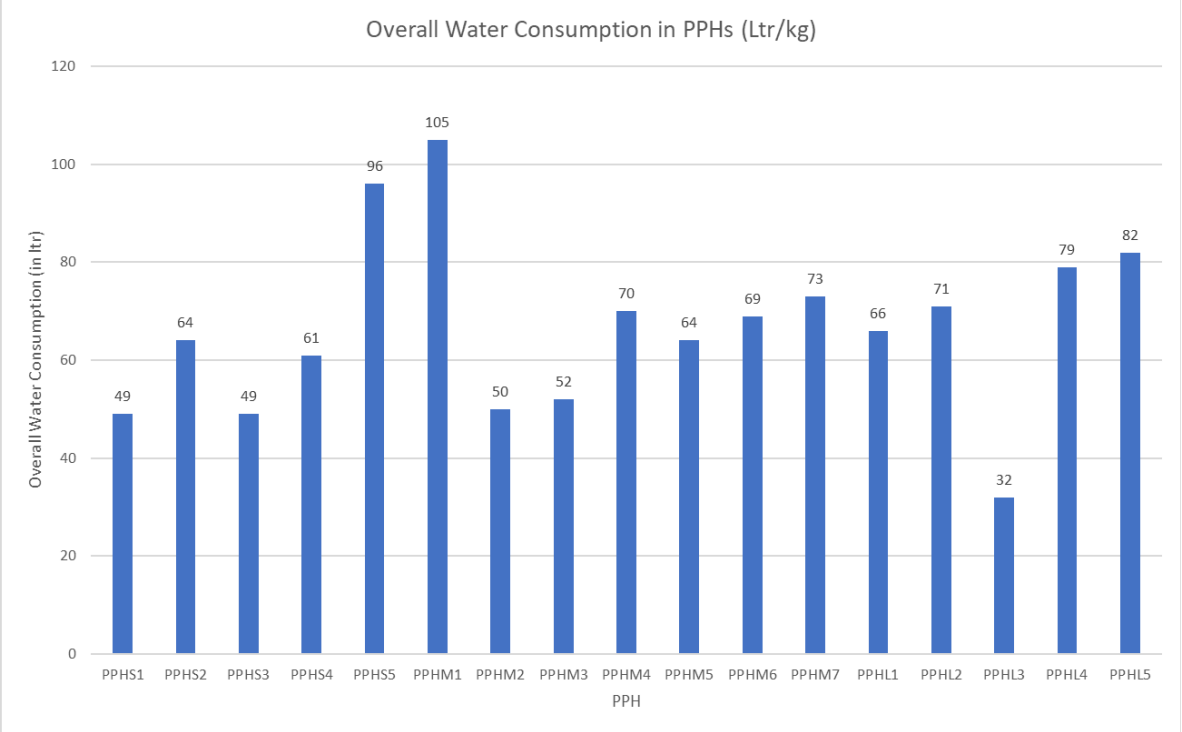


Figure 3.11- Overall Water Consumption in PPHs

Table 3.25 - Machine wise water consumption

Scale of Industry	Industry Code Name	Drum In (Ltr/kg)	Sofleena In (Ltr/kg)	Jet Dyeing In (Ltr/kg)	Printing	Print Wash Water In (Ltr/kg)	Total Water Consumption
Small	PPHS1	13	9	14	1	12	49
	PPHS2	36	0	18	1	9	64
	PPHS3	15	7	10	1	16	49
	PPHS4	15	-	20	1	25	61
	PPHS6	30	18	24	1	23	96

Medium	PPHM1	40	20	30	1	14	105
	PPHM2	15	10	10	1	14	50
	PPHM3	27	-	12	1	12	52
	PPHM4	25	11	16	1	17	70
	PPHM5	22	-	23	1	18	64
	PPHM6	23	18	13	1	14	69
	PPHM7	23	8	27	1	14	73
Large	PPHL1	25	5	15	1	20	66
	PPHL2	30	-	25	1	15	71
	PPHL3	10	4	3	1	14	32
	PPHL4	30	19	30	-	-	79
	PPHL5	25	20	20	1	16	82

While PPH typically uses three baths for the drumming process, some industries only use two baths by skipping the first grey wash bath. This lowers their water usage overall. Additionally, some PPH recycles Drum effluent, which is described as BAT in Chapter 4.

Similar to drumming, the weight-reduction procedure in Sofleena involves three washes. For major variety of polyester fabric, weight reduction process is mostly done in jet dyeing machine to save time and cost. For a delicate variety of fabric where weight reduction needs to be monitored, PPH are using the Sofleena machine. In softleena, PPH avoids the third bath, pH neutralisation, because they find it quicker to do with a jet-dyeing machine, as the next step is dyeing.

The fabric processed in a jet dyeing machine is typically either coloured or white dyed with OBA to prepare the fabric for printing, as shown in Table 3.24. As these PPH are performing reduction cleaning to remove unfixed dyes and hence, increases the number of washes, the water consumption for colour-dyed fabric is on the higher side compared to fabric that has been whitened. Therefore, in this case, lower consumption does not always imply effective use; it is also possible that the data are specific to the fabric-whitening procedure exclusively.

PPHL3 shows extraordinary figures for water consumption in sofleena and jet dyeing because the continuous weight reduction machine and air flow jet dying machine respectively is used to process fabric.The only time fresh water is used in the printing process overall is while making the paste, and all other cleaning in the printing area is done using recycled water to save fresh water. As a result, the printing section's water consumption is displayed as 1 ltr/kg in Table 3.25, which depicts the water used to prepare the printing paste.

Rope form washing is being done by every PPH in order to wash prints. To prevent water from mixing in adjacent tanks, PPH often includes open tanks in series with squeegees on top of tanks. Few PPHs have closed-system continuous washing ranges to save energy during hot washes. A few instances of water cycling can also be seen in print washing, which is described as BAT in Chapter 4.

Monitoring Frequency

As per GPCB's Environment Audit Scheme laid out on order of Honourable Gujarat High Court Order dated 20.12.1996 and modified vide its order dated 13.03.1997, Textile Processing Industries having daily effluent discharge of one lakh ltr. per day or more are required to carry out an environment audit each year (three times a year) by GPCB appointed Schedule II Auditor.

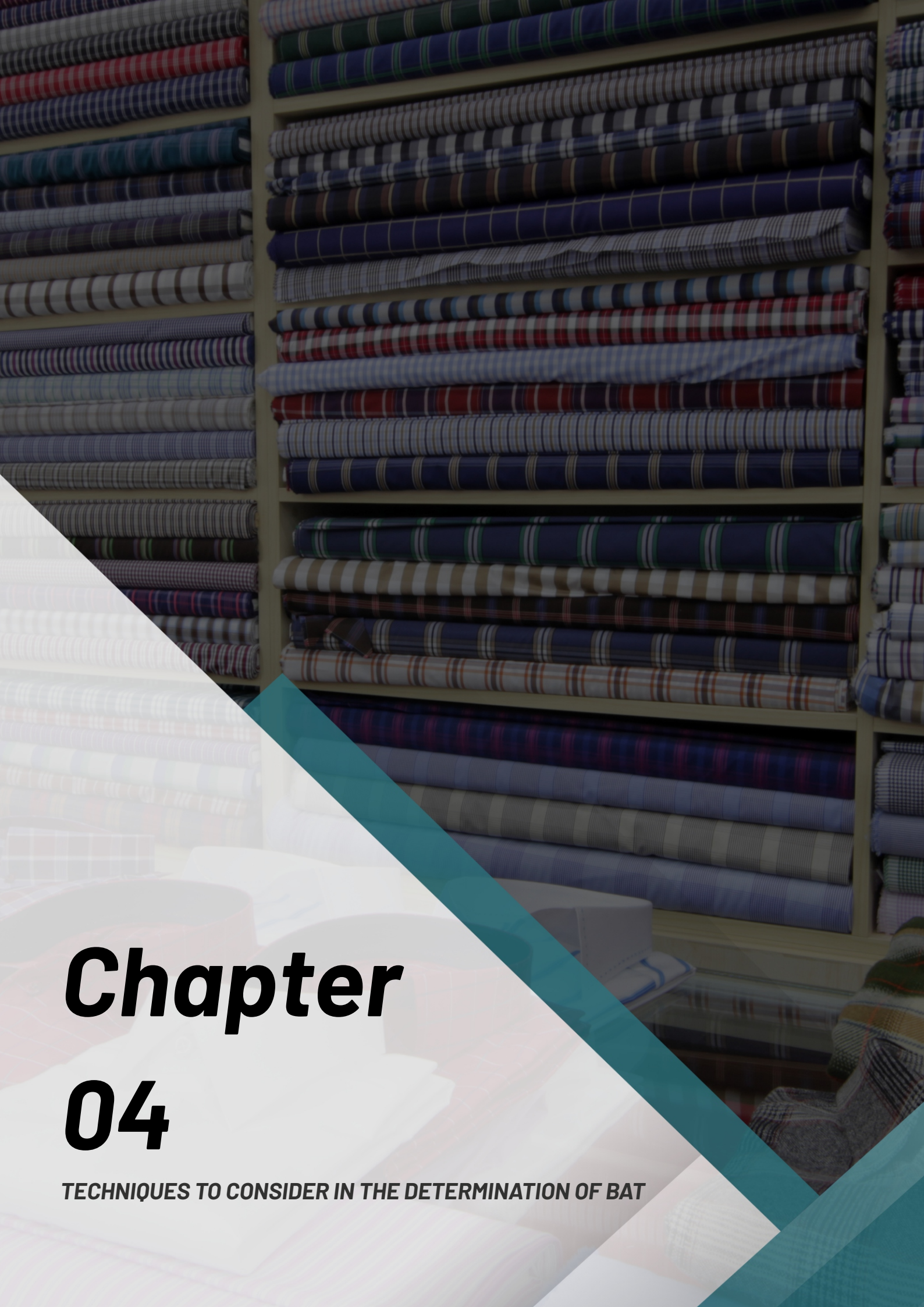
Generally, some medium scale and all large-scale industries fall under this scheme due to their water discharge effluent. The charts presented under section 3.4.3 represent the data of these medium and large-scale units as rest industries don't have any monitoring system in place. But GPCB visits these industries and collects effluent samples to monitor the discharge norms.

Type of discharge

In Gujarat, all three clusters have separate CETPs for the textile sector. Most industrial units in Ahmedabad discharge their effluent to the Common Effluent Treatment Plant (CETP).

In the Jetpur Cluster, Major industries are MSMEs and discharge their effluent to two CETPs.

In Surat, the textile industries are scattered in four regions namely Pandesara, Sachin, Kadodara and Palsana. These four regions have CETP in the region where it is treated.



Chapter 04

TECHNIQUES TO CONSIDER IN THE DETERMINATION OF BAT

This chapter elaborates on the techniques required for efficient manufacturing by identifying the Best Available Techniques (BAT) in the textile industry.

These measures are documented so that other textile industries in the cluster can benefit from them. Each measure is presented in a specific format as shown in,v to provide maximum information to the implementer to help him decide how to implement it.

Multiple techniques are presented as a well-defined loop in the trailed discussion. It covers techniques for the following:

- Process-integrated practices.
- Waste prevention and management, including waste minimisation and recycling procedures
- Reduction in the consumption of raw materials, water and energy (optimising use and reuse)
- Prevention or limiting of the environmental consequences of accidents and incidents
- Prevention or reduction of emissions under other than normal operating conditions (such as start-up and shut down operations, leaks, malfunctions, momentary stoppages and the definitive cessation of operations)

This document's current scope only includes wet processing (fabric pre-treatment, dyeing, printing and finishing). This chapter does not necessarily provide an exhaustive list of techniques that could be applied in the sector. Other techniques may exist or may be developed, which could be considered in determining BAT for an individual installation.

The chapter is divided into the following four sections for the reader's convenience.



Figure 4.1. : Different sections of Chapter 4

Table 4.1 - Information for each technique

HEADING WITHIN THE SECTIONS	TYPE OF INFORMATION INCLUDED
TECHNICAL DESCRIPTION	A brief description of the technique with a view to being used in the BAT conclusions. It includes detailed yet concise descriptions using, as appropriate, chemical or other equations, pictures, diagrams and flow charts.
ACHIEVED ENVIRONMENTAL BENIFITS	The main potential environmental benefits to be gained through implementing the technique (including reduced consumption of energy; reduced emissions to water, air and land; raw material savings; production yield increases, reduced waste, etc.)

OPERATIONAL DATA	Actual and plant-specific performance data (including emission levels,consumption levels – of raw materials, water, energy – and amounts of residues/wastes generated) from well-performing installations/plants (with respect to the environment taken as a whole) applying the technique accompanied by the relevant contextual information. Any other helpful information on the following items: • How to design, operate, maintain, control and decommission the technique; • Emission monitoring issues related to the use of the technique; • Sensitivity and durability of the technique; • Issues regarding accident prevention. Links between inputs (e.g. nature and quantity of raw material and fuel, energy, water) and outputs (emissions, residues/wastes, products) are highlighted, in particular, where relevant to enhancing and understanding of different environmental impacts and their interaction. For example, trade-offs have been made between different outputs such that certain environmental performance levels cannot be achieved simultaneously.
CROSS-MEDIA EFFECTS	There are relevant negative effects on the environment due to implementing the technique, allowing a comparison between techniques to assess the impact on the environment as a whole. This may include issues such as: • Consumption and nature of raw materials and water; • Energy consumption and contribution to climate change; • Stratospheric ozone depletion potential; • Photochemical ozone creation potential; • Acidification resulting from emissions to air; • Presence of particulate matter in ambient air (including microparticles and metals); • Eutrophication of land and waters resulting from emissions to air or water; • Oxygen depletion potential in water; • Persistent/toxic/bioaccumulable components (including metals); • Generation of residues/waste; • Limitation of the ability to reuse or recycle residues/waste; • Generation of noise and/or odour; • Increased risk of accidents.

Economics	Information on the costs (capital/investment, operating and maintenance costs including details on how they have been calculated/estimated) and any possible savings (e.g. reduced raw material or energy consumption, waste charges, reduced payback time compared to other techniques), or revenues or other benefits including details on how these have beenculated/estimated. Cost data are indicated in Rupees (INR). If a conversion is made from another currency, the data in the original currency and the year when the data were collected are indicated. The price/cost of the equipment or service is accompanied by the year it was purchased. Information relevant to both newly built, retrofitted and existing plants are included. This should allow assessment, where possible, of the economic viability of the technique for the sector concerned. It is indicated whether the technique can be applied throughout the sector. Otherwise, the main general technical restrictions on the use of the technique within the sector are indicated. These may be: An indication of the type of plants or processes within the sector to which the technique cannot be applied; constraints to implementation in certain generic cases, considering, e.g.: • Whether it concerns a new or an existing plant, taking into account factors involved in retrofitting (e.g. space availability) a interactions with techniques already installed • Plant size, capacity or load factor • Quantity, type or quality of product manufactured • Type of fuel or raw material used • Animal welfare • Climatic conditions. These restrictions are indicated together with the reasons for them. These restrictions are not meant to be a list of the possible local conditions that could affect the applicability of the technique for an individual plant.
Driving force for implementation	Where applicable, specific local conditions, requirements (e.g. safety measures, legislation,) or non-environmental triggers (e.g. increased yield, improved product quality, economic incentives – e.g. subsidies, tax breaks) which have driven or stimulated the implementation of the technique to date are provided. This subsection should be very short and use a list of bullet points.
Example plants	Reference to a plant(s) where the technique has been implemented and from which information has been collected and used in writing the section. An indication of the degree to which the technique is in use in Gujarat, India or worldwide.

4.1. General Techniques

This section covers the general techniques that can be performed at the industrial level to increase any textile unit's overall efficiency.

4.1.1. General Management Techniques

The management system is how an organization manages the interrelated parts of its business to achieve its objectives. These objectives can relate to several topics, including product or service quality, operational efficiency, environmental performance, workplace health and safety, and many more. The General Management Techniques (GMT) includes various segments with specific techniques, making it a "living" document continuously evolving.

The benefits of an effective management system to an organization include:

- More efficient use of resources and improved financial performance
- Improved risk management and protection of people and the environment
- Increased capability to deliver consistent and improved services and products, thereby increasing value to customers and all other stakeholders

Management System Standards (MSS) result from consensus among international experts with expertise in global management, leadership strategies, and efficient and effective processes and practices. Any industry, large or small, can implement MSS standards.

ISO is an independent, non-governmental international organization with a membership of 167 national standards bodies. Its members bring together experts to share knowledge and develop voluntary, consensus-based, market-relevant International Standards that support innovation and solve global challenges.

ISO standards set requirements or guidance to help industries manage their policies and processes to achieve specific objectives .

For instance,

- **Quality management standards** to help work more efficiently and reduce product failures.
- **Environmental management standards** help reduce environmental impacts, reduce waste and be more sustainable.
- **Health and safety standards to** help reduce accidents in the workplace.
- **Energy management standards** to help cut energy consumption.

ISO Certification is recognised worldwide as the best practice in various management techniques. However, achieving ISO Certification, the formality, complexity, and cost can be off-putting for many MSMEs.

Various international agencies are in the market to guide the MSMEs towards standardization.

[1] *https://www.iso.org/management-system-standards.html*

Parallel to the quality of the product, the environment is an important priority. Hence, when EMS is developed and integrated into the organizational structure, it will help diminish pollution threats and provide an opportunity to be efficient and organized.

Sr. No.	Technique Name
1.	Environmental Management System
2.	Resource Efficiency & Cleaner Production
3.	Monitoring and control of operational parameters
4.	Textile production planning & scheduling
5.	Certifications for Textile Industry to reduce the addition of hazardous process chemicals in the supply chain

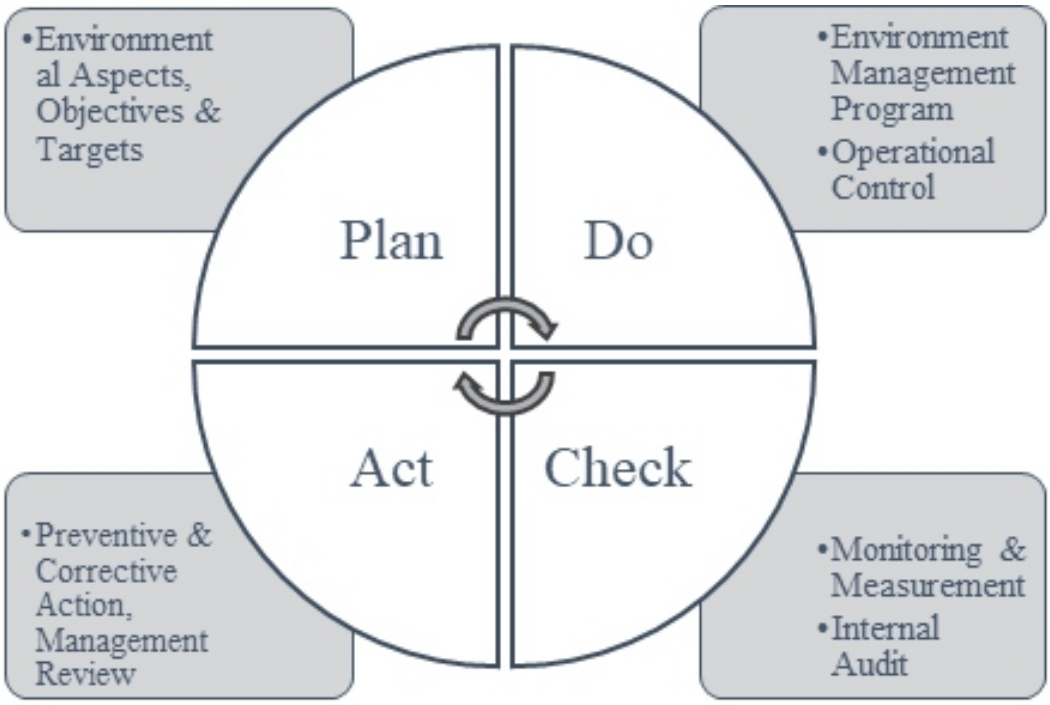


Figure 4.2 - Main steps in the ISO 140001 EMS

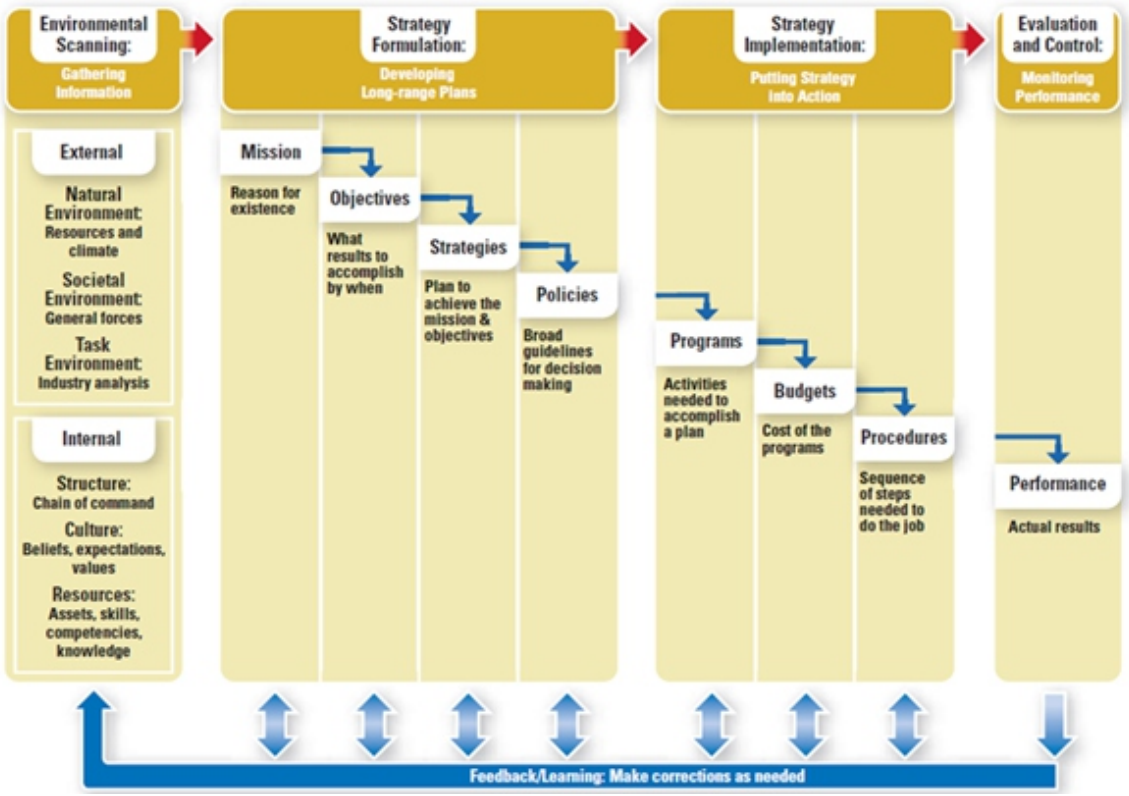


Figure 4.3 - Main steps in the ISO 140001 EMS

Technical Description

An Environment Management System (EMS) is a way for an industry to handle its environmental problems and opportunities in a planned manner.

An EMS can be either standardised or not standardised (also called "customised"). It is a cost-effective way for the unit to meet its environmental responsibilities. Textile companies are now aware of the link between environmental quality and economic growth. Consumers want companies to address specific environmental issues, quality, cost, and production flexibility. Textile companies are now paying more attention to the environment because there is a demand for environmentally-friendly garments and clothing.

ISO 14001 is one of the most sought-after certifications for EMS worldwide.

But for small-scale industries of Gujarat, it can seem like a massive project. In that case, there are lighter options like

- Green Mark,
- EIA Quality Mark by IEMA (Institute of Environmental Management and Assessment),
- BS 8555:2016 and
- EU Eco-Management and Audit Scheme (EMAS).

Achieved Environmental Benefits

- Savings in the resources consumption (chemicals, auxiliaries, fresh water and energy)
- Minimisation of waste generated from the processing.
- Reduce the risk of accidents.

Operational Data

Green Mark[2] is a low-cost alternative to ISO 14001. Certification to this scheme is internationally recognised, and membership comes with plenty of support and guidance.

The **EIA Quality Mark** is a voluntary programme, and organisations can decide for themselves if they are ready to follow the seven EIA Commitments.[3] The industries must apply for IEMA[4] membership, which comes on several levels. It provides expertise and supports to set up an environmental management system.

BS 8555:2016 is also a phased approach to implementing an Environmental Management System.

[2] greenmark.co.uk
[3] https://www.iema.net/
[4] https://www.iema.net/

The British Standards Institution (BSI) developed it to meet the needs of Small and Medium-sized organisations (SMEs) and for a staged implementation of an ISO 14001-based Environmental Management System.

However, BSI withdrew the standard earlier in 2020 as ISO 14005 was seen as its replacement & under ISO and European Standards obligations.

EMS technique can assist industries in:

- Preventing pollution,
- Reducing waste,
- Enhancing internal management system efficiency,
- Optimizing utilization of resources and
- To comply with legal and regulatory requirements.

The ISO 14000 standards give industries a blueprint or framework for systematising and enhancing their environmental management initiatives. The process approach and continuous improvement are the foundations for the standards' requirements. The ISO 14000 standards are not intended to assist in implementing environmental regulations. They do not regulate the environmental activities of organizations. The adoption of these standards is optional.

The main steps of the ISO 14001 EMS outlined in Figure 4.2 are

- Establishes and communicates its environmental commitment and goals through its environmental policy actively promoted by top management,
- Plans programs for controlling the environmental aspect and impact of its products, processes . and integration of environment with the organization's business and operations management,
- An organizational structure responsibility plus accountability along with implementation Systems, Checks results and corrects problems,
- Reviews and improves the performance of the systems[5].

Figure 4.3[6] represents a detailed planning model of the steps. It presents what a textile industry should do in the strategic management process.

Specifically, for the textile industry, it is also essential to incorporate the following potential features in the EMS:

- An inventory of input and output streams (see Technique 2)
- A water efficiency plan (see section 4.1.2)
- An energy efficiency plan (see section 4.1.3)
- A raw materials management plan (see Technique 4 and Technique 5)

[5]*Environmental management systems for the textile industry : A case study (Indian Journal of Fibre A Textile Research Vol.26. March-June 2001. pp. 33-38)*
[6]*Strategic Management and Business Policy Globalization, Innovation and Sustainability*

- A chemicals management system (see section 4.1.5) and
- A waste management plan (applicable to large-scale industries having their own ETP, rest of MSME are discharging to CETP)

Cross Media Effects

None Indentified

Economics

Investment Cost	Variable
Cost Indicative	**Investment (In Rupees)**
Very Low	< 1 Lakh
Low	< 10 Lakh
Moderate	10 - 20 Lakhs
High	20 - 50 Lakhs
Very High	> 50 Lakhs

The technique requires multiple investments and will vary according to the current implemented level of a particular industry.

Driving Force for Implementation

The driving forces for the implementation of an EMS include:

- Achieve market-place recognition through the enhanced corporate image;
- Satisfy regulatory and legal requirements;
- Reduced liability, insurance and non-compliance;
- Reduce operating cost and downtime;
- Improved environmental performance;
- Improve operational efficiency by better utilization of materials and resources and product quality improvement;
- Improved personnel productivity (e.g. managers can have confidence that environmental impacts are controlled and employees are working in a better work environment);

Reference Industry

M/s. Arvind Ltd. (Santej Unit), Ahmedabad
M/s. Shanti Processors Pvt. Ltd., Ahmedabad

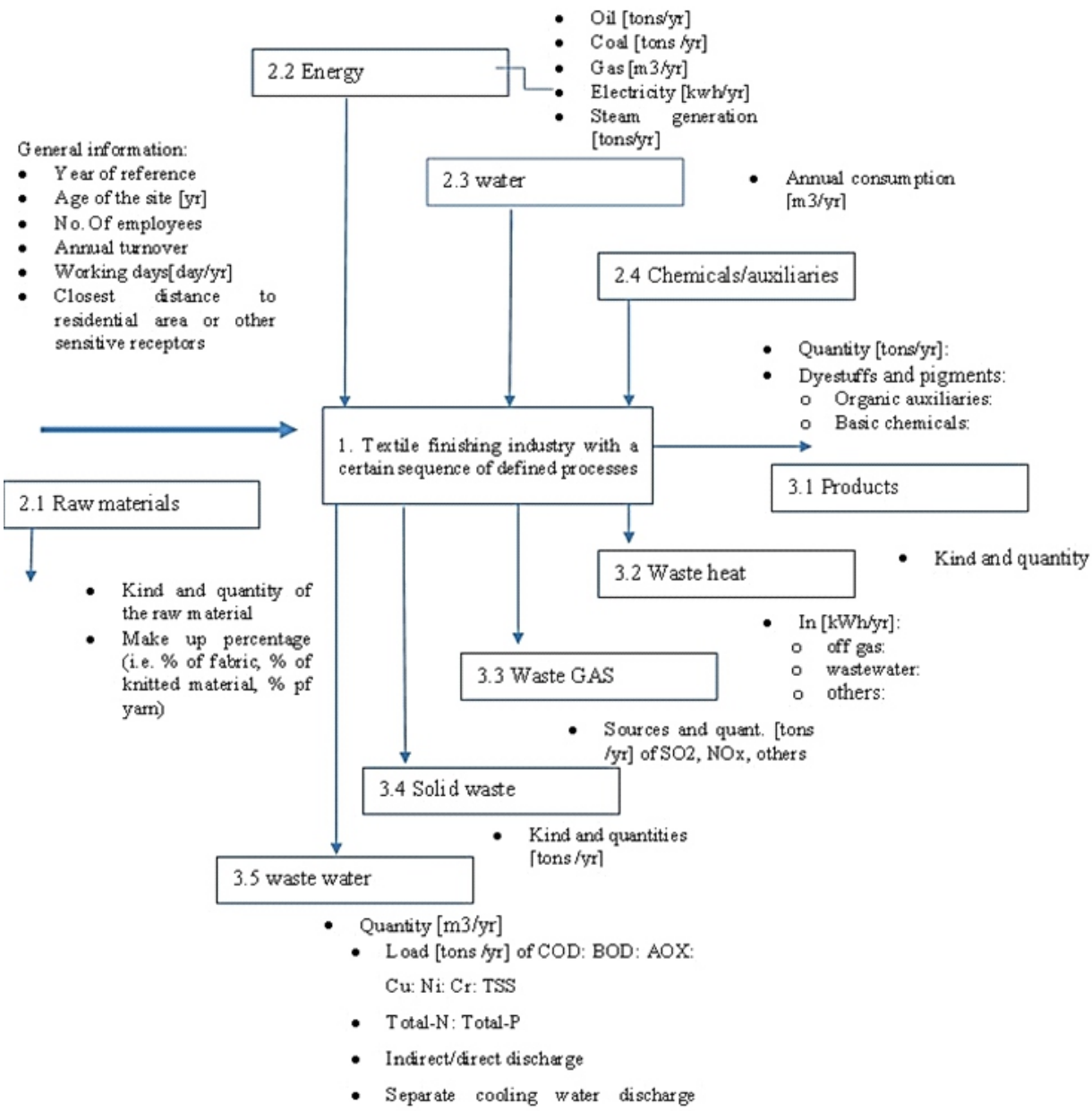


Figure 4.4 - Scheme for annual input/output overview at site level

Technical Description

It's essential to keep track of the flow of resources into and out of an industry (e.g. inputs like materials, energy, water, and outputs like waste gases, waste waters, wastes, energy losses, etc.). In the resource streams, there are hazardous substances with the relevant primary toxicity, composition, and quantities. The collected data can also be used to do mass balances, plan water-energy efficiency, and monitor various water and air emissions.

Checking incoming raw materials (like fibres, chemicals, dyestuffs, accessories, etc.) is very important for pollution prevention. The supplier should give the industry enough information for proprietary products to make a responsible environmental evaluation.

The supplier should give thorough information to the finisher on textile raw materials that goes beyond the technical details of the textile substrate. It also considers the kind, quantity, and presence of biocides (such as ectoparasiticides for wool), metals, and residual monomers on the fibre. They enter the process as compounds or contaminants. They contribute significantly to the textile mills' pollution load. Understanding these mass streams must thoroughly identify optimization potentials and their priorities. This is equally crucial to achieve environmental pollution prevention and control and to maximise economics. A manufacturer can stop or control the emissions from using the raw material more effectively.

Figure 4.4 shows the input and output streams that are important. It is important to track and evaluate the chemicals used (dyes and pigments, textile auxiliaries, and basic chemicals) for categorising critical compounds.

Achieved Environmental Benefits

- Essential management tool for identifying optimum potential, both environmental and economic.
- Prerequisite for a continuous improvement process.
- It helps in identifying priority areas and options for improving environmental performance.

Operational Data

Input/output stream inventories can be drawn up for the usage of[7]:

- Pre-treatment agents
- Auxiliaries
- Dyestuff & pigments and
- Basic chemicals

From the annual resource consumption (for example, the amount of water used per kg of processed textiles or the amount of chemical oxygen demand (COD) in wastewater per kg of processed textiles), the tool can figure out the input and output factors for each textile substrate. Such a management tool requires highly qualified and experienced staff and management commitments.

The inventory contains the following information:

i. Information about the textiles production processes, including:
   (a) Simplified process flow sheets showing the emissions' origin (Refer to Figure 4.5).;
   (b) Descriptions of process-integrated techniques and waste water/waste gas treatment techniques to prevent or reduce emissions, including their performance (e.g. abatement efficiency).

[7]Munksgaard, Jesper & Wier, Mette & Lenzen, Manfred & Dey, Christopher. (2005). Using Input-Output Analysis to Measure the Environmental Pressure of Consumption at Different Spatial Levels. Journal of Industrial Ecology. 9. 169 - 185. 10.1162/1088198054084699.

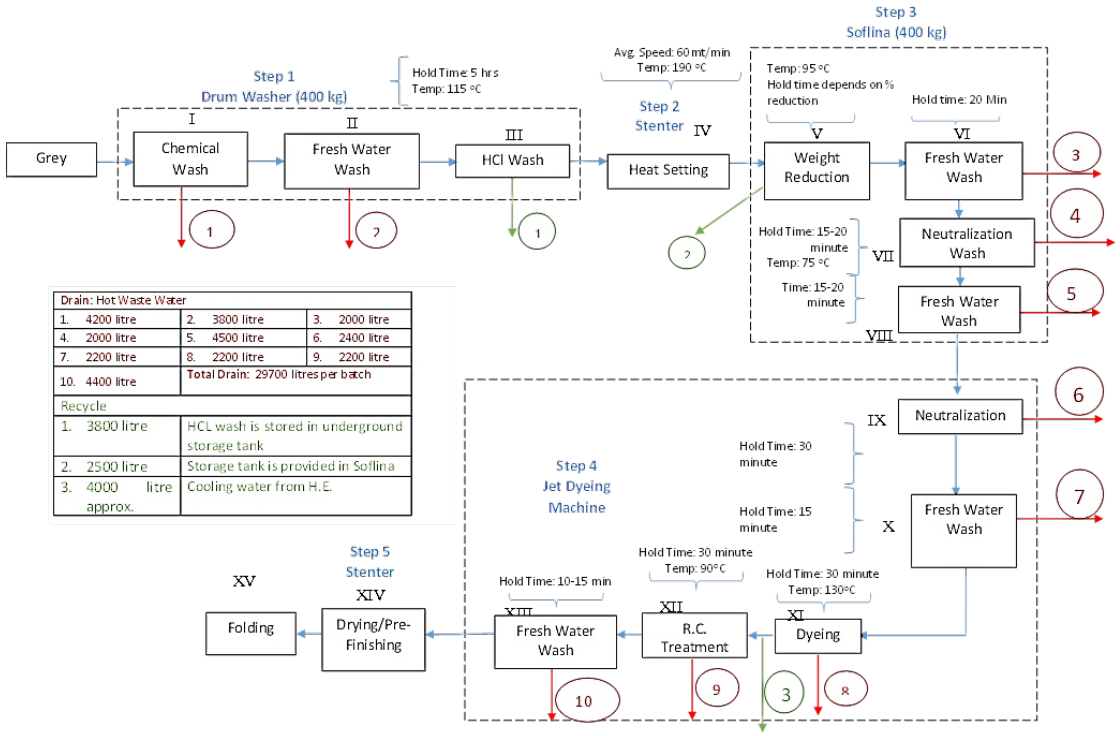


Figure 4.5 - Example of Process Flow Diagram of Reference Polyester Processing House

Information on water use and consumption (such as flow diagrams and water mass balances) and suggestions for reducing water use and waste water volume (Refer to Figure 4.5).

ii. Information about the quantity and characteristics of the waste water streams, such as:
   (a) Average values and variability of flow, pH, temperature, and conductivity;
   (b) Average concentration and load values of relevant substances/parameters and their variability (e.g. COD/TOC, nitrogen species, phosphorus, metals, priority substances, microplastics);
   (c) Data on bioeliminability (e.g. BOD, BOD to COD ratio, Zahn-Wellens test, biological inhibition potential (e.g. inhibition of activated sludge).

iii. Information about the characteristics of the waste gas streams, such as:
   (a) Average values and variability of flow and temperature;
   (b) Average concentration and load values of relevant substances/parameters and their variability (e.g. dust, organic compounds);
   (c) Flammability, lower and higher explosive limits, reactivity;
   (d) Presence of other substances that may affect the waste gas treatment system or plant safety (e.g. water vapour, dust).

iv. Information about energy consumption and usage.

vi. Information about the quantity of raw materials used, the quantity and characteristics of residues generated, and the identification of actions for continuous improvement of resource efficiency (e.g. use of solvents through a solvent management plan).

vii. Identify and implement an appropriate monitoring strategy to increase resource efficiency, considering energy, water, and raw material consumption. Monitoring can include direct measurements, calculations or recordings with a proper frequency. The monitoring is broken down at the most appropriate level (e.g., process or plant/installation).

The output stream inventory typically consists of the products, waste heat, off-gases, solid waste, and wastewater produced throughout the operation. The quality of the stream is affected by the numerous operating parameters, raw materials, chemicals used, and processing steps. Identifying key components in waste water depends on systematically identifying and evaluating applied chemicals (dyestuffs and pigments, textile auxiliaries, and basic chemicals). Chapter 3 presents the data for wastewater generation for various fibre types at each process stage. The table below shows how the types and grades of chemicals employed in each processing stage affect the characteristics of waste water:

Table 4.2 - Process wise waste water characteristics of woven cotton CPH

Process	Chemical used	Auxiliary	Wastewater Constituents	Wastewater Characteristics
Desizing	Starch, glucose, PVA, resins, fats, waxes	Desizing agents, Wetting agent	Enzymes, starch, waxes, ammonia	BOD (34-50% of total), high COD, temp: 70-80 °C
Scouring	Caustic soda, soda ash, sodium silicate	Scouring agent	Disinfectants and insecticide residue, NaOH, surfactants, soaps	Oily fats, BOD (30% of total), high pH, temp 70-80°C, dark colour
Bleaching	Hypochlorite, chlorine, caustic soda, hydrogen peroxide, peroxide stabilizer, acetic acids	-	H_2O_2, AO_X, $NaOCl_2$, organics	High pH, TDS
Mercerising	Caustic soda	Mercerizing agent	NaOH	High BOD, high pH, dissolved solids
Dyeing	Dye stuff such as (reactive dyes), alkali, salts, acetic acids, and soap	Dye fixing agents, wetting agents, Reducing agents like sulphides, After treatment agents for fastness improvement	Colour, metals, sulphide, salts, acidity/alkalinity, formaldehyde	High toxicity, BOD (6% of total), high dissolved solids, high pH
Printing	Dyes/pigments, gum, binders, thickener	-	Urea, solvents, colour, metals	High toxicity, high COD, high BOD, high dissolved solids, high pH, colour
Finishing	Softeners and other finishing chemicals as required	-	Softeners	Low alkalinity, low BOD, high toxicity

Cross Media Effects

There are no cross-media effects to be mentioned.

Economics

There is no specific information available on economic aspects

Diving Force for Implementation

- Savings in raw materials and production costs.
- This approach helps to implement environmental management systems under ISO 14001.

Reference Industry

Many industries in Ahmedabad and Surat keep track of their input and output streams by installing various measuring equipment like flow meters PLC etc.

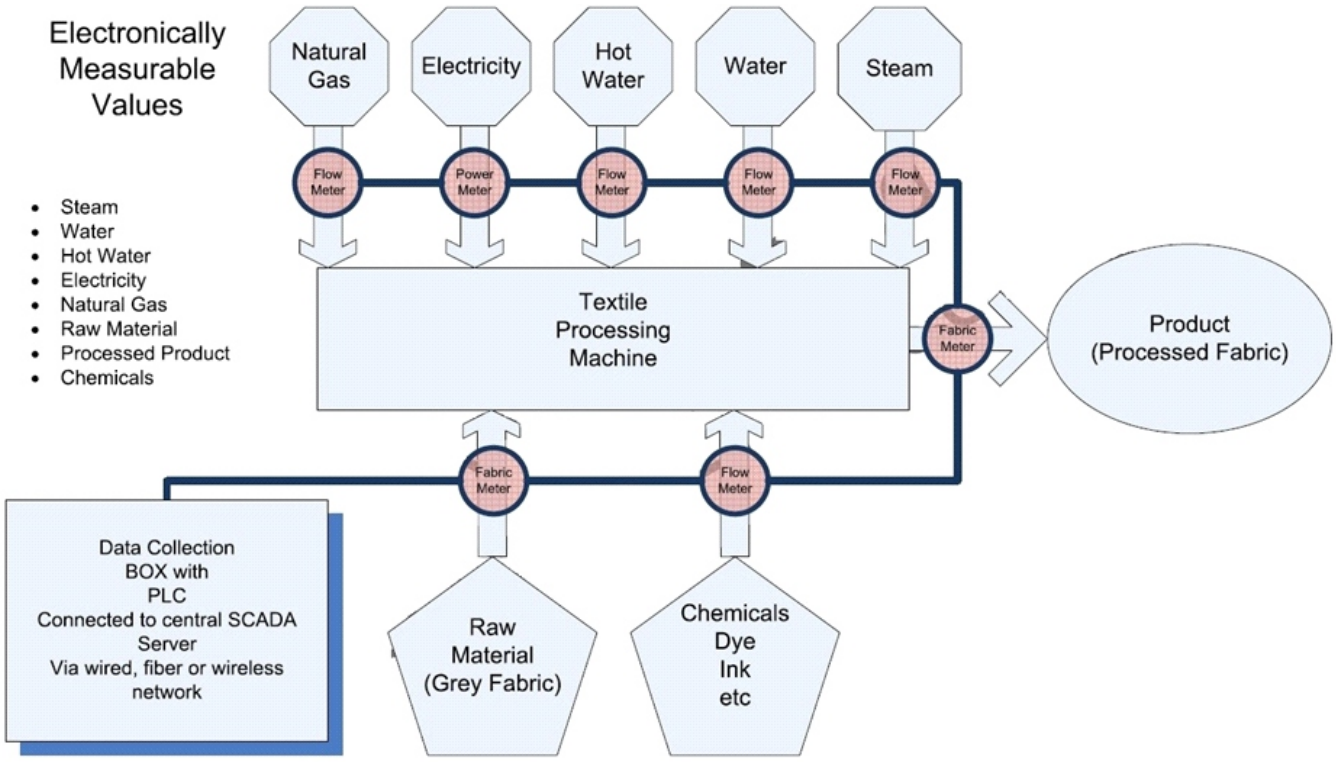


Figure 4.6 - Electronically controlled Parameters

Technical Description

As shown in Figure 4.6, key operational and process parameters are monitored and/or controlled by online integrated computer control systems like SCADA at both the process/machine and plant levels. For example, sensors controlled by PIC/PLC (process-integrated/logic controllers) or microprocessors are used at the process/machine level, while microprocessors are used at the plant level.

The properties of the textile, the raw materials, liquor, and the treatment conditions all affect the variables mentioned below.

- Volume, dosage, temperature, pH, concentration, liquor ratio and control of uptake of liquors and treatment conditions in wet treatments;
- Temperature, humidity and heat supply control in thermal treatment;
- Machine rate control;

Sophisticated systems monitor water, energy, and chemical consumption to improve fundamental control and provide feedback on important operating factors. It also records processes and recipes to track alterations that can be implemented.

Achieved Environmental Benefits

Reduced effluents, chemicals, water and energy consumption.

Operational Data

Improvements in process control may individually only have a little impact on costs and water and energy consumption. Still, when combined, they have a considerable impact (cumulative effect). Controlling the rinsing process step involves online monitoring and advanced process control after pre-treatment, dyeing, or finishing. To control the process and identify whether all the dyes, chemicals, and other auxiliaries have been completely washed away, conductivity and COD concentration are generally measured.

The rinsing steps can be managed through monitoring; It shows the time and amount of fresh water used. During the bleaching process, the amount of reducing or oxidising agents on the fabric and how well H_2O_2 is removed after bleaching can be monitored to prevent the excessive use of chemicals.

Cross Media Effects

None Identified.

Economics

Investment Cost	Variable
Cost Indicative	**Investment (In Rupees)**
Very Low	< 1 Lakh
Low	< 10 Lakh
Moderate	10 - 20 Lakhs
High	20 - 50 Lakhs
Very High	> 50 Lakhs

The investment will vary based on the scale of industry, number of machines installed and type of flow meter installed.

Driving Force for Implementation

- Reduced water, energy, and chemical consumption.
- Reduced operating costs.

Reference Industry

Many reference industries in Ahmedabad and Surat have implemented this technique. In majorly all these reference plants water and chemical consumption is metered for optimum usage while energy consumption is metered in very few reference plants.

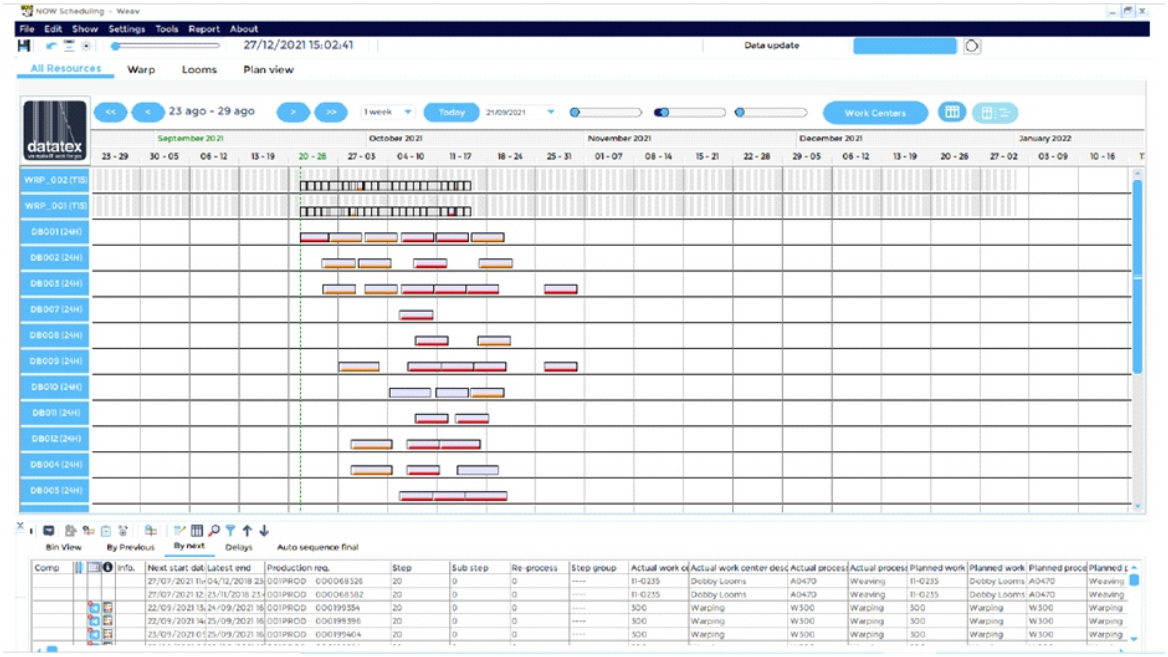


Figure 4.7 - Graphical display showing in a single view the list of jobs to be assigned and the queue of jobs already programmed for each machine (Source – Datatex A.G.)

(Source – Datatex A.G.)

Technical Description

Consumers want more significant product differentiation (an extensive range of styles, small lots) to express their personalities through their purchases. Moreover, there is a higher demand for shorter lead times, pressure to improve the product value and increasing complexity of production processes (e.g. sophisticated finishing).

It is important to plan pre-treatment processes and different dyeing shades for different batch lots in the best way possible to improve plant performance and efficiency. The planning makes the scheduling process easier and faster, which is usually complicated and slow. Scheduling and planning also make it possible to keep track of the status of each lot size given by the client.

A scheduling tool (software) or MQM (Machine Queue Management) enables final capacity scheduling for textile and apparel plants (refer to Figure 4.7). It increases efficiency and productivity and maximizes on-time deliveries.

Achieved Environmental Benefits

Significant savings in overall batch time and resource consumption

Operational Data

The main objective of the tool is to manage the schedule of planned jobs on machines. The tool allows scheduling at a single machine level and a view at the work centre level.

The tool aims to find the best way to put Production Demand Steps in order on machines at the machine level. The tool is important for getting the product to the customer swifly and reducing the number of times resources need to be set up or changed in the plant.

The tool works at the level of single departments (spinning, weaving, knitting, dying, finishing, garments, etc.) and looks at a single machine. The tool suggests a time window to meet the deadlines. Depending on what you need and want, you can schedule manually and automatically by setting different constraints that let you set production rules.

Cross Media Effects

It requires skilled personnel and the main difficulty faced in implementing this process is the absence of data monitoring.

Economics

Investment Cost	**Very Low - Low**
Cost Indicative	**Investment (In Rupees)**
Very Low	< 1 Lakh
Low	< 10 Lakh
Moderate	10 - 20 Lakhs
High	20 - 50 Lakhs
Very High	> 50 Lakhs

Driving Force for Implementation

- Resource and Manpower Management.
- Stability of operation.

Reference Industry

M/s. Arvind Ltd. (Santej Unit), Ahmedabad

Organic Standards	GOTS	OCS	ROC	-	-
Fair Conditions Certification	FAIRTRADE	SEDEX	-	-	-
Chemical Control	ZDHC	OEKO TEX	BLUESIGN	RESPONSIBLE CARE	-
Overall Standards	CRADLE TO CRADLE	GRS	RCS	LEED	ISO

Figure 4.8 - Various Certifications in Textile Industries

(Source: https://www.onlineclothingstudy.com/2022/03/20-popular-certifications-and-standards.html)

Technical Description

The textile industry has historically been associated with environmentally harmful processing, animal welfare issues and complex social compliance issues such as child labour, workers' wages, benefits, and health and safety. The demand for certified, sustainable products is now growing.

The figure 4.8 illustrates the various voluntary certification programmes, campaigns, and labels designed to restrict the presence of hazardous substances along the supply chain (e.g. GOTS, Textile Standard, OEKO-TEX, bluesign, ZDHC).

Restricted Substance Lists determine the thresholds of undesired impurities/residues in response to legislative measures (e.g., REACH, EU Ecolabel, sustainability product requirements) and non-governmental efforts(e.g., Greenpeace Detox campaign).

Achieved Environmental Benefits

Reduced chemical load in the effluent.

Operational Data

Organic Standards

Global Organic Textile Standard (GOTS) - GOTS is the worldwide leading textile processing standard for organic fibres, including ecological and social criteria, backed up by independent certification of the entire textile supply chain. GOTS certified final products may include fibre products, yarns, fabrics, clothes, home textiles, mattresses, personal hygiene products, as well as food contact textiles and more. This standard aims to define worldwide recognized requirements that ensure the organic status of textiles, from harvesting raw materials, through environmentally and socially responsible manufacturing up to labelling to provide a credible assurance to the end consumer. Textile processors and manufacturers are enabled to export their organic fabrics and garments with one certification accepted in all major markets.

Organic Content Standard (OCS) - The OCS 100 relies on third-party verification to confirm whether a final product contains the accurate amount of a given organically grown material. OCS allows for transparent, consistent and comprehensive independent evaluation and verification of organic material content claims on products. It covers the processing, manufacturing, packaging, labelling, trading and distribution of a product that contains at least 95 percent certified 'organic' materials. It can be used as a business-to-business tool to give companies the means to ensure that they are selling quality and getting what they pay for.

ROC- Regenerative Organic Certified™ (ROC) is a new certification for food, textiles and personal care ingredients. ROC™ farms and products meet high standards in the world for soil health, animal welfare and farmworker fairness.

Fair Conditions Certification

FAIRTRADE - This certification is to facilitate change in textile supply chains and related business practices. This comprehensive approach engages manufacturers and workers in the supply chain to bring about better wages and working conditions, and engages brands to commit to fair terms of trade. This includes, but is not restricted to, ginners, spinning, weaving, knitting, and cut-make-trim stages of textile production.

SEDEX - The world's largest data platform for supply chain assessment, to store, analyse, share, and report on sustainability practices.

Chemical Standards

The mission of ZDHC is to advance towards Zero Discharge of Hazardous Chemicals in the textile, leather and footwear value chain to improve the environment and people's wellbeing. Its vision is widespread implementation of sustainable chemistry and best practices in the textile, leather and footwear industries to protect consumers, workers and the environment. Including a collaboration of 27 signatory brands, 81 value chain affiliates & 17 associates.

The Zero Discharge of Hazardous Chemicals – Manufacturing Restricted Substance List, ZDHC –MRSL is a list of chemical substances that are banned from intentional use in textile materials and trim parts in apparel and footwear. The ZDHC MRSL establishes acceptable concentration limits for for substances in chemical formulations used within manufacturing facilities. It is a living document that will be updated whenever needed. The ZDHC MRSL intends to manage the input of chemicals to the suppliers and remove those hazardous substances from the manufacturing process.

The International Association for Research and Testing in the Field of Textile and Leather Ecology (OEKO-TEX Association) is a union of 18 independent textile research and test institutes in Europe and Japan and their worldwide representative offices. The member institutes are responsible for the joint development of test methods and limit values which form the basis of the product labels (e.g. OEKO-TEX STANDARD 100, MADE IN GREEN), the production site certifications (e.g. STeP - Sustainable Textile Production) and the chemical management tool DETOX TO ZERO.

They must also carry out the corresponding laboratory tests and site audits. Additional services of the OEKO-TEX Association are the MySTeP database for supply chain management and the ECO PASSPORT certification to verify chemicals and auxiliaries.

ECO PASSPORT by OEKO-TEX is an independent testing and certification system for chemicals, colourants and auxiliaries used for manufacturing textiles. It is a 3 stage verification process that analyses whether the chemical products and each ingredient meet specific requirements regarding sustainability, safety and compliance with statutory regulations.

The 3 stages are:

- Screening Restricted Substance List (RSL) and Manufacturing Restricted Substance List (MRSL),
- Analytical verification at an OEKO-TEX member institute laboratory &
- Verification of product stewardship measures regarding working conditions and environmental management.

Products passing the ECO PASSPORT requirements by OEKO-TEX certification will be entered into the OEKO-TEX buying guide. The guide is the OEKO-TEX® central sourcing platform of pre-certified articles and materials.

Bluesign technologies AG was founded in Switzerland in 2000. The unique combination of expertise in key segments of textile production as chemistry, textile technology, environment technology and supply chain management, characterizes our company. The bluesign system, the solution for sustainable textile production, eliminates harmful substances right from the beginning of the manufacturing process.

The bluesign® FINDER offers a 'positive' list of more than 12 500 process chemicals that are commercially available for various applications in textile (and other) industries (as of January 2020).

Overall Standards

Cradle to Cradle - Cradle to Cradle certification attempts to measure the invention's environmental and social sustainability in five categories: material health, material reutilization, renewable energy & carbon management, water stewardship, and social fairness.

Global Recycled Standard (GRS) – it is an international, voluntary, full product standard that sets requirements for third-party certification of Recycled Content, chain of custody, social and environmental practices, and chemical restrictions. The goal of the GRS is to increase use of Recycled materials in products and reduce/eliminate the harm caused by its production.

The Global Recycled Standard is intended for use with any product that contains at least 20% Recycled Material. Each production stage must be certified, beginning at the recycling stage and ending at the last seller in the final business-to-business transaction. Material Collection and Material Concentration sites are subject to self-declaration, document collection, and on-site visits. The GRS does not address quality or legal compliance. The GRS uses the ISO 14021 definition of Recycled Content, with interpretations based on the US Federal Trade Commission Green Guides; the intention is to comply with the most widely recognized and stringent definitions.

Recycled Claim Standard - The RCS verifies the presence and amount of recycled material in a final product. This happens through input and chain-of-custody verification from a third party. It allows for the transparent, consistent and comprehensive independent evaluation and verification of recycled material content claims on products.

LEED - LEED certification is a globally recognized symbol of sustainability achievement and leadership. The LEED framework informs all building types including new construction, interiors, operations and maintenance, and core and shell.

ISO – This standard has been elaborately explained in Technique 1 under EMS.

Cross Media Effects

The additional (purity) requirements on the quality of incoming raw textile materials, including process chemicals, may increase their price. Incoming textile materials with known history and proven impurity/residual content may be more costly.

Economics

Alternative chemicals may be more expensive and require special treatment – all of these could affect the economic costs of production.

Driving Force for Implementation

- Environmental regulations for pollutants.
- Chemical regulations (REACH, CLP, BPR, PPP and POPs).
- Economics (Market reputation of the brands).
- Product standards (internal, national, international).
- It reduces effluent treatment costs.

Reference Industry

M/s. Arvind Ltd. (Santej Unit), Ahmedabad
M/s. Siddhivinayak Knots and Prints Pvt. Ltd., Surat

4.1.2. Water Efficiency

Sr. No.	Technique Name
1.	Condensate recovery system
2.	Reuse of Reverse Osmosis (RO) plant's concentrate
3.	Reuse of cooling water from singeing machines
4.	Reuse of post bleaching washes as pre-washes at pre-treatment machine
5.	Reuse of neutralization wash from Mercerizer & CBR
6.	Reuse of vapor condensate of Caustic Recovery Plant
7.	Installation of automatic water shut-off valves at rotary and flatbed printing machines' blanket washing water
8.	Water management through water monitoring
9.	Partial/full waste water recovery in drum machine

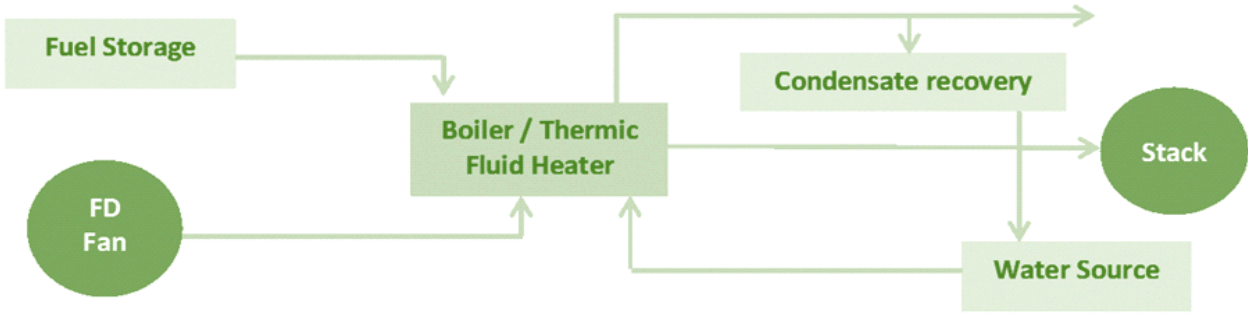


Figure 4.9 - Typical Steam Flow Process with condensate recovery

Technical Description

Steam at a working pressure of 3 kg/cm^2 is used in the textile processing units in several machines.

E.g. zero-zero machines are used for finishing operations wherein the fabric is rotated in a circular rubber drum with a blanket of steam rotating around it.

After the latent heat release, steam is transformed into condensate, which still has sensible heat. Installing a condensate recovery system is intended to recover and reuse as much of the sensible heat of this condensate.

Condensate can be reused mainly as heated feed water to the boiler. Recovering condensate instead of throwing it away can lead to significant energy savings, chemical treatment, and water savings.

Achieved Environmental Benefits

Reduction in fuel consumption due to supply of hot water in the form of condensate from the process.

Operational Data

The Condensate Recovery System (CRS) is an integrated system comprising a flash steam generator, steam-operated condensate transfer pump and deaerator unit with an immersion tube.

This system efficiently recovers flash steam and hot condensate and feeds them to the feed water tank through a well-designed deaerator unit with an immersion tube.

The system's installation will allow 100% recovery of condensate formed during the process operation. The technology can be suitably modified for mechanical or sensor-based control.

Many vendors are providing complete solution for condensate & flash steam recovery system with their Pressure Powered Package Pumping Unit (PPPPU) which is one of the most efficient ways of recovering condensate. It does not need any storage and electrical pump.

Cross Media Effects

No relevant cross-media effect is known.

Economics

Investment Cost	Low to Moderate
Cost Indicative	**Investment (In Rupees)**
Very Low	< 1 Lakh
Low	< 10 Lakh
Moderate	10 - 20 Lakhs
High	20 - 50 Lakhs
Very High	> 50 Lakhs

Driving Force for Implementation

- Financial benefits
- Resource conservation (Steam and Fresh water)

Reference Industry

Many reference industries of Ahmedabad and Surat cluster have installed this technique.



Figure 4.10 - Reverse osmosis plant for preparing water for wet finishing processes and boilers

Technical Description

Raw water, usually groundwater, often contains high dissolved solids content. The use of high TDS water in textile wet processing leads to quality issues in the fabric and relatively higher consumption of chemicals during wet processing. This water also cannot be used for steam boilers. Therefore, in most of the textile finishing industries, raw water with high dissolved solids is pre-treated through reverse osmosis (RO) plant to minimize its total dissolved solids (TDS) and hardness to provide process water at required quality both for wet finishing processes and boiler feed water (See Figure 4.10).

As a separation technology, the RO produces permeate and concentrate, the concentrate is highly concentrated with the salts and is called reject water. Usually, this reject water is often wasted.

Reject water cannot be used for a wet finishing process but for general purposes where high-quality water is not required. It should be collected and used for general purposes as given below:

- At colour kitchen for washing the floors and chemical drums
- Showering water at solid fuel-fired boilers, wet scrubbers
- Toilets
- Printing machine screens washing
- Showering water in the cooling rooms
- Vehicular washing
- Coal moisturizing for boilers
- Water injection at water ejectors of caustic recovery plant (CRP)
- Showering water at fluff scrubber at singeing machines

RO reject water rate can also be decreased by increasing the number of membranes (stages) of the RO plant.

Achieved Environmental Benefits

- Water conservation
- Groundwater protection
- Reduction in the hydraulic load of the wastewater treatment plant

Operational Data

Mostly RO reject water is 30% of the total input to the RO plant, but it can vary from industry to industry.

The RO reject water from the RO plant will be collected in an underground storage tank. This tank will be attached with a pump and discharge pipeline. The discharge pipeline will be connected to multiple areas/sources with valves where this water is intended to be used.

Cross Media Effects

Salt accumulation can occur where this RO reject water is used due to its high salt content. The use places will require frequent cleaning and removal of adhered salts on the surfaces.

Economics

Investment Cost	**Very Low**
Cost Indicative	**Investment (In Rupees)**
Very Low	< 1 Lakh
Low	< 10 Lakh
Moderate	10 - 20 Lakhs
High	20 - 50 Lakhs
Very High	> 50 Lakhs

Driving Force for Implementation

- Financial benefits
- Resource conservation (Fresh water, electricity)
- Sustainability of textile business

Reference Industry

Most of the reference plants are using RO reject water for domestic purpose.

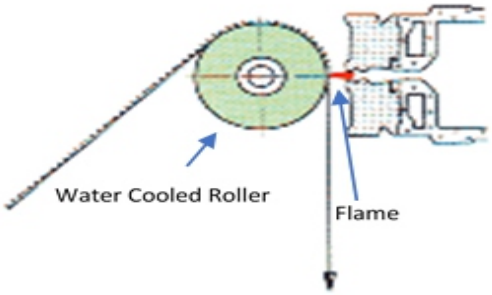


Figure 4.11 - Water cooled roller



Figure 4.12 - Cooling water drainage from singeing machine

Technical Description

In the woven fabric textile finishing industries, singeing is the first process step, passing the grey fabric through the singeing machine before wet pre-treatment. Singeing operation is employed to destroy singes and tufts on the fabric's surface, by its direct exposure to the flame, for a short time. This process is required to improve the chemical uptake of the fabric, by preventing uneven impregnation.

Grey fabric is allowed to pass over the open flame of the burners through rollers where loose hairy fibres protruding from the fabric's surface are burnt. Cooling water is continuously supplied inside the rollers of the singeing machine to keep them cool, which becomes hot by the direct exposure of the flame. This cooling water absorbs the heat of the rollers and becomes warm at about 40-45°C temperature. This warm, clean water stream is generally wasted from the singing machines (See Figure 4.11).

This warm water stream can be collected and reused in any wet process machine. Generally, it is raw water. This water can be used as washing water in the process.

Achieved Environmental Benefits

- Water conservation
- Reduction in thermal energy (warm water will require less steam for heating, in case if this water is used in the hot washes)

Operational Data

This measure applies to all the woven textile finishing industries where grey fabric is singed before wet processing. The industry can collect the cooling water from the singeing machine in a small underground pit with a small pump and discharge pipeline. This measure does not require major intervention in the process, no major infrastructure development, or technical human resource requirement.

The pipeline can be connected to multiple machines/sources with valves where this water is intended to be reused. In case of water is required for a specific machine, the operator will open the valve for that machine.

Cross Media Effects

No relevant cross-media effect is known.

Economics

Investment Cost	Very Low*
**Price indicative of piping cost*	
Cost Indicative	**Investment (In Rupees)**
Very Low	< 1 Lakh
Low	< 10 Lakh
Moderate	10 - 20 Lakhs
High	20 - 50 Lakhs
Very High	> 50 Lakhs

Driving Force for Implementation

- Financial benefits
- Resource conservation (Fresh water)
- Sustainability of textile business

Reference Industry

Many industries of Ahmedabad cluster are performing this technique.

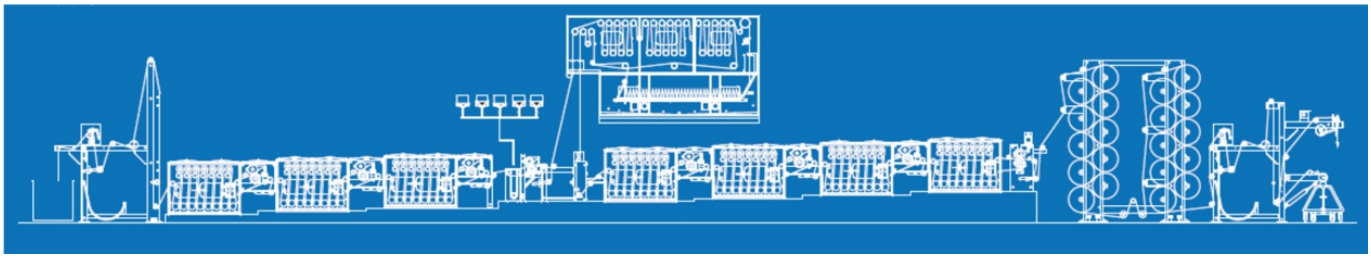


Figure 4.13 - Schematic of CBR Machine
Source: Bhatt Bros. (Textile Processing Machinery Manufacturer)

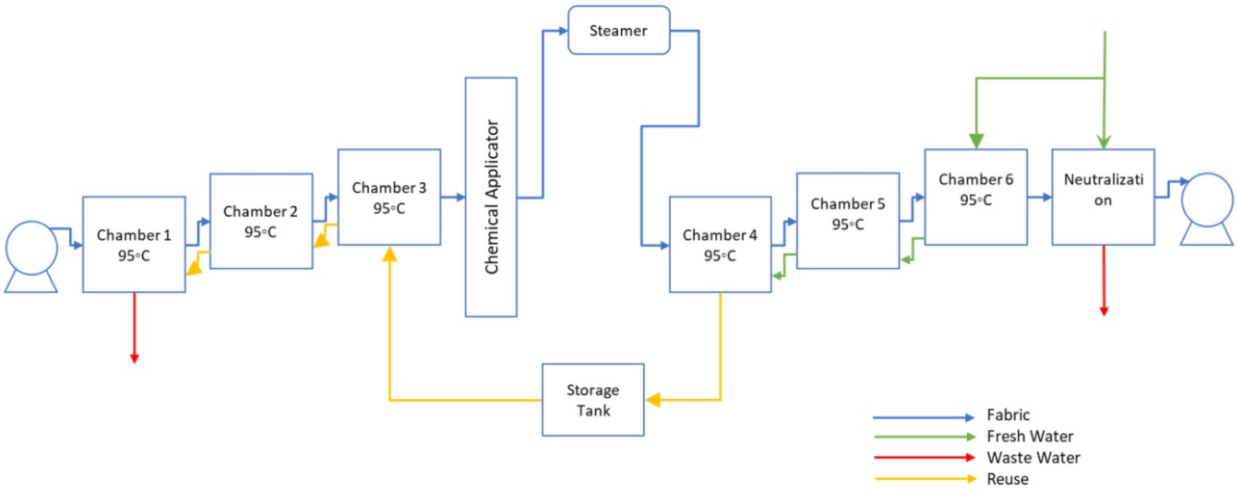


Figure 4.1 4 Water reuse diagram in CBR Machine

Technical Description

Many textile industries already practice counter-current washing which means counter-current washing to wash out sizing agents, and to wash the fabric after scouring and bleaching.

For desizing washing, high-quality water is generally not required, and bleaching wash water can be a good option for such washing. As shown in figure 4.14, the bleaching wash water drained from chamber 4 in the continuous pre-treatment machine. This discharged water can be reused as desizing washing water by directing discharge pipeline of scouring section wash water into the underground storage tank and providing supply line to desizing wash boxes (See Figure 4.14).

Achieved Environmental Benefits

- Water conservation
- Thermal energy conservation (reduction in steam for heating the washing water)
- Reduction in fuel due to reduced steam demand)

Operational Data

This measure does not require significant intervention in the process, no major infrastructure development, or technical human resource requirement.

The influence of pH and fluff content should be checked for the use of bleaching washing water for desizing washes. In case of fluff issues, the bleaching washes should be passed through the screens before feeding into desizing wash boxes. The bleaching wash water supply should be stored in storage tanks to provide uninterrupted supply to desizing wash boxes.

The implementation cost would include the cost of a storage tank, pipes, valves and pump.

Cross Media Effects

None

Economics

Investment Cost	**Low***
**Cost indicative of piping network and storage system*	
Cost Indicative	**Investment (In Rupees)**
Very Low	< 1 Lakh
Low	< 10 Lakh
Moderate	10 - 20 Lakhs
High	20 - 50 Lakhs
Very High	> 50 Lakhs

- Financial benefits
- Resource conservation (Fresh Water and Steam)
- Sustainability of textile business

Reference Industry

M/s. Shanti Processors Pvt. Ltd., Ahmedabad

Mercerizer

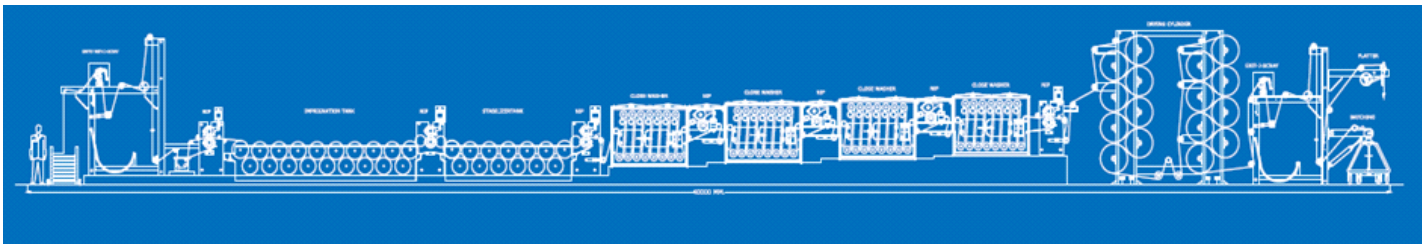


Figure 4.15 - Schematic of Mercerization Machine
Source: Bhatt Bros. (Textile Processing Machinery Manufacturer)

Continuous Bleaching Range

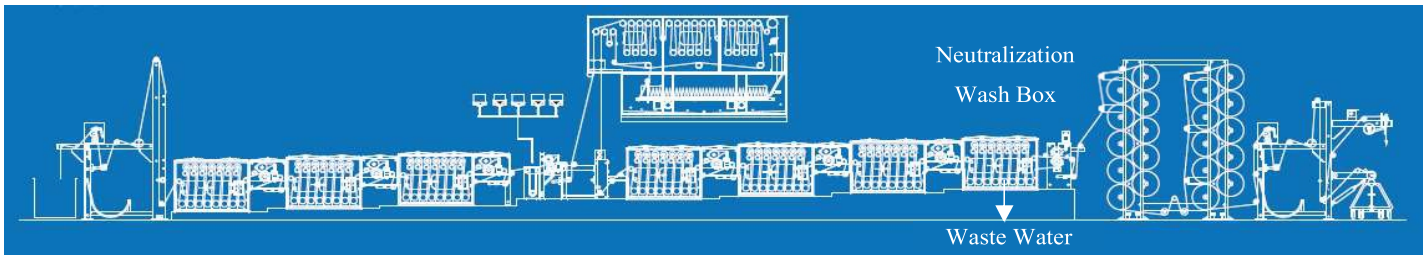


Figure 4.16 - Schematic of CBR Machine
Source: Bhatt Bros. (Textile Processing Machinery Manufacturer)

Technical Description

In the mercerization machines, the fabric is first allowed to dip into the caustic soda solution of the required concentration (generally 22 to 28°Bé). It provides a specific residence time of 40 – 60 secs for the reaction between fabric and caustic soda. Post reaction, some unreacted caustic remains on fabric which is then finally washed to remove it from the fabric.

The wash box series are in the counter-current arrangement. Water in the wash box contains a substantial amount of caustic soda (6 to 7 °Bé) that is collected along with caustic overflow from the stabilization zone and it is sent to the Caustic Recovery Plant (CRP) for concentrating and reusing in the mercerization process.

As shown in the Figure 4.15 and 4.16, neutralisation is carried out in the last wash box to remove traces of caustic soda from the fabric and is discharged to ETP. The washing water is slightly alkaline and contains TDS not possible to reuse everywhere.

This water can be collected in the storage tank and reused as washing water for desizing wash post scouring.

Note: Generally, textile finishing industries receive caustic soda of 50% °Bé and dilute it to 22 to 28 °Bé by adding water. Instead of fresh water, the discharged washing water from mercerisation machine can also be used for dilution, reducing water consumption and caustic soda consumption.

Achieved Environmental Benefits

- Water conservation
- Reduction in the hydraulic load of the wastewater treatment plant

Operational Data

The discharged water needs to be checked for TDS value as generally, acetic acid is added to the wash box to neutralize the caustic on the fabric. This result in increased TDS in drain water of neutralization box.

The quantity of discharged water varies from industry to industry, depending upon the quantity of fabric mercerized. It is observed that usually, 0.5 ltr/kg – 2 ltr/kg flow is maintained for the last tank.

Cross Media Effects

No relevant cross-media effect is known

Economics

Investment Cost	**Low***
**Cost indicative of piping network and storage system*	
Cost Indicative	**Investment (In Rupees)**
Very Low	< 1 Lakh
Low	< 10 Lakh
Moderate	10 - 20 Lakhs
High	20 - 50 Lakhs
Very High	> 50 Lakhs

Driving Force for Implementation

- Financial benefits
- Resource conservation (Fresh Water)
- Sustainability of textile business

Reference Industry

None

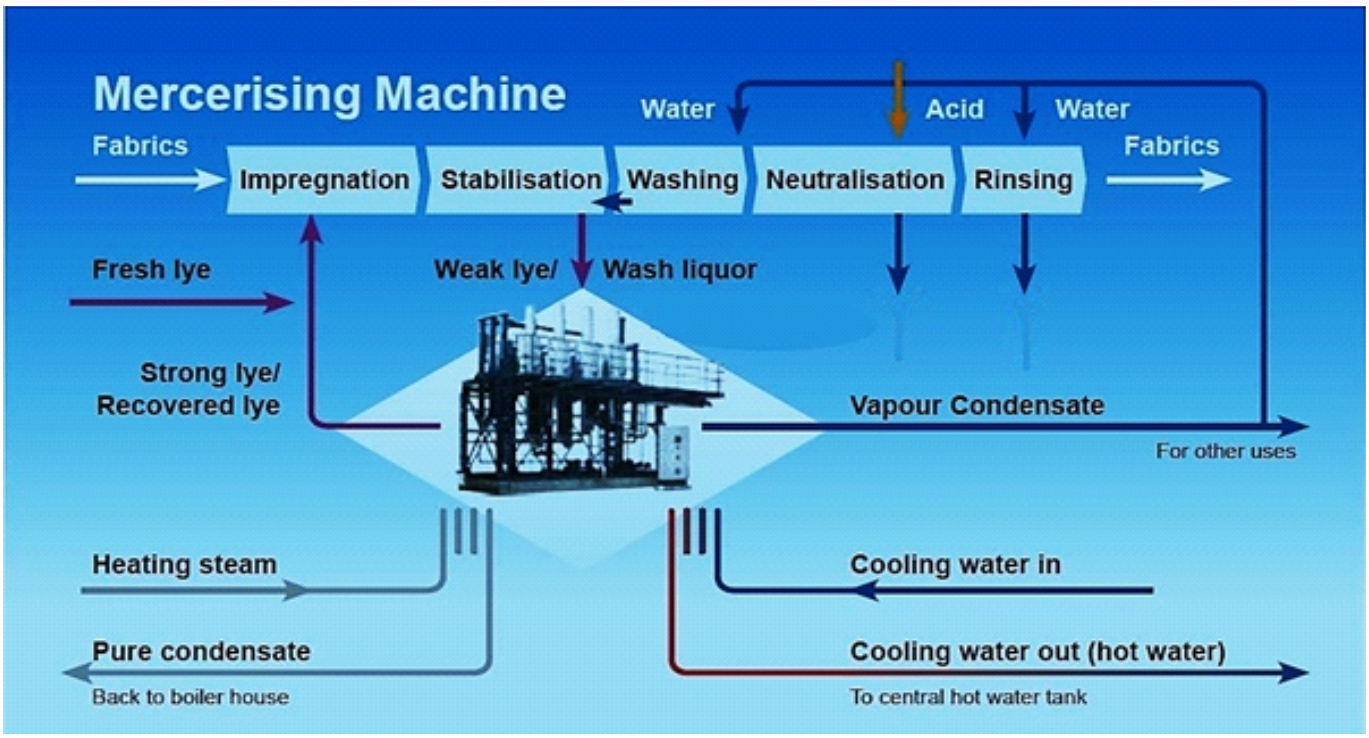


Figure 4.17- Schematic of CRP System
Source: Körting Hannover AG (https://www.koerting.de/en/caustic-recovery-plants.html)

Technical Description

Caustic Recovery Plants (CRP) are installed in woven cotton fabric textile finishing companies where they are used to recover caustic soda discharged from the drain of the mercerization process. These are multi-effect evaporators that separates water (condensate) and caustic concentrate through evaporation. The concentrate is reused in mercerization process while condensate is usually discharged. This condensate can be reused in process house.

Achieved Environmental Benefits

- Water conservation
- Reduction in the hydraulic load of the wastewater treatment plant

Operational Data

The CRP purpose is to concentrate dilute caustic soda solution (weak lye) of 5 to 10oBé concentrations discharged from the mercerization machines into 20-25°Bé concentration by evaporating water from the weak lye through multi-effect evaporators. The vapour from weak lye is condensed into hot water through condensers (As shown in the figure 4.17). Generally, this hot alkaline water with temperature of about 60 to 80 °C is wasted.

This water can be collected and reused at:

- Post-mercerization wash box

- Pre and post-wash box of continuous textile pre-treatment machines (desizing, scouring and bleaching)
- Caustic soda lye dilution

Cross Media Effects

No relevant cross media effect is known

Economics

Investment Cost	**Low***
**Cost indicative of piping network and storage system*	
Cost Indicative	**Investment (In Rupees)**
Very Low	< 1 Lakh
Low	< 10 Lakh
Moderate	10 - 20 Lakhs
High	20 - 50 Lakhs
Very High	> 50 Lakhs

Driving Force for Implementation

- Financial benefits
- Resource conservation :Fresh water and in thermal energy (hot water will require less steam for heating, in case if this water is used as hot washes)
- Sustainability of textile business

Reference Industry

Many reference plants in the Ahmedabad cluster are utilizing this technique.



Figure 4.18 - Printing blanket washing device
(Source: https://www.zimmer-klagenfurt.com/)

Technical Descriptions

Rotary and flatbed printing machines are employed to print woven fabric continuously. The printer table blanket is washed with forced water jets (See Figure 4.18), using two or three rows of multiple nozzles placed underneath the table in a cross direction to remove the stains adhered to the blanket during the printing operation.

Generally, the blanket washing water at the printing machines is kept running and wasted during machine stoppage (due to maintenance or change over). This water wastage can be avoided by installing an automatic water shut-off valve at the printing machines. Whenever the printing machine is stopped, the jet spray will also stop.

Achieved Environmental Benefits

- Water conservation
- Reduction in the hydraulic load of the wastewater treatment plant

Operational Data

This measure requires technical human resources for installation. The sensor systems rely on a moving belt. So, the blanket washing water supply will be stopped whenever the machine is stopped. This supply will be synchronized with the operation of the printing machine.

Cross Media Effects

No relevant cross-media effect is known.

Economics

Investment Cost	Very Low*
**Cost indicative for one machine only*	
Cost Indicative	**Investment (In Rupees)**
Very Low	< 1 Lakh
Low	< 10 Lakh
Moderate	10 - 20 Lakhs
High	20 - 50 Lakhs
Very High	> 50 Lakhs

Driving Force for Implementation

- Financial benefits
- Resource conservation (Water)
- Sustainability of textile business

Reference Industry

M/s. Arvind Ltd. (Santej Unit), Ahmedabad

Table 4.3 - Example for monitoring the water consumption for different continuous wet processing machines

Date of month	Continuous pre-treatment line 1 (desizing, scouring and bleaching)	Merceri-sation	Pad steam line/ CPB Line	Continuous washing machine								
	[m/d]	[m^3/d]	[l/kg]	[m/d]	[m^3/d]	[l/kg]	[m/d]	[m^3/d]	[l/kg]	[m/d]	[m^3/d]	[l/kg]
1	137700	349	7.2	62800	188	8.6	100300	583	16.6	40500	549	42
2	130500	345	8.7	50000	102	12.3	56300	434	22	25800	323	35.7
3	118500	304	8.7	46900	223	12.3	51600	456	25.3	28900	366	36.2
4	121000	365	8.7	44500	154	12.3	24700	240	27.3	14700	167	32.5

Technical Description

All the wet processes are based on water. Water consumption is directly or indirectly related with energy and chemicals consumption and wastewater hydraulic load. Excess water consumption increases the processes' thermal and electrical energy and chemical consumption. Water management is crucial in the textile finishing industry to reduce resource consumption and sustain textile processes. Water management will only be possible if water consumption in the processes is measured, monitored and controlled. Water consumption in the textile finishing industry is not measured, monitored and managed due to its abundant availability, particularly where fresh water costs are low. The management and workers often do not realize the importance of water and associated resource wastage due to its inappropriate use in the process.

Water measurement is important for water management by installing water flow meters at main water pump, different wet process sections, process machines and utilities.

After water measurement, its analysis to find consumption pattern and benchmarking is important to assess the status of water consumption in the industry and to know whether its consumption is optimum or consumes a vast amount of water as compared with other similar industries. Establishing water consumption benchmarking i.e. litre of water consumed per kilogram of finished fabric, and its improvement by taking water conservation measures will improve water management in the industry.

Achieved Environmental Benefits

- Water conservation
- Reduction in the hydraulic load of the wastewater treatment plant

Operational Data

This measure applies to all the textile finishing industries. The water flow meters should be selected carefully. Most of the time, the water flow meters malfunction due to water quality issues. The price of the flow meter depends upon its type and size. The electromagnetic type water flow meters are preferred due to their durability, whereas the impeller type flow meters malfunction due to clogging and scaling. The electromagnetic type flow meters are more expensive than the impeller type.

Cross Media Effects

No relevant cross-media effect is known.

Economics

The direct calculation of the benefits of implementing water flow meters is impossible. However, monitoring is usually associated with significant savings of water and energy, especially directly after the implementation of water meters.

Driving Force for Implementation

- Financial benefits
- Resource conservation (Fresh Water)

Reference Industry

M/s. Mukesh Industries Pvt. Ltd., Ahmedabad
M/s. Arvind Ltd. (Santej Unit), Ahmedabad
M/s. Shanti Processors Pvt. Ltd., Ahmedabad
M/s. Siddhivinayak Knots and Prints, Surat
M/s. Hi-Choice Processors Pvt. Ltd., Surat

Majorly all reference plants of Surat have installed water meters for monitoring.

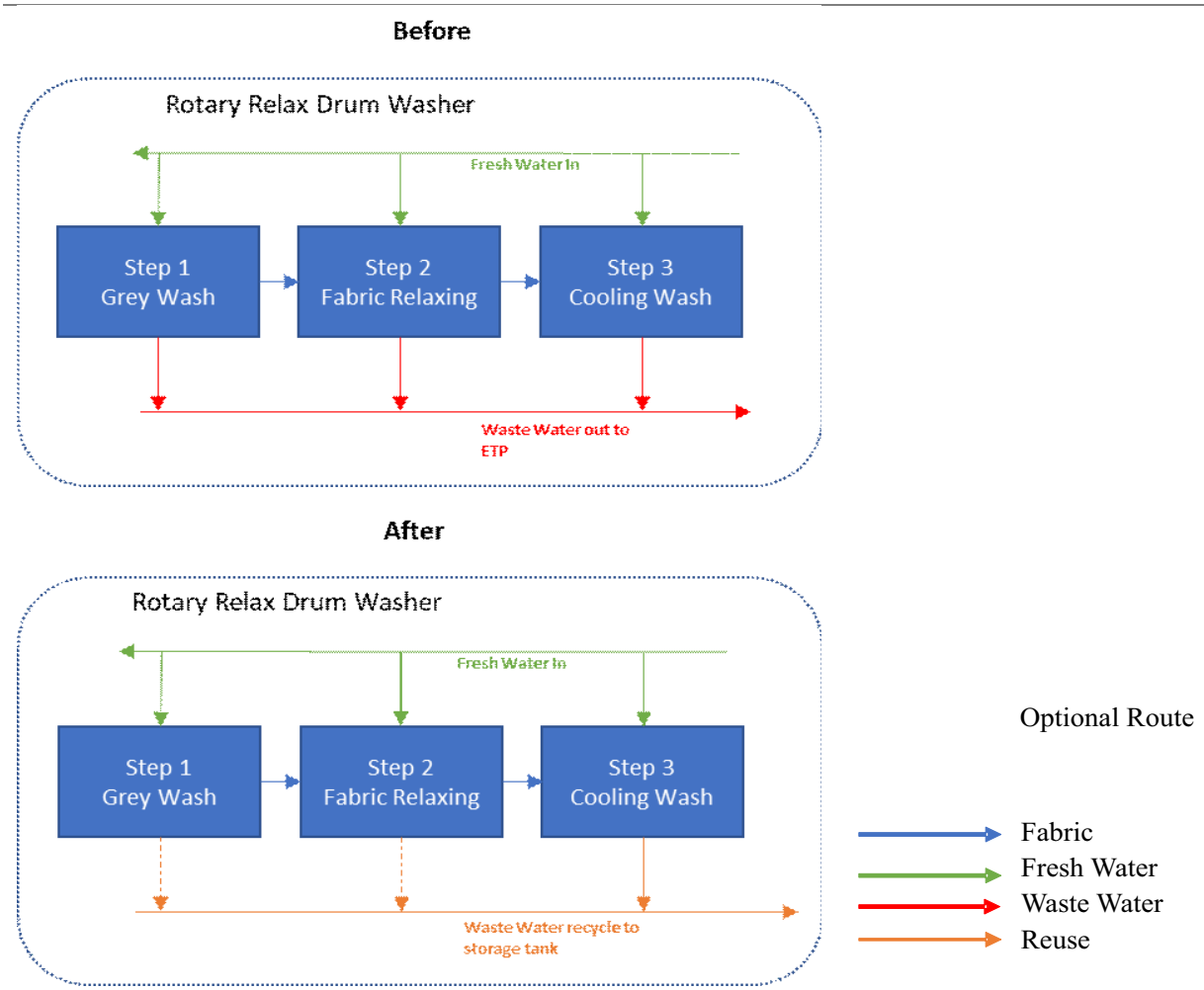


Figure 4.19 - Waste water recovery in Relax drum machine

Technical Description

Various polyester textile mills use rotary relax drum washer (Drum Machine) to relax high twist polyester fabric. Generally, a particular batch process involves three steps, as shown in Figure 4.19 . Usually, water is drained from all three steps.

Industry can partially or fully reuse the waste water discharged from these three steps.

Achieved Environmental Benefits

- Water conservation
- Reduction in the hydraulic load of the wastewater treatment plant

Operational Data

It will be necessary to store the waste water from the drum in a storage tank to partially or wholly recover the waste water. Additionally, some modest adjustments to drum machines are also required. It needs two inlet and outlet valves, for example, to accommodate both recovered waste water and fresh water. The outflow can be directed through one valve to a storage tank and another to an ETP.

Additionally, a filtration system is needed to purify waste water.

Cross Media Effects

No relevant cross-media effect is known

Investment Cost	**Moderate**
**Cost indicative for one machine only*	
Cost Indicative	**Investment (In Rupees)**
Very Low	< 1 Lakh
Low	< 10 Lakh
Moderate	10 - 20 Lakhs
High	20 - 50 Lakhs
Very High	> 50 Lakhs

Economics

The building of the storage tank and the pipe infrastructure would incur the most expense.
Driving Force for Implementation

- Financial benefits
- Resource conservation (Fresh Water)

Reference Industry

M/s. Aaiswarya Dyeing Mills Pvt. Ltd., Surat
M/s. Siddhivinayak Knots and Prints Ltd., Surat

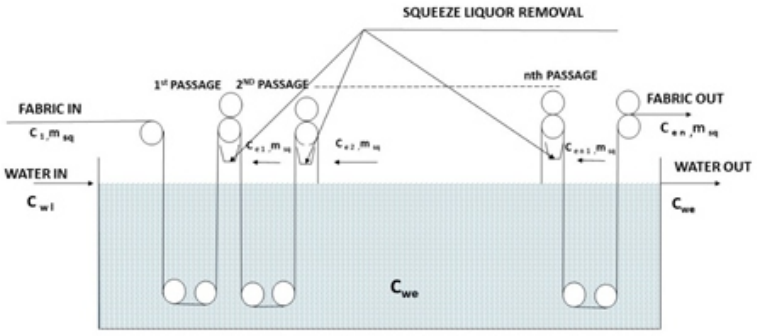


Figure 4.19 (a): Squeeze liquor removal

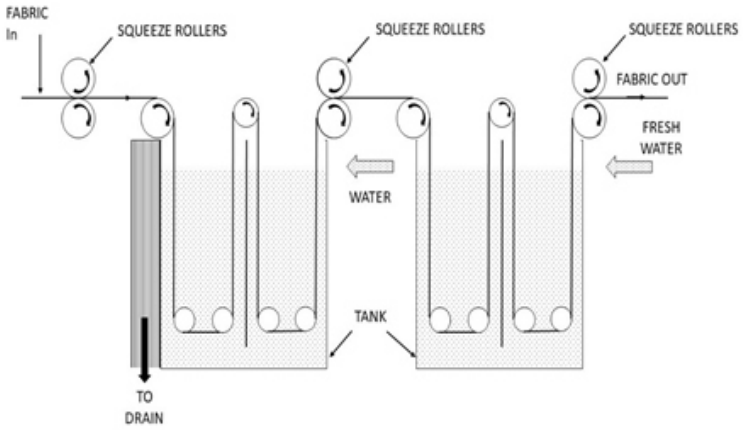


Figure 4.19 (b): Open width washing machine with counter current flow

Technical Description

In the Wet Processing Department, Washing of Textiles after each Chemical Treatment consumes about 30% of the total water consumption of an average size textile mills. So, the following measures implemented by ATIRA in several mills are used to save water in washing.

1. Squeeze liquor removal

Washing system is composed of a basically squeeze-dilute-diffuse sequence. A washing unit with a dip of fabric with squeeze liquor removal after each dip is shown in Fig. 4.19 (a). The washing unit with squeeze liquor removal needs less water than the one without squeeze for removal of same amount of impurity from the fabric.

2. Open width washing machine with counter current flow

A schematic diagram of the open width washer with counter current arrangement is shown in Fig. 4.19 (b). The counter current arrangement will help reduce the water consumption for the same amount of impurity removal as the one without.

Achieved Environmental Benefits

Reduction in fresh water consumption by 20%

Investment Cost	Very Low
Cost Indicative	**Investment (In Rupees)**
Very Low	< 1 Lakh
Low	< 10 Lakh
Moderate	10 - 20 Lakhs
High	20 - 50 Lakhs
Very High	> 50 Lakhs

Cross Media Effects

No relevant cross-media effect is known.

Economics
Driving Force for Implementation

- Reduction in fresh water consumption

Reference Industry

None

Sr. No,	Technique Name
1.	Energy efficiency plan and energy audit
2.	Cogeneration with low-pressure steam turbine
3.	Replace reciprocating compressor with screw compressor and installation of air pressure monitoring to reduce air leakages and maintain optimum pressure
4.	Installation of demand controller and reduce contract demand
5.	Installation of Variable Frequency Drive (VFD) and soft starter
6.	Power factor correction
7.	Self-cleaning heat exchanger
8.	Heat recovery from hot wastewater in continuous process
9.	Heat recovery from hot wastewater in jigger dyeing machine
10.	Heat recovery from exhaust dyeing bath
11.	Minimisation of energy consumption of stenter frames and dryers
12.	Heat recovery from stenter flue gas

Technique 16: Energy efficiency plan and energy audits.

Technical Description

An energy efficiency plan and energy audits are part of the environmental management system (EMS) and include:

- Energy flow diagrams;
- Establishment of energy efficiency objectives;
- Implementation of actions to achieve these objectives.

Energy audits are carried out at least annually to ensure that the objectives of the energy efficiency plan are met.

Achieved Environmental Benefits

Utilising an energy efficiency plan can reduce the energy consumption and the environmental emissions of that energy use.

Operational Data

◊ The techniques applicable to increase the energy efficiency of textile plants are as follows:
◊ Appraising the costs and benefits of different energy options.
◊ Monitoring energy flows (consumption and generation by source – see Technique 2) and the targeting of areas for reductions.
◊ Defining and calculating the specific energy consumption of the activity (or activities), and setting key performance indicators on an annual basis (e.g. MWh/tonne of textile produced).
◊ Carrying out an energy survey to identify the opportunities for further energy savings.
◊ Using combined heat and power (CHP) (see Technique 16).
◊ Applying operating, maintenance and housekeeping measures to the most relevant energy consuming systems such as:
  - Air conditioning, process refrigeration and cooling systems (leaks, seals, temperature control, evaporator/condenser maintenance);
  - Operation of motors and drives (e.g. high-efficiency motors);
  - Compressed gas systems (leaks, procedures for use – se Technique 17);
  - Steam distribution systems (leaks, traps, insulation);
  - Room heating and hot water systems
  - Lubrication to avoid high friction losses (e.g. mist lubrication);
  - Boiler maintenance, e.g. optimising excess air;
  - Other maintenance relevant to the activities within the plant;
  - Reviewing equipment requirements on a regular basis.
◊ Using techniques that reduce energy consumption and thereby reduce both direct (heat and missions from on-site generation) and indirect (emissions from a remote power station) emissions.

For example:

- Building insulation
- Use of energy-efficient site lighting;
- Efficient plant layout to reduce pumping distances
- Variable speed drives;
- Heat recovery (see Technique 22,Technique 23,Technique 24 and Technique 26);
- Ensuring equipment is switched off, if safe to do so, when not in use;

◊ Applying basic, low-cost, physical techniques to avoid gross inefficiencies; including insulation, containment methods (for example, seals and self-closing doors) and avoiding unnecessary discharges of heated water or air (for example, by fitting simple control systems).

◊ Setting the time of operation of the high-energy equipment to off-peak periods (see Technique 18).

◊ Optimising boiler houses (reuse of condensed water, preheating of air supply, heat recovery in combustion gases) and optimising boiler design according to energy demand profile.

◊ Segregation of hot and cold waste water streams prior to heat recovery and heat recovery from the hot stream by waste water abatement and reuse or heat exchange.

◊ Optimised production planning of finishing jobs to avoid downtimes of the stenter frame and related heating periods.

◊ Installing heat recovery systems for waste gases from stenter frames and waste gas treatment devices applying air/air or air/water heat exchange systems – an example is given in Technique 26.

◊ Optimisation of air conditioning systems (e.g. by sections or by direct conditioning of specific weaving machines for individual adaptation of volume and humidity).

◊ Optimisation of the compressed air system and evaluation of a separate system with low pressure (see Technique 17).

◊ Use of the heat content of the cooling air of the compressor (for process water heating by air/water heat exchange or for yarn drying).

◊ Optimisation of the cold and hot water system (installation of a pressure compensation tank, priority circuit for several pressure-boosting pumps, shut-off during shutdown of the plant).

◊ Monitoring and controlling the moisture content in the circulating air and on the textile in the stenters (see Technique 30).

◊ Proper adjustment of drying/curing temperature and drying/curing time.

◊ Installing covers on nips and tanks; the fitted covers are easily removable to allow quick access.

◊ Unnecessary high steam pressure is avoided for both direct and indirect steam heating.

◊ Point-of-use gas-fired water heaters can be used to enable processes to be run independently of the plant's central boiler systems. This means that boiler and distribution losses associated with centralised systems (which can be as much as 50 % of the fuel input) can be eliminated. Point-of-use heating also offers greater flexibility, allowing operation outside the main boiler operating hours.

◊ Using cold pad-batch for pre-treatment (e.g. desizing or bleaching) or dyeing of cotton (see Technique 34).

◊ Avoiding overheating of the baths and optimising the temperature of rinsing water (see Technique 29);

Cross Media Effects

None identified.

Economics

Energy-efficient systems typically have higher investment costs. However, their operating costs are usually lower (or the revenues higher).

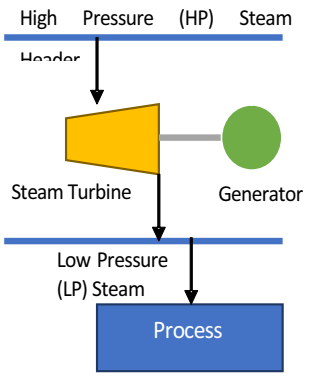
The energy efficiency improvement needs to be balanced with the cost of achieving it.

Driving Force for Implementation

Energy and cost savings.

Reference Industry

M/s. Arvind Ltd. (Santej Unit), Ahmedabad
M/s. Siddhivinayak Knots and Prints Ltd., Surat
M/s. Bhavin Textile Pvt Ltd., Surat
M/s. Akash Fashions Pvt. Ltd., Ahmedabad
M/s. Gopi Synthetics Pvt. Ltd., Ahmedabad
M/s. Mukesh Industries Pvt. Ltd., Ahmedabad
M/s. Kankariya Textile Industries Pvt. Ltd., Ahmedabad



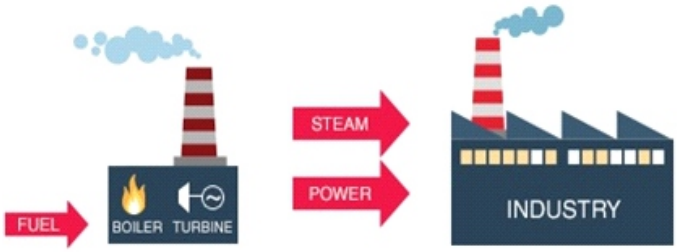


Figure 4.21- Co-generation Model

Figure 4.20- Power generation through HP Steam

Technical Description

Steam and Power are generated from a single primary source of fuel. Steam is used in various processes as a heating medium. The steam produced by the boiler is initially used to power a turbine, producing low-pressure steam that is then supplied to a process house.

Achieved Environmental Benefits

- Reduction in electricity consumption (indirectly as there will be a reduction in electricity consumption from the DISCOM supply chain)

Operational Data

The two types of steam turbines most widely used are the back pressure and the extraction-condensing types. The choice between a back pressure turbine and an extraction-condensing turbine depends mainly on the quantities of power and heat, quality of heat, and economic factors. The extraction points of steam from the turbine could be more than one, depending on the temperature levels of heat required by the processes.

Back Pressure Steam Turbines (BPSTs) produce low-pressure (LP) exhaust steam that can be used for process heating (refer to Figure 4.20). The objectives are to provide the process with the steam of the quantity and pressure required while generating the maximum power to reduce the need for power purchase. Because BPSTs cogenerate two energy products (i.e., steam and power) simultaneously.

A Back Pressure Steam Turbine is used in industrial applications requiring low or medium pressure steam for process heating. When high-pressure steam enters a back-pressure steam turbine, some of its thermal energy is turned into mechanical energy when the steam expand. The mechanical energy is utilized to power an electric generator. The needed pressure outlet steam leaves the back pressure steam turbine, and the steam flows to the plant for process steam applications such as heating or drying.[8] Back-pressure turbines are inexpensive, thermally efficient, compact, and usually the most economical proposition for partial generation schemes, but inflexible. Power generation depends on the steam flow

[8] https://turtleturbines.com/difference-between-back-pressure-turbine-and-condensing-turbine/

required to meet process requirements and the pressure drop over the turbine.

Extraction-condensing turbines are employed when steady power generation and steam extraction at a fixed pressure are required. Extraction pressure is controlled internally in the turbine, allowing a wide range of extraction flow rates.[9] The extraction control valve implements adjustment of process steam flow. The turbine output is adjusted by the main control valve for the inlet steam flow in conjunction with the LP turbine flow, which is affected by the extraction control valve. The extraction condensing turbine can independently change the electric power and process steam flow by adjusting inlet and process steam flow. That is to say, the extraction condensing turbine has both features of the condensing turbine and the back pressure turbine and can fulfil both the requirements of the electric power supply and the process steam flow.

Cross Media Effects

No relevant cross-media effect is known.

Economics

Investment Cost	High to Very High
Cost Indicative	**Investment (In Rupees)**
Very Low	< 1 Lakh
Low	< 10 Lakh
Moderate	10 - 20 Lakhs
High	20 - 50 Lakhs
Very High	> 50 Lakhs



4.22 - Back Turbine Installed for cogeneration at reference unit

Driving Force for Implementation

- Financial benefits
- Resource conservation (Thermal Energy)

Reference Industry

M/s. Akash Fashions Pvt. Ltd., Ahmedabad
M/s. Aaiswarya Dyeing Mills Pvt. Ltd., Surat
M/s. Hi Choice Processors Pvt. Ltd., Surat

[9]https://power.mhi.com/products/steamturbines/lineup/industrial/extraction#:~:text=Extraction%2Dcondensing%20turbines%20are%20employed,for%20processes%20in%20the%20plant.

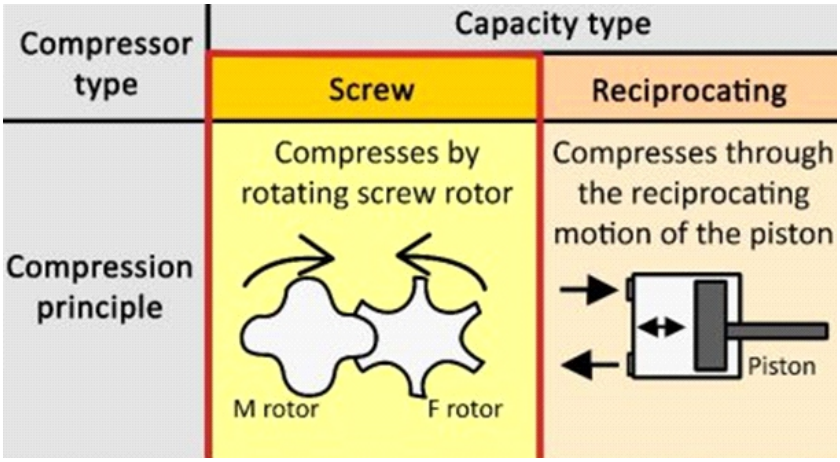


Figure 4.23 – Screw Compressor Vs Reciprocating Compressor
Source: 1. https://empoweringpumps.com/how-to-select-a-compressor-part3-compressor-selection/
2. https://www.indiamart.com/kalkiautomations/

Technical Description

Recently, more and more textile operations rely on compressed air and are sometimes called the 4th utility of any industry. Compressed air is used for controlling processes.

The two most common compressors are rotary screw air compressors and reciprocating (or piston) air compressors.

Reciprocating air compressors, also called "piston" air compressors, are widely used throughout various service industries due to their price and availability. Textile Industries use reciprocating air compressors because they are only familiar with what they've traditionally used.

But reciprocating air compressors are not the only option. Rotary screw air compressors provide better performance and often require less space, which makes them an attractive alternate option.

- Compressed air leaks are a significant source of energy wastage in compressed air systems.
- Compressed air leaks can also contribute to problems with system operations, including:
    - ◊ Fluctuating system pressure can cause air tools and other air-operated equipment to function less efficiently, possibly affecting production
- Excess compressor capacity, resulting in higher than necessary costs
- Due to unnecessary cycling and increased run time, decreased service life and increased equipment maintenance.

Although leaks can occur in any part of the system, the most common problem areas are: couplings, hoses, tubes, fittings, pipe joints, quick disconnects, FRLs (filter, regulator, and lubricator), condensate traps, valves, flanges, packings, thread sealants, and point of use devices.

Fixing the compressed air leaks is not enough. Incorporating a leak prevention strategy into the facility's operations is essential to ensure air compressors are not consuming unnecessary power.

It is imperative to monitor the efficiency of the air compressor through air monitoring equipment which may include the following parameters: on/off time, load/unload duration, pressure, flow, humidity, and power consumption.

Additionally, by monitoring these parameters, facility maintenance team can conduct preventative maintenance.

Achieved Environmental Benefits

Energy Savings

Operational Data

Cross Media Effects

No relevant cross-media effect is known.

Economics

Investment Cost	**Low**
**Cost indicative for 30HP screw compressor*	
Cost Indicative	**Investment (In Rupees)**
Very Low	< 1 Lakh
Low	< 10 Lakh
Moderate	10 - 20 Lakhs
High	20 - 50 Lakhs
Very High	> 50 Lakhs

Driving Force for Implementation

- Financial Benefit

Reference Industry

M/s. Akash Fashions Pvt. Ltd., Ahmedabad
M/s. Aaiswarya Dyeing Mills Pvt. Ltd., Surat

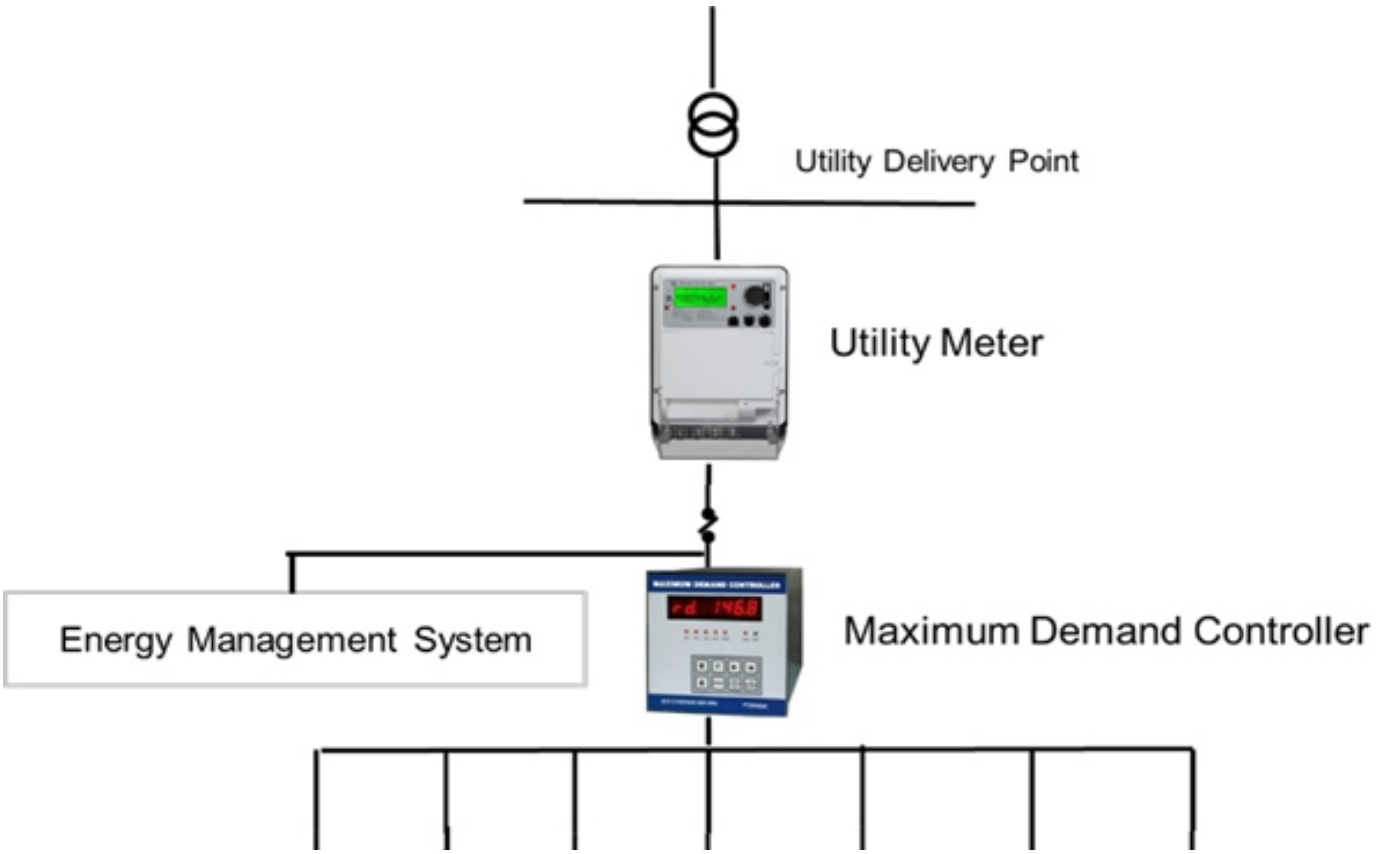


Figure 4.24 – Maximum Demand Controller
Source: (https://www.sandsindia.com/maximum-demand-controller)

Technical Description

Many textile companies have to pay an additional charge over and above the normal charge for units of electricity consumed as the maximum demand charge. This is due to a fee levied by the utility company if the factory uses more energy than the agreed-upon maximum consumption. This amount makes up a significant portion of the bill. It is traceable to a single 30-minute period of heavy power usage during a start of the day or month.

The maximum power consumed in factories over a calculated period, normally between 8 to 30 minutes, is known as maximum demand. In many countries, 15 minutes is the most common period.

A maximum demand controller is an energy-efficient electrical device that helps control the kW demand during high power usage periods by shedding non-critical loads. A substantial amount of the electricity bills can be saved by controlling power usage and switching off non-essential loads during such periods.

Industry can determine the actual demand in KVA and the difference between actual and contract demand based on the study of electricity bills.

Industry can reduce its contract demand if actual demand is lower to save energy costs.

Achieved Environmental Benefits

Energy Efficiency

Operational Data

A value is present in the maximum demand controller when it is connected to the power line. When the demand approaches this value, an alarm is sounded. The alarm is a signal to take corrective action. The controller switches off less important loads in a sequence if the necessary action is not taken. In some factories, loads such as compressors, air conditioners, pumps, fans can be disconnected. The user can decide the order in which the non-essential loads are disconnected and accordingly programmed into the device. The necessary equipment is then restarted at the appropriate time.

Cross Media Effects

No relevant cross media effect is known.

Economics

Investment Cost	**Very Low**
Cost Indicative	**Investment (In Rupees)**
Very Low	< 1 Lakh
Low	< 10 Lakh
Moderate	10 - 20 Lakhs
High	20 - 50 Lakhs
Very High	> 50 Lakhs

Driving Force for Implementation

Financial Benefit to Industry

Reference Industry

M/s. Akash Fashions Pvt. Ltd., Ahmedabad
M/s. Aaiswarya Dyeing Mills Pvt. Ltd., Surat

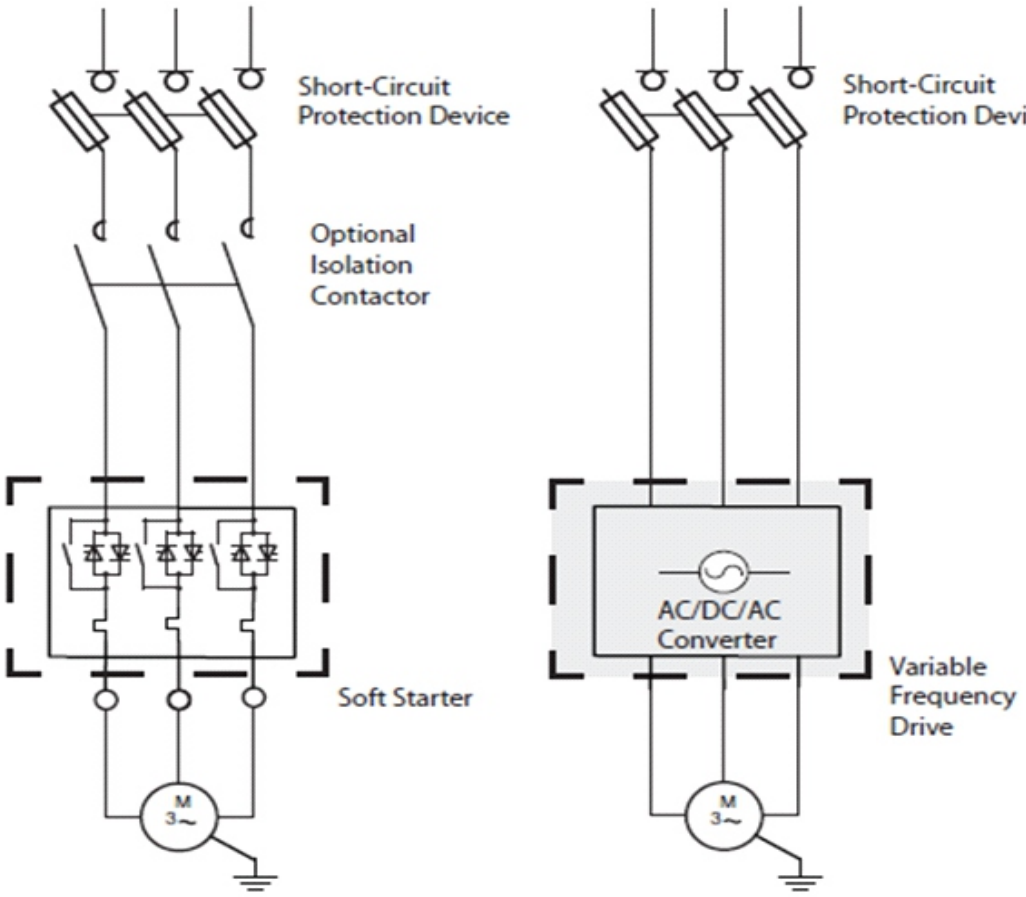


Figure 4.25 – Schematic of Soft Starter and VFD
Source: (https://www.sandsindia.com/maximum-demand-controller

Technical Description

Variable frequency drives and soft starters are widely used in industrial motor and pump control.

Both are semiconductor devices. Although working on similar principles, VFD and soft starters differ.

Variable frequency drives are semiconductor devices mainly used for motor torque-speed control and protection. It can start and stop a motor smoothly. The motor's speed torque characteristics can be controlled throughout its operation based on the application by using a VFD. The motor speed can be controlled from 0 to its rated speed (sometimes above the rated speed) by varying the frequency of the motor supply.

A motor soft starter is a device used with AC electrical motors to temporarily reduce the load and torque in the powertrain and electric current surge of the motor during start-up. This reduces the mechanical stress on the motor and shaft, as well as the electrodynamic stresses on the attached power cables and electrical distribution network, extending the lifespan of the system .[10]

[10] https://en.wikipedia.org/wiki/Motor_soft_starter#cite_note-Siskind-1

Achieved Environmental Benefits

Energy Savings.

Variable Frequency Drive

VFDs offer the most significant energy savings for fans and pumps. The adjustable flow method changes the flow curve and drastically reduces power requirements.

Operational Data

Variable Frequency Drive

VFDs control the motor by varying the frequency and voltage of the input supply. The speed of a motor is directly proportional to its supply voltage. In a VFD, the input supply is first converted into DC and then inverted back to AC of the desired voltage. Motor Speed varies from zero to full speed by smoothly varying the supply frequency from 0 Hz to the rated motor frequency. VFDs can offer smooth start, stop, and complete control over motor speed and torque.

VFDs offer the most significant energy savings for fans and pumps. The adjustable flow method changes the flow curve and drastically reduces power requirements.

Soft Starter

A soft starter is a solid-state device that protects AC electric motors from damage caused by sudden influxes of power by limiting the large initial inrush of current associated with motor startup. They provide a gentle ramp up to full speed and are used only at startup (and stop, if equipped). Ramping up the initial voltage to the motor produces this gradual start. Soft starters are also known as reduced voltage soft starters (RVSS).

Since the soft starter only reduces the supply voltage during starting & stopping of the motor, it cannot vary the motor speed during normal operation. Therefore, Soft starters are often the more economical choice for applications that require speed and torque control only during motor start-up. They are often the ideal solution for applications where space is a concern, as they usually take up less space than variable frequency drives.

Choosing a soft starter or a variable frequency drive depends on your application. Soft starters are smaller and less expensive. VFDs take up more space and are usually more expensive than soft starters. While VFDs are used in larger horsepower applications.

Cross Media Effects

No relevant cross-media effect is known.

Economics

Investment Cost	Very Low*
**Cost indicative for one VFD instrument*	
Cost Indicative	**Investment (In Rupees)**
Very Low	< 1 Lakh
Low	< 10 Lakh
Moderate	10 - 20 Lakhs
High	20 - 50 Lakhs
Very High	> 50 Lakhs

Driving Force for Implementation

- Financial benefits
- Resource conservation (Thermal Energy)

Reference Industry

Majorly all reference plants have installed VFD in some of their plant machinery. Very few reference plants have fully installed VFD in all machinery like

M/s. Kankariya Textile Industries Pvt. Ltd., Ahmedabad

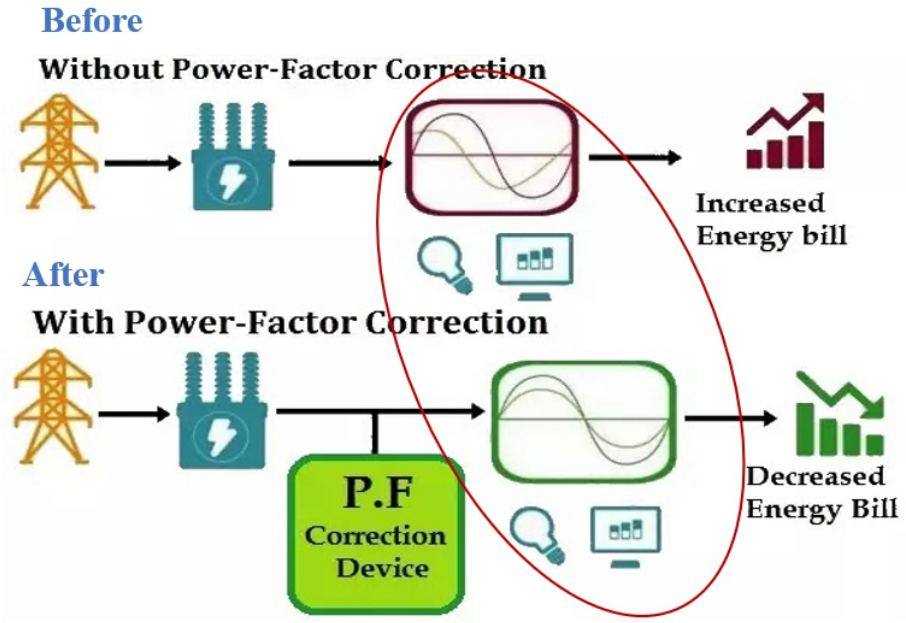


Figure 4.26 – Before & After PF correction scenario

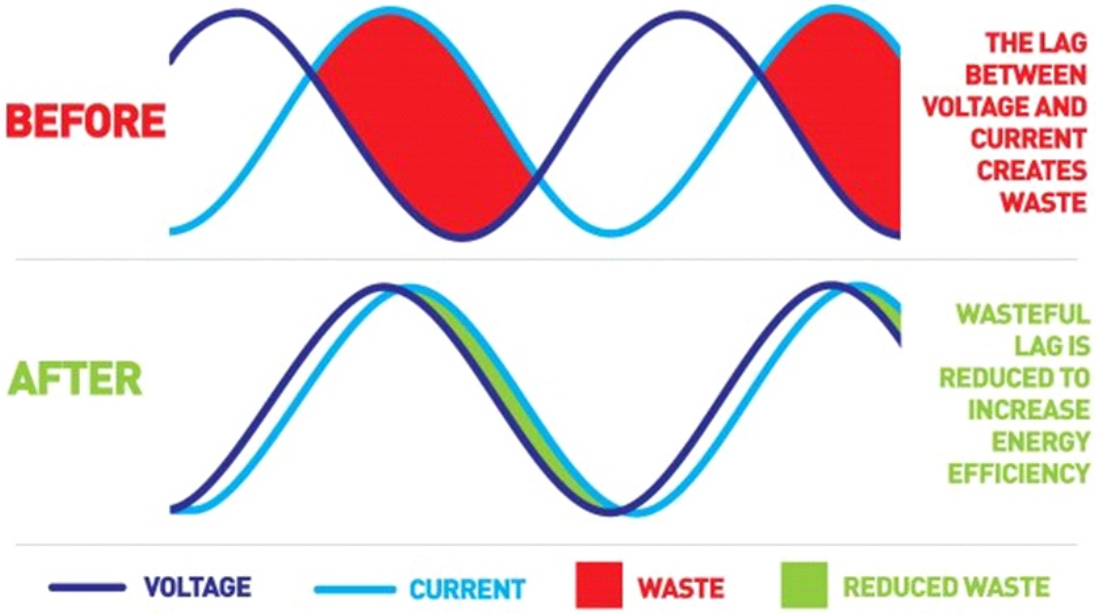


Figure 4.27 – Lag between Voltage and Current

Source:
(1. https://electricalapprentice.co.uk/power-factor-correction-what-is-it-why-is-it-required-how-is-it-achieved/
2. https://brightgreenconnect.com/resources/power_factor_correction
3. https://www.electrical-technology.com/2019/05/power-factor-correction.html)

Technical Description

Power factor measures how efficiently incoming power is used in an electrical installation. It is the ratio of Working Power to apparent power when:

- Working Power (P) = the power needed for useful work such as providing light or pumping water, expressed in Watt or KiloWatt (kW)
- Reactive Power (Q) = a measure of the stored energy reflected the source which does not do any useful work, expressed in var or Kilovar (kVAR)
- Apparent Power (S) = the sum of working and reactive power, expressed in Volt Amperes or in KiloVolt Amperes (kVA)

All motors that come in the form of a machine, such as conveyors, mixers, compressors, lifts and escalators, all have an efficiency rating known as a Power Factor. It is a measure of "efficiency" and has values ranging from 0 to 1, where one is 100% efficient. A bad power factor – is less than 0.95, resulting in more current required for the same amount of work.

Example:
At a power factor of 0.75, a single-phase induction motor uses 10 Amps of line current overall. In that case, 10 x 0.75 = 7.5 A will be the useful current. The motor's useable power is 230 x 7.5, or 1.725 kW. However, the motor's required total input power is 230 divided by 10, or 2.3 kVA.

So, without power factor correction, to achieve the required output of 1.725 kW (7.5 A), we have to supply a power of 2.3 kVA (10 A) to the motor. Also current of 10 A is flowing in the circuit, but only 7.5 A of that current produces valuable output. Hence, the burden on the system and utility bills increases due to poor power. Low power factors also negatively impact the environment due to wasted energy in transmission lines and generators and transformers consuming more fossil fuels and generating more pollution and higher costs. Power factor correction improves the electrical system's power factor near unity (1). It uses extra electrical equipment to absorb or supply reactive power to the circuit.

Achieved Environmental Benefits

- Reduced energy consumption.

Operational Data

The various methods of Power-factor improvement are:

- By using a capacitor bank.

In this method, a bank of capacitors is connected in parallel across the load. Since the capacitor takes maximum reactive power, the overall reactive power taken from the source decreases. Hence the system power factor improves. A control system usually monitors the system's power factor and switches the capacitor ON and OFF as per requirement.

- By using a synchronous condenser,

A 3-phase synchronous motor runs in overexcited mode, draws a maximum current and behaves as a capacitor. Hence, a synchronous condenser is nothing but an overexcited synchronous motor running without mechanical load (at No-load).

- By using phase advancer

This AC exciter is mainly used to improve the PF of an induction motor. It improves the power factor by providing exciting ampere turns to produce the required flux at the given slip frequency. They are mounted on the motor shaft and connected to the motor's rotor circuit. Suppose the power factor of the consumer's installation in any month is above 95%. In that case, the consumer will be entitled to a rebate at the rate of 0.5% (half percent) in excess of 95% power factor on the total amount of the electricity bill for that month under the head "Energy Charges" for every 1 % rise or part thereof in the average power factor during the month above 95%.

Cross Media Effects

No relevant cross-media effect is known.

Economics

Investment Cost	**Low**
Cost Indicative	**Investment (In Rupees)**
Very Low	< 1 Lakh
Low	< 10 Lakh
Moderate	10 - 20 Lakhs
High	20 - 50 Lakhs
Very High	> 50 Lakhs

Driving Force for Implementation

- Energy Saving
- Financial Benefits

Reference Industry

M/s. Akash Fashions Pvt. Ltd., Ahmedabad
M/s. Kankariya Textile Industries Pvt. Ltd, Ahmedabad

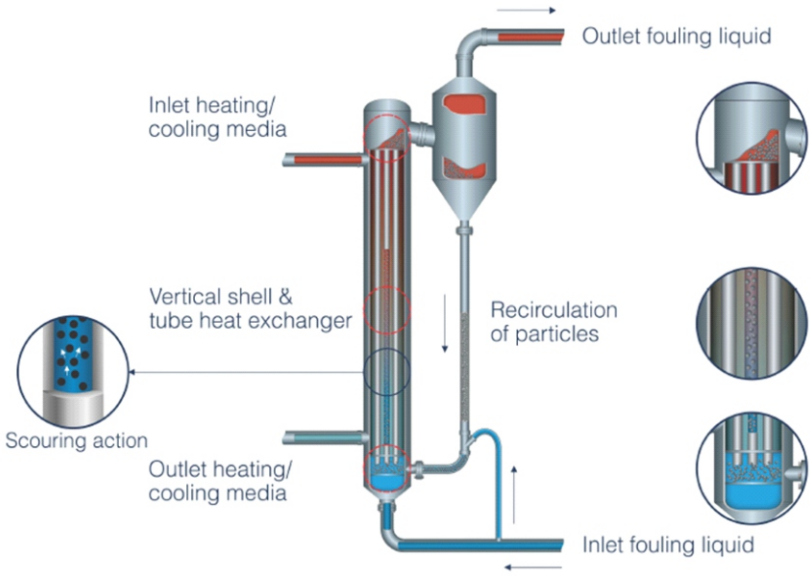


Figure 4.28 Shell and Tube Heat Exchanger

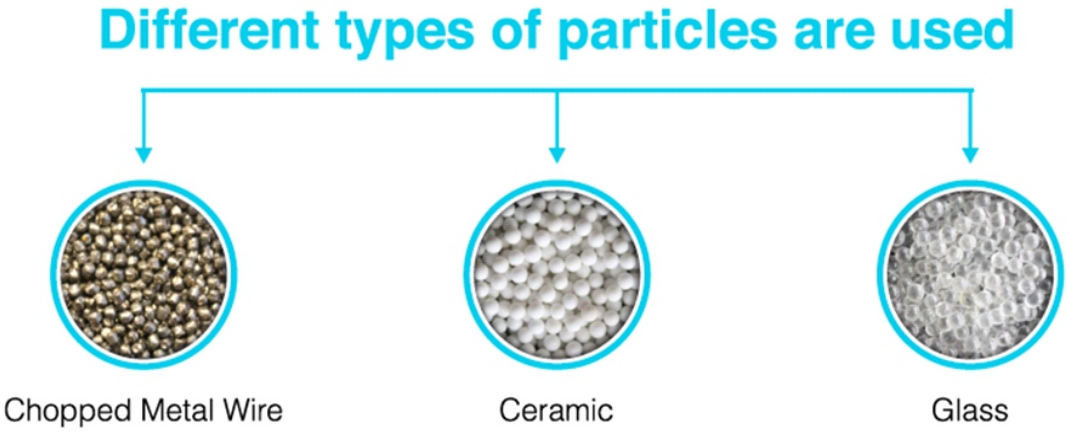


Figure 4.29- Different Packing used in Heat Exchanger

Source: https://www.lenntech.com/processes/Brine-Treatment/self-cleaningfluidized-bed-heat-exchanger.htm#ixzz7bXacSJuR

Technical Description

During wastewater heat transfer, the pollutants are concentrated in the heat exchanger of the evaporation system. This results in scaling on the inner heat exchanger surface and might even end up in blocking the heat exchanger pipes.

For shell and tube heat exchangers that experience fouling, an alternative to cleaning and redundancy can be to equip the heat exchanger with a self–cleaning system based on fluidized bed technology.

Consequently, system availability is reduced, and extensive manual cleaning efforts are necessary. In addition, the scaling reduces the efficiency of the evaporation system. Energy consumption is increased as well as the amount of evaporation residue.

As shown in figure 4.28, the self-cleaning heat exchanger reduces the scaling and blocking of pipes already during the evaporation process.

Achieved Environmental Benefits

- Reduction in thermal energy (preheated process water will require less steam for heating)
- Reduction in fuel consumption due to less steam demand in the process
- Reduction in wastewater temperature will enhance the efficiency of the wastewater treatment plant

Operational Data

Tiny ceramic balls in the heat exchanger act as grinding balls. Due to high flow rates inside the heat exchanger pipes, those grinding balls are circulated, reducing scaling reliably. Consequently, operating efforts are reduced since no extensive chemical and manual cleaning of the heat exchanger pipes is necessary.

The operating principle of the self-cleaning fluidized bed heat exchanger (refer to fig 4.29) is based on the circulation of cleaning particles through the tubes of a vertical shell and tube heat exchanger. The particles are fluidized by the upward flow of the liquid, where they create the mild scouring effect on the wall of the heat exchanger tubes, thereby removing any deposit at an early stage of fouling formation. After the tube bundle, the particles disengage from the liquid in the separator. They are returned to the inlet channel through an external downcomer, which repeats the cycle. A cyclone or gravity separator depends on the type of liquid in a sieve.

The random movement of particles gives:

- An impact with tube wall, removing the fouling layer
- A break-up of the boundary layer, increasing heat transfer
- A shear thinning effect, reducing the viscosity

To control the volume fraction of the particles in tubes, a part of the inlet flow to the heat exchanger is used to push the cleaning particles from the downcomer into the inlet channel of the heat exchanger. The cleaning particles used in the system are made of cut metal wire, ceramic or glass with diameters varying from 1.5 to 4 mm. The technology can be applied for new build heat exchangers as well as for the revamp of existing heat exchangers into a self-cleaning configuration.

Cross Media Effects

No relevant cross-media effect is known.

Economics

Investment Cost	Moderate
Cost Indicative	**Investment (In Rupees)**
Very Low	< 1 Lakh
Low	< 10 Lakh
Moderate	10 - 20 Lakhs
High	20 - 50 Lakhs
Very High	> 50 Lakhs

Driving Force for Implementation

- Financial benefits
- Resource conservation (Thermal Energy)

Reference Industry

None in Gujarat

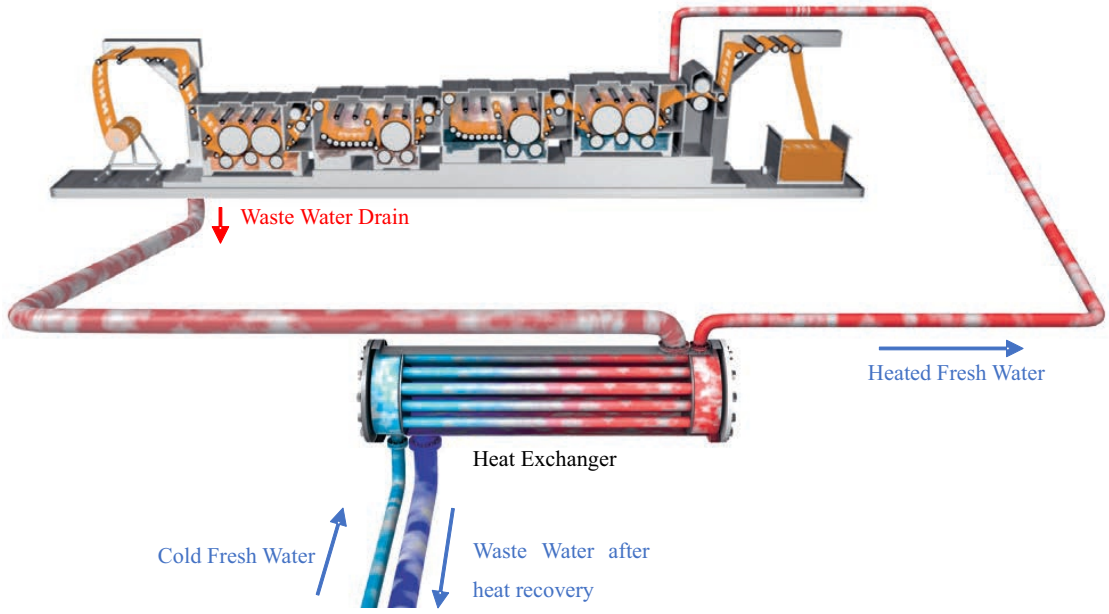


Figure 4.30 –Heat Recovery from Hot Wastewater in Continuous Process
Source: Based on Benninger – Brochure on Resource Management

Technical Description

Extensive hot washes are carried out in the textile finishing industries to wash impurities, undesired chemicals and unfixed dyes and pigments. Hot wastewater from these washes contains substantial thermal energy, costing millions of rupees annually.

These wastewater streams are discharged at a temperature of 60-95oC from various processes, given as follows:

- Desizing washing water
- Scouring and bleaching washing water
- Mercerization hot washing water
- Dyeing hot washing water discharge
- Continuous washing of cold pad batch-dyed fabric or fabric printed with reactive dyestuffs or vat dyes
- Hot washing water discharge from exhaust dyeing
- Washing water from soapers

Significant factors for evaluating the viability and effectiveness of heat transfer are the temperature and the flow of the stream under consideration. Thermal energy from wastewater streams can be recovered. It is not practicable to recover energy from all the wastewater streams, but there are a few streams from where energy can be recovered effectively.

The thermal energy of the hot washes can be recovered by installing plate-type or shell and tube type heat exchangers (shell and tube heat exchangers are a bit less efficient than plate-type heat exchangers but need much less maintenance). Hot washes are first collected in a small covered storage tank to

implement this option. It is then pumped into the heat exchanger while passing through the filter on the tube side, whereas fresh water, which will be heated and used as hot water in the process, flows on the shell side (in the case of shell and tube type heat exchanger). The freshwater is heated and used in the washings. Under such an arrangement, less steam will be required to heat the washing water up to the required temperature as it is already hot.

Also, hot wastewater from the machine can be directly fed into the heat exchanger while passing through the filter instead of first collecting in the storage tank and then pumped to the heat exchanger.



Figure 4.31 - Shell and tube Heat Exchanger installed at continuous Pre-treatment machine

Achieved Environmental Benefits

- Reduction in thermal energy (preheated process water will require less steam for heating)
- Reduction in fuel consumption due to less steam demand in the process
- Reduction in wastewater temperature will enhance the efficiency of the wastewater treatment plant

Operational Data

The energy contents of hot wastewater will vary from industry to industry. It depends upon the quantity and temperature of the wastewater. Before the exchanger, a well-designed fibres/fluff removal device will be installed to protect the exchanger against clogging and malfunctioning. Tube and shell heat exchangers need much less maintenance as they clog much more slowly, whereas plate heat exchangers tend to clog rapidly.

The hot wastewater discharge pipeline will be connected to the tube side of the heat exchanger via a rotary filter or strainer (for shell and tube heat exchanger). The filter will be necessary to remove the fluff coming from the wastewater. Daily filter cleaning will be essential for the effective operation of the heat exchanger. The freshwater line will be connected to the shell side of the exchanger. The outlet of the fresh hot water can be connected to different machines or hot water storage tanks for use at different places.

Cross Media Effects

No relevant cross-media effect is known.

Economics

Investment Cost	**Moderate**
Cost Indicative	**Investment (In Rupees)**
Very Low	< 1 Lakh
Low	< 10 Lakh
Moderate	10 - 20 Lakhs
High	20 - 50 Lakhs
Very High	> 50 Lakhs

Driving Force for Implementation

- Financial benefits
- Resource conservation (Thermal Energy)

Reference Industry

M/s. Akash Fashions Pvt. Ltd., Ahmedabad

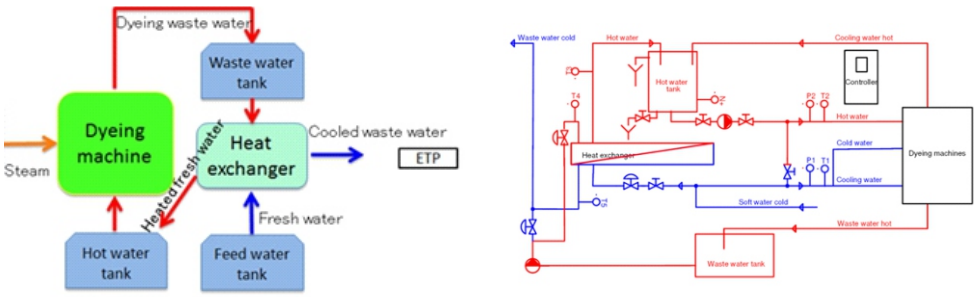


Figure 4.32 – Common Heat Recovery System Layout
Source: http://gec.jp/jcm/projects/p_archive/14fs_ban_01/

Technical Description

In the textile processing industry, many jigger machines are used for various operations that need hot water at about 85^{0}C. The hot water is used to perform hot washes to wash impurities, undesired chemicals and unfixed dyes and pigments. Hot wastewater from these washes contains a substantial amount of thermal energy, which can be recovered with the help of a heat recovery system. Hence, a common heat exchanger across the industry can be placed to recover heat from all jigger machines. But, the placement of heat exchangers at an individual unit is costly. The figure 4.32 shows the schematic of the Common Heat Recovery System that can be made.

Achieved Environmental Benefits

- Reduction in thermal energy (preheated process water will require less steam for heating)
- Reduction in fuel consumption due to less steam demand in the process
- Reduction in wastewater temperature will enhance the efficiency of the wastewater treatment plant

Operational Data

Before the exchanger, a well-designed fibres/fluff removal device will be installed to protect the exchanger against clogging and malfunctioning. A highly effective heat recovery module that allows heat recovery from wastewater to make hot water can be added to the water supply system, as illustrated in the figure to feed textile machines with hot water. Optionally, the system can be supplied with a cold-water module. The line pressure can be constantly supervised by the controller and regulated by the increasing or decreasing pump speed depending on the pressure measured.

Cross Media Effects

No relevant cross-media effect is known.

Economics

Investment Cost	Moderate
Cost Indicative	**Investment (In Rupees)**
Very Low	< 1 Lakh
Low	< 10 Lakh
Moderate	10 - 20 Lakhs
High	20 - 50 Lakhs
Very High	> 50 Lakhs

Driving Force for Implementation

- Financial benefits
- Resource conservation (Thermal Energy)

Reference Industry

None in reference plants

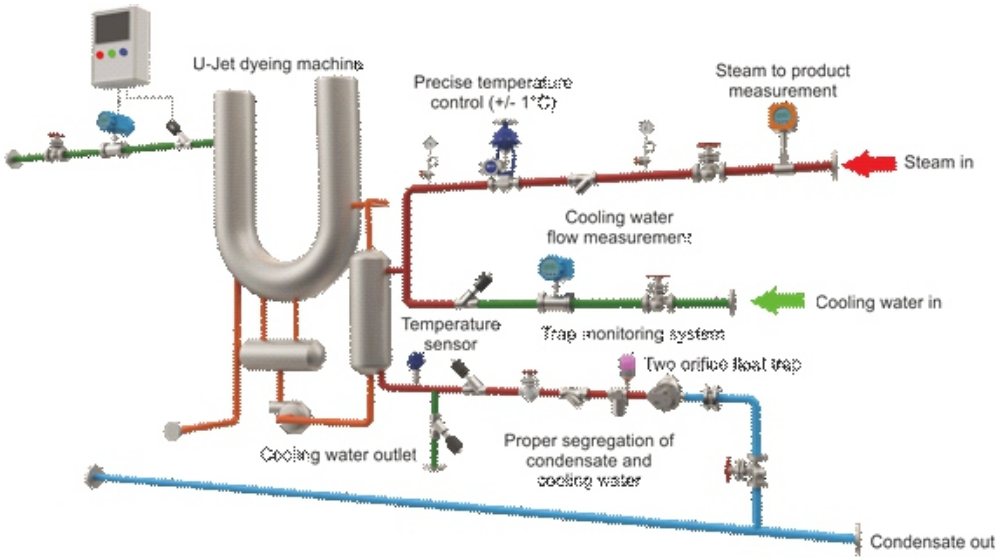


Figure 4.33- Schematic representation of Utility in Jet Dyeing Machine
Source: Forbes Marshall

Technical Description

In the polyester textile finishing industries, dyeing of the polyester fabric or polyester part of the blended fabric is carried out at a higher temperature of about 130°C in the jet dyeing machines. After completion of the dyeing process, the temperature of the dye bath is reduced to about 80°C by circulating the hot dye bath through the heat exchanger (attached with the dyeing machine- See Figure 4.3). The hot dye bath transfers its heat to the freshwater, which gets warm. The heat exchanger's warm, clean cooling water, which has a temperature between 50 and 60 degrees Celsius, is discharged in the drain.

Achieved Environmental Benefits

1. Water conservation
2. Reduction in the hydraulic load of the wastewater treatment plant

Operational Data

Each dyeing machine's cooling water discharge line can be connected to the new pipeline for reuse. The cooling water will be sent to the storage tank through a small covered collection pit. The pump will connect the small pit to the hot water storage tank. The water supply will be through an already installed hot water supply pipeline for reusing this warm water in the dyeing machines. Whenever hot water is required in the process, the hot water valve will be opened, and the machine will be filled with warm or hot water. In this way, water heating time and energy will be saved.

Cross Media Effects

No relevant cross-media effect is known.

Economics

Investment Cost	Moderate
**Cost indicative for one VFD instrument*	
Cost Indicative	**Investment (In Rupees)**
Very Low	< 1 Lakh
Low	< 10 Lakh
Moderate	10 - 20 Lakhs
High	20 - 50 Lakhs
Very High	> 50 Lakhs

.Driving Force for Implementation

- Financial benefits
- Resource conservation (Fresh water and Thermal energy (less steam will be required for heating collected warm water as hot process water)
- Sustainability of textile business

Reference Industry

Majorly all reference units of the Surat cluster are utilizing this technique.

Technique 26: Minimisation of energy consumption of stenter frames and dryers.

Technical Description

Stenters are mainly used in textile finishing for heat-setting, drying, thermosol processes and finishing. It can be roughly estimated that, in fabric finishing, each textile substrate is treated on average 2.5 times in a stenter.

The main energy requirements need for a stenter are for air heating and evaporation. Therefore, the fabric moisture content should be minimised before the fabric enters the stenter and the exhaust airflow within the oven is reduced.

Achieved Environmental Benefits

- Savings in energy consumption
- Minimisation of emissions associated with energy production

Operational Data

Energy savings in stenters can be achieved by applying the following techniques.

a) Mechanical dewatering of the fabric

The water content on of the incoming fabric can be minimised using mechanical dewatering equipment such as centrifugation, vacuum extraction systems, optimised squeezing rollers, etc. (the latter is less efficient but less energy-consuming). Up to 15 % energy savings in the stenter (depending on the type of substrate) can be obtained if moisture content of the fabric is reduced from 60 % to 50 % before it enters the stenter.

For synthetic fibres, vacuum extraction achieves approximately 20 % better dewatering efficiency compared to squeezing rollers; the opposite is true for cotton fibres, where squeezing rollers prove more efficient

b) Wet-on-wet dyeing or finishing

Dyestuff or finishing liquor is applied directly to the wet fabric, thus avoiding the need for an intermediate drying step.

c) Optimising exhaust airflow

Exhaust airflow optimisation is another determining factor. Many stenters are still poorly controlled, relying on manual exhaust adjustment and operator estimation of fabric dryness. For optimum performance, exhaust humidity is maintained between 0.1 kg and 0.15 kg water/kg of dry air. It is not unusual to find It is not unusual to find that less efficient stenters have with an exhaust humidity of only 0.05 kg water/kg of dry air, indicating that the exhaust volume is too high and excessive energy is being

used to heat air. Energy consumption for air heating can reach up to 60 % of the total energy consumption requirement, if the airflow is not monitored.

Equipment is available (dampers and variable-speed fans) which will automatically adjust the exhaust airflow according to the moisture content of the exhaust air or according to the moisture content or temperature of the fabric after the process. A reduction of fresh air consumption from 10 kg fresh air/kg of textile to 5 kg fresh air/kg of textile results in a 57 % energy saving. The exhaust dampers are partially or fully closed during idling time (changing of batches, etc.).

d) Insulation

Proper insulation of stenter encasement reduces heat losses to a considerable extent. Savings in energy consumption of 20 % can be achieved if the insulation thickness is increased from 120 mm to 150 mm (provided that the same insulation material is used).

The insulation of end sections of cylinder dryers can reduce heat waste, thereby saving fuel. This measure, however, is more practical for cylinders with a diameter of one metre or more. This may not be practicable for small diameter cylinders since the steam pipe, condensate pipe and safety valve get in the way.

e) Optimised air circulation

The circulation of hot air within the stenter is optimised: the number of air injection nozzles is adapted to the width of the fabric, the distance between nozzles and fabric is as short as possible, and the pressure drop caused by the stenter internal components is as small as possible.

f) Avoiding over-drying

Fibres have a natural moisture level (see) below which it is useless to dry them. It is therefore important to monitor the moisture content of the fabric and to adapt the residence time of the fabric in the stenter/dryer so that the natural moisture level is not exceeded. Hand-held moisture meters can be used with a roller sensor to monitor the moisture content of fabrics leaving the stenters or drying cylinders.

Table 4.4 - Natural moisture level of some fibres

Fibre	Natural moisture level (%)
Cotton	7
Wool	16-18
Viscose	12.5
Triacetate	4.5
Nylon 6.6	4.3
Nylon 6	4.4
Polyester	0.4
Acrylic	1.5
Polypropylene	0

Source: EU BREF 2022

g) Instrumentation and control of the stenters

The stenter operation and the energy consumption are optimised by measuring and controlling the following parameters:

- Exhaust air humidity, in order to load exhaust air most efficiently with humidity; this reduces the volume of hot exhaust air, and thus energy losses, dramatically;
- Residual moisture of the fabric to avoid overdrying and overheating of fabric;
- Fabric and air temperature; several fabric temperature sensors placed inside the stenter along with the fabric provide a good system for the supervision and optimisation of heat treatment processes, mainly for controlling the residence time of the fabric in the stenter.

h) Optimal scheduling of batches

Careful scheduling of fabric batches arriving at the stenters or cylinder dryers can reduce idling time, thereby saving energy. Proper scheduling in finishing minimises machine stops and heating-up/cooling-down steps and is therefore a prerequisite for energy saving.

i) Avoiding loss of latent heat in cylinder dryers

The cylinder dryers are regularly maintained to avoid steam leaks. The condensate is recovered and returned to the boiler. In addition, flash steam produced when condensate is reduced to atmospheric

pressure can be recovered as low-pressure steam, and used to heat water or other low-pressure steam processes.

Cross Media Effects

None identified.

Economics

The cost depends on the no of techniques applied and whether the it is new plant or existing plant. Due to retrofitting in an existing plant, the overall cost will be higher in the existing plant compared to the new plant.

Driving Force for Implementation

Minimisation of energy consumption (and therefore costs) is the main reason to retrofit optimised stenter technology.

Reference Industry

Many reference plants across Gujarat are practising techniques for minimizing energy consumption in the stenter frames.

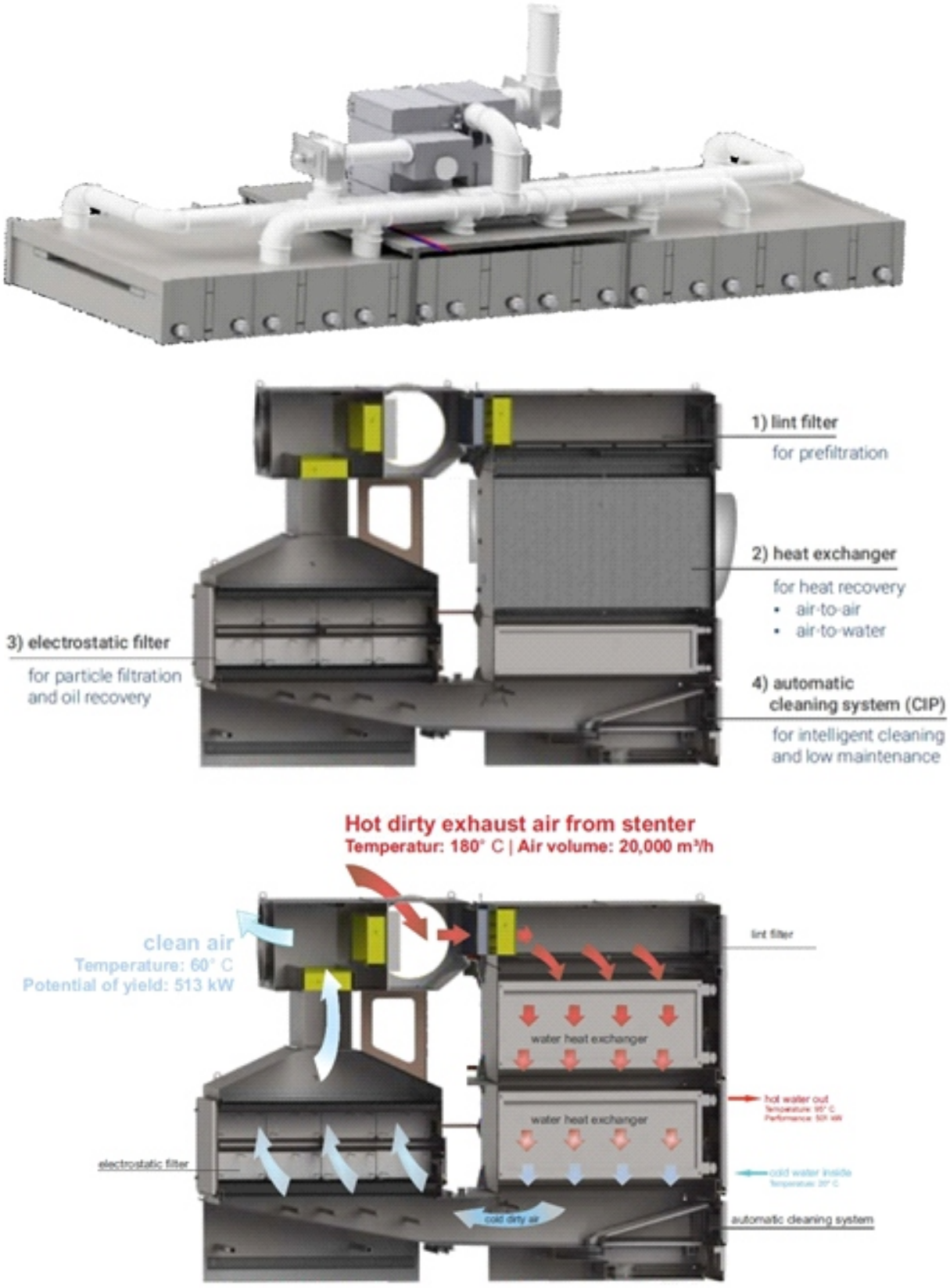


Figure 4.34 – Stenter with Heat Recovery Unit

Technical Description

Energy recovery is an effective instrument to reduce operating costs in the textile industry. Stenter frames can be operated with more than 200°C temperatures depending on production mode or fabric type. The stenter requires high energy consumption for its operation – usually by cost-intensive gas or thermal oil heating.

The valuable waste heat from the stenter can be energy efficiently reused. The integrated heat exchanger systems can recover the process heat from the stenter. The recovered heat is then used for follow-up processes:

It can heat the supply air (e.g., for the stenter frame) and/or heat water (e.g., for the washing water in the dyeing mill).

Achieved Environmental Benefits

- Reduction in thermal energy (preheated process water/air will require less team/thermal oil for heating)
- Reduction in reduction in fuel consumption due to less steam/thermal oil demand in the process

Operational Data

As shown in the figure 4.34, the heat recovery system consists of three major modules:

1. **Pre-filtration – lint separation**

Processing rough materials from coarsely woven fibres usually creates high amounts of lint ball particles. Here, a pre-filtration of the exhaust air is imperative.

2. Heat recovery by highly efficient heat exchangers

In an integrated heat exchanger system, recovery of the process heat is made possible, in addition to air purification. The recovered heat from the exhaust air heat can be used afterwards for follow-up processes (e. g. air or water heating).
A cross-flow heat exchanger (air-to-air operation mode) or liquid/air heat exchangers for heating up liquids like water can be used to pre-heat supply air.

3. Particle filtration and oil recovery by high-performance electrostatic precipitators

Electrostatic filter cells ensure the highly effective smoke, dust and fine mist separation.

It can also provide an automatic cleaning system to clean all integrated filter media, such as

electrostatic collection cells or heat exchanger units.

Cross Media Effects

No relevant cross-media effect is known.

Economics

Investment Cost	Moderate
Cost Indicative	**Investment (In Rupees)**
Very Low	< 1 Lakh
Low	< 10 Lakh
Moderate	10 - 20 Lakhs
High	20 - 50 Lakhs
Very High	> 50 Lakhs

Driving Force for Implementation

- Financial benefits
- Resource conservation (Thermal Energy)

Reference Industry

M/s. Arvind Ltd. (Santej Unit), Ahmedabad

4.1.4. Process Optimization and Equipment Modification

Sr. No.	Technique Name
1.	Mechanical Dewatering of the Fabric
2.	Replacement of Open Jigger with Closed Maxi Jigger
3.	Installation of Temperature Controller in Processing Machine
4.	Residual Moisture control in Drying Cylinders
5.	Automated Colour Kitchen for Dyeing Section
6.	Automation in Jet Dyeing and Drum Machine
7.	Airflow Jet Dyeing Machine
8.	Cold Pad Batch Dyeing
9.	Continuous dyeing processes (Pad-Steam/ PAD-DRY and PAD-STEAM process)
10.	Automated Colour Kitchen for Printing Section
11.	Digital Printing

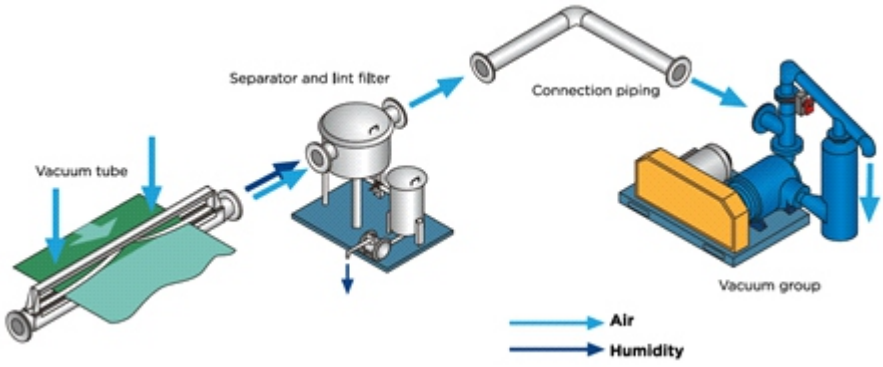


Figure 4.35 – Unbound Moisture Removal Vacuum System

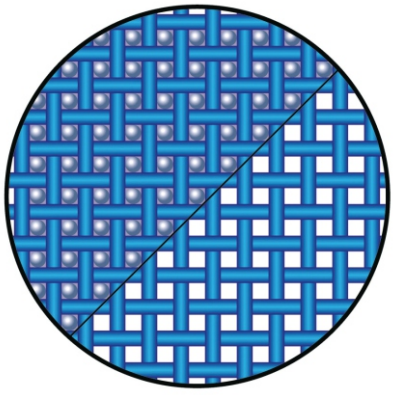


Figure 4.36 – Unbound Residual Moisture

Technical Description

The fabric has two kinds of humidity in it, bound and unbound moisture (See figure 4.36).

Bound moisture:

- It is absorbed into the fibre interior.
- A mechanical system cannot eliminate it.
- It can only be reduced by thermal drying over a prescribed period.

Unbound moisture:

- Is captured within the fabric interstices.
- Mechanical systems can eliminate it.

In the textile industry, the standard way to eliminate unbound moisture in a wide roll of fabric has traditionally been using squeeze rollers, also known as foulard or padders.

Contrary to squeeze roller systems, vacuum systems use a determined air speed at a vacuum level to remove humidity which does not cling to the fibres.

The vacuum technology fulfils the function of extracting moisture from the fabric.

Achieved Environmental Benefits

- Energy savings in the drying process

Operational Data

The vacuum level varies according to the specified characteristics of every fibre. For example, hydrophilic fibres need a higher vacuum level than synthetic ones.

The system can be installed between wash boxes to provide more efficient separation of baths,

avoiding the transportation of contaminants from the preceding washing box.

It can also be used before the cylinder drying range to increase drying speed and decrease steam consumption.

Cross Media Effects

No relevant cross-media effect is known.

Economics

Investment Cost	**High**
Cost Indicative	**Investment (In Rupees)**
Very Low	< 1 Lakh
Low	< 10 Lakh
Moderate	10 - 20 Lakhs
High	20 - 50 Lakhs
Very High	> 50 Lakhs

Driving Force for Implementation

- Financial benefits
- Energy conservation

Reference Industry

None in the reference plant



Figure 4.37 – Open Jiggur



Figure 4.38: closed maxi Jiggur

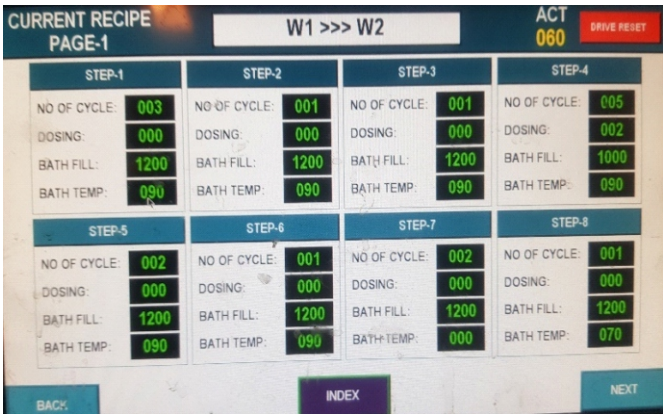


Figure 4.39 – PLC on Maxi-Jiggur

Technical Description

Jigger machines have been used for decades, and many changes have been made to simplify or ease the dyeing process. For processes including scouring, bleaching, and dyeing, open jigger machines are still used by major industries. This open jigger can be substituted with a maxi-type jumbo jigger machine.

Achieved Environmental Benefits

- Water conservation
- Reduction in thermal energy (closed space will ensure optimum steam for heating)

Operational Data

The Maxi Jigger's top is covered, reducing heat loss to the atmosphere, maintaining an even temperature throughout the fabric, and reducing the time of the liquor and the fabric exposure to the air.

The following parameters are controlled by the fully automated Maxi Jigger machine.,

- Tension adjustment,
- Fabric speed and metering,
- Smooth and jerk-free start and stop,
- Counters for the number of spins,
- Automatic temperature control, etc.

These automated functions decrease processing time and manual errors.

Cross Media Effects

No relevant cross-media effect is known.

Economics

Investment Cost	**Moderate to High**
Cost Indicative	**Investment (In Rupees)**
Very Low	< 1 Lakh
Low	< 10 Lakh
Moderate	10 - 20 Lakhs
High	20 - 50 Lakhs
Very High	> 50 Lakhs

Driving Force for Implementation

- Financial benefits
- Resource conservation (Fresh water and Thermal Energy)
- Sustainability of textile business

Reference Industry

M/s. Mukesh Industries Pvt. Ltd., Ahmedabad
M/s. Kankariya Textile Industries Pvt. Ltd., Ahmedabad

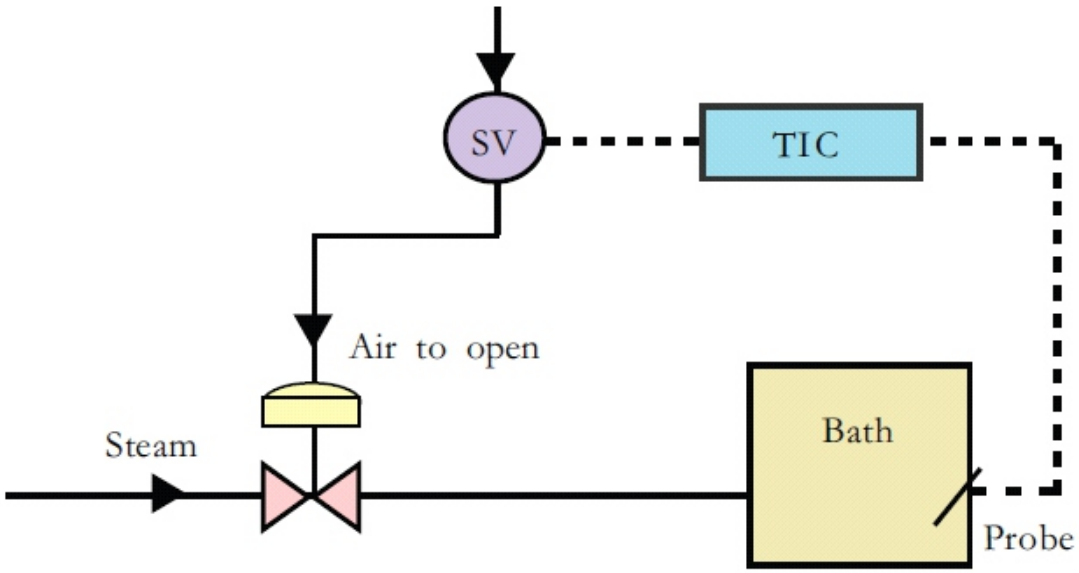


Figure 4.40 - Schematic diagram of TIC controller for processing

Technical Description

In textile processing, many machines, viz., washers, jiggers, etc., need hot water at about 85^{0}C. The heating of water takes place by direct injection of steam. If the temperature monitoring is done manually, the water bath temperature can reach upto 95^{0}C, resulting in excess steam consumption. If the bath temperature can be auto-controlled, substantial savings in steam quantity can be achieved.

Achieved Environmental Benefits

- Reduction in thermal energy (hot water will require less steam for heating, in case if Temperature is controlled in hot washes)

Operational Data

The Temperature Indicating Controller (TIC) is set to a temperature of 85^{0}C. When the bath temperature exceeds 85^{0}C, a signal is sent to the steam control valve to close the valve. The probe continuously senses the temperature of the bath, and the steam control valve is accordingly regulated.

Cross Media Effects

No relevant cross-media effect is known.

Economics

Investment Cost	Very Low*
*Cost indicative of one TIC instrument	
Cost Indicative	**Investment (In Rupees)**
Very Low	< 1 Lakh
Low	< 10 Lakh
Moderate	10 - 20 Lakhs
High	20 - 50 Lakhs
Very High	> 50 Lakhs

Driving Force for Implementation

- Financial benefits
- Resource conservation (Thermal Energy)
- Sustainability of textile business

Reference Industry

M/s. Mukesh Industries Pvt. Ltd., Ahmedabad
M/s. Akash Fashions Pvt. Ltd.,Ahmedabad
M/s. Kankariya Textile Industries Pvt. Ltd., Ahmedabad

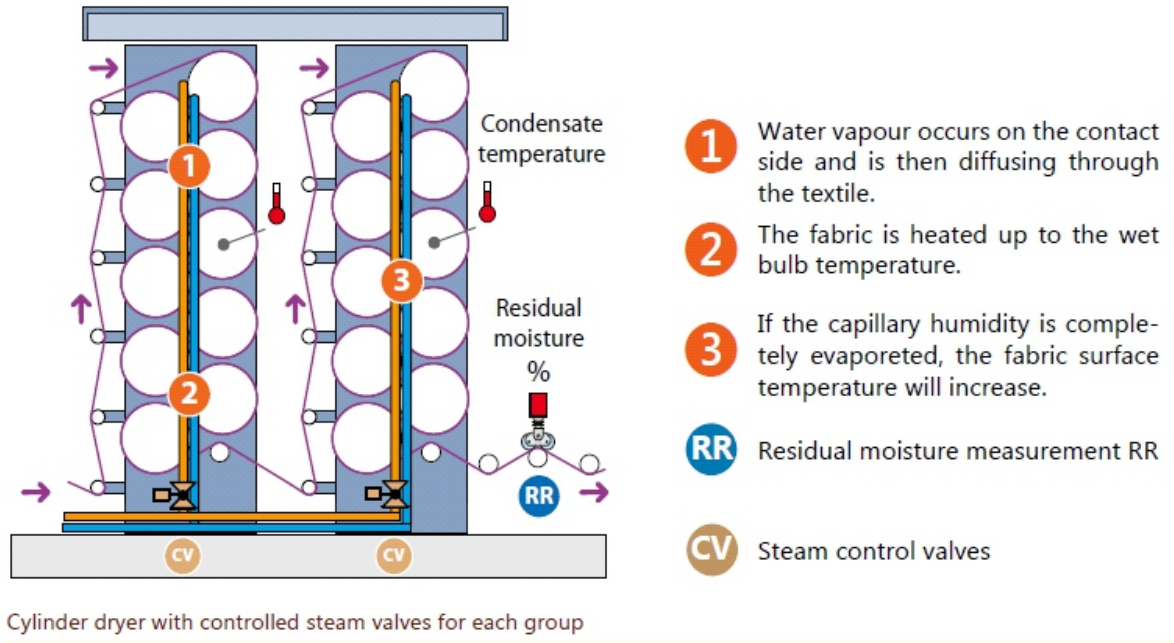


Figure 4.41 - PLC controller for Vertical Drying Range
Source: Cintex AG

Technical Description

The Drying Range or **VDR** (Vertical Drying Range) is one of the most widely used processing machinery in woven dyeing & printing units. While integrating a drum dryer into a continuous open with range (CBR, washing, mercerizing, pad steam, etc.) the number of drums is always determined by the highest speed combined with the heaviest fabric. It implies that all fabric, regardless of their GSM, goes through the same drying capacity leading to continuous steam loss and over-dried fabric.

Because cotton fabric is often dried in cylinder dryers, the over-dried fabric absorbs moisture from the air due to its hygroscopic nature. The normal moisture content of cotton is 8.5 per cent; if exposed to a very moist environment, this value may even rise. Consequently, the outer layers of the fabric roll on the trolley may have moisture of probably 10 per cent, whilst the core of the batch remains over-dried with zero per cent residual moisture.

Uncontrolled drying leads to higher energy consumption than the theoretical requirement to evaporate the moisture on the fabric. And, residual moisture gap can also lead to uneven dyeing in Cold Pad Batch application.

A fabric residual moisture controller can be provided at the exit of the drying range. The controller's feedback either controls the machine's speed or steam flow (depending on the process requirement).

Achieved Environmental Benefits

- Reduction in thermal energy (preheated process water will require less steam for heating)
- Reduction in fuel consumption due to less steam demand in the process

Operational Data

The cylinder dryer's controller can control the drying process by varying the steam valve position according to the condensate temperature of the dry cans and depending on the residual fabric moisture at the outlet.

The control loops control the cylinder dryer steam valves. It acts as an overlapping control loop on the set value of the last steam valve. The required energy is regulated as a function of the condensate temperature by controlling the continuous steam valves. The desired degree of drying is determined with the residual moisture measurement.

Cross Media Effects

No relevant cross media effect is known.

Economics

Investment Cost	**Low**
Cost Indicative	**Investment (In Rupees)**
Very Low	< 1 Lakh
Low	< 10 Lakh
Moderate	10 - 20 Lakhs
High	20 - 50 Lakhs
Very High	> 50 Lakhs

Driving Force for Implementation

- Financial benefits
- Resource conservation (Thermal Energy)

Reference Industry

None in the reference plant.

Dyeing kitchen

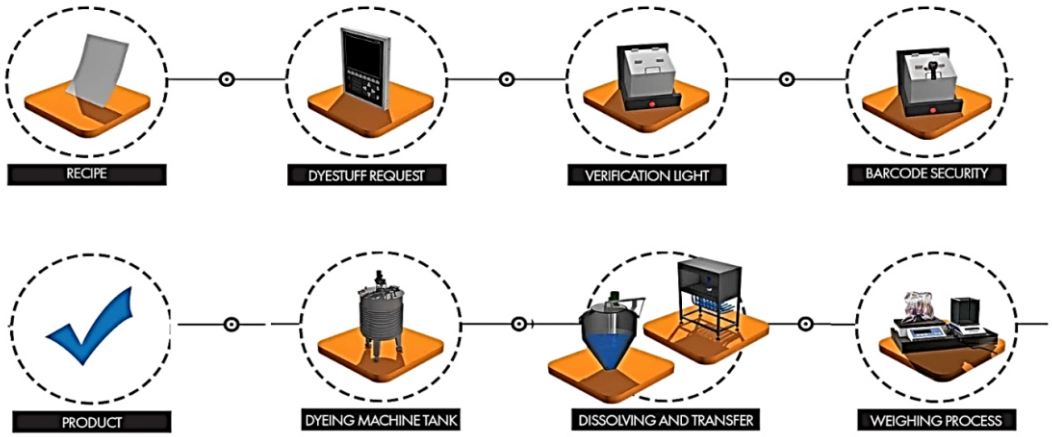


Figure 4.42 Steps in Automated Dyeing Section



Figure 4.43 –Automated Dyeing System
(Source: https://eliar.com/en/paternoster-and-tbt-powder-dyestuff-weighing-system/)

Technical Description

Dyeing right the first time is mandatory to hold down costs, meet customer deliveries, avoid uncontrolled weighing mistakes, and avoid waste of products (both for chemicals, auxiliaries and powder dyes).

The current procedure comprises a manual labour process. The dye liquor is mixed with manual stirring. Manual intervention leads to many manual errors, resulting in loss of time, chemicals, and manpower.

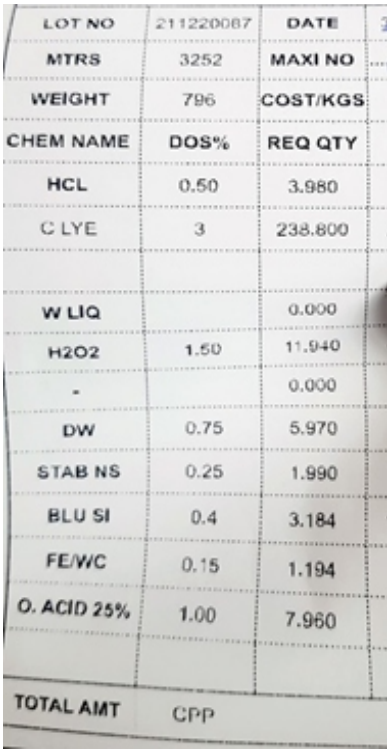
The automated dosing technology is meant to replace old and inefficient dosing methods that would never allow for safe, fast, and accurate dosing.

Achieved Environmental Benefits

- Reduction in Chemical Usage and Wastage
- Reduction in effluent concentration load will enhance the efficiency of the wastewater treatment plant

Operational Data

The dyehouse automation system consists of dyestuff and chemical dispensing, weighing, dissolving, and dispensing lines, and salt and soda mixing storage and dispensing systems.



LOT NO	211220087	DATE
MTRS	3252	MAXI NO
WEIGHT	796	COST/KGS
CHEM NAME	DOS%	REQ QTY
HCL	0.50	3.980
C LYE	3	238.800
W LIQ		0.000
H2O2	1.50	11.940
-		0.000
DW	0.75	5.970
STAB NS	0.25	1.990
BLU SI	0.4	3.184
FE/WC	0.15	1.194
O. ACID 25%	1.00	7.960
TOTAL AMT	CPP	

Figure 4.44 - Barcode Scanned Recipe from automated Kitchen

Cross Media Effects

No relevant cross-media effect is known.

Economics

Investment Cost	High to Very High
Cost Indicative	**Investment (In Rupees)**
Very Low	< 1 Lakh
Low	< 10 Lakh
Moderate	10 - 20 Lakhs
High	20 - 50 Lakhs
Very High	> 50 Lakhs

Driving Force for Implementation

- Financial benefits
- Resource conservation (Chemicals)

Reference Industry

Semi-Automated Dye house

M/s. Mukesh Industries Pvt. Ltd., Ahmedabad

Fully Automated Dye house

M/s. Arvind Ltd. (Santej Unit), Ahmedabad



Figure 4.45 – Batch Controller for Jet Dyeing Machine

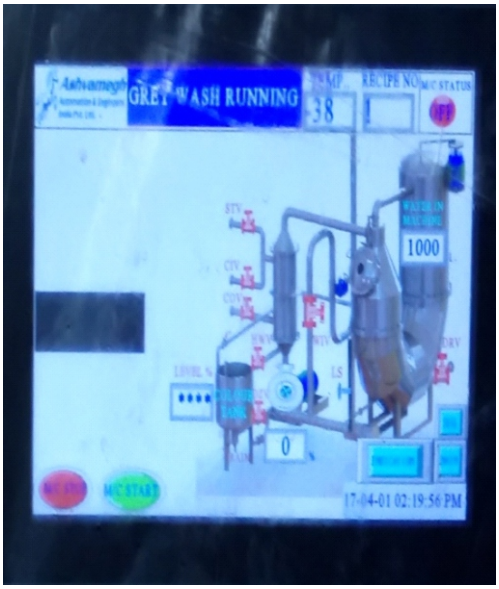


Figure 4.46 –PLC controller installed on Jet Dyeing Machine

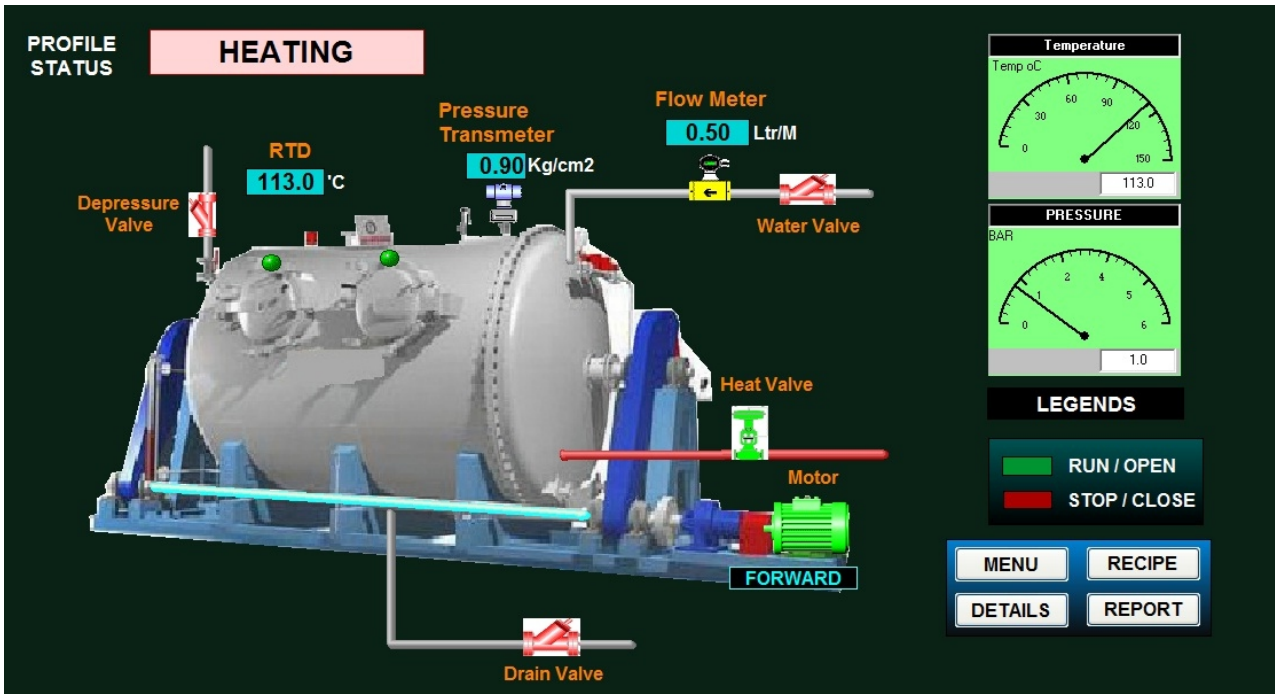


Figure 4.47 – PLC Controller installed on Drum Machine

Technical Description

Polyester Textile processing units are equipped with jet dyeing machines and drum machines, most of which are operated manually. It is used for dyeing the cloth by forcibly contacting the jet flow of the dyestuff chemical. It is done so that the cloth gets dyed evenly with relatively fewer chemicals without applying much tension to keep the fabric's quality intact.

The steam is used to raise the temperature of the dyeing solution through the heat exchanger. This process undergoes both the heating and cooling cycle. This operation is carried out manually, and the

batch time varies according to the operator's expertise. Furthermore, the competence level of each operator affects how much water and chemicals are needed to finish the procedure. An automation and control system can be installed in the jet dyeing machine to reduce the wastage of utilities, including steam, water and chemicals.

Achieved Environmental Benefits

- Reduction in thermal energy (controlled use of steam will reduce wastage of steam)
- Reduction in fuel consumption due to less steam demand in the process
- Reduction in the hydraulic load of wastewater will enhance the efficiency of the wastewater treatment plant

Operational Data

The Dyeing Machine Automatic Operation Programmer is widely used to regulate temperature, water, and chemicals. These programmers possess a high level of accuracy and are acclaimed for their durable standards and rugged construction.

Cross Media Effects

No relevant cross-media effect is known.

Economics

Investment Cost	**Very Low to Low***
**Cost indicative of PLC per machine*	
Cost Indicative	**Investment (In Rupees)**
Very Low	< 1 Lakh
Low	< 10 Lakh
Moderate	10 - 20 Lakhs
High	20 - 50 Lakhs
Very High	> 50 Lakhs

Driving Force for Implementation

- Financial benefits
- Resource conservation (Fresh water, Chemicals and Thermal Energy)

Reference Industry

Many reference plants have installed PLC on Drum and Jet Dyeing machine.

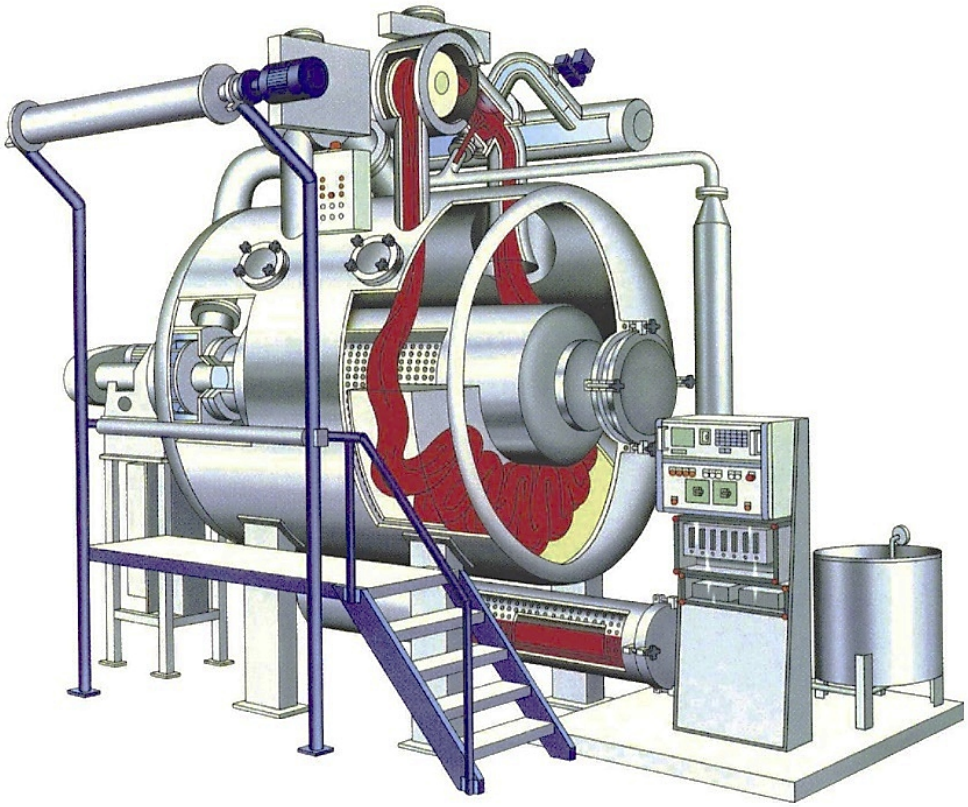


Figure 4.48 – Schematic of Airflow Jet Dyeing Machine
(Source: https://fongs.eu/site/assets/files/1055/then_synergy_eng_2017-1.pdf)

Technical Description

A jet dyeing machine is used to dye polyester fabric with disperse dyes. In these machines, the fabric and the dye liquor are in motion, facilitating faster and more uniform dyeing. In a jet dyeing machine, there is no fabric drive reel to move the fabric. The fabric movement by only the force of water.

Air Dyeing is a revolutionary method of dyeing that causes minimum harm to the environment. The innovation in the jet dyeing machines uses air instead of dyed liquor as a transport medium for piece goods, and this reduces the consumption of chemicals and water to a great extent. The Air Dye process is 2-sided, and the hand feel of the finished fabric is luxurious and clean.

Achieved Environmental Benefits

- Water conservation
- Reduction in thermal energy (airflow machine requires less steam)
- Reduction in fuel consumption due to less steam demand in the process
- Reduction in the hydraulic load of the wastewater treatment plant

Operational Data

As shown in figure 4.48, the air suction pipe, designed as a filter, is in the centre of the dyestuff vessel. The blower and the airline, which leads to the transport nozzle, can be seen in the background. The fabric

skein is drawn off from the dyestuff vessel by the winder, fed to the nozzle line and then returned to the storage chamber via the cutter.

In the airflow dyeing machine, dyeing liquor is first atomized, mixed with high-pressure airflow, and then sprayed on fabric to be dyed. Because water serves as a solvent of dyeing liquor and the dye chemicals directly contact the fabric, only a little water is consumed. Compared with overflow dyeing machines, airflow dyeing machines have the merits of high efficiency, energy saving, and environmental protection.The basic principle underlying the aero-dynamic system is that the fabric passes through an air-steam mixture emitted from a blower. The material is in constant motion from feeding to the end of the process and during drainage and filling procedures. This means that contrary to a hydraulic dyeing machine, neither a dye bath nor an aqueous medium is needed for fabric transport. In other words, the fabric passage is possible without liquor.

Cross Media Effects

No relevant cross-media effect is known.

Economics

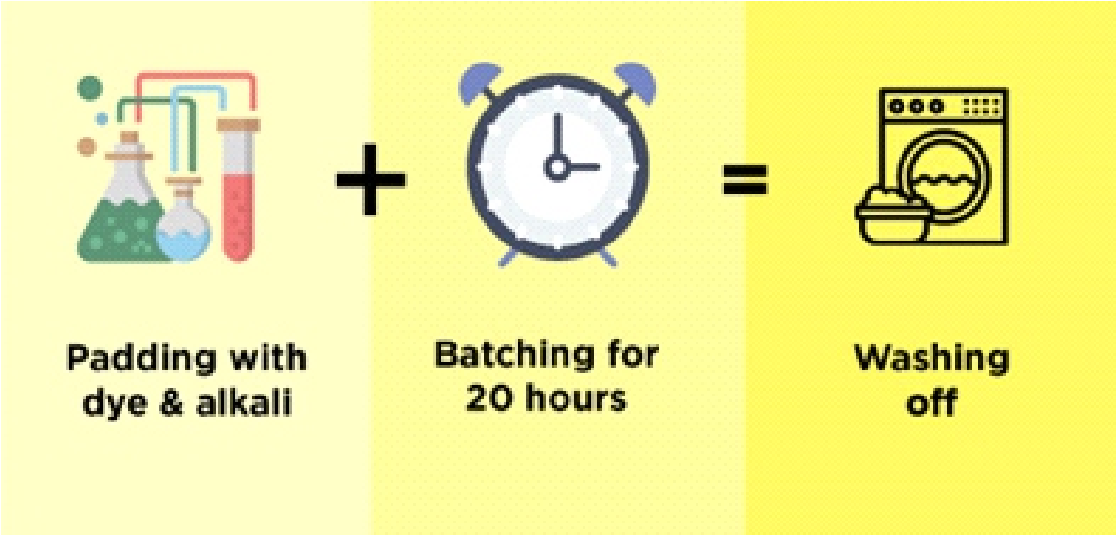
Investment Cost	**Very High**
Cost Indicative	**Investment (In Rupees)**
Very Low	< 1 Lakh
Low	< 10 Lakh
Moderate	10 - 20 Lakhs
High	20 - 50 Lakhs
Very High	> 50 Lakhs

Driving Force for Implementation

- Financial benefits
- Resource conservation (Fresh water, Chemicals and Thermal Energy)
- Sustainability of textile business

Reference Industry

M/s. Durga Processors Pvt. Ltd., Surat
M/s. Siddhivinayak Knots and Prints Pvt. Ltd., Surat



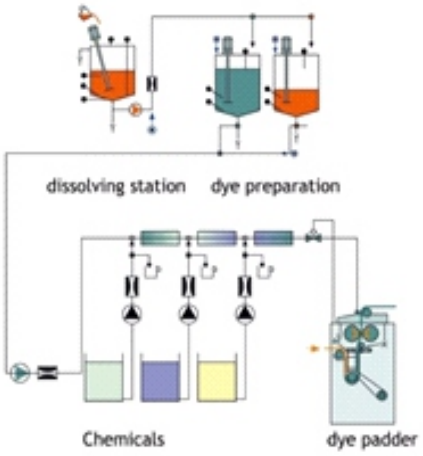


Figure 4.49 – Dosing System for CPB Dyeing

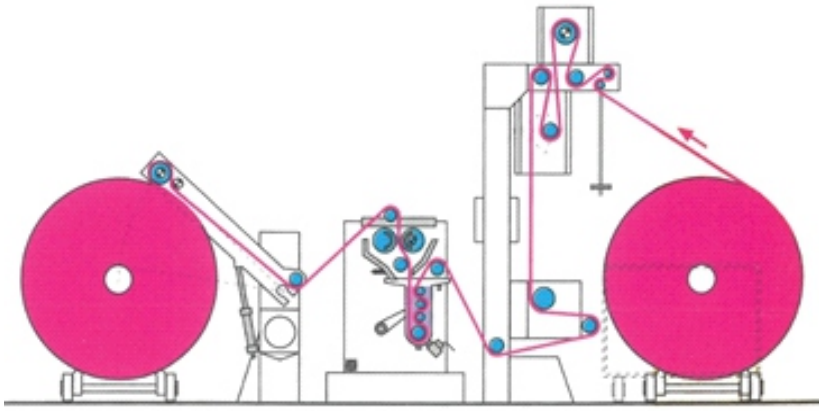


Figure 4.50 – Pad Dyeing

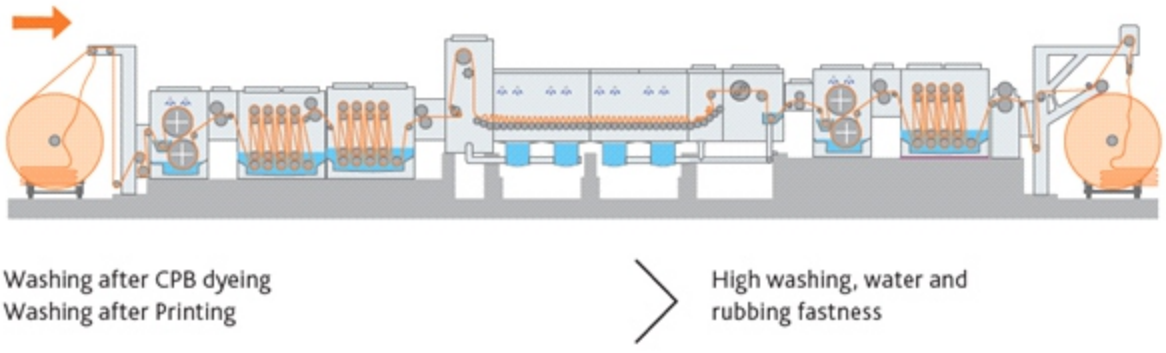


Figure 4.51 – Post CPB Batching wash

(Source: Kusters Calico & Benninger AG)

Technical Description

Reactive dyes are used to colour cotton, viscose, and other cellulosic fibres. However, reactive dyeing requires a lot of salt, water, and energy. The process is also ineffective, so fixation rates are low (around 75%).

This means that the unfixed dye must be removed by rinsing more than once, which uses more water and energy (as rinse water is often heated). Wastewater from reactive dyeing contains salt and dye, making it difficult to treat. Cold pad batch dyeing (CPB) is an alternative to reactive exhaust dyeing that uses fewer resources.

Salt is one of the biggest problems in the textile industry, which makes treating wastewater and recycling it hard. So, Cold Pad Batch Dyeing for cellulosic fibre is the best way to get rid of salt in the waste stream of the textile industry. It also helps reduce the amount of energy and water used to dye the fabric.

Also, CPB does not need to use heat during the process.

Achieved Environmental Benefits

- Water conservation
- Reduction in thermal energy (operates at room temperature)
- Reduction in steam utilization
- Reduction in chemical consumption (no salt is required for the CPB process)

Operational Data

The figure 4.50 shows that the Cold Pad dying process has four key sections.

Chemical Dosing: The dye and alkali solutions usually are mixed in a ratio of 4:1 and added to the padding trough immediately before the start of padding. Dye and alkali solutions are prepared separately and mixed into the trough through a metering and mixing device.

Thus, dyestuff and the required amount of urea are prepared in 80%, sodium silicate and caustic soda solution in 20% of total liquor. Only the required quantity of boiling water (approximately 2 to 4 times the total quantity of dyestuff) is used to dissolve dyestuff.

This concentrated solution is poured through a fine-mesh sieve into the required quantity of cold water. The required quantity of urea (50 to 200 gm./l) is added at this stage to improve the dye solubility. Urea should not be dissolved together with the dyes.

Urea is sprinkled in the solid form directly into the cooled padding liquor and dissolved with stirring. Special equipment has been devised for dye and alkali dissolution and mixing, which greatly ensures the reproducibility of the dyeings.

Padding Unit: Here, chemical comes from the storage tank to maintain an even range on the padding tank. A padder or padding mangle is required with the lowest possible trough volume and highest possible speeds of goods, especially dyeing lightweight fabrics. Pre – scoured, cooled goods are padded at room temperatures (25^0C to 30^0C). This ensures high liquor exchange.

As it is desirable to replace the liquor at a faster rate. The liquor pick–up should be 60 – 70 % for cotton and 90 – 100% for viscose fabric. Padding pressure is predetermined according to pick up required & fabric speed.

Batching: After padding, the fabric is directly rolled into the batcher & packed with a poly bag. Care should be taken that the selvedge are perfectly aligned on the roller. The distance between the padding mangle and the batching roller should be as short as possible.

Large batches should be kept in rotating conditions to avoid liquor seepage. The goods are batched up with the sides aligned after padding, covered with plastic film and tied to exclude air. This prevents partial neutralization of the fixation alkali with carbon dioxide from the air.

The selvedge should also be adequately covered; otherwise, the effect of alkali is weakened due to the action of atmospheric carbon dioxide. Make sure the minimum fixation time for the recommended temperature is observed. The roll must be rotated during fixation.

The theoretical minimum fixation time recommended is 6 hours per batch. Practically it varies from 16 to 20 hours.

Washing: Finally, fabric is washed, soaped, neutralised, and dried

Cross Media Effects

No relevant cross-media effect is known.

Economics

Investment Cost	**High to Very High**
Cost Indicative	**Investment (In Rupees)**
Very Low	< 1 Lakh
Low	< 10 Lakh
Moderate	10 - 20 Lakhs
High	20 - 50 Lakhs
Very High	> 50 Lakhs

Driving Force for Implementation

- Financial benefits
- Resource conservation (Fresh Water, Chemicals and Thermal Energy)
- Sustainability of textile business

Reference Industry

M/s. Akash Fashion Pvt. Ltd., Surat
M/s. Shanti Processor Pvt. Ltd., Surat
M/s. Arvind Ltd. (Santej Unit), Ahmedabad

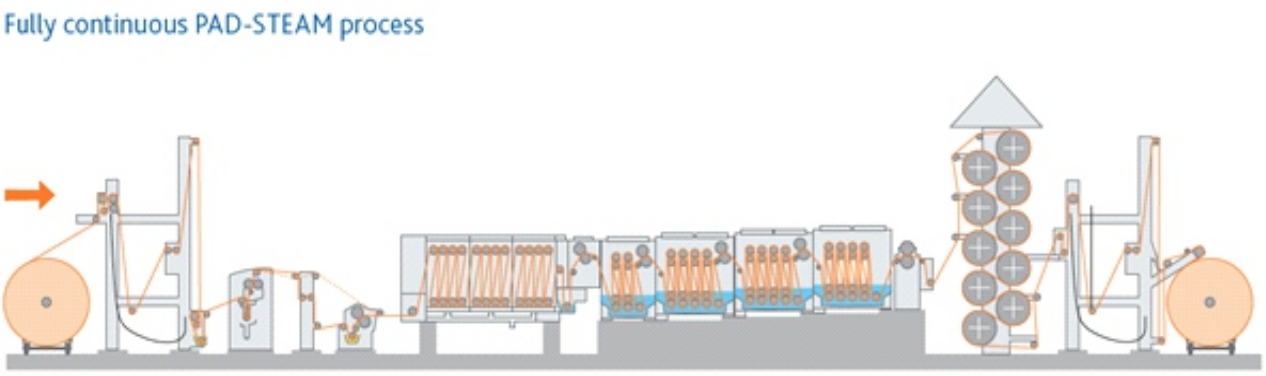


Figure 4.52 – PAD-STEAM continuous dyeing process

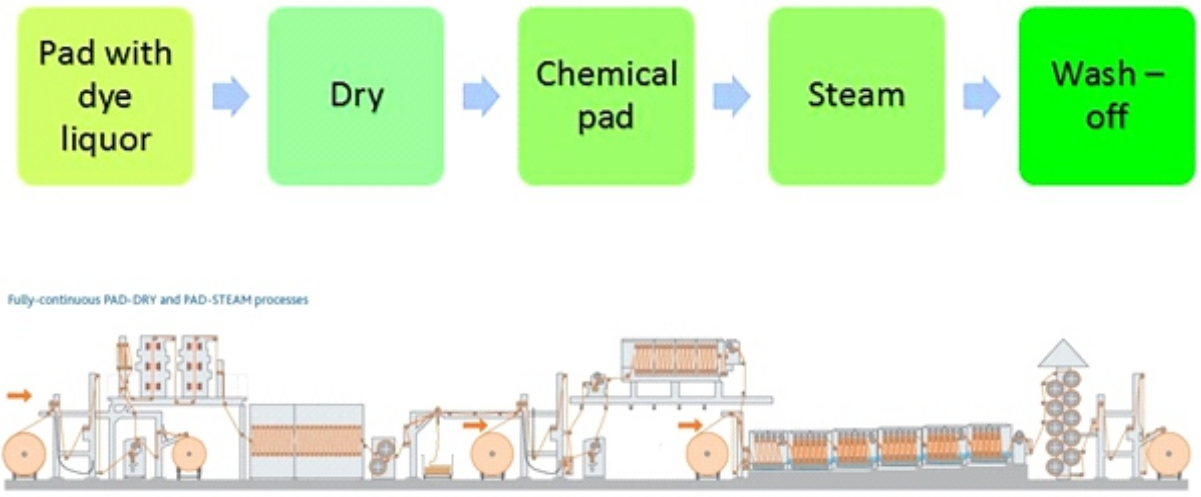


Figure 4.53 – PAD-DRY and PAD-STEAM continuous dyeing process

Technical Description

The dyeing process can be carried out as batch, semi-continuous, or continuous. Still, majorly industries are performing batch dyeing on jiggers with high water and energy consumption.

Continuous and semi-continuous dyeing methods can help reduce water usage, replace wasteful practices like running dhulai, and uneven water intake per batch with efficient and cost-effective ones, and minimize the environmental impact.

Achieved Environmental Benefits

- Water conservation
- Reduction in thermal energy (operates at room temperature)
- Reduction in steam utilization
- Reduction in chemical consumption (fewer chemicals are required for the CPB process)

Operational Data

The continuous dyeing process typically consists of the following.

- Dye application,
- Dye fixation with heat or chemicals and
- Washing.

Various sequential operations are used for the continuous dyeing of fabric. An initial padding stage is common to all sequences. It involves immersion of the fabric in the dye liquor contained in a trough of minimal volume, which is constantly replenished from a stock tank to maintain the dye concentration in the liquor. A liquor ratio as low as 1:1 be used; generally, low-substantive dyes are used in continuous dyeing. Next, the fabric passes in open width through a 'nip'. The nips are the padding mangle, in which heavy rollers (called bowls), pressed closely along their length, are rotated in opposite directions to carry the fabric through the system at a constant speed, squeezing out the superfluous dye liquor.

The fabric, now uniformly impregnated with dye and the appropriate dye bath auxiliaries, usually passes directly to a steamer or dry heater for fixation. After fixing, the fabric passes from the fixing chamber to the washing range and is dried on heated cylinders.[11]

Pad steam dyeing is a procedure of steady colouring in which the texture in open width is padded with dyestuff and then steamed. It is an ideal dyeing machine for reactive dyeing. Light, pale and medium shades can be dyed in this machine. A continuous roller steamer is used to diffuse reactive, vat, sulphur dyes and direct dyes into cellulosic fibres in an atmosphere of heat and moisture created by saturated steam injected into the steamer.[12]

In Pad Dry process, the fabric is padded in a padder with reactive dye in the presence of an alkali then the padded fabric is passed through a squeezing roller into a dryer. A dryer cylinder, stenter etc. may be used. During drying, due to higher temperature, the fixation of dye in fibre increases and at the same time, water is removed by evaporation. After drying, the fabric is washed in a machine to remove the unfixed dyes.

Cross Media Effects

No relevant cross-media effect is known.

[11]*https://textileapex.blogspot.com/2015/02/continuous-dyeing-method.html#:~:text=It%20involves%20immersion%20of%20the,used%20in%20continuous%20dyeing%20process*
[12]*https://textileinsight.blogspot.com/2014/08/pad-steam-dyeing-machineprocess.html*

Economics

Investment Cost	Very High
Cost Indicative	**Investment (In Rupees)**
Very Low	< 1 Lakh
Low	< 10 Lakh
Moderate	10 - 20 Lakhs
High	20 - 50 Lakhs
Very High	> 50 Lakhs

Driving Force for Implementation

- Financial benefits
- Resource conservation (Fresh water, Chemicals and Thermal Energy)
- Sustainability of textile business

Reference Industry

M/s. Shanti Processor Pvt. Ltd., Ahmedabad
M/s. Arvind Ltd. (Santej Unit), Ahmedabad

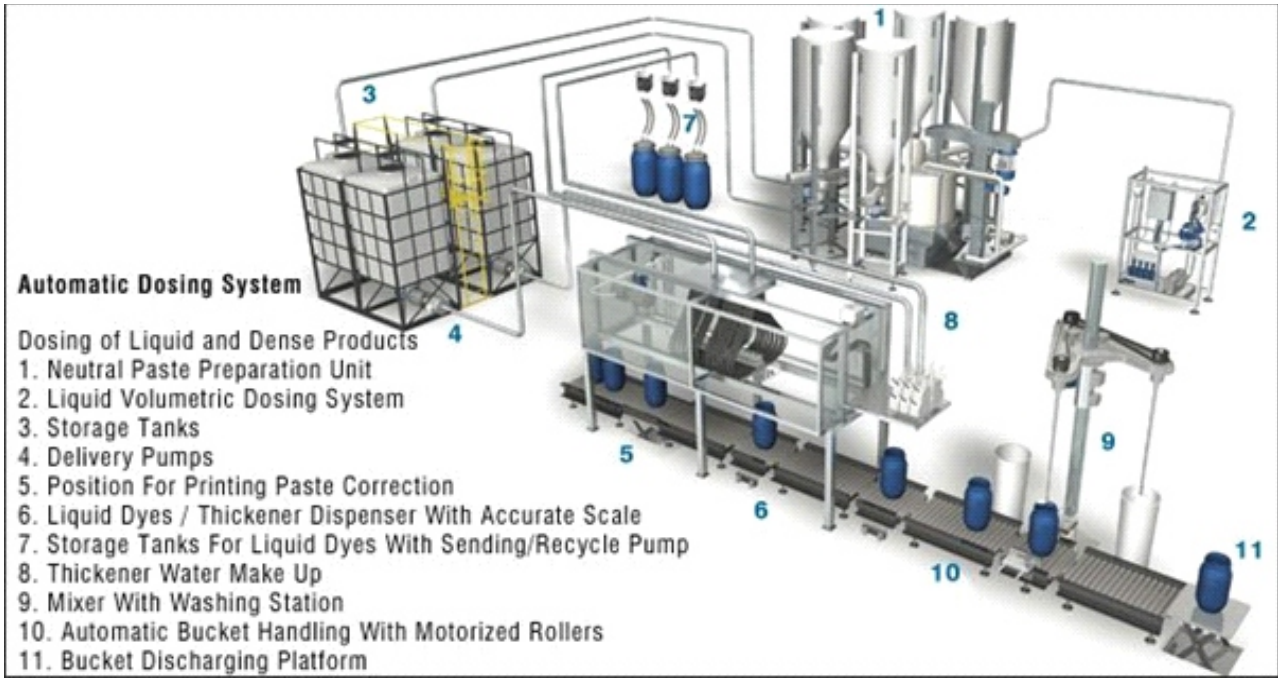


Figure 4.54 – Schematic diagram of TIC controller for processing

Technical Description

With an increased demand for rotary and flatbed printing machines, the demand for printing paste automation has shown an upward trend. Textile printers use dyes in powder or liquid forms for printing. In fact, 90% of printers use only powder dyes such as reactive, pigment and disperse powder dyes, etc. (though these must be first dissolved before application and always need to be prepared fresh before every application). So, the dye preparation process requires care.

Also, the Textile industry usually faces issues in the printing department, such as:

- The excess prepared print paste goes waste;
- Stored print paste becomes hard and cannot be made fluid again;
- A large area is required for storing the ready paste carboys for the whole day's printing;
- Human error in handling the print paste;
- Inconsistency in paste preparation.

These colour preparation challenges can be easily overcome by installing an appropriate automatic print paste dispensing system in a dye house in the printing department.

Achieved Environmental Benefits

- Reduction in Chemical Usage and Wastage
- Reduction in effluent concentration load will enhance the efficiency of the wastewater treatment plant

Operational Data

The automatic printing colour kitchen comprises two main units – a thickener preparation unit and a paste dosing unit. Both units can work either in standalone mode or together.

Thickener preparation unit

The thickener preparation unit cooks the thickener automatically with minimal manual support. All powdered and liquid ingredients can be dispensed automatically and used with different recipes. The unit has fibreglass silos for powder chemicals and a dispenser for liquid chemicals so that powders and liquids can be added to the mix. The unit lets you set the amount and the order in which the powders and liquids need to be added. A strong stirrer and a scraper mix the ingredients well and make a homogenous thickener. The thickener is sent to a storage tank by a gear pump and a collector.

A level sensor is included in each thickener tank to monitor the level of the thickener. A pneumatic diaphragm pump is used for liquid filling, while a blower pump is used for powder dyes. The operator is not required to do anything throughout the process except for filling liquid chemical tanks and powder silos. Level sensors are present in every liquid and powder silo.

Printing paste dosing unit

The machine picks up a drum and transports it to an initial thickening dosing head based on the required print paste. A tiny amount of thickener is dosed here from the drum to prevent the colours from adhering. The machine adds the dyes to the thickener's initial layer. But for powder dyes, the drum goes to a powder dosing unit on a conveyor. Upon powder dosing completion, the drum returns to the paste dosing unit. The drum is moved to the next stage to complete the remaining amount of thickener. Before the drum is sent to the stirrer unit, a label is placed on it to specify the content, batch, print machine, etc.

To ensure appropriate mixing, both the stirrer and the drum are rotated. Two stirrers are available for usage in different combinations.

Cross Media Effects

No relevant cross-media effect is known.

Economics

Investment Cost	Very High
Cost Indicative	**Investment (In Rupees)**
Very Low	< 1 Lakh
Low	< 10 Lakh
Moderate	10 - 20 Lakhs
High	20 - 50 Lakhs
Very High	> 50 Lakhs

Driving Force for Implementation

- Financial benefits
- Resource conservation (Chemicals)

Reference Industry

M/s. Mukesh Industries Pvt. Ltd., Ahmedabad
M/s. Arvind Ltd. (Santej Unit), Ahmedabad
M/s. Siddhivinayak Knots and Prints Pvt. Ltd., Surat

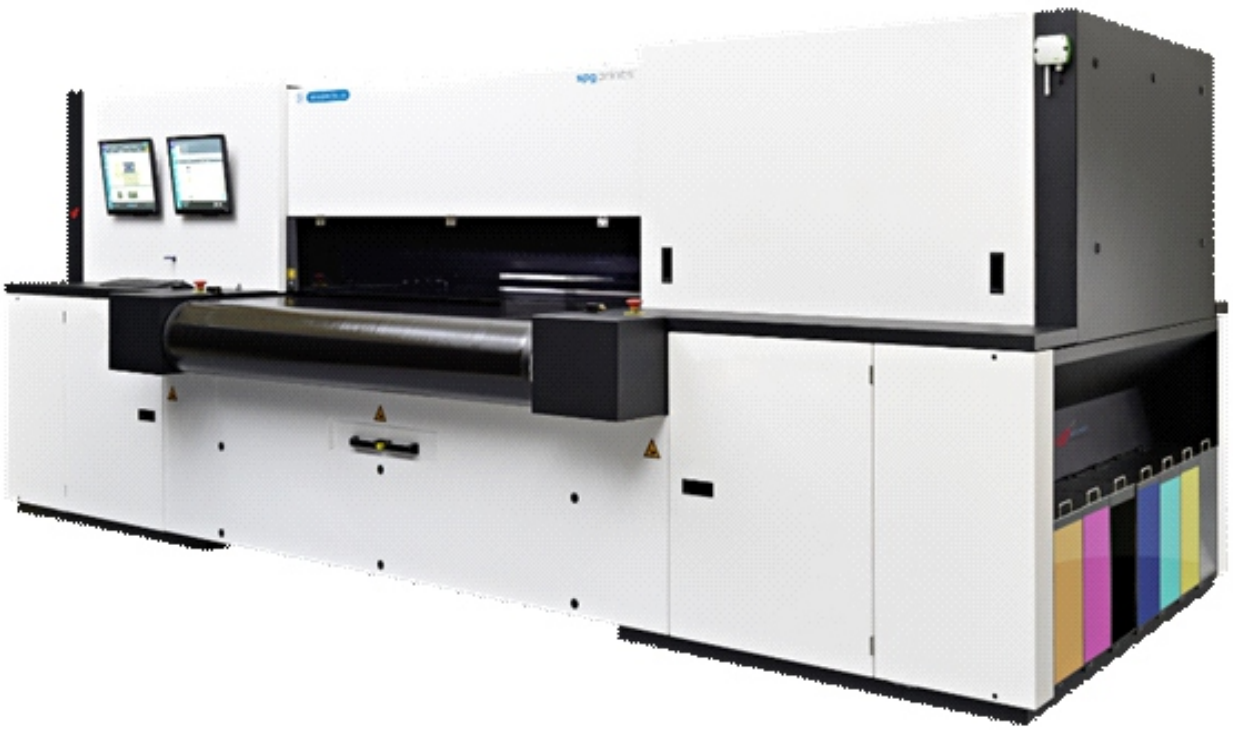


Figure 4.55 – Digital Printer

Technical Description

The textile printing market is expanding due to significant trends such as population increase, increased purchasing capability, and quickly shifting fashion trends. This puts tremendous pressure on the time to market for textile printing companies, resulting in quicker sampling, higher print rates, more efficiency, flexibility, and better design.

To meet such objectives, the market only needs to consider several approaches to printing on cloth. Digital textile printing is one answer to those problems.

The significant difference between traditional and digital textile printing is how colours, geometry, and designs are pressed onto the fabric. While conventional printing uses rotating screens with patterns, digital printing uses printable images, 9+ designs, or graphics.

Achieved Environmental Benefits

- Reduction in energy consumption,
- Waste Minimization,

Operational Data

A BAT description cannot adequately cover the vast subject of digital textile printing. For more details, see the separate annexure 4 on digital textile printing.

Cross Media Effects

No relevant cross-media effect is known.

Economics

Investment Cost	**High to Very High**
Cost Indicative	**Investment (In Rupees)**
Very Low	< 1 Lakh
Low	< 10 Lakh
Moderate	10 - 20 Lakhs
High	20 - 50 Lakhs
Very High	> 50 Lakhs

Driving Force for Implementation

- Financial benefits
- Resource conservation (Water, Chemicals and Thermal Energy)
- Sustainability of textile business

Reference Industry

Many reference industries of the Surat cluster are performing digital printing.

Sr. No.	Technique Name
1.	Chemicals Management System
2.	Selection of process chemicals
3.	Chemical storage and handling
4.	Chemicals inventory

Technical Description

The chemicals management system is part of the EMS (see) and is a set of technical and organisational measures to limit the impact of the use of chemicals on the environment

The chemicals management system (CMS) contains the following components:

- A policy to reduce the consumption and risks associated with process chemicals, including a procurement policy to select less harmful process chemicals and their suppliers to minimise the use of and risks associated with hazardous substances and substances of serious concern as well as avoiding the procurement of an excess amount of process chemicals. The selection of process chemicals is based on:

    a. The comparative analysis of their bio eliminability, ecotoxicity and potential to be relased into the environment (which in the case of emissions to air can be determined by using emission factors;
    b. The characterisation of the risks associated with the process chemicals, based on the chemicals' hazard classification, pathways through the plant potential release and level of exposure;
    c. The potential for recovery and reuse (see sections 4.3, 2 and 4.4);
    d. The regular (e.g. annual) analysis of the potential for substitution with the aim to identify potentially new available and safer alternatives to the use of (groups of) hazardous substances and substances of very high concern, such as PFAS, phthalates, brominated flame retardants, chromium-(VI)-containing substances; this may be achieved by changing process(es) or using other process chemicals with no or lower environmental impacts;
    e. The anticipatory analysis of regulatory changes related to hazardous substances and substances of very high concern, and safeguarding compliance with applicable legal requirements.

The inventory of process chemicals (see Technique 41) may be used to provide and keep the information needed for the selection of process chemicals.

The criteria for selecting process chemicals and their suppliers may be based on certification schemes or standards. In that case, the compliance of the process chemicals and their suppliers with these schemes or standards is regularly verified.

- Goals and action plans to avoid or reduce the use of and risks associated with hazardous substances and substances of very high concern.
- Development and implementation of procedures for the procurement, handling, storage and use of process chemicals (see Technique 40), disposal of waste containing process chemicals and return of unused process chemicals to prevent or reduce emissions to the environment.

Achieved Environmental Benefits

- Reduction of the use of hazardous chemicals.
- Reduction of emissions of hazardous chemicals to air, water, groundwater and soil.
- Reduction of the amount of hazardous chemicals in waste.

Operational Data

The selection of chemicals and chemical suppliers is facilitated by adhesion to voluntary certification schemes, private initiatives or cooperation in which hazardous chemicals are controlled along the supply chain, and chemicals and preparations are regularly screened for compliance against criteria and thresholds of established manufacturing restricted substance lists. Examples of such certification schemes include GOTS, Textile Standard, OEKO-TEX (ECO PASSPORT), bluesign, ZDHC and others (see Technique 5).

Effective communication between downstream users and suppliers at all stages in the REACH process also helps to ensure that relevant information is provided in the supply chain

Methodologies and tools for conducting qualitative and/or quantitative chemical risk assessments are available (e.g. REACH Annex I or XII, the European Union System for the Evaluation of Substances (EUSES) software and Exchange Network on Exposure Scenarios (ENES)).

Precisely estimating the quantities of chemicals/preparations needed in formulations for treating textiles (production planning) lower the quantities of leftover chemicals. To free up storage space and reduce the risks of chemical expiry (and the potential risks and costs of treating them as waste), the unused chemicals (in their original packaging) are preferably returned to the supplier before their expiration date for possible resale and use. This is achieved predominantly by using innovative business models like chemical leasing, closed-loop chemical management, etc.

The information on unwanted hazardous substances in the purchased chemicals/preparations and the quantities of returned unused leftover chemicals/preparations is also used in overviews of material flows through the installation (see Technique 1 and Technique 2).

More details about the operational data of some components of the CMS may be found in 0 (see Technique 40 and Technique 41).

Information about substituting hazardous chemicals is given in process-specific sections of Chapter 4 (Sections 4.2 and 4.3).

Cross Media Effects

None reported.

Economics

No information is available.

Driving Force for Implementation

The driving forces for the implementation of a CMS include:

- Improved environmental performance;
- Compliance with regulations (e.g. chemical, product safety) and/or certification schemes;
- Optimized consumption of hazardous chemicals.

Reference Industry

M/s. Arvind Ltd. (Santej Unit), Ahmedabad.

Technical Description

The technique aims to reduce the amount or presence of hazardous substances by using screening tools based on restricted substance lists and environmental labelling or look for alternative process chemicals (dyestuffs, pigments, finishing agents, etc.) containing ingredients with a lower environmental impact (e.g., toxicity, biodegradability/bioeliminability).

Achieved Environmental Benefits

Reduced pollutant loads in the effluents from textile processing.

Operational Data

Chemicals whose use or presence has been banned or otherwise regulated by organisations, governments, or producers are considered restricted substances. Textile factories can employ items marked or approved as suitable for use in a particular labelling scheme in place of dyestuffs or chemicals that include these substances (e.g. Type I, II or III product labels according to ISO 14 020). There are many voluntary labelling (restriction) programmes available, including the EU Ecolabel and programmes offered by ZDHC, OEKO-TEX, bluesign, GOTS, AFIRM, GUT, and others (see technique 5)

Substances are restricted for various reasons: environmental, health and safety concerns for workers or consumers, or legislation. A substance restriction (in the MRSL scheme) is usually accompanied by a test (standard) method to verify if a chemical is present and if so, to ensure the chemical is below the restricted level. These labelling schemes can also be used to select raw materials and chemical suppliers.

The entities mentioned above (ZDHC, OEKO-TEX, GOTS, bluesign, AFIRM, GuT) carry out certification/labelling according to their restriction schemes (Manufacturing Restricted Substance Lists – MRSL). If the product is to be labelled/certified according to these schemes, certain restricted substances must be absent or present in limited concentrations from the manufacturing inputs (raw materials) and outputs (e.g. emissions, effluents) or the finished textile products.

Chemical screening tools like ChemSTEER[13] for finding suppliers of alternative chemicals or mixtures (without restricted substances) are available online.

Cross Media Effects

None identified.

[13] *htpp://www.epa.gov/*

Economics

It is possible that alternative chemicals are more expensive, needed in higher quantities and require special treatment – all of these could affect the economic costs of production.

Driving Force for Implementation

- Environmental and product safety regulation (e.g. Ecolabel).
- Chemical regulation (e.g. REACH).
- Market demands (customer pressure).

Reference Industry

M/s. Arvind Ltd. (Santej Unit), Ahmedabad
M/s. Siddhivinayak Knots and Prints Pvt .Ltd., Surat



Figure 4.56 - Chemical Labelling (left) and good chemical handling at reference plant (right)

Technical Description

Chemical storage and handling are the foundation of CMS. Adequate storage and handling can prevent incidents such as spillages and accidents. Procedures should be provided for handling chemicals in the safest way possible. Relevant training should be given to employees to make sure they have the knowledge to implement the procedures.

Achieved Environmental Benefits

- Reduction of chemical spillage and accidents

Operational Data

Chemical Labelling

Chemical containers and packaging should clearly identify the chemical products they contain. The labels convey chemical safety information to the employees using simple and understandable words (in official or local language) and images to document the hazard characteristics and safe handling requirements.

Any chemical container must be maintained in good condition with a legible label. The chemical label must contain the following information at a minimum:

- Product Identifiers such as chemical name or trade name
- Chemical Formulator Name and contact details
- Lot number
- Harmonised signal word, where applicable

- Hazard pictograms such as GHS pictogram(s) or equal, where applicable
- Hazard statement (H-statement), where applicable
- Precautionary statement (P-statement), where applicable

The information on the chemical label should support the traceability of products/materials.

Best practices for labelling include other information such as:

- Manufacturing date
- End-of-life date

If the packaging is too small or oddly shaped to contain all relevant information, include chemical identification and refer to where the additional required data may be found.

Chemical Handling

Chemical handling covers all types of chemical use, storage and transportation. Well-defined chemical handling practices help to prevent the risk of environmental pollution, personal injury and economic implications.

The minimum requirements for proper chemical handling are:

- All actions recommended through chemical assessments must be implemented. This includes measures across chemical storage, PPE, etc.
- Clear communication of hazards must exist, including appropriate signage. So any
- employee knows whether the substance could expose them to hazardous property.
- All employees who handle chemicals must have appropriate training and qualifications
- Employees who handle chemicals shall be knowledgeable in hazard communication implementation, such as GHS standards
- Develop an SOP for Chemical Storage (incl. separation/segregation/isolation),
- Transportation, and Use. The SOP should contain information on handling chemicals in the safest way possible

Cross Media Effects

None identified

Economics

The chemical supplier supplies the labelling information, so this strategy requires very little expenditure. However, specific appropriate tools and equipment are needed for handling.

Driving Force for Implementation

- Resource savings (reduction in chemical wastage)

Reference Industry

M/s. Arvind Ltd. (Santej Unit), Ahmedabad
M/s. Kankariya Textile Industries Pvt. Ltd., Ahmedabad
M/s. Siddhivinayak Knots and Prints Ltd., Surat

Foundational

Information on Chemical Product				Volume related information					Storage location	LOT Number	Expiry Date- OPTIONAL	SDS information
Chemical Product Name	**Chemical Formulator Name (manufacturer)**	**Chemical Supplier Name**	**ZDHC use category**	**Monthly usage (amount)**	**Monthly usage (Unit)**	**ZDHC MRSL Conformance level, if registered**	**Name/type of certification**	**Valid until**				**SDS date of issue**
Insert the full name of the formulation including any prefix/suffix to the name. This is the formulation name naws detailed on the packaging of the container and on any accompanying paperwork(delivery note, SDS etc).I	Insert the name of the chemical formulator of the formulation as given in the SDS or container label	Insert the name of the supplier of the formulation in case it is not purchased from the manufacturer (formulator)	Choose from the dropdown menu the use category that best describes the intended use of this formulation.	Insert the amount of this chemical formulation used within the month of the CIL	Define the unit of monthly usage e.g. kg, litres etc	Choose level (Not- Registered, Registered 1,2,3) from dropdown	Insert certification standard	Write the date of validity of the certificate (dd/dd/yyyy)	Add location of storage on site	Add the lot number of the drum/chemical product in storage	Expiry date of the chemical product (dd/mm/yyyy)	Instert date as written on the SDS document (dd/mm/yyyy)- if blank that means SDS is missing
WETTOL-DT	BRIGHT AUXICHEM GmbH	Mega Marketing Enterprise	1.2.a. Bleaching	300	Kg	Level 1	GOTS 5.0 TOX FMD	20.10.2020 01.05.2022				15.10.2018

Progressive

Hazardous Substances Indicated in SDS		Hazard Information in SDS			Precautions for identified hazards			Compatibility information
CAS number of Hazardous substances	**% of Hazardous substances Reported in SDS**	**Physical**	**Health**	**Environmental**	**Storage**	**Handling**	**Discharge**	**Non-compatibile materals**
Write the CAS number of the hazardous substance listed in Section 3 of SDS	Insert the percentage (%) of hazardous substance within the formulation as given in Section 3 of SDS	Select the H-Statement from dropdown box if mentioned in Section 2 of SDS	Select the H-Statement from dropdown box if mentioned in Section 2 of SDS	Select the H-Statement from dropdown box if mentioned in Section 2 of SDS	Refer to the P-Statement given in Section 2 of SDS and also Section 7.2 for specific storage requirements	Refer to the P-Statement given in Section 2 of SDS and also Section 7.2 and Section 8	Refer to the P-Statement given in Section 2 of SDS and Section 13	Describe materials or chemicals that are not compatibile for storage – Refer Section 7.1 and 10.5 of SDS
1015447-12-777-92-2	35% 2%	H-242: Heating may cause a fire	H-318: Causes eye damage	H-412: Harmful to aquatic life with long lasting effects	Keep away from heat, hot surfaces, sparks, open flames and other ignition sources	Wear protective gloves and eye/face PPE	Do not drain to environment without proper treatment	Not known

Aspirational

Phase - Out	Environmental Indicators					Toxicological information				Resource Efficiency	
Action required to replace with safer alternative	COD (MG O2/G)	AOX %	Inherent biodegradability	Bio eliminability	Aquatic toxicity (LC/EC 50 value in mg/L)	Oral toxicity (LD 50 value in mg/kg)	Skin/Eye damage	CMR data	STOT Data	Reduction in water usage	Reduction in energy usage

Technical Description

Textile plants use many chemical products (100-300) for different processes (pre-treatment, dyeing, printing and final finishing). So, creating and keeping track of a chemical inventory is required to develop and implement the CMS.

In order to ensure the availability and completeness of information necessary for responsible chemical management, the relevant data for the process chemicals used are entered, collected and managed in one dedicated computer-based inventory. From this inventory, tailored information can be generated.

The chemicals inventory and tracking system is computer-based and contains information about:

- The identity of the process chemicals;
- The quantities, location and perishability of the process chemicals procured,recovered (see Technique 38, Technique 40 & Technique 41), stored, used and returned to suppliers;
- The composition and physicochemical properties of process chemicals (e.g. solubility, vapour pressure, n-octanol/water partition coefficient), including properties with adverse effects on the environment and/or human health (e.g. ecotoxicity, bioeliminability / biodegradability).

Such information may be retrieved from Safety Data Sheets, Technical Data Sheets or other sources.

The main and most used data sources for the different chemical products are the Safety Data Sheets (SDS) and, to some extent, the Technical Instruction Sheets. It is essential to link the inventory to a comprehensive modern production planning and control system to facilitate evaluations.

The inventory may be used for the following purposes

- Identification of process chemicals with acute and chronic aquatic and sediment toxicity.
- Identifying process chemicals containing substances in the candidate list of
- substances is of very serious concern.
- Identification of process chemicals which are readily, inherently, or non-
- biodegradable in waste water treatment.
- Qualitative and/or quantitative risk assessment of the process chemicals.
- Identify all combustible/flammable products and those that can decompose (thermally or by reaction with other chemicals).
- To plan the use of consumption and implement adequate storage and handling. This also allows reducing the risks of chemicals' expiry (and potential risks and costs of treating them as waste) and for the unused chemicals to be returned to the supplier before their expiration date,for possible resale and use.
- Assessing compatibility of process chemicals and storing the process chemicals accordingly
- I Compilation of data relevant for communication and reporting (with competent authorities or customers) and/or certification purposes (e.g. OEKO-TEX (STeP), GOTS).
- Cross-verification with restriction, authorisation and candidate lists under the REACH Regulation and manufacturing restricted and/or positive substances lists (e.g. ZDHC Manufacturer restricted substances list, bluesign system substances list), specific customer restricted substances lists or other lists.

Concerning emissions to air from stenters, a reference may be made to the product-specific emission factors for chemical products used for finishing on these machines.

Achieved Environmental Benefits

- Reduced risks associated with the storage and handling of hazardous substances.
- Reduction of chemical leftovers.
- Systematic identifying substances with undesirable environmental and toxicological (adverse) properties allows risk-driven prioritisation of management actions such as substituting process chemicals and abatement of emissions to air and water.

Operational Data

The software application for establishing and implementing the inventory and associated evaluation tools can be obtained from a range of providers available on the market (as part of an integrated business or stand-alone applications) or can be developed in-house.

A Chemical Inventory List lists all chemicals and/or chemical products kept or used in the facility, processes, and tooling/operations. An organisation should have a robust process for creating and updating a CIL.

The content of CIL should include, at a minimum:

- The chemical name
- SDS location
- Identification numbers (CAS no.) of hazardous substances
- Hazard information
- Conformance of the chemical products to the MRSL
- Amount of stock take or delivery or usage
- Storage location

If chemical information is missing, there must be a corrective action plan to obtain this data from chemical formulators.

The following actions can compile the Chemical Inventory List:

- Stock take (items and quantities held in storage);
- Delivery information (items and quantities delivered); and
- Use information (items and quantities used).

The Chemical Inventory List should be regularly updated and its information maintained. It is recommended to follow, at minimum, the following frequency:

- Stock take, annually
- Delivery, monthly
- Usage information, monthly

The CIL should be maintained by a responsible person wherever and whenever chemicals are purchased, stored or used. The revision date should be clearly documented.

Cross Media Effects

None identified

Economics

The investment and operating costs for a chemical inventory depend on the sophistication intended.

Savings usually arise from streamlined stocks, improved management of surplus chemicals, simplification or automation of procedures/processes (e.g. by using chemical inventory software), simplification of the verification of compliance with the chemicals regulations as well as indirectly from reduced environmental management costs based on the gradual substitution of hazardous chemicals and emissions to the environment.

Driving Force for Implementation

- Reduction of chemical leftovers.
- Certification schemes.
- Chemicals regulations.

Reference Industry

M/s. Arvind Ltd. (Santej Unit), Ahmedabad.
M/s. Siddhivinayak Knots & Prints Pvt. Ltd., Surat.

Sr. No.	Technique Name
1.	Minimising sizing agent add-on by pre-wetting the warp yarns
2.	Oxidative Desizing
3.	Bio Scouring
4.	Enzymatic washing to remove residual Hydrogen Peroxide after bleaching
5.	Recovery of caustic soda used for mercerising
6.	Replacing acetic acid with mix. of organic acids (Formic acid and acetic acid solution)
7.	Environment-friendly surfactants
8.	Low emission preparation agents
9.	Substitution of phosphorus or nitrogen-containing complexing agents

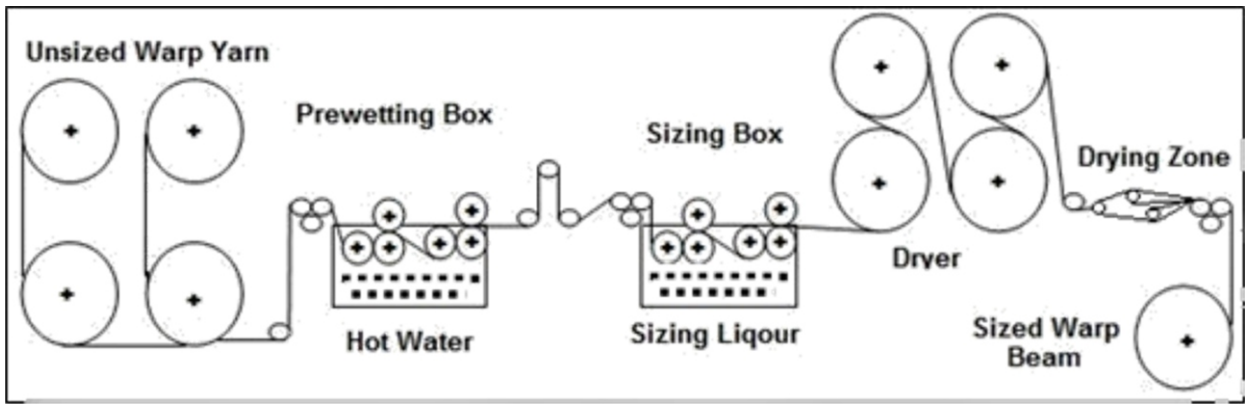


Figure 4.58 - Prewetting of warp yarn before sizing
Source: Techniques of Warp Yarn Sizing in Weaving Preparatory Process (https://textilelearner.net/techniques-of-warp-yarn-sizing/)

Technical Description

The first wet finishing process used on woven fabrics is desizing, intended to remove the size material from the warp strands. Desizing accounts for 50 to 70 % of the total COD in the waste water at woven cotton finishing mills.

Minimising the size applied to the warp yarn during fabric processing is one of the most effective pollution prevention techniques for reducing the organic load caused by sizing agents.

Sizing agents help yarn withstand high mechanical stress when it is woven. The basic idea of pre-wetting treatment is to pad the warp with hot water. Then the yarns can be padded with the traditional sizing solution. This reduces the amount of sizing agent that is needed.

Achieved Environmental Benefits

- Reduced organic load in the effluent

Operational Data

Denim manufacturing facilities and composite/integrated mills that produce blend fabrics can use this approach. Through online monitoring and controlling mechanisms, the process parameters can be managed.

The warp yarn is administered through hot water as part of the pre-wetting approach before the sizing procedure. A pair of squeeze rollers and two immersion rollers are often employed. The warp sheet can be penetrated with the help of this thorough washing and wetting. Dust and other contaminants that are loosely attached to fibre are removed by the hot water, which also partially dissolves wax

Pre-wetting improves adhesion of the size material, lowers yarn hairiness, and enables a more uniform sizing effect. Hot water moistens the yarn before being impregnated with the size solution, improving the size's surface adherence and preventing it from penetrating too deeply. As a result, less size can be

added to the fibre without reducing weaving efficiency.

Technical problems may be observed concerning the efficient measurement and control of high humidity percentage and calibration of the machine.

Existing sizing machines with two sizing boxes can be reconstructed/upgraded using the first sizing box for pre-wetting and the second for sizing.

Cross Media Effects

None identified

Economics

The reduced sizing agents on fabric decrease the chemical, water, and energy consumption in the desizing process.

Driving Force for Implementation

- Resource conservation (Water and energy consumption)
- Increase in weaving efficiency
- Reduction of load in waste water (reduced sizing agent release in wastewater)

Reference Industry

The method can be used with composite mills in general. Additionally, by using this technique, CPH can request that the vendor reduce the fabric's sizing.

Technical Description

Many woven fabrics contain various sizing agents, depending on the origin and quality of the substrate. Most textile finishers working on job work basis has to manage many different types of fabrics, and hence require quick sizing agents removal, so they are interested in fast, consistent and reliable removal of non-fibrous material (be it the impurities and fibre-adjacent material or any preparation agent) independent of the origin of the fabric. Currently, major woven cotton CPHs are using enzymatic desizing.

Oxidative desizing with hydrogen peroxide in the presence of sodium hydroxide can be used for desizing woven cotton fabric.

Achieved Environmental Benefits

- Reduction in COD load compared to enzymatic desizing

Operational Data

Under specific conditions (above pH 13), H2O2 generates free radicals, which efficiently and uniformly degrade all sizes and remove them from the fabric. This process provides a clean, increased absorbency, and uniform base for subsequent dyeing and printing, no matter which size or fabric type is involved

The sizing polymers have already significantly degraded due to the free radicals produced when hydrogen peroxide is activated. The process results in glucose and shorter, less-branched molecules like oxalate, acetate, and formate, which are simpler to wash off with less water in effective washing machines.The pre-oxidation of size polymer is also advantageous at the waste water treatment level (improved treatability).

Due to the chemical similarities between size and cellulose, non-selective OH* assault on the cellulose polymer is feasible. If OH* production is not controlled during bleaching in an oxidative alkaline medium (containing hydrogen peroxide), there is a chance that fibre damage will occur. Applying hydrogen peroxide at a pH level over 13 is crucial when eliminating starch-like size to get good results and prevent fibre damage. These working conditions reduce the amount of OH* radicals, which cause cellulose degradation.

The method is appropriate for higher GLM woven cotton fabric since the extent of damage is higher in lower GLM fabric compared to higher GLM fabric.

Cross Media Effects

Temperatures, dwell times, and chemical concentrations must be controlled extremely well to carry out oxidative desizing; otherwise, it can lead to oxidative damage to the cotton itself, producing oxycellulose.

The occurrence of pin holes on cotton fabric is also caused by the reaction of hydrogen peroxide with iron ions in water.

Economics

The quick removal of sizing agent via oxidative desizing reduces overall processing time leading to cost savings.

Driving Force for Implementation

- Reduction in raw material cost (enzyme are costlier than H_2O_2),
- Energy savings (multiple hot washes are required post enzymatic desizing).
- Decrease in waste water treatment costs (lower COD concentration).

Reference Industry

M/s. Arvind Ltd. (Santej Unit), Ahmedabad
M/s. Shanti Processors Pvt. Ltd., Surat

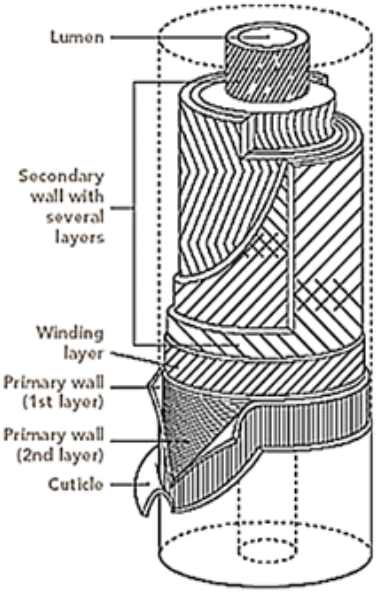


Figure 4.59 - A schematic representation of cotton fibre showing its various layers
Source - Comparative Study of Conventional Alkali Scouring and Bio Scouring of Cotton Knitted Fabrics (https://textilelearner.net/conventional-scouring-and-bio-scouring/)

Technical Description

Desizing, scouring with strong alkali, and bleaching are typical pre-treatment steps in cotton finishing mills. Often scouring and bleaching steps are combined. Scouring improves the wettability of cotton fibres. With scouring, non-cellulose substances (wax, pectin, proteins, hemicelluloses etc) that surround the fibre cellulose core are removed. As a result, fibres become hydrophilic and suitable for bleaching, dyeing and other processing.

Enzymatic desizing, using amylases, has been an established process for many years. The alkaline scouring process can be replaced with enzymes (generated from genetically modified microorganisms). More recently, trials with pectin enzymes are promising in replacing the traditional alkaline scouring treatment. An enzymatic process has also been introduced to remove cotton's hydrophobic and other non-cellulosic components. The enzyme-scoured fabric has a better bleaching activity, allowing bleaching to be done with fewer bleaching chemicals and auxiliary materials.

Enzymatic scouring or bio-scouring makes it possible to effectively scour fabric without negatively affecting the fabric or the environment. This type of process involves the use of enzymes to break down the pectin in the cotton and thus assists in removing waxes, oils and other impurities from the fabric.

Achieved Environmental Benefits

- Lower energy consumption (due to lower treatment temperature)
- Reduces COD, BOD and TDS load in the waste water.

Operational Data

Mainly waxy materials are primarily responsible for the non-absorbent characteristics of raw cotton. Non-cellulosic elements make up a very small percentage of the weight of the fibre, as shown in Figure 4.59 . The cuticle and the lumen contain these amorphous elements. The cuticle forms a protective layer to shield the cotton from climate attacks and water penetration.

The major portion of the non-cellulosic constituents of cotton fibre is present in or near the primary wall. Pectin is located mainly in the primary wall of the fibre. Non-cellulosic impurities, such as fats, waxes, proteins, pectins, natural colourants, minerals, and water-soluble compounds found to a large extent in the cellulose matrix of the primary wall and to a lesser extent in the secondary wall strongly limit the water absorbency and whiteness of the cotton fibre.

Pectin is like a powerful biological glue. The mostly water-insoluble pectin salts bind the waxes and proteins together to form the fibre`s protective barrier. Removing pectin makes it easier to remove all other non-cellulosic substances. The processes of bio-scouring that are in use today are based on the decomposition of pectin by the enzymes called pectinases.

As this measure requires only the replacement of alkali (NaOH) by a bio-scouring enzyme, it is easy to implement. No change in plant and machinery is needed. In continuous and discontinuous processes, the enzymatic scouring process can be applied to cellulosic fibres and their blends (for woven and knitted goods). When enzymatic de-sizing is applied, it can be combined with enzymatic scouring. The process can be applied using jet, overflow, winch, pad-batch, pad-steam and pad-roll equipment.

Cross Media Effects

The waxes cannot be reduced completely with enzymatic scouring and may interfere in the later wet processing steps.

Economics

The benefits of enzymatic treatment versus conventional chemicals must be weighed against their typically higher cost and compatibility with other processing steps.

Driving Force for Implementation

- Cost savings through reduction in water, chemical, electricity and fuel consumption
- Regulatory Compliance

Reference Industry

Pilot measure implemented in M/s. Mangal Textile, Ahmedabad & M/s. Komal Texfeb, Ahmedabad

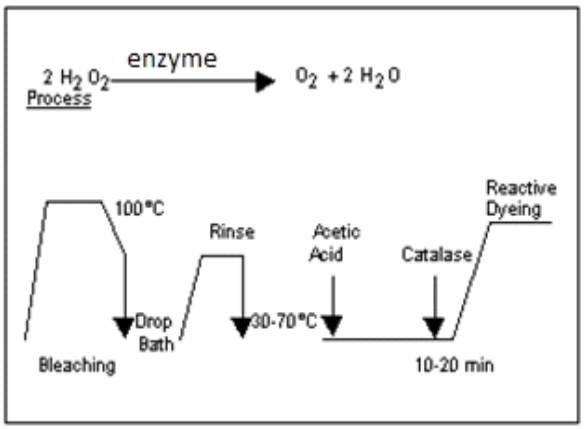


Figure 4.60 - Enzymatic washing to remove residual Hydrogen Peroxide after bleaching
Source - https://www.kenencoregroup.com/peroxide-removal.html

---

Technical Description

To achieve reproducible bleaching results, residual hydrogen peroxide content of 10-15% of the initial quantity should still be available after bleaching. The residual hydrogen peroxide content must be completely removed to prevent any shade change with dyestuffs that are sensitive to oxidation.

Reducing agents and several rinsing steps are necessary for common peroxide removal techniques. High energy and water consumption and using sulphur-containing reducing agents are the main disadvantages of the conventional technique.

Special enzymes (peroxidases) catalyse the reduction of hydrogen peroxide to oxygen and water. No side reactions with the substrate or with dyestuffs occur.

Achieved Environmental Benefits

- Peroxidases are completely biodegradable.
- Savings in energy and water consumption (less rinsing required to remove H_2O_2).
- Reduction in wastewater generation.

Operational Data

A typical process sequence, as shown in figure 4.60 is as below:

Peroxide bleaching - liquor change - one rinsing bath (hot water) - liquor change – enzymatic peroxide removal – dyeing without previous liquor change.[14]

Peroxidases are entirely biodegradable. Rinsing steps after peroxide bleaching can be reduced (normally, only one rinsing step with hot water is necessary). Peroxidases have no negative influence on the downstream dyeing process

[14]*Best Available Techniques in Textile Industry by Dr. Harald Schönberger and Dr. Thomas Schäfer*

Cross Media Effects

There are no cross-media effects.

Economics

Enzymatic removal of Hydrogen peroxide reduces the cost and time of rinsing fabric with water.

Driving Force for Implementation

- Use of environmental friendly auxiliaries
- Cost saving potentials

Reference Industry

M/s. Shanti Processors Pvt. Ltd., Ahmedabad
M/s. Arvind Ltd. (Santej Unit), Ahmedabad

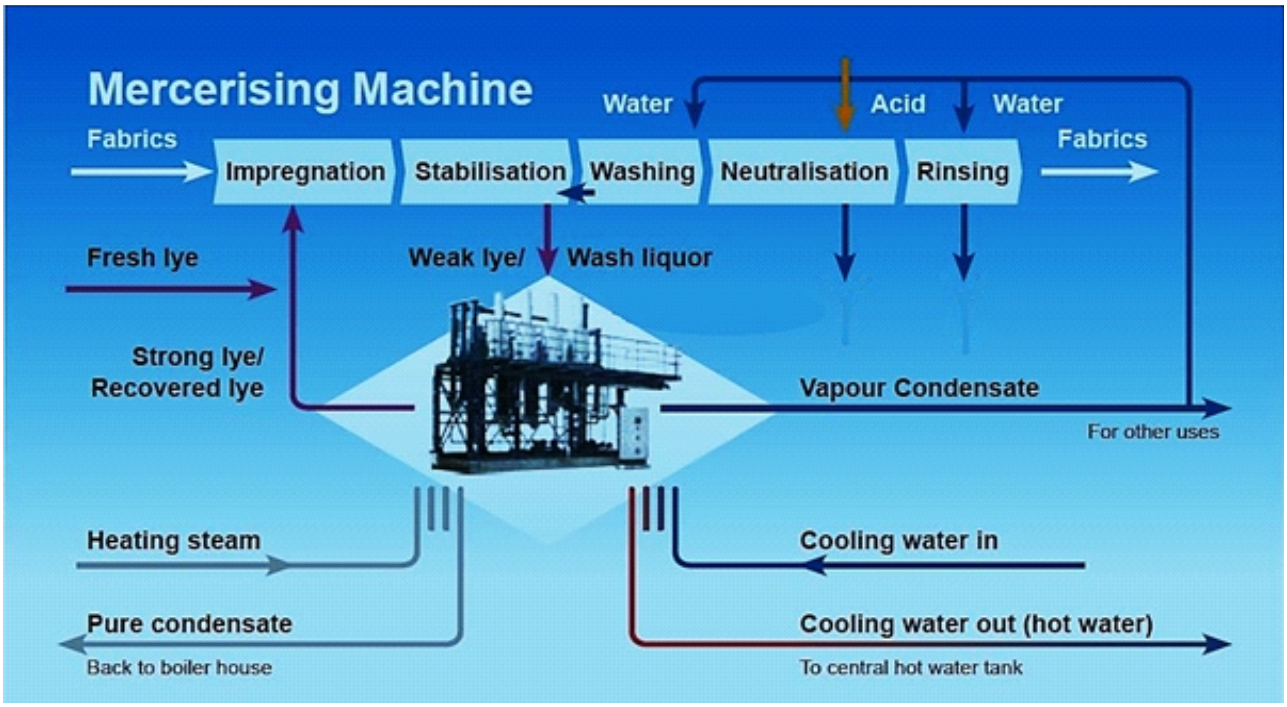


Figure 4.61 - Caustic Recovery System
Source: Körting Hannover AG (https://www.koerting.de/en/caustic-recovery-plants.html)

Technical Description

During the mercerisation process, cotton yarn or fabric (mainly woven fabric but also knitted fabric) is treated under tension in a solution of concentrated caustic soda (270-300 g NaOH/l, or also 170-350 g NaOH/kg of the textile substrate) for about 40-50 seconds. The textile substrate is then rinsed to remove caustic soda. This rinsing water is called weak lye (40-50 g NaOH/l) and can be concentrated by evaporation for recycling. The principle is shown in Figure 4.61.

Achieved Environmental Benefits

- The alkaline load of the wastewater is reduced drastically.
- Acid required for wastewater neutralisation is minimised.

Operational Data

Before evaporation, self-cleaning curved screens and microfiltration remove fluff, fibres, and other solid particles. In the pre-cleaning stage with curved screens, the crystallization of caustic soda occurs via contact of the lye with the carbon dioxide contained in air, resulting in a higher cleaning efficiency than rotary filters.

Weak lye is concentrated in the downstream evaporation plant in two, three or four steps. In the final purification stage, hydrogen peroxide oxidation destroys the strong lye's unwanted yellow colour. Suppose the lye is reused after oxidative desizing. In that case, decolouring can be achieved without adding auxiliaries because the bath contains excess hydrogen peroxide.

Subsequent cleaning is done by flotation. The recovered lye is cooled before reuse. Subsequently, the cooling water can be used for hot processes.

In raw mercerisation, the concentration of impurities is significantly higher, as is the viscosity, which makes it difficult to reach higher concentrations (because the circulation in evaporators is less efficient).

Cross Media Effects

- In the case of lye purification with hydrogen peroxide, additional auxiliaries are needed.
- Energy is needed for the evaporation of the weak lye.

Economics

Investment Cost	**Moderate to High**
Cost Indicative	**Investment (In Rupees)**
Very Low	< 1 Lakh
Low	< 10 Lakh
Moderate	10 - 20 Lakhs
High	20 - 50 Lakhs
Very High	> 50 Lakhs

Driving Force for Implementation

- Reduction in chemical consumption
- Reduction in acid usage to neutralize caustic soda in ETP

Reference Industry

Majorly all reference plants are using this technique.

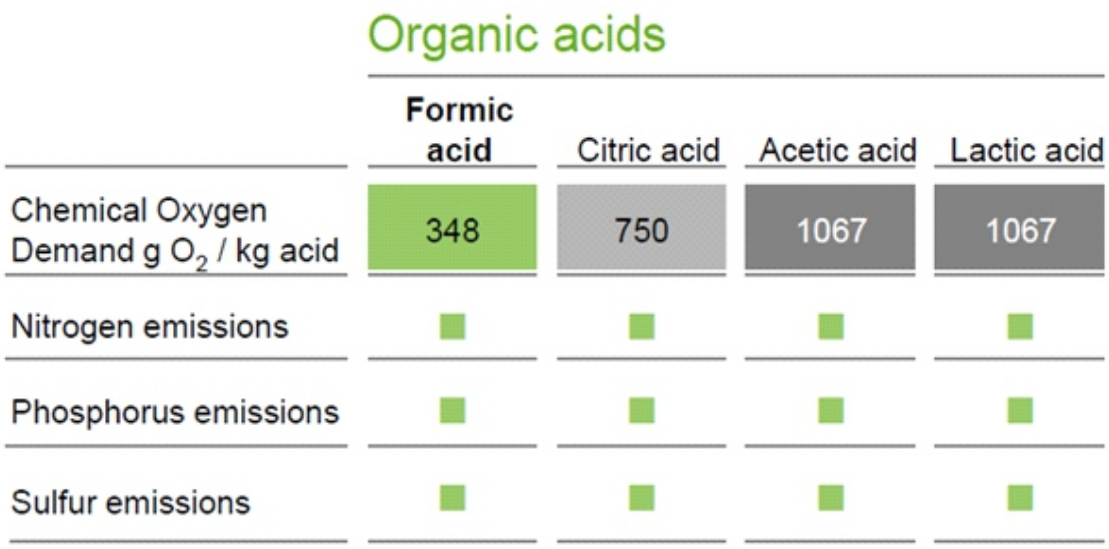


Figure 4.62 - Comparison of COD of different organic acids
Source: BASF

Technical Description

The acetic acid can be replaced with formic acid, which is more efficient, requiring less to achieve identical results, potentially lowering operating costs.

But, since the formic acid cost is higher, a solution mix of formic acid and acetic acid can also be used to reduce the overall acetic acid consumption.

Achieved Environmental Benefits

- Reduction in wastewater COD load will enhance the efficiency of the wastewater treatment plant

Operational Data

In the following textile processes:

- Scouring
- Bleaching
- Mercerizing
- Dyeing

Above processing step takes place in an alkaline medium, and post-processing, a wash is required with acetic acid to neutralize the excess sodium hydroxide to neutral the pH.

Post mercerization, the fabric is rinsed with acid to make its surface neutral to avoid its shrinkage.

Cross Media Effects

No relevant cross-media effect is known.

Economics

The Mix. of Organic Acids price is comparable to Acetic Acid considering higher consumption of Acetic Acid compared to the Mix. of Organic Acids.

Driving Force for Implementation

- Financial benefits
- Resource conservation (Fresh water and Chemicals)
- Regulatory Compliance

Reference Industry

M/s. Arvind Ltd. (Santej Unit), Ahmedabad

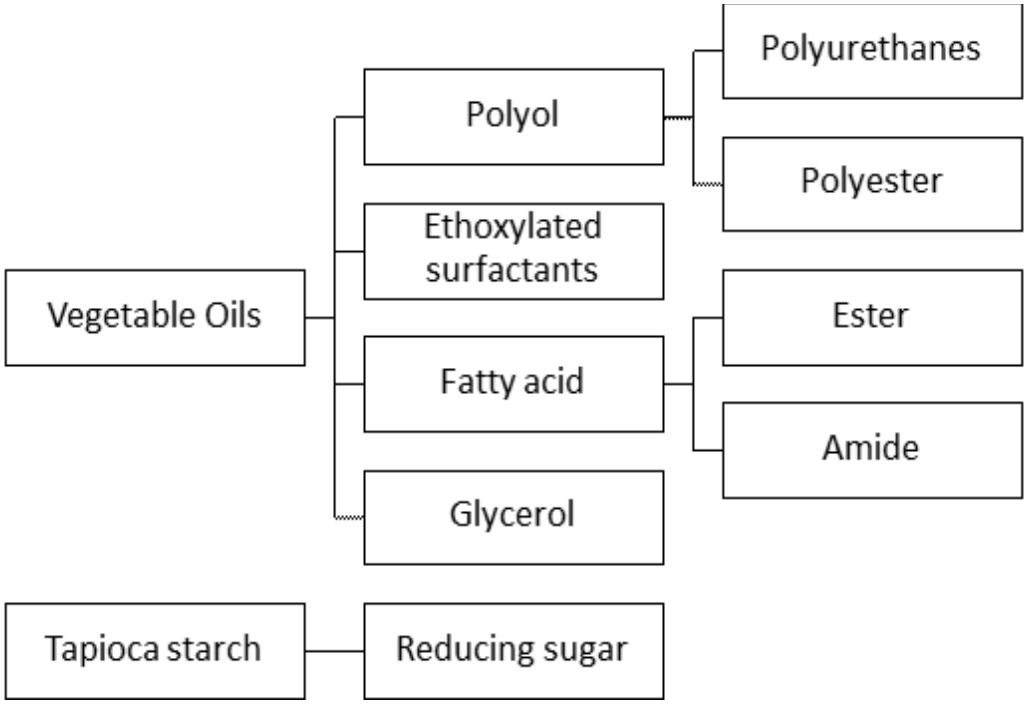


Figure 4.63 - Origin of Eco-friendly Surfactants

Technical Description

Surfactants (organic polar compounds with at least one hydrophobic part and at least one hydrophilic group) are widely used in the textile finishing industry. Different kind of surfactants i.e. anionic, non-ionic, cationic and amphoteric) are in use—however, anionic and non-ionic are majorly used. Due to its versatile characteristics Surfactants in the textile industry is used in form of detergents, wetting agents, deaeration agents, levelling agents, dispersing agents, softening agents, emulsifying agents, spotting agents, anti-electrostatics, after-treatment agents for fastness improvement, felting agents, fixing acceleration agents for continuous dyeing and printing.

The following chemical substances are mainly in used in surfactant:

Anionic surfactants:

Alkyl sulfates, alkyl ether sulfates, alkane sulfonates, alkyl aryl sulfonates, fatty acid condensation products, alkali salts of fatty acids (soaps), lignine sulfonates, condensation products of formaldehyde and naphthaline sulfonic acid.

Non-ionic surfactants:

Hydrophilic part: polyethylene oxide or polypropylene oxide; hydrophobic part: fatty alcohol, fatty amine, fatty acid amide, fatty acid, alkyl phenol, alkyl naphthol.

Cationic surfactants:

Derivatives of quaternary ammonia salts.

Amphoteric surfactants (very rare):

Betaine derivatives.

Many surfactants give rise to environmental concerns due to their poor biodegradability, toxicity (including that of their metabolites) and potential to act as endocrine disrupters.

Concerns in the textile sector currently focus on alkylphenol ethoxylates (APEO) and in particular on nonylphenol ethoxylates (NPE), which are often may be contained in the formulations of detergents and many other auxiliaries (e.g. softeners, desizing, fixing, wetting and dispersing agents, emulsifiers, spinning lubricants).

Alkylphenol ethoxylates are themselves believed to be endocrine disruptors and to cause feminisation of male fish with a known oestrogenic effect. More importantly, they produce metabolites that are believed to be many times more potent as endocrine disruptors than the parent compounds. The most potent of these are octyl- and nonylphenol.

BAT is to use Surfactants that are biodegradable and bio eliminable are used in pre-treatment, dyeing, printing and finishing processes instead of alkylphenols and alkylphenol ethoxylates (AP/APEO).

Achieved Environmental Benefits

Degree of biodegradation of wastewater increases

Operational Data

The main alternatives to NPE are (mostly linear) alcohol ethoxylates (AEs). The properties of these non-ionic surfactants can be adjusted by the alcohol selection and the hydrophilic polyethylene glycol chain length. The properties of AEs are affected by the length and the structure of the alkyl chain and the length of the polyoxyethylene chain. The challenge of replacing NPEs with AEs is to balance their good wetting and detergent properties, with sometimes inferior emulsifying and dispersion properties, which are additionally needed in most applications. Therefore, selecting appropriate AEs is often a compromise, and not a straight replacement of NPE.

The most effective are AE mixtures comprising AEs of different alkyl chain lengths and single cut alcohols (from C_6 to C_{22}).

A recent study has identified the following substances as possible alternatives to be used as

detergents:

- C9-11 alcohols, ethoxylated (6 EO);
- C12-15 alcohols, ethoxylated (9EO);
- Oxirane, methyl-, polymer with oxirane, mono(2-ethylhexyl ether); Ecosurf EH-9;
- D-glucopyranose, oligomeric, decyl octyl glycosides;
- Benzenesulphonic acid, C10-13-alkyl derivatives, sodium salt;
- Sodium lauryl sulphate;
- Polyoxy(1,2-ethanediyl), alpha-sulfo-omegadodecyloxy-, sodium salt;
- Sorbitan monostearate.

To minimise ecological load in wastewater caused by surfactants, the following principles should be regarded.

- No use of APEO-containing products (with the exception to APEO- containing coating pastes which are not released to wastewater);
- Use of readily biodegradable surfactants;
- Aquatic toxicity of the products should be considered as well as possible critical by-products concerning the workplace atmosphere.

Cross Media Effects

There are no cross-media effects to be mentioned.

Economics

The benefits of bio surfactants versus conventional surfactants need to be weighed against their typically higher cost and their compatibility with other processing steps.

Driving Force for Implementation

- Improvement of the environmental performance

Reference Industry

M/s. Arvind Ltd. (Santej Unit), Ahmedabad

Technique 50. Low emission preparation agents

Technical Description

Man-made fibres cannot be produced and processed without auxiliaries. Preparation agents are applied on their way to yarns and fabrics. In wet processing, esp. in pre-treatment (heat setting and washing), these auxiliaries find their way into the waste water and exhaust air of finishing mills.

Conventional preparation agents are mainly based on mineral oils with their well-known disadvantages concerning low-temperature stability, low biodegradability, and generation of non-sedimentable sludge in biological wastewater treatment.

Alternatives for the mineral oil containing conventional systems are low-emission preparation agents based on the following chemistry:

- Polyester-/polyether polycarbonates
- Special polyol esters or
- Special steric hindered fatty acid esters.

Achieved Environmental Benefits

- Reduced emission levels of organic volatile compounds in the exhaust air

Operational Data

Yarn producer

- Some machine components have to be of refined steel due to potential corrosion problems.
- With polyester/polyethercarbonate-based products compatibility problems with conventional hydrophobic preparation systems means that thorough equipment cleaning is needed following use.

Finishing mill

- Processes in pre-treatment have to be adjusted to the new preparation systems. Partly washing steps in pre-treatment can be simplified or omitted.

A comparison of the emission behaviour between these new products and the conventional systems at the heat setting of grey materials is given in Table 4.5.

Table 4.5 - Emission factors and corresponding Organic-C concentration in the off-gas (Preparation add-on: 2%; air/textile ratio:20 m^3/kg; heat setting temperature: 190 °C; curing time 1.5 min)

Substance	Emission factor(app.) [g C/kg textile]	Concentration(app.) [mg C/m^3]
Conventional products		
Mineral oils	10 - 16	500 – 800
Classic fatty acid esters	2 - 5	100 – 250
Optimized products		
Steric hindered fatty acid esters	1 – 2	50 – 100
Polyol esters	0.4 – 4	20 – 200
Polyester-/ polyether polycarbonates	0.2 – 1	10 – 50

Low emission preparation agents are applicable on PES, PA 6.6, PA 6, CV and cotton, wool and their blends with PES or CV. However, it should be noted that the applicability is fibre, yarn, fabric processing, and end-use specific.

Traditional preparation agents are more affordable, and spinning mills focus primarily on the economics and the effectiveness of a particular chemical throughout the spinning process. Spinning mills do not prioritise the environmental issues caused by the finishing mill's downstream operations.

Cross Media Effects

Since new products are less volatile, off-gas emissions are reduced, but a higher amount remains on the fabric after heat-setting and eventually ends up in the waste water.
However, because of the lower quantities applied and the better biodegradability of the new products, the replacement will always bring benefits

Economics

The benefits of low-emission preparation agents versus conventional preparation agents need to be weighed against their typically higher cost and the better working environment that low-emission preparation agents create for workers.

Driving Force for Implementation

- Minimising off-gas loads caused by preparation agents and;
- Compliance with regulatory standards

Reference Industry

M/s. Siddhivinayak Knots and Prints, Surat

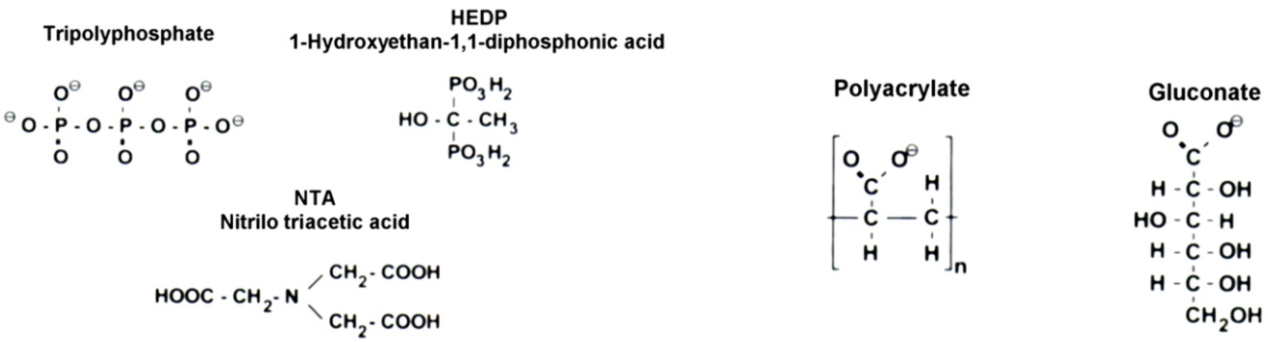


Figure 4.64 - Chemical structure of some N- or P-containing complexing agents (left) Chemical structure of some N- and P-free complexing agents (right)

Technical Description

In aqueous solutions, complexing agents are used as sequestering agents to hide the hardening effect caused by alkaline-earth cations and transition-metal ions and to eliminate their damaging effect, especially in pre-treatment processes (e.g. catalytic destruction of hydrogen peroxide), and also during dyeing operations.

Typical sequestering agents are polyphosphates (e.g. tripolyphosphate), phosphonates (e.g. 1-hydroxyethane 1,1-diphosphonic acid) hydrocarboxylic and amino carboxylic acids (e.g. EDTA, DTPA, and NTA)(see figure 4.64.).

Achieved Environmental Benefits

The substitution of conventional complexing agents with the product mentioned above has the following positive effects:

- Reduced eutrophication in the receiving water;
- Improved biodegradability of the final effluent;
- Reduced risk of remobilisation of the heavy metals from sediments.

Operational Data

Complexing agents containing phosphorous (e.g. tripolyphosphate) or nitrogen (e.g. polycarboxylic acids such as EDTA, DTPA or NTA) used in the wet processes (e.g. pretreatment, dyeing and finishing) are substituted by biodegradable substances e.g:

- Polycarboxylates (e.g. polyacrylates and copolymers of acrylic and maleic acids);
- Hydroxy carboxylic acids (e.g. gluconates, citrates);
- Sugar-based acrylic acid copolymers.

When complexing agents are used, polycarboxylates or substituted polycarboxylic acids (e.g. polyacrylates and polyacrylate-maleic acid copolymerisates), hydroxy carboxylic acids (e.g. gluconates, citrates) and some sugar-acrylic acid copolymers are convenient alternatives to the conventional sequestering agents. None of these products contain N or P in their molecular structure (see figure 4.64.). In addition, the hydroxy carboxylic acids and sugar-acrylic acid copolymers are readily biodegradable.

Table 4.6 - Qualitative assessment of commercially available complexing agents

Ecological property	EDTA, DTPA	NTA	Poly-phosphate	Phosphonates	Poly-carboxylates	Hydroxy carboxylic acid	Sugar copolymers
Biodegradability	No	Yes	Inorganic	No (1)	No	Yes	Yes
Bioeliminability	No	Yes	NI	Yes (1)	Yes	NI	NI
N-content	Yes	Yes	No	No	No	No	No
P-content	No	No	Yes	Yes	No	No	No
Remobilisation of heavy metals	Yes	No	No	No	No	No	No

(1) Under UV photocatalytic degradation is observed
NB: NI: No information
Source: EU BREF 2022

Table 4.7 - Effectiveness of complexing agents

Property	EDTA, DTPA	NTA	Poly-phosphate	Phosphonate	Poly-carboxylates	Hydroxy carboxylic acid	Sugar copolymers
Softening	+	+	+	++	+	0	+
Dispersing	-	-	0	+	+	-	+
Stabilisation of peroxide	+	-	-	++	0	-	+ (special products)
Demineralisation	++	+	0	++	0	0	0

NB: Effectiveness increases in the following order: -, 0, +; ++

The complexing agents described in this section can be used in continuous and discontinuous processes.

The product requirements may restrict the applicability.

Cross Media Effects

Regarding the application of conventional complexing agents, there are no cross-media effects of concern. With polyacrylate-based complexing agents, the residual monomer content in the polymer should be taken into account (note that acrylates are also widely used in large volumes in other sectors as detergent builders, thus overloading the waste water treatment plants more significantly than textile effluents do).

Economics

The costs for sugar-acrylic copolymers are about 30-50 % higher than those of amino carboxylic acids like EDTA, DTPA or NTA because of the higher quantities needed (for the same effect) and higher costs.

Driving Force for Implementation

- Eco-labelling schemes

Reference Industry

Information not available.

Sr. No.	Technique Name
1.	Use of Glauber salt instead of common salt and its recovery and reuse
2.	Replacing soda ash with liq. alkali solution
3.	Minimisation of dye liquor uptake in pad dyeing techniques
4.	Exhaust dyeing of cellulosic fibres with polyfunctional reactive dyestuffs
5.	Enzymatic removal of unfixed dyestuff in reactive dyeing
6.	Optimised rinsing of cotton dyed with reactive dyes
7.	Dispersing agents with higher bio-eliminability in dye formulations
8.	Dyeing with levelling agents made from recycled vegetable oil
9.	Environment-friendly reductive treatment post polyester dyeing

Table 4.8 - Comparison between Sodium Chloride and Glauber salt

Drawbacks of Sodium Chloride:	Benefits of Sodium Sulphate
The fabric handle with common salt becomes rough.	Fabric handle with Glauber salt becomes smoother.
Sodium chloride adds TDS to the dye bath and adds load on effluent.	The dye exhaustion is higher using Glauber salt than common salt, resulting in a darker shade.
Water Hardness increases due to chloride ions of common salt.	Glauber salt's concentration is less than common salt to get a similar depth of shade. Therefore, the hardness of water by using Glauber salt is least increased.
Common salt causes dyeing machines' corrosion due to chloride ions in it.	Glauber salt does not cause any corrosion to dyeing machines.

Technical Description

To combine, the textile substrate (fabric) and dye molecule, which don't have the same properties, readily react with each other. In such a case, we require some catalyst to facilitate dyeing action on fabric. Salt plays this crucial role as a catalyst. As salt has an extremely high affinity for water. Broadly speaking,

Salt is necessary to drive dye into the fabric during the dyeing process, leading to maximum exhaustion of dye molecules. It works as an electrolyte for migration, adsorption and fixation of the dyestuff to the cellulose material.

During the Dyeing Process, it is better to use Glauber's salt instead of common Salt (NaCl) because it is purer and easier to recover for Reuse.

Achieved Environmental Benefits

- Minimize water and salt consumption.
- Reduced brine discharge to waters

Operational Data

Sodium Chloride (NaCl) is a colourless crystalline inorganic compound. It comprises sodium and chlorine ions, in which ionic bonds hold the two components and make it soluble in water. It has a key role in the textile dyeing process in maintaining electrolyte balance in the textile dyeing process.
Glauber salt is the decahydrate form of sodium sulphate $Na_2SO_4.10\ H_2O$; it occurs as white or colourless monoclinic crystal structure.

In the actual dyeing mechanism, cotton fibres contain cellulose which ionizes in the water

$$Cell - OH \rightarrow Cell - O^- + H^+$$

While reactive dye goes in the water, giving dye anions and sodium cations

$$Reactive\ dye - SO_3Na + Water \rightarrow Reactive\ dye - SO_{3-} + Na^+$$

(Dye anion) (Sodium cation)

During dyeing, both the negative ions of dye and cellulose repels each other in the absence of salt, and thus no exhaustion or very little exhaustion is done, but in the presence of salt, it will ionize as follows,

For Common salt: $NaCl \rightarrow Na^+ + Cl^-$

For Glauber's Salt: $Na_2SO_4 \rightarrow 2Na^+ + SO_4^-$

Thus, the salt neutralizes the negative ion of the cellulose and facilitates exhaustion,

$$(Cell - O^- + H^+) + Na^+ + Cl^- \rightarrow Cell - ONa$$

$$Cell - ONa + SO_{3-} - Reactive\ dye \rightarrow Cell - O - Reactive\ dye$$

(Exhausted dye on the substrate)

Thus, the presence of salt in the reactive dyeing increases the affinity of the dye toward the Cellulosic substrate.

Glauber salt (Na_2SO_4) produces (Na^{2+}) ion, which is twice the Common salt (NaCl), so Glauber salt can influence more dye uptake. In addition, Glauber salt as an electrolyte in the dye bath reduces Total Dissolved Solid (TDS) levels to approximately 15 – 20%. This reduces the load on ETP, in turn, provides cost advantages. Therefore, the hardness of water by using Glauber salt increases less, and to get a similar depth of shade, the necessity of the Glauber salt's concentration is less than that of common salt.

The concentrated dye effluent with Glauber's salt is pre-treated to remove colour from the effluent. It is passed through Multiple Evaporators and gets concentrated. The concentrated solution is chilled in a vacuum crystallizer, and the Glauber's salt is crystallized. The crystallized Glauber's salt is stored and is ready for reuse in the dyeing process.

Cross Media Effects

None Identified

Economics

By factoring the costs for both the purchase, processing and recovery of salt, Glauber salt is preferable than common salt.

Driving Force for Implementation

- Compliance with Environmental Standards
- Financial benefits
- Resource conservation (Chemical)

Reference Industry

M/s. Arvind Ltd. (Santej Unit), Ahmedabad

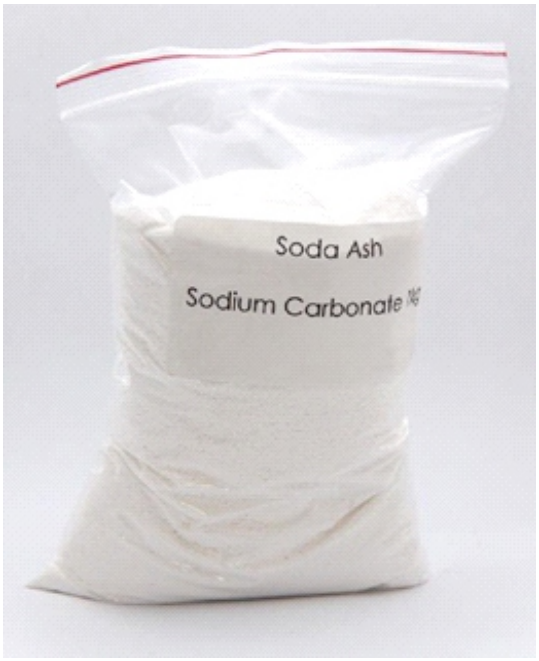




Figure 4.65 - Soda Ash Powder (left) and Liq. Alkali Solution (right)

Technical Description

Reactive dyes are widely used in the dyeing of cotton and cotton blend fibres and fabrics. These dyes are easy to apply and produce brilliant shades, fastness, penetration and levelling. An alkaline dye bath is required to achieve the desired reaction or "fixing" between the dye molecule and the fibre.

For dye house operations, sodium carbonate (soda ash) is the most popular option to make dye liquor alkaline. Due to its solid structure, during manual prepartion of the dye solution solid lumps are developed as a result of poor mixing..

These undissolved soda ash lumps flow into machinery and clog drain lines. During the bath's neutralisation stage, a significant amount of acetic acid is required to neutralise the weakly soluble soda ash powder that remains on dyed fabric after washing with water.

The Soda ash can be replaced with liq. alkali solution for better performance and reduced consumption.

Achieved Environmental Benefits

- Reduction in water consumption for washing
- Reduction in wastewater TDS load will enhance the efficiency of the wastewater treatment plant

Operational Data

Liq. alkali buffer solution is formulated using a combination of Potassium Hydroxide, Potassium Carbonate, Potassium Citrate and Potassium Polyacrylate. The solution provides a higher pH and buffering action in a pre-selected range for the particular processing operation. It provides conditions that promote uniform chemical bond formation between the dye and cellulosic textile material, resulting in uniform dyeing. The firm chemical bond between the dye and the cellulosic textile material is responsible for excellent wash fastness produced on cellulosic with reactive dyes.

The solution constituents are environment-friendly. It is biodegradable and has less load on ETP than soda ash powder. Also compared to Soda Ash powder, it requires less acetic acid to neutralise dyed fabric, which is an additional financial gain.

Table 4.9 - Comparison of Soda ash and Liquid Alaki Solution

Sr. No.	Shade (%)	Soda ash (GPL)	Liq. Alkali (GPL)	Glauber Salt (GPL)	pH	Conductivity (mS/cm)	TDS-LOD (PPM)
1.	0.5	12	-	15	11.32	31.3	26400
		-	3.10	15	11.54	19.7	19000
2.	0.5-1	15	-	30	11.37	57.7	43300
		-	3.25	30	11.89	39.2	31500
3.	1-3	20	-	45	11.39	88	62700
		-	3.80	45	11.42	61.1	45500
4.	3-6	20	-	60	11.89	105	75200
		-	4.75	60	12.00	83.3	59700
5.	>6	20	-	80	11.97	131	89900
		-	4.75	80	12.01	121	82000

Source: Arvind Ltd. (Santej Unit) R&D Centre

Cross Media Effects

No relevant cross-media effect is known.

Economics

By factoring in the costs involved in dyeing steps required for both chemicals, Liq. alkali is comparable in price to soda ash.

Driving Force for Implementation

- Financial benefits (Reduction in use of water and acetic acid will lead to financial savings)
- Water and Chemical (Acetic Acid) conservation
- Effluent generated will have less load on ETP

Reference Industry

M/s. Arvind Ltd. (Santej Unit), Ahmedabad

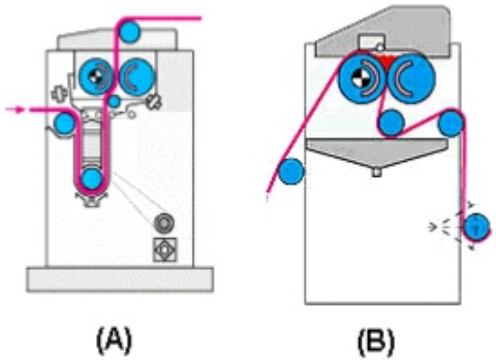


Figure 4.66 - Representation of U-shaft (A) and nip (B) dye liquor application systems

Technical Description

The main emission sources in pad dyeing processes arise from the discharge of the residual dyeing liquor contained in the pad, pumps and pipes at the end of each lot when a new colour is started. These losses can be reduced by carrying out the impregnation step in a nip (see configuration B in Figure 4.66) or by minimising the capacity of the dip trough with, for example, flex-shaft or U-shaft systems.

Achieved Environmental Benefits

- Resource efficiency
- Reduction in dye liquor (chemicals) to ETP

Operational Data

Conventional pad-bath troughs have a capacity ranging from 30 litres up to 100 litres. Changing over to U-shaft troughs (12-litre capacity) enables a reduction of the residues of unused liquor from 60 % to nearly 90 % per batch, compared to the conventional system. Similarly, in the case of nip dyeing (5-litre capacity), up to 95 % reduction is achieved.

U-shaft is used in the semi-continuous dyeing of cotton fabrics with reactive dyes (cold pad-batch). Often, the U-shaft is combined with a dosing system, and shortly before the application, dye and alkali solution are mixed in a static mixer. In that case, the residual liquor is lost because hydrolysis of the reactive dyes starts immediately after mixing of dye and alkali solution, and recovery for reuse dye and alkali solution is impossible.

Separate dispensing of chemicals and colourants avoids unnecessary wastage of raw materials that cannot be considered for further reuse if already pre-mixed. The preparation of the dye liquor batch based on on-line measurement of the pick-up allows a reduction of the residual dye liquor in the feeding tanks from 150 litres down to 5-15 litres, and for fabrics with larger width down to 50 litres.

Routine maintenance is essential to ensure the equipment's precision and proper performance. In particular, the precision of the dosage system (e.g. pumps) and pick-up measurement should be checked at regular intervals. In measuring the pick-up, the fabric's specific weight must be determined

before dyeing and not before pre-treatment.

The techniques described are applicable both for new and existing continuous and semi-continuous dyeing machines. However, it is often more convenient to install completely new machinery rather than upgrade parts of the existing machine.

Cross Media Effects

None Identified

Economics

Investment Cost	**Moderate to High**
Cost Indicative	**Investment (In Rupees)**
Very Low	< 1 Lakh
Low	< 10 Lakh
Moderate	10 - 20 Lakhs
High	20 - 50 Lakhs
Very High	> 50 Lakhs

Driving Force for Implementation

- Increased reproducibility (right-first-time) and productivity achieved due to improved process control.

Reference Industry

None

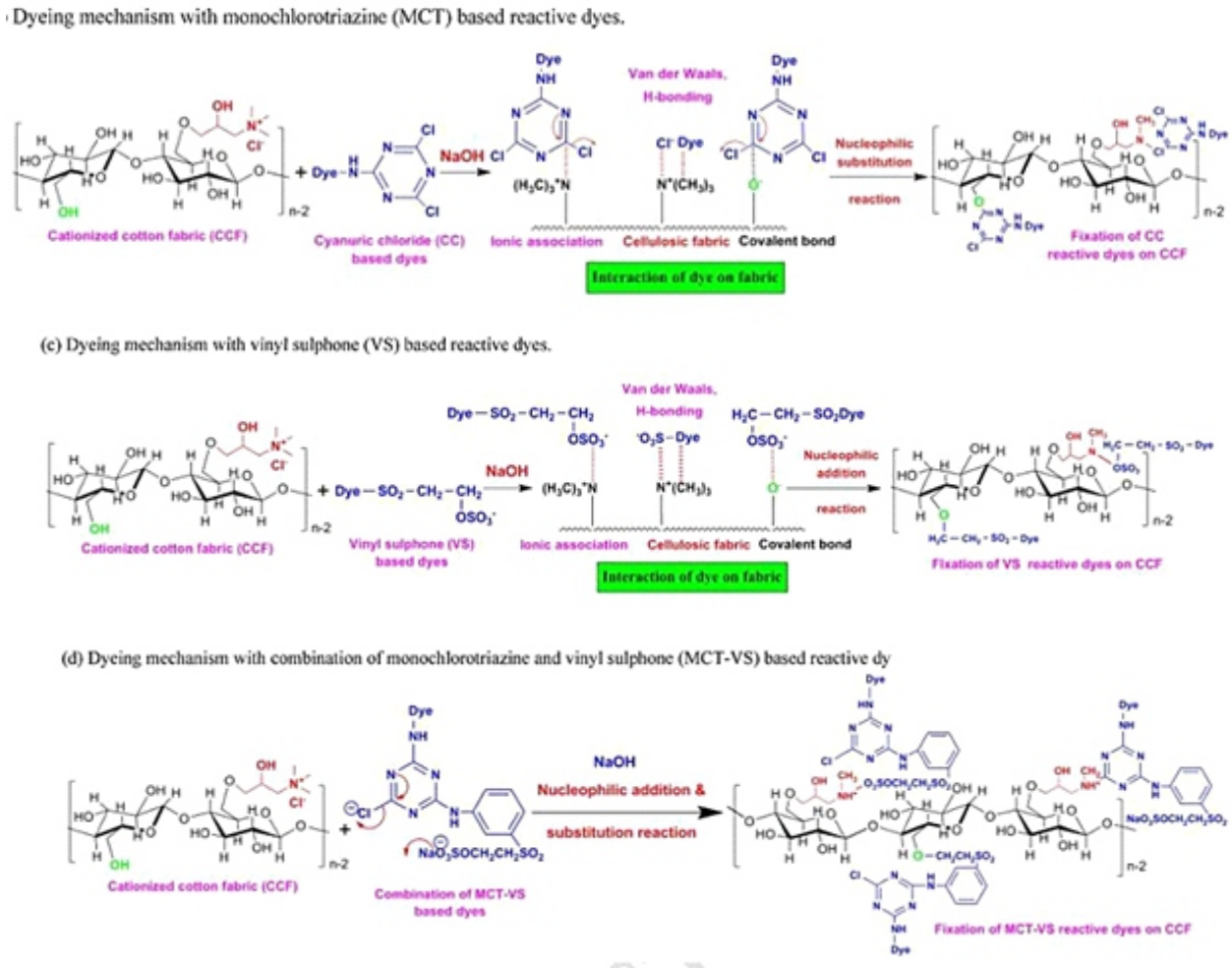


FIGURE 4.67 - Examples of Reactive Dyeing Mechanisms of Bifunctional Reactive Dyes

---

Technical Description

In exhaust dyeing, bifunctional reactive dyes with two comparable or different reactive systems give incredibly high fixation levels. Since they have two reactive groups, bifunctional reactive dyes have a higher likelihood of a chemical reaction with cellulose fibres than monofunctional dyes with a single reactive group.

During the dyeing process, if one of the reactive groups hydrolyzes, the other one can still chemically react with the hydroxyl groups of cellulose. Furthermore, integrating two reactive systems in a single dye yields the benefits of the two separate groups (e.g. high degree of fixation with high fastness levels and wash-off). Polyfunctional dyes are not always superior, though, they are preferable to traditional mono-reactive dyes only when the proper combination of reactive groups is present.

The figure illustrates the examples of reactive dyeing mechanisms of polyfunctional reactive dyes. Most of these dyes are bifunctional dyes with monoflurotriazine (MFT) and monochlorotriazine (MCT) functional groups. Furthermore, the vinyl sulphone (VS) functional group is combined with trifunctional

reactive dyes.

Use of polyfunctional reactive dyes with more than one reactive functional group to provide a high level of fixation in exhaust dyeing. These dyes require a lower salt concentration.

Achieved Environmental Benefits

- Reduction of unused dyestuff ending up in the waste water stream (reduced colour and organic load)
- Reduction of chemical consumption
- Lower salinity of emissions to water

Operational Data

High-fixation reactive dyes can be applied in all types of dyeing machines but offer a particular advantage on the most modern low-liquor-ratio dyeing machines fitted with multi-task controllers where additional advantages in terms of reduced energy and water consumption can be exploited.

In particular, new reactive dyes with very good solubility can be applied at ultra-low liquor ratios. Salt consumption for exhaust dyeing of cellulose fibres is reduced by about one-third of the quantity needed for conventional reactive dyestuffs, with positive effects on effluent salinity and smooth running of waste water treatment units.

Cross Media Effects

None identified

Economics

Compared to conventional reactive dyes, polyfunctional reactive dyestuffs are more expensive, but the higher fixation efficiency, the savings on salt usage and the reduced water and energy consumption significantly reduce the total cost.

Drivning Force for Implementation

- Environmental legislation
- Reduction of total processing costs is possible thanks to high dye fixation
- Water scarcity
- Salt-induced corrosion

Reference Industry

M/s. Shanti Processors Pvt. Ltd., Ahmedabad

Technique 56. Optimized removal of unfixed dyestuff in reactive dyeing.

Technical Description

Dyeing and printing with reactive dyes entails a number of soaping and rinsing steps to remove the unreacted and hydrolysed dye from the substrate. Removing all unfixed dyestuff from the fibre is essential for obtaining optimum wet-fastness while contributing significantly to the overall dyeing process's energy, water and chemical consumption.

An enzymatic treatment removes the non-fixed dyestuff from the fibre and the exhausted dye bath.

In addition, newly developed products for after-soaping based on vinyl polymers (e.g. poly(vinyl pyridine-N-oxide) and poly(vinyl pyridine betaine) polymers) prevent renewed uptake of unfixed dyestuff on the fibre in shortened rinsing passages.

The number of rinsing baths depends on the depth of shade. Significant savings can be reached for light shades by minimising the number of rinsing baths.

Achieved Environmental Benefits

- Reduction of emissions to water.
- Reduction of water consumption

Operational Data

The application of the enzymatic compounds usually takes place in the fourth or fifth rinsing step and shows that one or two hot rinsing steps can be avoided when using enzymatic after-treatment or vinyl polymers, respectively. In the latter case, overflow rinsing is also avoided. Savings in water, energy and detergent consumption are the main advantages achievable with this technique.

Table 4.10 - Comparison of the sequence steps between a conventional and an enzymatic after-soaping treatment (exhaust dyeing)

The typical sequence in the case of conventional after-soaping	The sequence in the case of enzymatic after-soaping
5 min overflow rinsing 10 min 40 °C 10 min 40 °C; neutralisation 10 min 95 °C 10 min 95 °C 10 min 50 °C 10 min 30 °C	5 min overflow rinsing 10 min 40 °C; neutralisation 10 min 60 °C 10 min 95 °C 15 min 50 °C; enzymatic treatment 10 min 30 °C
Source - UBA, BAT reference document - Germany, 2001.	

Table 4.11 - Comparison of the sequence steps between a conventional soaping treatment and a soaping treatment with vinyl polymers (exhaust dyeing)

The typical sequence in the case of conventional after-soaping	The sequence in the case of optimised after-soaping with vinyl polymers
5 min overflow rinsing 10 min 40 °C 10 min 40 °C; neutralisation 10 min 95 °C 10 min 95 °C 10 min 50 °C 10 min 30 °C	10 min 30 °C 10 min 70 °C; neutralisation 10 min 95 °C; treatment with vinyl polymers 10 min 70 °C 10 min 30 °C
Source – 1. UBA, BAT reference document - Germany, 2001. *2. ÖKOPOL, BAT for the Textile Industry, 2011*	

Cross Media Effects

None identified.

Economics

Savings in water and energy consumption and reduced process time are among the economic benefits achievable.

Driving Force for Implementation

- Improved quality (higher fastness) of the final product

Reference Industry

Plants mentioned in EU BREF 2019.

Technique 57. Optimised parameters for rinsing of cotton dyed with reactive dyes

Technical Description

Both international literature and practical experience in textile mills show that detergents do not improve the removal of hydrolysed reactive dyestuffs from the fabric. On the contrary, high temperatures do have an impact on rinsing effectiveness. Tests carried out with rinsing at 90-95 °C have shown that rinsing is more effective and faster at high temperatures. About 30 % more unfixed hydrolysed reactive dyestuff is rinsed out after 10 minutes of rinsing at 95 °C than at 75 °C.

Achieved Environmental Benefits

- Reduction in detergents consumption(Surfactant, which are toxic to water bodies)
- Pollutant load discharged to the waste water

Operational Data

The high degree of fixation and good wash-off properties typical of some new low-salt, polyfunctional reactive dyes are important factors that help obtain sufficient wash fastness with hot rinsing without needing detergents.

Many dye houses already carry out hot rinsing without detergents after reactive dyeing. The product quality is not negatively affected. On the contrary, the fabric's fastness is usually better after the hot rinsing than after the traditional rinsing with detergents, complexing agents and neutralisation in the first rinse. Energy is recovered when using large volumes of hot process water. Energy can be recovered either by heat exchange between the hot outgoing process water and the cold incoming fresh water or by reclamation of the hot water and reusing both energy and water.

Chemicals to decompose reactive dyes are not used in the washing process because they destroy the dye. If degradation is intended, surfactants are needed to transport the poorly soluble dye fragments off the fibre and out of the washing bath. This is especially the case for discontinuous processes like jet or jig processes.

Cross Media Effects

- Hot rinsing leads to higher energy consumption unless thermal energy from the rinsing effluent is recovered

Economics

The only change in operating procedures is to avoid the addition of detergents. Savings will depend on the number of reactive dyeings carried out at the company.

Driving Force for Implementation

- Savings in chemical consumption.
- Compliance with Environmental standards

Reference Industry

Many reference plants in Ahmedabad cluster are practising this technique.

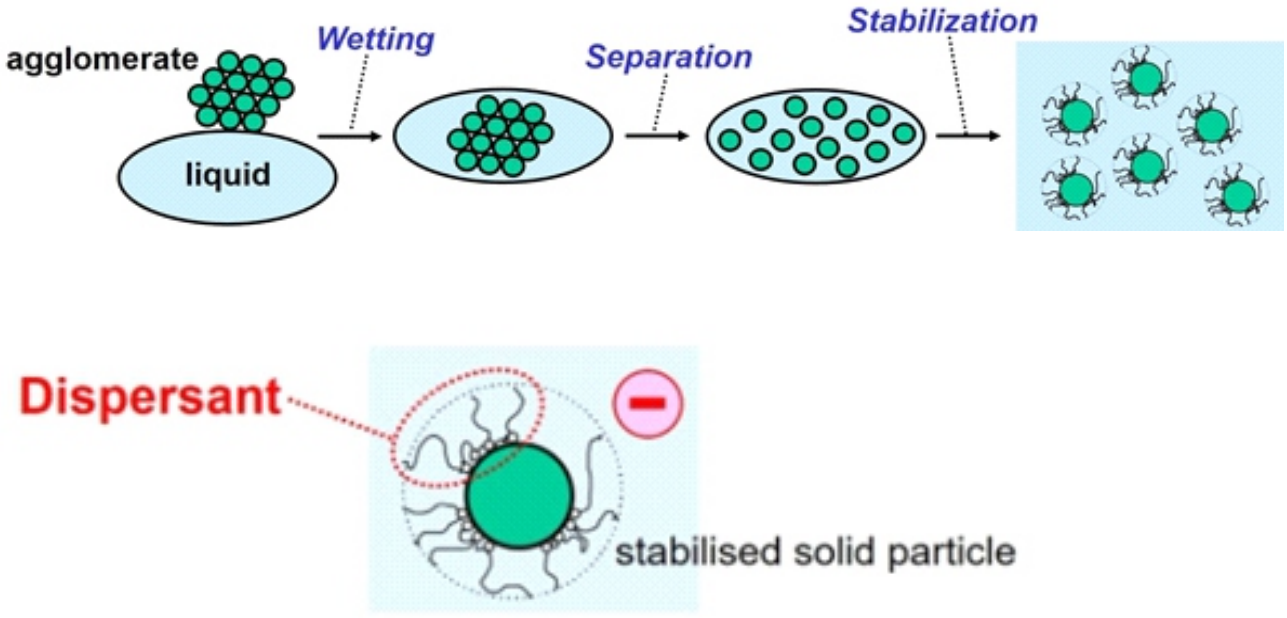


Figure 4.68 - Action of dispersing agent
Source: https://knowledge.ulprospector.com/10613/pc-the-differences-between-wetting-agents-and-dispersants/

Technical Description

Dispersing agents are present in disperse, vat and sulphur dye formulations (further added in the subsequent steps) to ensure uniform dispersion throughout the dyeing and printing processes.

The dispersing agents end up in the final effluent because they don't bind to the fibres. The majority of the organic waste that is challenging to dispose of originates from dyeing and printing operations because these procedures involve numerous dispersion agents that are typically difficult to degrade or eliminate.

Specifically, the lignosulphonates and the end products of the condensation of naphthalene sulphonic acid with formaldehyde are frequently used as dispersion agents. Due to this, COD levels (lignosulphonates) can reach 1200 mg/l and 650 mg/l, respectively (naphthalene sulphonic acid condensation products). Biological wastewater treatment cannot eliminate both compounds. As a result, they contribute to the residual (recalcitrant) COD in treated wastewater.

Achieved Environmental Benefits

- Improved bio-eliminability
- Increase in ETP efficiency

Operational Data

Option A (applicable only to liquid formulations of disperse dyestuffs):

Fatty acid esters are the primary constituents of a combination of dispersion agents. This method partially replaces traditional dispersion agents with optimised products made of fatty acid esters. After some time, the product's dispersing ability surpasses traditional dispersing agents, allowing the formulation's dispersing agent content to be significantly lowered. Due to the formulation's increased dyestuff content, an additional benefit is seen in the dye's increased tinctorial strength, which increases (from 100% to 200%).'

Option B (applicable to common dispersing agents in powder and granulate formulations):

It is a method of using dispersion agents based on combinations of sodium salts of aromatic sulphonic acids. According to reports, these products are modified versions of the typical condensation products made with naphthalene sulphonic acid and formaldehyde. This chemical alteration results in better bio-elimination rates because of the enhanced adsorption rate to the biomass. They continue to be non-biodegradable substances, nonetheless.

Cross Media Effects

None believed likely.

Economics

Dye formulations containing dispersing agents with improved bio-eliminability are generally more expensive than conventional ones.

Driving Force for Implementation

- Improvement in ETP performance
- Compliance to Regulatory standards

Reference Industry

None

Technical Description

Vegetable oil (e.g. olive oil from restaurants) is used as a recyclable raw material to manufacture a levelling agent.

Levelling agents based on recycled vegetable oils are used under high-temperature (HT) conditions in exhaust dyeing of polyester and show dispersion and migration action comparable to standard dyeing.

In addition, dispersing and levelling agents based on recycled vegetable cooking oil is available for dyeing protein fibres (wool or wool-silk blends) with reactive, acid or metal complex dyes and polyamide with acid or metal complex dyes. They are applied to control the dye uptake during the heating phase, promoting a uniform distribution of the dyes.

Achieved Environmental Benefits

- Resource efficiency.
- Reduced emissions to water

Operational Data

Butyl benzoate and benzyl benzoate are typical carriers used in formulating conventional levelling agents for polyester. Levelling agents based on recycled vegetable oils show less aquatic toxicity and achieve similar bioeliminability rates.

Table 4.12 - Aquatic toxicity (algae) of raw materials used for the formulation of levelling agents for PES dyeing

Raw materials for the formulation of levelling agents	Test method	EC50 after 72h (1)
Butyl benzoate CAS 136-60-7	OECD 201: Freshwater algae and cyanobacteria, Growth Inhibition Test	2.9 mg/l (2)
Benzyl benzoate CAS 120-51-4		0.475 mg/l (2)
Intermediate made from recycled vegetable oil (proprietary)		> 100 mg/l (3)

(1) Concentration bringing 50 % of inhibition of growth after 72 hours.
(2) Source: ECHA.
(3) Test has been carried out at LAUS GmbH on the raw materials used for the formulation
Source: EU BREF 2022

Table 4.13 - Bioeliminability of selected levelling and dispersing agents

Type of levelling agent	Bioeliminability
Sodium or potassium salt of naphthalene sulphonic acid polymer with formaldehyde	70 % according to OECD 301A
Dispersing and levelling agent for polyester based on recycled vegetable oil	The degree of bioelimination reached was 60 % after 28 days (OECD 302B). (1)
Levelling agent for polyester based on ethoxylated castor oil	> 70 % according to OECD 302B
Type of (amphoteric) levelling agent for dyeing polyamide and protein fibres	50-60 % according to OECD 301F
Levelling agent for polyamide (slightly cationic)	92 % according to OECD 302B
Levelling agent based on recycled vegetable oil for dyeing protein and polyamide fibres	The degree of bioelimination reached was 79 % after 28 days (OECD 302B). The elimination is based on adsorption on the sludge. (1)
(1) Test has been carried out at LAUS GmbH on the final products. Source: EU BREF 2022	

Dyeing of polyester, protein fibres (wool or wool/silk blends also with reactive dyes that do not contain chromium) and polyamide using levelling agents made from recycled vegetable oil is carried out with no observed differences in application, dyeing conditions, temperature and energy demand, process time and dyeing results (e.g. fastness).

Cross Media Effects

None identified.

Economics

When you factor in the costs for both the purchase and the processing, levelling agents made from recycled vegetable oil are comparable in price to traditional levelling agents.

Driving Force for Implementation

- Compliance with Environmental Standards.

Reference Industry

None

Technical Description

Wash fastness is a major problem in the dyeing of polyester fibres and polyester blends using disperse dyestuffs. To meet washing fastness requirements, an after-treatment step is carried out, which removes the non-fixed disperse dyes from the fibre.

Reductive clearing is normally preferred over simple washing with surfactants because disperse dyestuff molecules absorbed on the surface are broken down into smaller, often colourless and more readily water-soluble fragments. In conventional after-treatment, sodium dithionite is used as a reducing agent. In the conventional process, after dyeing the polyester at 130 °C, the dye bath (acidic) needs to be cooled down to 70 °C before draining, in order to bring the fibre below its glass transition temperature.

The reductive clearing is carried out in a new bath using hydrosulphite and a dispersing agent in alkaline conditions (the temperature is raised again to 80 °C during the process). Afterwards the bath is drained and one or two more rinsing steps are needed in order remove the remaining alkali and reducing agent. The pH of the fabric before entering the steamer needs to be between 4 and 7 in order to avoid yellowing. Rinsing is therefore carried out in acidic conditions.

Two different approaches are proposed:

- Reducing agents based on unique short-chain sulfinic acid derivatives that can be added directly in the exhausted acidic dye bath. This reducing agent is liquid and can therefore be metered automatically. Moreover, it has very low toxicity and is readily biodegradable.
- Use of disperse dyes that can be cleared in alkaline medium by hydrolytic solubilisation instead of reduction. These are azo disperse dyes containing phthalimide groups.

Achieved Environmental Benefits

For Approach A)
This reducing agent can be applied in the acidic pH range, significant water and energy savings can be achieved. Compared to conventional processes, up to 40 % of water can be saved.

Moreover, these aliphatic short-chain sulphinic acid derivatives are readily biodegradable (the product is non-volatile and water-soluble, with more than 70 % DOC reduction within 28 days, under the OECD test 302B). The sulphur content of the product is approximately 14 %, compared to 34 % of sodium dithionite and the amount of by-products (sulphites and sulphates) can be reduced by half relative to the conventional process.

And, unlike sodium dithionite, the product is non-corrosive, non-irritant, non-flammable and does not have an unpleasant odour. As a result, workplace safety compared to dithionite is improved and odour nuisances are minimised.

Approach B)
With alkali-dischargeable dyes the use of hydrosulphite or other reducing agents can be avoided, which means a lower oxygen demand in the final effluent.

There is the possibility of dyeing PES/cotton blends using a one-bath two-step dyeing method, as alkali-clearable dyes can be applied in the same bath with cotton reactive dyes. This brings about additional environmental benefits in terms of water and energy consumption.

Operational Data

Approach A)
In most cases concentrated hydrosulphite can be replaced by the same quantity of the referenced product. In a typical process 1.0 – 1.5 ml/l of reducing agent (for medium shades) and 1.5 – 2.5 ml/l (for dark shades) are added to the exhausted dye bath. The process is carried out for 10 – 20 min at 70 – 80 °C. Hot and cold rinsing follow [179, UBA, 2001].

In order to derive the maximum environmental and economic benefit from the proposed technique, it is of primary importance that only the strict amount of reducing agent needed to reduce the dyestuff is consumed. Consumption of the reducing agent by the oxygen in the machine should therefore be avoided as much as possible. One effective technique to ensure this is to use nitrogen to remove oxygen from the liquor and the air in the machine [182, VITO,2001].

For some types of polyesters that show a higher percentage of oligomers migrating to the surface during the dyeing process, it is advantageous to carry out the after treatment in a fresh bath.

The technique can be used in all types of dyeing machines, not only for polyester fibres, but also for PAC, CA and their blends. The only limitation on applicability is with blends with elastane fibres.

Approach B)
The example below gives a comparison between two equivalent recipes, one with alkali clearable dyes and the other with standard disperse dyes:

The example below gives a comparison between two equivalent recipes, one with alkali clearable dyes and the other with standard disperse dyes

(Recipe with alkali-clearable dyes) • Dye 40 g/kg • pH stabiliser 25 g/kg • Equalisation agent 10 g/kg	(Recipe with standard dye) • Dye 55 g/kg • Acetic acid 25 g/kg • Equalisation agent 10 g/kg • Levelling agent 5 g/kg • Dispersing agent 12 g/kg • Detergent 12 g/kg

With alkali-clearable disperse dyes there is no need for levelling agents, dispersing agents or detergent. Moreover, the amount of dye used is reduced. The resulting environmental benefits are evident.

Alkali-clearable dyes are currently applied for both for PES and PES/cotton blends, with greater environmental and economic advantages being achieved with PES/cotton blends.

Cross Media Effects

Approach A) When the product is used in the dye bath, the unfixed dispersed dye particles are destroyed by reduction so that the effluent is largely free of colour. On the other hand, the byproducts of the reductive reaction may be more hazardous than the original dyestuff (e.g. aromatic amines originating from reduction of azo dyes). Therefore, The effluent must be treated before being discharged (for polyester oligomers and aromatic amines).

Approach B) None believed likely

Economics

Approach A) Significant savings can be achieved as a result of higher productivity, reduced consumption of energy, water and chemicals and a lower burden on waste water.

Approach B) The use of alkali-clearable dyes implies higher recipe costs compared to conventional disperse dyestuffs. However, Approach B is expected to bring savings in time (higher productivity) and reduce water, energy and chemical costs, (particularly when these dyes are applied for PES/cotton blends).

Driving Force for Implementation

Cost savings (higher productivity) and improvement of the environmental performance (especially regarding sulphite content in the waste water) are the main reasons for applying both these techniques.

Reference Industry

None in Gujarat

Sr. No.	Technique Name
1.	Volume minimisation of printing paste supply systems in rotary screen-printing machines
2.	Recovery of residual printing paste in rotary screen printing
3.	Reuse of residual printing pastes
4.	Use of printing chemicals with improved environmental performance

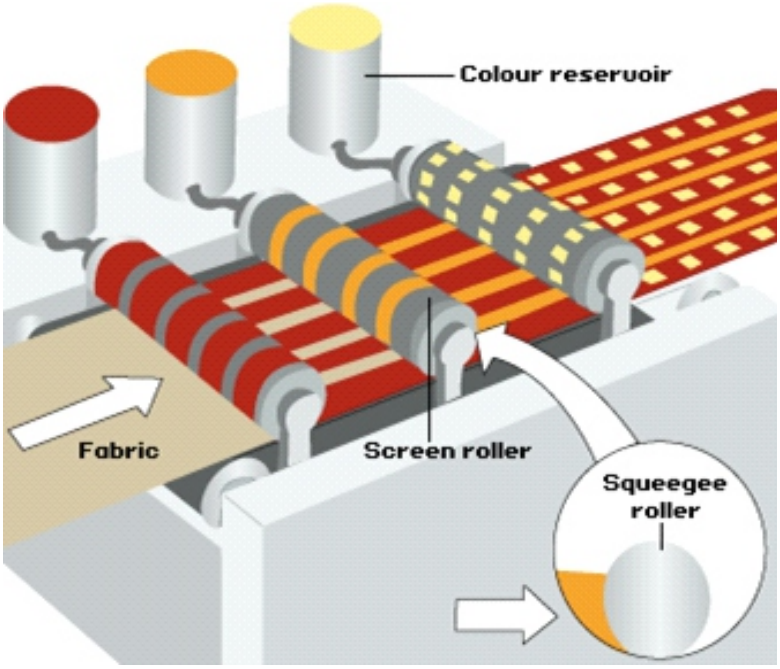


Figure 4.69 - Working of rotary screen printing
Source: Rotary screen making techniques (https://textilelearner.net/rotary-screen-making/)

Technical Description

The utilization of a conventional paste feeding system for rotary-screen printing machines leads to higher quantities of paste waste being generated. This paste residue needs to be minimized by reusing or recovering. Thus, the supply system required a modification to reduce the paste supply.

Achieved Environmental Benefits

- Reduction in printing paste consumption and wastage leading to lower concentration load to ETP

Operational Data

The volume depends on the diameter of the feeding pipes and squeegees, pump design and the length of the pipes. In an exemplary optimised system with a width of 300 cm, the squeegee has a diameter of 0.5 cm compared to 1.5 cm in a conventional system. The length of the optimized feeding pipe is 350 cm when compared to 450 cm in a conventional system.

Printing paste supply systems, there may be up to 20 roller screens per printing machine that must be cleaned at each change of colour or pattern. This way, a considerable amount of printing paste finds its way into the waste water. For fashion patterns, a typical number of colours per design is 7 to 10.

Minimising the system volume, therefore, has a significant role in reducing printing paste emissions to waste water. Diameters of pipes and squeegees have been reduced to 20 - 25 mm, leading to substantial

reductions.

Along with minimum-volume supply systems, paste residues can be minimised by improving paste recovery from the supply system itself. New pumps can be operated in both directions. Thus, the printing paste can be partly pumped back into the drum at the end of each run.

Additional measures are:

- Using squeegees with an even paste distribution over the whole width (minimisation of residual printing pastes in the screens). It has to be assured that the paste distribution inside the stencil is permanently, even as otherwise irregular printing may occur on large print areas. This is no problem with today's producers.
- Manual stopping of printing paste supply shortly before finishing a run in order to minimise the residual printing pastes in the rotary screens.

Particularly for small-run lengths, the following measures may also be considered:

- For patterning runners, not using the supply system, instead of that injecting small quantities of printing paste (1 - 3 kg) directly into the squeegee manually or by manual insertion of small troughs (with a cross-section of 3x3 cm or 5x5 cm).
- Minimise pipes by supplying the printing pastes through funnels positioned directly above the pumps.

System volumes and consequential losses can be reduced substantially (according to industrial experience, a reduction of up to one-third is possible), depending on the age of the equipment. Optimized machines reduce the system volume and, therefore, the printing paste losses by more than 50%.

Typical system volumes in conventional and optimised printing paste supply systems for textiles are shown in Table 4.14.

Table 4.14 - Volume of conventional and optimised printing paste supply systems in rotary screen-printing machines

Printing width (cm)	Conventional system (litres)	Optimised system (litres)	Printing paste saved (litres)	Reduction [%]
164	5.1	2.1	3.0	59%
184	5.2	2.2	3.0	58%
220	5.5	2.3	3.2	58%
250	5.8	2.4	3.4	59%
300	6.2	2.6	3.6	58%
320	6.5	2.7	3.8	58%
Notes: including pipes, pump, and squeegee				

In addition to this volume, residual printing paste in the rotary screens has to be taken into account, which may be about 1 - 2 kg. Thus, conventional systems' loss per supply system is up to 8 kg.

A trained and motivated staff is required as a measure for the manual injection or insertion of printing paste and the manual stopping of the printing paste supply system shortly before the end of the run, needs. Meanwhile, some companies have put the manual injection of printing paste into practice. Still, others report that the technique is difficult to apply even for small lots (up to 120 m). Reproducibility may be affected because the quantity of printing paste to be injected varies according to the pattern, which is difficult to be managed by staff. Moreover, a constant level of printing paste within the screen cannot be maintained, which may affect the constituency of printing quality.

Cross Media Effects

None believed likely. Non attention during a manual injection can lead to interruptions of paste supply shortly before the end of the run, leading to rejects and products of secondary quality.

Economics

The cost will include the installation of 12 sets of volume-minimised pipes and squeegees.

Driving Force for Implementation

- Minimisation of production costs.

Reference Industry

None

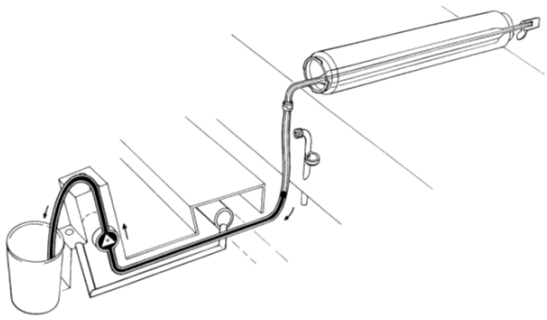


Figure 4.70 - Recovery of printing paste from the paste supply system by back-pumping an inserted ball
Source: EU BREF 2022

Technical Description

Residual printing paste in the supply system is pushed back to its original container (e.g. by a ball controlled by air pressure).

Achieved Environmental Benefits

Reduced generation of waste and wastewater leading to lower concentration load to ETP.

Operational Data

This technique allows the recovery of the printing paste remaining in the supply system in rotary screen-printing machines at the end of each run. Before filling the system, a ball is inserted in the squeegee and then transported to its end by the incoming paste. After finishing a print run, the ball is pressed back by controlled air pressure, pushing the printing paste in the supply system back into the drum for reuse. Systems available for reusing residual printing paste are described in another technique.The technique illustrated in figure 4.70 shows a ball during the phase in which the pump is transporting the paste back to the drum.

Cross Media Effects

None identified.

Economics

None

Driving Force for Implementation

- Reduction of printing paste losses for economic and environmental reasons

Reference Industry

M/s. Arvind Ltd. (Santej Unit), Ahmedabad

Technique 63. Reuse of residual printing pastes.

Technical Description

The residual printing paste is collected, sorted by type, stored and reused. The degree of reuse of printing paste is limited by its perishability.

Achieved Environmental Benefits

The quantity of residual printing pastes to be disposed of is significantly reduced both as wastewater and solid waste.

Operational Data

Companies using a variety of printing pastes with a predominant use of one printing paste can result in the effective recycling methods detailed here.

Printing pastes are prepared with computerised systems (each printing paste has its specific recipe saved electronically). At the end of a run, the residual paste is weighed and sent to a defined location in a storage facility. The composition is saved electronically, and computer programs calculate the formulation of new printing pastes, considering the amount, composition, and durability (which is not usually a problem) of the residues to be reused.

In companies using various printing pastes, managing many different mixtures may be difficult (logistical problems, limited capacity of the storage area.

Cross Media Effects

None identified.

Economics

Reusing printing paste generally does not have a cost factor, as it requires only open space for storage.

Driving Force for Implementation

- Economic considerations in terms of savings in printing paste supply and costs related to residual printing paste disposal

Reference Industry

Major plants in Gujarat are following this technique.

Technique 64. Use of printing chemicals with improved environmental performance.

Technical Description

Use of printing chemicals with improved environmental performance includes:

- Thickeners with no or low contents of volatile organic compounds;
- Fixation agents with low potential for formaldehyde release;
- Binders with low contents of ammonia and low potential for formaldehyde release.

Achieved Environmental Benefits

- Reduction of emissions of organic compounds, formaldehyde, and ammonia to air;
- Formaldehyde emissions are entirely prevented when using formaldehyde-free pigment printing systems.

Operational Data

The final stages in pigment printing consist of drying and fixing the printed fabric with hot air. In both stages, emissions of volatile organic compounds to air may be significant.

New-generation thickeners contain minimal amounts of volatile organic solvents. They are based on polyacrylic acid or polyethene glycol compounds instead of mineral oils. Products that do not contain any volatile solvent have also been developed. They are supplied in the form of non-dusting granules or powders.

According to the Ecolabel criteria for textile products, the printing pastes used shall not contain more than 5 % w/w VOCs. Additionally, according to the EU CLP Regulation, formaldehyde triggers the labelling of the mixture as a carcinogen 1B as of 0.1% w/w. No specific standards are available for Indian context.

Another potential source of emissions to air in pigment printing is fixing agents. The cross-linking agents in these auxiliaries are based mainly on methylol compounds (melamine compounds or urea-formaldehyde pre-condensates) that give rise to formaldehyde and alcohols (mainly methanol) in the exhaust air. New low-formaldehyde products are now available. Acrylate dispersions are used as binders, and, in some cases, synthetic thickeners may also be sources of formaldehyde emissions. The development of a formaldehyde-free printing system based on helizarin binders allows the high-quality standard of pigment printing to be maintained without the result of formaldehyde emissions.

Additionally, APEO is not present in optimised printing pastes (pigment printing auxiliaries may be found in the wastewater due to cleaning operations, etc.) and has less ammonia. Ammonia is added as an additive in binders and is also a source of air pollution.

Cross Media Effects

Thickeners based on powders may generate dust or block the stencils.

Economics

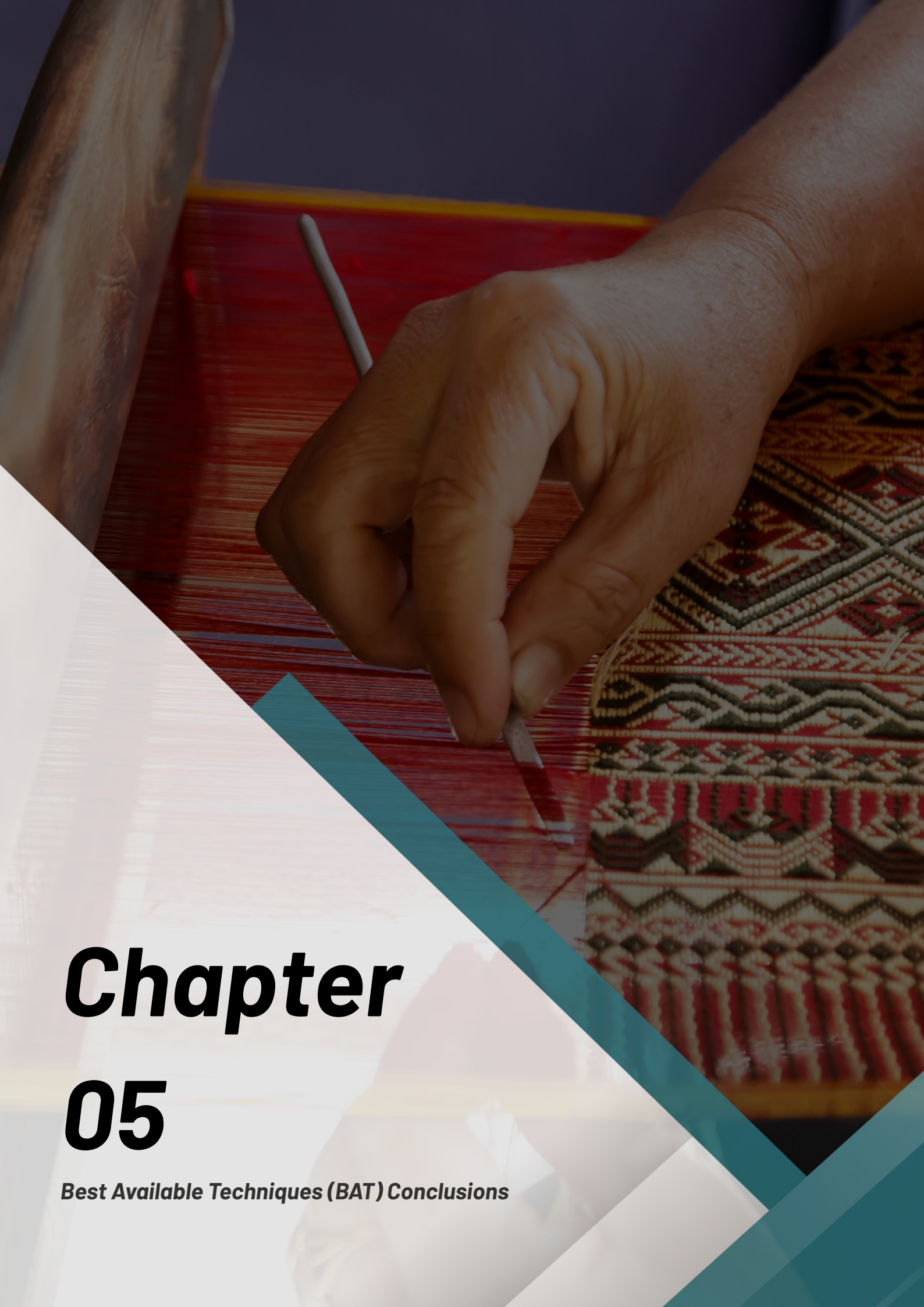
The higher costs of the printing pastes are offset by the reduced air treatment costs (better working environment).

Driving Force for Implementation

Better productivity due to better working environment (lower emissions of volatile organic compounds, formaldehyde and ammonia) is the main motivation for the use of optimised printing pastes.

Reference Industry

M/s. Arvind Ltd. (Santej Unit), Ahmedabad



Chapter 05

Best Available Techniques (BAT) Conclusions

This chapter shows techniques that are thought to be good for the sector. It also reflects, in many cases, how some units in the sector are doing presently. When consumption levels are stated as "associated with best available techniques," they are appropriate for the industry. It reflects the environmental results that could be anticipated if the installations employed mentioned techniques, keeping in mind that the definition of "BAT" calls for a balance between costs and benefits.

However, they are not consumption caps; industries shouldn't regard them that way. Getting better emission or consumption levels may be technically possible in some cases.

The general "BAT" in this chapter is meant to judge the current performance of an existing installation or a proposal for a new installation and help figure out what "BAT"-based conditions should be used for that installation. New installations could be made to work as well as or even better than the general "BAT" levels shown here.

It is also considered that many existing installations could reasonably be expected, over time, to move towards the general "BAT" levels or do better.

The following techniques or a combination of techniques are considered BAT for textile finishing industries. The priority order and technique selection will differ according to local circumstances. Any additional technique or set of techniques that achieve the same performance or efficiency may also be considered; these additional techniques may be in development, emerging, or already in use but not stated or defined in this document.

It must be noted that the selection of BAT, particularly in textile finishing mills, depends on several site-specific factors; as a result, the choice for each industry for implementation may differ.

5.1 Scope

These BAT conclusions cover:

The following activities, as they are various stages in the manufacturing and pre-treatment of the woven cotton and polyester fabric is mentioned:

- Pre-treatment of grey fabric
- Dyeing
- Printing

These BAT conclusions do not cover:

- The wastewater treatment from individual MSMEs is not covered, as the effluent from these MSMEs is sent to CETP for further primary, secondary treatment and disposal.
- In textile finishing, chemical and mechanical processes are performed to achieve the intended aesthetic or functional results. Various finishing processes such as wrinkle-resistant, flame-retardant and antibacterial are performed on the fabric. Since most textile mills perform job work, the finishing is custom-tailored to customer specifications. Maintaining the records of finishing process carried out per day by specific CPH is difficult. Therefore, author couldn't get authentic records from these CPHs. Hence, it is not covered.
- Processes for raw materials apart from cotton, and polyester are not included as this type of fabric is not involved in the BAT conclusions due to the presence of very few fabric production units in the shortlisted cluster for the present document.
- Generally, even though formaldehyde and VOCs are generated from the process side and as per the GPCB environment audit scheme, "The Quality of emission from each flue gas stack & process stack & the extent of deviation from them" needs to be measured but the emission to air is monitored for Boiler section only in case of textile industries, process house emission could not be found in environment audit reports of reference plants. Hence, it is not covered as data could not be found.

The scope focuses most on water, chemical and energy consumption; thus, the content seems to be limited but is exhaustive. The major reason for the restricted content is that the current BREF is first time covering the major operations occurring in Gujarat, involving water, chemical as well as energy.

BAT Conclusion

Section 5.1 - General Considerations

- BAT - AEPL

Section 5.2 - General BAT conclusion

- Overall Environmental Performance
- Monitoring
- Water Consumption and wastewater generation
- Energy Efficiency
- Chemicals

Section 5.3 - BAT conclusions for Pre-treatment

Section 5.4 - BAT conclusions for Dyeing

Section 5.5 - BAT conclusions for Printing

Figure 5.1 - Different sections of Chapter 5

GENERAL TERMS	
Cellulosic materials	Cellulosic materials include cotton and viscose.
Channelled emissions	Emissions of pollutants to air through any kind of duct, pipe, stack, etc.
Continuous Measurement	Measurement using an automated measuring system permanently installed on site.
Desizing	Removal of sizing chemicals.
Diffuse emissions	Non-channelled emissions to air.
Direct discharge	Discharge to a receiving water body without further downstream waste water treatment.
Dry cleaning	Cleaning of textile materials with an organic solvent.
Existing plant	A plant that is not a new plant.
Finishing	Physical and/or chemical treatment aiming at giving the textile materials end - use properties such as visual effect, handle characteristics, waterproofing or non-flammability.
Hazardous waste	Hazardous waste as defined in sub-section 17 of section 3 in chapter 1. Hazardous
Indirect discharge	Discharge to a receiving water body with a primary wastewater treatment.
Liquor ratio	For a batch process, the weight ratio between the dry textile materials and the process liquor used.
Major plant upgrade	A major change in the design or technology of a plant with major adjustments or replacements of the process and/or abatement technique(s) and associated equipment.
Mass flow	The mass of a given substance or parameter which is emitted over a defined period of time.
New plant	A plant first permitted at the site of the installation following the publication of these BAT conclusions or a complete replacement of a plant following the publication of these BAT conclusions.
Periodic measurement	Measurement at specified time intervals using manual or automated methods.
Pick-up	For a continuous process, weight ratio between the chemical liquid taken up by the textile materials and the dry textile materials.
Process chemicals	Substances and/or mixtures as defined in Article 3 of Regulation EC/1907/2006 and used in the process(es), including sizing chemicals, bleaching chemicals, dyes, printing pastes and finishing chemicals.
Process liquor	Solution and/or suspension containing process chemicals.
Sizing	Impregnation of yarn with process chemicals aiming to protect the yarn and provide lubrication during weaving.
Synthetic materials	Synthetic materials include polyester, polyamide and acrylic.
Textile materials	Textile fibres and/or textiles.
Thermal treatment	Thermal treatment of textile materials includes drying, curing, fixing or heat-setting which is carried out as a process step of the activities covered by these BAT conclusions.

POLLUTANTS AND PARAMETERS	
Term used	**Definition**
AOX	Adsorbable organically bound halogens, expressed as Cl, include adsorbable organically bound chlorine, bromine and iodine.
BODn	Biochemical oxygen demand. Amount of oxygen needed for the biochemical oxidation of the organic matter to carbon dioxide in n days (n is typically 3, 5 or 7). BODn is an indicator of the mass concentration of biodegradable organic copounds.
Chromium	Chromium, expressed as Cr, includes all inorganic and organic chromium compounds dissolved or bound to particles.
CO	Carbon monoxide. It is a colourless, practically odourless, and tasteless gas.
COD	Chemical oxygen demand. Amount of oxygen needed for the total chemical oxidation of the organic matter to carbon dioxide using dichromate. COD is an indicator of the mass concentration of organic compounds.
Copper	Copper, expressed as Cu, includes all inorganic and organic copper compounds dissolved or bound to particles.
Dust	Total particulate matter (in the air).
HOI	Hydrocarbon oil index. The sum of compounds extractable with a hydrocarbon solvent (including long-chain or branched aliphatic, alicyclic, aromatic or alkyl-substituted aromatic hydrocarbons).
NH_3	Ammonia. It is a colorless gas with a characteristic pungent smell, which dissolves in water to give a strongly alkaline solution.

Process liquor	**Solution and/or suspension containing process chemicals.**
Sizing	Impregnation of yarn with process chemicals aiming to protect the yarn and provide lubrication during weaving.
Synthetic materials	Synthetic materials include polyester, polyamide and acrylic.
Textile materials	Textile fibres and/or textiles.
Thermal treatment	Thermal treatment of textile materials includes drying, curing, fixing or heat- setting which is carried out as a process step of the activities covered by these BAT conclusions.
Nickel	Nickel, expressed as Ni, includes all inorganic and organic nickel compounds dissolved or bound to particles.
NO_x	The sum of nitrogen monoxide (NO) and nitrogen dioxide (NO_2), is expressed as NO_2.
SO_x	The sum of sulphur dioxide (SO_2), sulphur trioxide (SO_3), and sulphuric acid, aerosols, is expressed as SO_2.
Sulphide, easily released	The sum of dissolved sulphides and those undissolved sulphides that are easily released upon acidification is expressed as S_2.
TOC	Total organic carbon, expressed as C (in water), includes all organic compounds.
TN	Total nitrogen, expressed as N, includes free ammonia and ammonium nitrogen (NH_4–N), nitrite nitrogen (NO_2–N), nitrate nitrogen (NO_3–N) and organically bound nitrogen.
TP	Total phosphorus, expressed as P, includes all inorganic and organic phosphorus compounds dissolved or bound to particles.
TSS	Total suspended solids. Mass concentration of all suspended solids (in water), measured via filtration through glass fibre filters and gravimetry.
TVOC	Total volatile organic carbon is expressed as C (in air).
VOC	The volatile organic compound is defined under Environment (Protection) Act, 1986.
Zinc	Zinc, expressed as Zn, includes all inorganic and organic zinc compounds dissolved or bound to particles.

BATs are used to derive BAT-associated environmental performance levels (BAT-AEPLs). These include BAT-associated emission levels (BAT-AELs) and other environmental performance levels like water, chemical, energy consumption etc.

BAT-associated environmental performance levels (i.e. other than the emission levels) can be related to the consumption of material, water or energy, the generation of waste, abatement efficiency on pollutants and duration of visible emissions. As such, BAT-AEPLs are not limited to preventing or reducing emissions of pollutants but can reflect sustainable chemistry, manufacturing efficiency, and other aspects of sustainable manufacturing practices.

BAT-AELs are – according to the European Union's Industrial Emissions Directive (IED) – "the range of emission levels obtained under normal operating conditions using a best available technique or a combination of best available techniques expressed as an average over a given period, under specified reference conditions".

The BAT-AELs are technologically driven; i.e. they reflect the environmental performance levels that can be achieved by implementing BAT or a combination of BAT, rather than being based on e.g. national emission targets and/or on the whole operating range of current performance of all installations.

The BAT Conclusions can help Regulatory Authority to constitute the references for setting industrial permit conditions.

5.2.1 BAT-associated environmental performance levels

Air Emissions levels associated with the best available techniques (BAT-AELs)

BAT-associated emission levels (BAT-AELs), for emissions to air given in these BAT conclusions, refer to concentrations (mass of emitted substances per volume of waste gas) under the following standard conditions:

Dry gas at a temperature of 273.15 K and a pressure of 101.3 kPa, without oxygen content correction, expressed in mg/Nm^3.

For averaging periods of BAT-AELs for emissions to air, the following definition applies

Type of measurement	Averaging period	Definition
Periodic	Average over the sampling period	The average value of three consecutive samplings / measurements of at least 30 minutes each. (1)
(1) For any parameter where a more representative sampling/or sampling or analytical limitations and/or operational conditions, a 30-minute sampling/measurement and/or an average of three consecutive samplings/measurements is inappropriate, a more representative sampling/measurement procedure may be employed.		

Waste gases from a single source, such as a stenter, are discharged through two or more distinct emission points but could, in the opinion of the competent authority, be released through a single emission point.

When determining the mass flows, these different emission points must be counted as a single emission point. This is so that channelled dust, organic compounds, and ammonia emissions can be monitored and avoided or reduced.

Water Emission levels associated with the best available techniques (BAT-AELs)

The BAT-AELs for emissions to water given in these BAT conclusions refer to concentrations (mass of emitted substances per volume of water) expressed in mg/l.

Averaging periods associated with the BAT-AELs refer to either of the following two cases:

- In the case of continuous discharge, daily average values, i.e. 24-hour flow-proportional composite samples.
- In the case of batch discharge, average values over the release duration are taken as flow-proportional composite samples, or, provided that the effluent is appropriately mixed and homogeneous, a grab sample is taken before discharge.

Time-proportional composite samples can be used, provided that sufficient flow stability is demonstrated. Alternatively, spot samples may be taken, provided the effluent is appropriately mixed and homogeneous.

Other environmental performance levels

Specific energy consumption

The environmental performance levels related to specific energy consumption refer to the yearly average calculated using the following equation:

$$Specific\ energy\ consumption = \frac{energy\ consumption}{activity\ rate}$$

Where:

Energy consumption: the total annual amount of heat and electricity consumed by a given process, minus the heat recovered from the process, expressed in MWh/year;

Activity rate: the total annual amount of textile materials treated in the process, expressed in t/year

Specific water consumption

The environmental performance levels related to specific water consumption refer to yearly averages calculated using the following equation:

$$specific\ water\ consumption = \frac{water\ consumption}{activity\ rate}$$

Where:

water consumption: the total annual amount of water consumed by a given process, including water used for washing and rinsing the textile materials and for cleaning the equipment, minus the water reused or recycled to the process, expressed in m^3/year;

activity rate: the total annual amount of textile materials treated in the process, expressed in t/year.

Caustic soda recovery

The environmental performance level related to caustic soda recovery refers to a yearly average calculated using the following equation:

$$caustic\ soda\ recovery = \frac{rate\ of\ caustic\ soda\ recovered}{rate\ of\ caustic\ soda\ recovery}$$

Where:

Rate of caustic soda recovered: the total annual amount of caustic soda recovered from spent mercerisation rinsing water, expressed in kg/year.

Rate of caustic soda before recovery: the total annual amount of caustic soda in the spent mercerisation rinsing water, expressed in kg/year.

5.3 General BAT conclusions

5.3.1 Overall environmental performance

BAT 1 To improve the overall environmental performance, BAT is to elaborate and implement an environmental management system (EMS) that incorporates all the following features:

1. Commitment, leadership, and accountability of the management, including senior management, to the implementation of an effective EMS;
2. A study that considers the organisation's context, the needs and expectations of interested parties, the installation's characteristics that may be linked to potential threats to the environment (or human health), and the appropriate environmental legal requirements;
3. Development of an environmental policy that includes the continuous improvement of the environmental performance of the installation;
4. Establishing objectives and performance indicators concerning significant environmental aspects, including safeguarding compliance with applicable legal requirements;
5. Making plans and putting them into action to achieve environmental goals and reduce environmental risks, including corrective and preventive measures as necessary;
6. Determination of structures, roles and responsibilities in relation to environmental aspects and objectives and provision of the financial and human resources needed;
7. Ensuring the necessary competence and awareness of staff whose work may affect the environmental performance of the installation (e.g. By providing information and training);

8. Internal and external communication;
9. Fostering employee involvement in sound environmental management practices;
10. Establishing and maintaining a management manual and written procedures to control activities with significant environmental impact as well as relevant records;
11. Effective operational planning and process control;
12. Implementation of appropriate maintenance programmes;
13. Emergency preparedness and response protocols, including the prevention and/or mitigation of the adverse (environmental) impacts of emergencies;
14. When (re)designing a (new) installation or a part thereof, consideration of its environmental impacts throughout its life, which includes construction, maintenance, operation and decommissioning;
15. Implementation of a monitoring and measurement programme; if necessary, information can be found in the Reference Report on Monitoring of Emissions to Air and Water from IED Installations;
16. Application of sectoral benchmarking on a regular basis;
17. Periodic independent (as far as practicable), internal auditing and periodic, independent external auditing to assess the environmental performance and to determine whether or not the EMS conforms to planned arrangements and has been appropriately implemented and maintained;
18. Evaluation of causes for nonconformities, implementation of corrective actions in response to non-conformities, review of the effectiveness of corrective actions, and determination of whether similar nonconformities exist or could potentially occur;
19. Periodic review by senior management of the EMS and its continuing suitability, adequacy and effectiveness;
20. Following and taking into account the development of cleaner techniques.

Specifically, for the textile industry, BAT is also to incorporate the following features in the EMS:

- Inventory of inputs and outputs (see BAT 2)
- Water management plan (see BAT 9)
- Energy efficiency plan (see BAT 12)
- Chemicals management system (see BAT 15)
- Waste management plan.

Note

Certification and proper putting into practice of ISO 14001 and environmental audit scheme in Gujarat can provide a platform to improve the overall environmental performance.

Applicability

The level of detail and the degree of normalization of the EMS will generally be related to the nature, scale and complexity of the installation, and the range of environmental impacts it may have.

[This BAT conclusion is based on the information given in Technique 1]

BAT 2 BAT is to build, maintain, and periodically review (including when a significant change happens) an inventory of inputs and outputs as part of the environmental management system (see BAT 1) that has all the following characteristics:

(I) Information about the production process(es), including:

a. Process flow sheets/diagram that reflects the prospect of water, air and solid waste emissions;
b. Various processes involved in the manufacturing/processing of the textile material along with the descriptions of relevant machines involved and techniques;
c. Abatement practices for wastewater/waste gas, these will aid in the prevention or reduction of emissions.

(ii) Information about the quantity as well as the quality of the products, including textile materials (both yarn and fabric) and process chemicals (including basic chemicals, dyestuff, pigments and auxiliaries)(see BAT 16);

(iii) Information about water consumption (both process-wise and equipment-wise);(iv)Information about energy consumption (both process-wise and equipment-wise);

(v) Information about the quantity and characteristics of the wastewater streams, such as:

a. Average values and variability of flow, pH, temperature, and conductivity;
b. Average concentration and mass flow values of relevant substances/parameters and their variability (e.g. COD/TOC, nitrogen species, phosphorus, metals);
c. Data on toxicity and bio eliminability (e.g. BODn, BODn to COD ratio, biological inhibition potential (e.g. inhibition of activated sludge);

(vi) Information about the characteristics of the waste gas streams, such as:

a. Average values and variability of flow and temperature;
b. Average concentration and mass flow values of relevant substances/parameters and their variability (e.g. dust, organic compounds);
c. Flammability, lower and higher explosive limits, reactivity;
d. Presence of other substances that may affect the waste gas treatment system or plant safety (e.g. water vapour, dust);

(vii) Information about the quantity and characteristics of waste generated.

Applicability

The scope (e.g. level of detail) and nature of the inventory will generally be related to the installation's nature, scale and complexity, and the range of environmental impacts it may have.

[This BAT conclusion is based on the information given in Technique 2]

BAT 3 To improve the overall environmental performance, BAT is to use advanced process monitoring and control systems.

Description

The monitoring and control of processes is carried out with on-line automated systems equipped with sensors and controllers using feedback connections to rapidly analyse and adapt key process parameters to reach optimal process conditions (e.g. optimal uptake of process chemicals).

Key process parameters include:

- Volume, pH, temperature and conductivity of the process liquor;
- Amount of textile materials treated;
- Dosage of process chemicals;
- Drying parameters (see also BAT 14 e).

[This BAT conclusion is based on the information given in technique 3]

BAT 4 To improve the overall environmental performance, BAT is to use both of the techniques given below.

Raw material	BAT
Man-made fibres	Select material treated with low-emission and biodegradable/ bioeliminable preparation agents (see technique 49)
Cotton	Select material sized with low add-on techniques (pre-wetting of the warp yarn, see technique 43)
	Use the available information to avoid processing fibre material contaminated with the most hazardous chemicals such as PCP (see technique 40)
	Use organically grown cotton when market conditions allow (GOTS approved) (see technique 5)

5.3.2 Monitoring

BAT 5 BAT is to monitor resource input and output at least once every year:

- The annual consumption of water, energy and materials used, including textile materials and process chemicals,
- The annual amount of wastewater generated,
- The annual amount of materials recovered, waste generated and waste sent for disposal.

Description

Monitoring includes direct measurements, calculations or recording, e.g. using suitable meters or invoices. The monitoring is broken down to process level and considers any significant changes in the processes.

[This BAT conclusion is based on the information given in techniques 2, 3 and 16]

BAT 6 For wastewater streams identified by the inventory of inputs and outputs (see BAT 2), the BAT is to monitor key parameters (like the flow, pH, and temperature of the wastewater) at key locations (like the entrance and/or exit of the pre-treatment, the entrance to the final treatment, and the point where the emission leaves the installation).

The monitoring will help installation to find suitable usage of waste stream if any based on observed key parameters.

[This BAT conclusion is based on the information given in Section 4.1.1]

BAT 7 BAT is to monitor emissions to water with at least the frequency given below and as per Central Pollution Control Board standards. If CPCB standards are unavailable, BAT is to use ISO, national, regional or other international standards that ensure the provision of data of equivalent scientific quality.

In 1996, the Hon'ble High Court of Gujarat in their verdict directed the Gujarat Pollution Control Board (GPCB) for implementation of an Environmental Audit Scheme for the industries in the State of Gujarat. This also enabled establishment of Common Effluent Treatment Plants for the industrial clusters, with facilities for safe disposal of treated effluent including setting up of Treatment Storage and Disposal Facilities for Solid Hazardous Waste.

<table>
<tr><th>Substance(s)/parameter</th><th>Activities / processes</th><th>Minimum monitoring frequency</th><th>Monitoring associated with</th></tr>
<tr><td>pH</td><td>All activities/processes</td><td rowspan="9">Thrice in a year</td><td rowspan="9">BAT 20</td></tr>
<tr><td>Colour</td><td>Dyeing</td></tr>
<tr><td>Total Suspended Solids</td><td rowspan="5">All activities/processes</td></tr>
<tr><td>Total Dissolved Solids</td></tr>
<tr><td>Biochemical Oxygen Demand (BOD)</td></tr>
<tr><td>Chemical Oxygen Demand (COD)</td></tr>
<tr><td>Oil & Grease</td></tr>
<tr><td>Sulphide</td><td>Dyeing with sulphur-dyes</td></tr>
<tr><td colspan="4">(1) The monitoring only applies when the substance(s)/parameter, including groups of substances or individual substances in a group of substances, concerned is identified as relevant in the waste water stream based on the inventory of inputs and outputs mentioned in BAT 2.</td></tr>
</table>

[This BAT conclusion is based on the information given in Section 3.3]

BAT 8 BAT is to monitor channeled emissions to air with at least the frequency given below and as per Central Pollution Control Board standards. If CPCB standards are unavailable, BAT is to use ISO, national or other international standards that ensure the provision of data of scientific quality.

Substance/parameter	Standard(s)	Activities / processes	Minimum monitoring frequency (1)
CO	EN 15058	Singeing	Once every 3 years
Dust	EN 13284-1	Singeing	Once every year (2)
		Thermal treatments associated with pre-treatment, dyeing, printing and finishing	
CMR (other than formaldehyde) (3)	No EN standards available	Finishing (4)	Once every year
		Thermal treatments associated with coating, lamination and finishing (4)	
Formaldehyde (3)	EN standard under development	Printing (4)	Once every year
		Singeing	
		Finishing (4)	
		Thermal treatment (4)	
Nh3 (3)	EN ISO 21877	Printing (5)	Once every year
		Finishing (4)	
		Thermal treatments associated with coating, printing and finishing (4)	
NOX	EN 14792	Singeing	Once every 3 years
SO 2 (5)	EN 14791	Combustion	Once every 3 years
TVOC (3)	EN 12619	Dyeing	Once every year (6)
		Finishing	
		Printing	
		Singeing	
		Thermofixation or heat-setting	
		Thermal treatments associated with coating, dyeing, lamination, printing and finishing	

The measurements are carried out at the highest expected emission state under normal operating conditions.

(2) In the case of a dust mass flow of less than 50 g/h, the minimum monitoring frequency may be reduced to once every 3 years.

(3) The monitoring only applies when the substance concerned is identified as relevant in the waste gas stream based on the inventory of inputs and outputs mentioned in BAT 2.

(4) In the case of a formaldehyde mass flow of less than 2.5 g/h, the minimum monitoring frequency may be reduced to once every 3 years.

(5) In the case of a NH3 mass flow of less than 50 g/h, the minimum monitoring frequency may be reduced to once every 3 years.

(6) The monitoring does not apply if natural gas only is used as fuel.

(7) In the case of a TVOC mass flow of less than 100 g/h, the minimum monitoring frequency may be reduced to once every 3 years.

5.3.3 Water consumption and wastewater generation

BAT 9 To reduce water consumption and wastewater generation, BAT is to use all of the techniques given below.

Technique	Description	Applicability	
Management techniques			
a)	Water management plan and water audits	A water management plan is part of the EMS (see BAT 1) which includes: • Flow diagrams and a water mass balance as part of the inventory of inputs and outputs mentioned in • Establishment of water efficiency objectives; • Implementation of water optimisation techniques (e.g. control of water usage, reuse/recycling, detection and repair of leaks). Water audits can be carried out annually to ensure compliance with the water management plan.	The level of detail of the water management plan and water audits will generally be related to the nature, scale and complexity of the plant
b)	Production optimisation	This includes: • Optimised combination of processes (e.g. pre-treatment processes are combined, bleaching of textile materials is avoided before dyeing in dark shades); • Optimised scheduling of batch processes (e.g. dyeing of the textile materials in dark shades is carried out after dyeing in light shades in the same dyeing equipment).	Generally applicable
Design and operation techniques			
c)	Segregation of polluted and unpolluted water streams	Water streams are collected separately, based on the pollutant content and on the required treatment techniques. Polluted water streams (e.g. spent process liquors) and unpolluted water streams (e.g. cooling waters) that can be reused without treatment are segregated from waste water streams that require treatment.	Applicability to existing plants may be restricted by the layout of the water collection system and the lack of space for temporary storage tanks
d)	Optimisation of the amount of process liquor used	• Install automatic controllers for control of fill volume and liquor temperature in batch machines • Batch processes are carried out with low-liquor- ratio systems. • Continuous processes are carried out with low-volume application systems (see technique 54).	Generally applicable
e)	Optimised cleaning of the equipment	This includes: • Water-free cleaning (e.g. by wiping or brushing the tank's inner surfaces, mechanical pre-cleaning of squeegees, rotary screens and drums containing printing pastes); • Multiple cleaning steps with low amount of water; the water of the last cleaning step may be reused to clean another part of the equipment or in other process.	
f)	Optimised batch processing, washing and rinsing of textile materials	This includes: • Use of auxiliary tanks for the temporary storage of: • spent washing or rinsing water; • fresh or spent process liquor; • Multiple drains and fill steps for rinsing and washing with less water.	

g)	Optimised continuous processing, washing and rinsing of textile materials	This includes: • Timely process liquor preparation based on online pick-up measurements; • Automatic closure of the washing water inflow when the washing machine stops; • Countercurrent rinsing and washing; • Intermediary mechanical dewatering of textile materials (see BAT 11 B) to reduce the carry-over of process chemicals present in wash water.	Generally applicable
Reuse and recycling techniques			
h)	Water reuse and/or recycling	• Water streams may be segregated (see BAT 9c and/or pre-treated before reuse and/or recycle waste water streams from continuous machines (preceded or not by water treatment), e.g. for cleaning, rinsing, cooling or processing textile materials. • The water reuse/recycling degree is limited by the content of impurities in the water streams.	Generally applicable
I)	Reuse of process liquor	• Process liquor, including the process liquor extracted from textile materials by mechanical dewatering (see BAT 11 B), is reused after analysis and make-up if needed. • The content of impurities limits the degree of reuse of process liquor.	

[This BAT conclusion is based on the information given in techniques 8,9,10,11,12,13,14 and 15]

BAT 10 To prevent or reduce emissions to soil and groundwater, BAT is to use all of the techniques given below.

Technique	Description	Applicability
Techniques to reduce the likelihood and environmental impact of overflows and failures of process and storage tanks	This includes: • Slow immersion into and withdrawal of textile materials from the process liquor to avoid spillages; • Automatic level adjustment of process liquor; • Avoiding direct injection of water to heat or cool the process liquor; • Overflow detectors; • Channelling overflows to another tank; • Location of tanks for liquids (process chemicals or liquid waste) in a suitable secondary contaminant their volume is sized to accommodate at least the complete loss of the liquid of the largest tank that is within the secondary containment; • Isolation of tanks and secondary containment (e.g. by closing valves); • Ensuring the surfaces of the process and storage areas are impermeable to the liquids concerned.	Generally applicable
Regular inspection and maintenance of plant and equipment	Routine maintenance and inspection of the plant and the equipment ensure proper functioning, which includes checking of the leak-free status of valves, pumps, pipes, tanks and containments/bunds, as well as the appropriate functioning of warning systems (e.g. overflow Detectors).	The applicability to existing plants may be restricted by space availability

[This BAT conclusion is based on the information given in Sections 4.1.2, and 4.1.4]

BAT 11 To reduce emissions to water from the use of sizing chemicals, BAT is to use all of the techniques given below.

Table 5.1 - BAT-associated environmental performance levels (BAT-AEPLs) for specific water consumption

Process House	**Specific process(es)**	**BAT-AEPL (Yearly average) (l/kg)**
Cotton (1)	Desizing	1-4
	Scouring	1.5 – 8
	Bleaching	1-5 – 12
	Mercerizing	1-5
	Dyeing	6 – 14
	Pigment Printing	2 -4
	Reactive Printing with Wash	11- 63
	Finishing	1 - 5
Polyester ([2])	Drumming & Scouring	10 - 40
	Weight Reduction	4 – 20
	Dyeing	3 – 30
	Print-wash	10 – 26
Note: 1. Both batch and continuous processes typically achieve the BAT-AEPL for all the processes for cotton textiles. 2. The BAT-AEPL for all the processes for polyester textiles is typically achieved by batch processes.		

The associated monitoring is given in BAT 5.

[This BAT conclusion is based on the information provided in Chapter 3].

In below, specific water consumption figures for different continuous washing processes are compiled which can be achieved in practice by applying counter-current washing, efficient washing boxes and machine-specific daily monitoring of water consumption.

Table 5.2 - Specific water consumption in continuous machines [l/kg]

Processes for woven fabric, if not otherwise indicated	**Total Water**	**of which hot water**
Pretreatment processes		
Washing for desizing	3 - 4	3 - 4
Washing after demineralizing	2 - 3	2 - 3
Washing after scouring	4 - 5	4 - 5
Washing after bleaching	4 - 5	4 - 5
Washing after cold bleaching	4 - 6	4 - 6
Washing after mercerization		
- Washing to remove NaOH	4 - 5 (hot)	4 - 5
- Neutralization without drying	1 - 2 (cold)	n/a
- Neutralization and drying	1 - 2 (warm)	< 1
Washing after dyeing*		
Reactive dyestuffs 0-5 g/l	8 - 10	4 - 5
Reactive dyestuffs 5.1-20 g/l	10 - 12	5 - 7
Reactive dyestuffs 21- 50 g/l	12 - 14	7 - 10
Reactive dyestuffs > 50 g/l	14 - 20	10 - 14
Vat dyestuffs	8 - 12	3 - 7
Sulphur dyestuffs	18 - 20	8 - 10
Naphtol dyestuffs	12 - 16	4 - 8
Washing after printing		
Reactive dyestuffs	15 - 20	12 - 16
Vat dyestuffs	12 - 16	4 - 8
Naphtol dyestuffs	14 - 18	6 - 10
Disperse dyestuffs	12 - 16	4 - 8

* "Washing after dyeing", the concentration g/L refers to the dyestuff concentration of the padding liquor
Source: Schönberger, H.; Schäfer, T., Best Available Techniques in Textile Industry all figures up-dated in November 2020.

5.3.4 Energy efficiency

BAT 12 To use energy efficiently, BAT is to use all of the techniques given below.

Technique	Description	Applicability	
Management techniques			
a)	Energy efficiency plan and energy audits	An energy efficiency plan is part of the EMS (see BAT 1) and includes: • Energy flow diagrams as part of the inventory of inputs and outputs (see BAT 2); • Setting objectives in terms of energy efficiency (e.g. MWh/t of textile materials processed); • Implementing actions to achieve these objectives. • Energy audits are carried out at least annually to ensure that the objectives of the energy efficiency plan are met.	The level of detail of the energy efficiency plan will generally be related to the nature, scale and complexity of the plant
b)	Production optimisation	Optimised scheduling of fabric batches to undergo thermal treatment to minimise the idling time of the equipment.	Generally applicable
Process and equipment selection and optimization			
c)	Use of general techniques	This includes: I. Burner maintenance and control; ii. Cogeneration; iii. Energy-efficient motors; iv. Energy-efficient lighting; v. Optimising steam distribution systems, e.g. by using point-of-use boilers; vi. Regular inspection and maintenance of the steam distribution systems to prevent or reduce steam leaks; vii. Process control systems; viii. Variable speed drives; ix. Optimising air conditioning and building heating.	Generally applicable
d)	Optimization of heating demand	I. Reducing heat losses by insulating equipment components and by covering tanks or bowls containing warm process liquor; ii. Optimising the temperature of the rinsing water; iii. Avoiding overheating of the process liquors;	Generally applicable
Heat recovery techniques			
e)	Recycling of warm cooling water	[See BAT 9 h.] This avoids the need for heating cold water.	Generally applicable
f)	Reuse of warm process liquor	[See BAT 9 i.] This avoids the need for heating cold process liquor.	
g)	Heat recovery from waste water	Heat from waste water is recovered by heat exchangers, e.g. to warm up process liquor.	
h)	Reuse and/or recycling of warm air	Warm cooling air (e.g. from air-cooled air compressors) is reused and/or recycled (e.g. for drying, after dedusting if needed).	
i)	Heat recovery from waste gases	The heat from waste gases (e.g. from thermal treatment of textile materials, steam boilers) is recovered by heat exchangers and used (e.g. to warm up process water or to preheat combustion air).	
j)	Heat recovery from steam use	Recovery of heat from hot condensate and boiler blowdown.	

This BAT conclusion is based on the information given in Sections 4.1.1 and 4.1.3]

BAT 13 To increase energy efficiency when using compressed air, BAT is to use all of the techniques given below.

Technique	Description	Applicability
Optimal design of the compressed air system	Compressed air production is stopped during long shutdown or idling times of equipment, and single areas can be isolated from the rest of the system, in particular if they are associated with rare uses.	Only applicable to new plants or major plant upgrades
Control of leakages in the compressed air system	The most common sources of air leakages are regularly inspected and maintained. (e.g. couplings, hoses, tubes, fittings, pressure regulators).	Generally applicable
Control of leakages in the compressed air system	The most common sources of air leakages are regularly inspected and maintained. (e.g. couplings, hoses, tubes, fittings, pressure regulators).	
Reuse and/or recycling of warm cooling water or warm cooling air from air compressors	See BAT 9 and BAT 12.	

BAT 14 To increase the energy efficiency of thermal treatment, BAT is to use all of the techniques given below.

Technique	Description	Applicability
Techniques for reducing the use of heating		
Wet-on-wet dyeing or finishing of the fabric	Dyeing or finishing liquors are applied directly to the wet fabric, thus avoiding an intermediate drying step.	Generally applicable
Mechanical dewatering of textile materials	The water content of textile materials is reduced by mechanical techniques (e.g. centrifugal extraction, squeezing and/or vacuum extraction).	
Avoiding over-drying of textile materials	The textile materials are not dried below their natural moisture level.	
Design and operation techniques		
Optimising air circulation in stenters	This includes: • The number of air injection nozzles is adapted according to the width of the fabric; • Ensuring the distance between the nozzles and the fabric is as short as possible; • Ensuring the pressure drop caused by the stenters' internal components is as small as possible.	Only applicable to new plants or major plant upgrades
Advanced process monitoring and control of drying	Following drying parameters are monitored and controlled: • Humidity content and temperature of the inlet air; • The temperature of textile materials and air within the dryer; • Humidity content and temperature of the exhaust air; • Drying efficiency is optimised by an appropriate humidity content (e.g. above 0.1 kg water/kg dry air); • The residual moisture content of the fabric. • The exhaust airflow is adjusted to optimise drying efficiency and is reduced during the idling time of drying equipment.	Generally applicable

a)	Microwave or radio-frequency dryers	Drying of textile materials with high-efficiency microwave or radio frequency dryers.	Only applicable to new plants or major plant upgrades
Heat recovery techniques			
b)	Heat recovery from waste gases	See BAT 12h.	Generally applicable

[This BAT conclusion is based on the information given in Section 4.1.4]

5.3.5 Chemicals

BAT 15 To improve the overall environmental performance, BAT is to elaborate and implement a chemicals management system (CMS) as part of the EMS (see BAT 1) that incorporates all of the following features:

I. A policy to reduce the consumption and risks associated with process chemicals, including a procurement policy to select less harmful process chemicals and their suppliers with the aim of minimising the use and risks associated with hazardous substances and substances of very high concern as well as avoiding the procurement of an excess amount of process chemicals. The selection of process chemicals is based on:

a. The comparative analysis of their bioeliminability/biodegradability, ecotoxicity and potential to be released into the environment (which in the case of emissions to air can be determined by using emission factors;
b. The characterization of the risks associated with the process chemicals, based on the chemicals' hazard classification, pathways through the plant, potential release and level of exposure;
c. The potential for recovery and reuse (see BAT 16);
d. The regular (e.g. annual) analysis of the potential for substitution with the aim to identify potentially new available and safer alternatives to the use of (groups of) hazardous substances and substances of very high concern, such as PFAS, phthalates, brominated flame retardants, chromium-(VI)-containing substances; this may be achieved by changing process(es) or using other process chemicals with no or lower environmental impacts;
e. The anticipatory analysis of regulatory changes related to hazardous substances and substances of very high concern, and safeguarding compliance with applicable legal requirements.

The inventory of process chemicals (see BAT 15) may be used to provide and keep the information needed for the selection of process chemicals.

The criteria for selecting process chemicals and their suppliers may be based on certification schemes or standards. In that case, the compliance of the process chemicals and their suppliers with these schemes or standards is regularly verified.

II. Goals and action plans to avoid or reduce the use of and risks associated with hazardous substances and substances of very high concern.

III. Development and implementation of procedures for the procurement, handling, storage and use of process chemicals, disposal of waste containing process chemicals and return of unused process chemicals, to prevent or reduce emissions to the environment.

[This BAT conclusion is based on the information given in Section 4.1.1, 4.1.4 and 4.1.5]

BAT 16 To improve the overall environmental performance, BAT is to elaborate and implement a chemicals inventory and tracking system as part of the CMS.

The chemicals inventory and tracking system is computer-based and contains information about:

- The identity of the process chemicals;
- The quantities and location of the process chemicals procured, recovered , stored, used and returned to suppliers;
- The characteristics of process chemicals include properties with adverse effects on the environment and/or human health.

[This BAT conclusion is based on the information given in Section 4.1.5]

BAT 17 In order to reduce emissions to water from the use of sizing chemicals affecting desizing process in woven cotton, BAT is to use all of the techniques given below.

Technique	Description	Applicability
Selection of sizing chemicals	Use of sizing chemicals with improved environmental performance in terms of required quantity, washability, recoverability and/or biodegradability (e.g. modified starches, certain galactomannans, polyvinyl alcohol and certain polyacrylates)are used.	Generally applicable
Pre-wetting of the cotton yarns	The cotton yarns are dipped into hot water prior to sizing. This allows a reduction of the amount of sizing chemicals.	

BAT 18 To reduce the chemical consumption, BAT is to use all of the techniques given below.

Sr. No.	Technique	Description	Applicability
a)	Reduction of the need for process chemicals	This includes: • Regularly reviewing and optimizing the formulation of process chemicals and liquors; • Using demineralised water in the processes to reduce the need for complexing agents; • Production optimisation (see BAT 9 b).	Generally applicable
b)	Treatment of textile materials with enzymes	Enzymes are selected (see BAT 15) and used to catalyse the reactions with textile materials to lower the consumption of harmful/hazardous process chemicals (like in desizing, scouring, bleaching).	Product specifications may restrict the applicability or the availability of suitable enzymes
c)	Automatic systems for preparation and dosing of process chemicals and process liquors	Automatic systems for weighing, dosing, dissolving, measuring and dispensing which ensures precise delivery of process chemicals and process liquors to the production machines. See Techniques 32 and 37.	The applicability to existing plants may be restricted by a lack of space, the distance between the preparation and the production machines or by frequent changes of process chemicals and process liquors.
d)	Optimisation of the quantity of process chemicals used	See BAT 9 b.	Generally Aapplicable
e)	Reuse of process liquor	See BAT 9 h.	
f)	Recovery and use of leftover process chemicals	Residual process chemicals are recovered (e.g. by thoroughly purging pipes or completely emptying packaging) and used in the process.	

[This BAT conclusion is based on the information given in Section 4..2, 4.3 & 4.4]

BAT 19 To improve the overall performance of the handling and storage of process chemicals, BAT is to use all of the techniques given below.

a)	Optimised storage location of process chemicals	The storage areas are located in such a way to eliminate or minimise the unnecessary transport of process chemicals within the plant (e.g. the transport distances on site are minimised).	The applicability to existing plants may be restricted by a lack of space.
b)	Dedicated area for unloading hazardous process chemicals	Hazardous process chemicals are unloaded in a bunded area connected to a dedicated drainage system.	
c)	Segregated storage of process chemicals	Process chemicals are segregated based on chemical inventory and respective tracking system	Generally Applicable
d)	Return of unused process chemicals	Unused process chemicals (i.e. which remain in their original containers) are returned to their suppliers.	
e)	Handling and storage of packaging containing process chemicals	Packaging containing liquid process chemicals is entirely emptied by gravity or mechanical means (e.g. brushing, wiping) without water use. Packaging containing process chemicals in powder is emptied using suction. Empty packaging is stored in a dedicated area.	

BAT 20 To eliminate or minimize the release of poorly biodegradable materials into the water by preventing or reducing use of poorly biodegradable substances during fabric wet processing, BAT is to use all of the techniques given below.

Technique	Description	Applicability
Substitution of alkylphenols and alkylphenol ethoxylates	Alkylphenols and alkylphenol ethoxylates (AP/APEO) are substituted by biodegradable surfactants, e.g. alcohol ethoxylates (AE).	Generally applicable
Substitution of poorly bio-degradable phosphorus-or nitrogen-containing complexing agents	Complexing agents containing phosphorus (e.g. triphosphates) or nitrogen (e.g. amino polycarboxylic acids such as EDTA or DTPA) are substituted by biodegradable substances, e.g: • Polycarboxylates (e.g. polyacrylates and copolymers of acrylic and maleic acids); • Hydroxycarboxylic acids (e.g. gluconates, citrates); • Sugar-based acrylic acid copolymers. • Methylglycinediacetic acid (MGDA), L-glutamic acid N,N-diacetic acid (GLDA) and iminodisuccinic acid (IDS); • Phosphonates (e.g. aminotris methylene phosphonic acid (ATMP), diethylenetriamine pentamethylene phosphonic acid (DTPMP) and 1-hydroxyl ethylidene-1,1-diphosphonic acid (HEDP).	Generally applicable

Substitution of mineral-oil-based antifoaming agents	Mineral-oil-based antifoaming agents are substituted by biodegradable substances, e.g. silicone-based antifoaming agents.	Generally applicable

[This BAT conclusion is based on information given in Techniques 49, 50 and 51]

5.4 BAT conclusions for the fabric pre-treatment

BAT 21 To use resources and energy efficiency and reduce water consumption and wastewater generation, BAT is to use one of the techniques given below.

Technique	Description	Applicability
Single desizing liquor	A single desizing liquor is used to remove different types of sizing chemicals. This solution is strongly alkaline (pH higher than 13) and contains hydrogen peroxide.	Generally applicable
Recovery and reuse of water-soluble sizing chemicals	When desizing is carried out by washing with hot water, water-soluble sizing chemicals (e.g. polyvinyl alcohol and polyacrylates) are recovered from the washing water by ultrafiltration. The concentrate is reused for sizing, whereas the permeate is reused for washing.	Only applicable in plants where sizing and desizing are carried out at the same plant.

[This BAT conclusion is based on information given in technique 44]

BAT 22 To use resources efficiently and to reduce the amount of alkali discharged to waste water treatment, BAT is to recover caustic soda used for mercerisation.

Description

Caustic soda is recovered from the rinsing water by evaporation and further purified if needed.

[This BAT conclusion is based on information given in technique 47]

BAT 23 To reduce emissions to air and to water from the use of oils, BAT is to avoid the use of mineral oils in spinning and knitting.

Description

Mineral oils are substituted by synthetic oils and/or ester oils, with improved environmental performance in terms of washability and biodegradability.

[This BAT conclusion is based on information given in Technique 50]

BAT 24 To prevent or reduce emissions to water of chlorine-containing compounds and complexing agents, BAT is to use one or both of the techniques given below.

Technique		Description
a	Chlorine-free bleaching	Bleaching is carried out with chlorine-free bleaching chemicals (e.g. hydrogen peroxide, peracetic acid or ozone), possibly catalysed with enzymes.
b	Optimised hydrogen peroxide bleaching	The use of complexing agents can be completely avoided or minimised by reducing the concentration of hydroxyl radicals during bleaching. This is achieved by: • Using demineralised water; • Prior removal of metal impurities from textile materials (e.g. by magnetic separation or chemical extraction); • Controlling the pH and the peroxide concentration during bleaching.

5.5 BAT conclusions for dyeing

The BAT conclusions in this section apply to dyeing and apply in addition to the general BAT conclusions in Section 5.1.

BAT 25 To use resources efficiently and to reduce emissions to water from dyeing, BAT is to use one or a combination of the techniques given below.

Technique	Description
Technique for batch and continuous dyeing	
Selection of dyes	Dyes without dispersing agents are used or, where this is not possible, with dispersing agents that are biodegradable (e.g. based on fatty acid esters).
Techniques for batch dyeing	
Optimised removal of unfixed dyestuff in reactive dyeing	Unfixed dyestuff is removed from the textile materials using enzymesand/or vinyl polymers.

[This BAT conclusion is based on the information given in Sections 4.3 and 4.4]

BAT 26 To use resources efficiently and to reduce emissions to water from the dyeing of cellulosic materials, BAT is to use one or a combination of the techniques given below.

Technique	Description	Applicability
Technique for dyeing with sulphur dyes		
Minimised use of sulphur-based reducing agents	Dyeing is carried out without sodium sulphide or hydrosulphite as reducing agents, where this is not possible, partially chemically pre- reduced dyes (e.g. indigo dyes) are used so that less sodium sulphide or hydrosulphite is added for dyeing.	The applicability may be restricted by product specifications.
Techniques for dyeing with reactive dyes		
Use of high-fixation reactive dyes	Use of poly-functional reactive dyes with more than one reactive functional group.	Generally applicable
Cold pad-batch dyeing	Dyeing is carried out with the cold pad-batch technique.	Only applicable to new plants or major plant upgrades.
Optimised rinsing	Rinsing after dyeing with reactive dyes is carried out at a high temperature (e.g. up to 95 °C) and without using detergents. The heat of the rinsing water is recovered (see BAT 12 f).	Generally applicable

Techniques for continuous dyeing with reactive dyes		
Use of concentrated alkali solution	In cold pad-batch dyeing, concentrated aqueous alkali solutions without sodium silicate are used for the fixation of dyes.	It may not be applicable to dyeing with dark shades.
Steam fixation of reactive dyes	The reactive dyes are fixed with steam, which avoids using chemicals for fixation.	The applicability may be restricted by the characteristics of the textile materials and by-product specifications.

[This BAT conclusion is based on the information given in Section 4.3]

BAT 27 To reduce emissions to water from the dyeing of polyester with disperse dyes, BAT is to use the technique given below.

Technique	Description	Applicability
Optimised desorption of unfixed dye in batch dyeing	This includes: • Using a desorption accelerator based on carboxylic acid derivatives; • Using a reducing agent that can be used in the acidic conditions of the spent dyeing liquor; • Using disperse dyes that can be desorbed in alkaline conditions by hydrolysis instead of reduction.	A reducing agent that can be used in acidic conditions may not apply to polyester-elastane blends. The use of dyes desorbable in alkaline conditions may be restricted by product specifications.

[This BAT conclusion is based on the information given in Technique 60]

5.6 BAT conclusions for printing

The BAT conclusions in this section apply to printing, and the general BAT conclusions in Section 5.1.

BAT 28 BAT optimises the printing equipment's cleaning to reduce water consumption and wastewater generation.

Description

This includes:

- Mechanical removal of the printing paste;
- Automatic start and stop of the cleaning water supply;
- Reuse and/or recycling of cleaning water (see BAT 8h).

[This BAT conclusion is based on the information given in Section 4.4 and Annexure 5]

BAT 29 To use resources efficiently, BAT is to use a combination of the techniques given below.

Technique	Description	Applicability
Selection of printing technology		
Digital jet printing	Computer-controlled injection of dye onto textile materials.	Only applicable to new plants or major plant upgrades
Transfer printing on synthetic textile materials	The design is first printed on an intermediate substrate (e.g. paper) using selected disperse dyes and is subsequently transferred to the fabric by applying high temperature and pressure.	
Design and operation technique		
Optimised use of printing paste	This includes: • Minimisation of the volume of the printing paste supply system (e.g. minimising pipe lengths and diameters); • Ensuring a uniform paste distribution over the whole width of the printing machine; • Stopping the supply of printing paste shortly before the end of the printing; • Manual addition of printing paste for small-scale usage.	Generally applicable
Recovery and reuse of printing paste		
Recovery of residual printing paste	Residual printing paste in the supply system is pumped back or pushed back to its original container.	The push-back system is only applicable to rotary screen printing
Reuse of residual printing paste	The residual printing paste is collected, sorted by type, stored and reused. The degree of reuse of printing paste is limited by its perishability.	Generally applicable

[This BAT conclusion is based on the information given in Sections 4.4 and Annexure E.]

BAT 30 To reduce emissions of organic compounds (e.g. formaldehyde) and ammonia to air from printing with pigments, BAT is to use printing chemicals with improved environmental performance.

Description

This includes:

- Thickeners with no or low contents of volatile organic compounds;
- Fixation agents with low contents of formaldehyde-containing compounds;
- Binders with low contents of ammonia and without formaldehyde-containing compounds.



CHAPTER 06

EMERGING TECHNIQUES

6.1 Use of chitosan-based auxiliaries and/or finishing agents

Description

Chitin is a widespread bioproduct produced naturally in the exoskeleton of crustaceans and insects (spiders, shrimps, crabs, and lobster), the radulae of molluscs and the cell wall of mushrooms, algae, and fungi.

The potential applications of the biopolymer chitosan or its derivatives in fibre and textile treatments are widespread due to its healing, stimulating, hygienic and complexing properties. In addition, chitosan is non-allergenic, non-toxic and biodegradable.

Operational Details

Cationic-modified chitosan derivatives are reported to be suitable for improving fastness when dyeing with direct dyes. Using chitosan as an exhausting agent reduces the dye amount necessary for dyeing the cotton fabric and improves the washing and rubbing fastness properties. Applying an acidic solution of chitosan on cotton fabric before dyeing can boost the exhaustion of the dye bath and improve the substantivity of reactive dyes.

Chitosan increases the dyestuff uptake, acts as a softening agent and binding agent for nonwovens and can be used as an additive in printing pastes and sizing agents. It is also of interest in wastewater treatment. With chitosan additives in printing pastes, the amount of urea can be minimised.

Environmental Benefits

- Reduced chemical consumption.
- Reduced emissions to water.
- Biodegradable

6.2 Use of ozone for bleaching cotton fabrics

Description

Ecological concerns have prompted a search for solutions to reduce the pollution resulting from the bleaching process. Conventional bleaching of cotton consumes large amounts of energy, water, and chemicals(hydrogen peroxide, etc.)and pollutes the water with chemical components and suspended solid particles. Utilising ozone (O_3) to prepare cotton is one way to decrease these environmental impacts.

Operational Details

O_3 's oxidation potential is 2.07 electron volts eV which is higher than that of the widely used bleaching agent, hydrogen peroxide (1.77 eV). O_3 is available in the molecular form at an acidic pH (Eren and Ozturk).

The use of O_3 for bleaching cotton is still under development. Various studies show that the whiteness of cotton fabric bleached with O_3 is comparable to that of conventionally bleached fabric but with greater decreases in degrees of polymerisation. The O_3 process is environmentally preferable to peroxide bleaching because, when O_3 is used, there is no need for other harmful chemicals, much less water is required, and bleaching is achieved in a very short time at room temperature without the need for heating or cooling energy (Perincek et al. 2007; Prabaharan et al. 2000)

The equipment used for O_3 bleaching has three components: the ozone generator, the applicator, and the ozone destroyer (Rane and Jadhav n. d.). The input for the generator is oxygen from a pressurised cylinder. The generator supplies the required concentration of O_3 - oxygen mixture to the applicator, a cylindrical glass tube with a diffuser at the bottom (Rane and Jadhav, n. d.). O_3 is produced by subjecting the 20% of oxygen present in air to pressure swing adsorption and raising its concentration to 90%; then, plasma discharge is used to generate O_3 (Ozone Bleach Association 2013a)[1].

Environmental Benefits

- Energy savings because bleaching is achieved at room temperature without requiring any heating or cooling energy
- Reduced CO_2 emissions
- Substantial water savings
- No use of harmful chemicals

6.3 Ultrasonic Washing

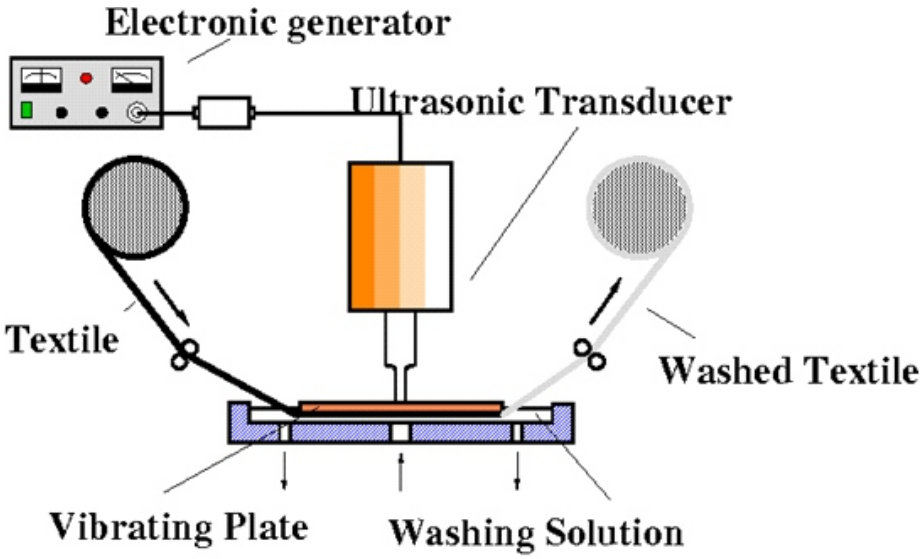


Figure 6.1 - Schematic of the Ultrasonic washing process[2].

[1] *Alternative and Emerging Technologies for an Energy Efficient, Water Efficient, and Low Pollution Textile Industry by Ali Hasanbeigi*

[1] *Ultrasonic system for continuous washing of textiles in liquid layers, Ultrasonics Sonochemistry 17 (2010) 234–238.*

Description

In textile wet processing, several operations usually require washing the fabric. Using ultrasonic energy in such operations may help speed up the process and improve the final product's quality.

Operational Details

The washing procedure is based on applying the ultrasonic energy to the textiles to be washed by employing special vibrating plate radiators that are directly or close to them. The textiles are submerged in a layer of liquid of a few millimetres in thickness and conveyed in a flat format through the ultrasonic radiator using a roller-type system. (See Fig 6.1)

Environmental Benefits

Main advantages with respect to a conventional washing system:

- Deeper and quicker cleaning effect
- Low energy consumption
- Reduced water consumption
- Reduced use of detergent and other auxiliaries

6.4 Use of biodegradable complexing agents based on poly aspartic acid and salts

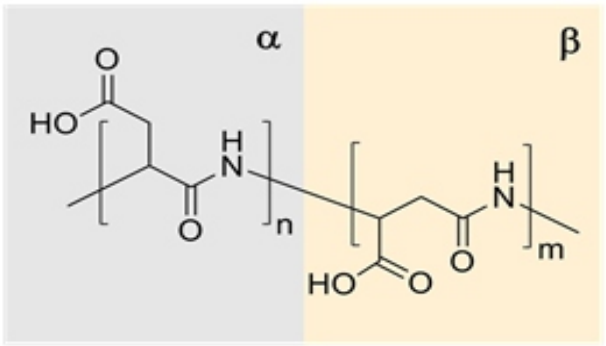


Figure 6.2 - Polyaspartic acid

Description

Polyaspartic acid (PAA) and its derivatives are biodegradable alternatives to EDTA or NTA in desizing or dyeing processes. They form stable complexes with metal ions and mobilise contaminating metal ions.

Operational Details

It is characterised by excellent calcium(II) tolerance, corrosion inhibition properties, stability in a wide pH range, as well as low environmental impact by low toxicity and good biodegradability.It is also an effective chelating agent of a new generation that can be applied for the removal of heavy metal ions.

As shown in figure 6.2, it consists of polymerised - and - as partyl residues, each containing carboxylic functional groups that can combine with metal ions to form M(II)-DS complexes.

Environmental Benefits

The technique reduces emissions to water from textile dyeing and finishing processes. PAA is biodegradable. It can be used as a biodegradable detergent and dispersant for various applications. Preliminary toxicity studies indicate that it is non-toxic.

6.5 Use of natural or biosynthetic dyes

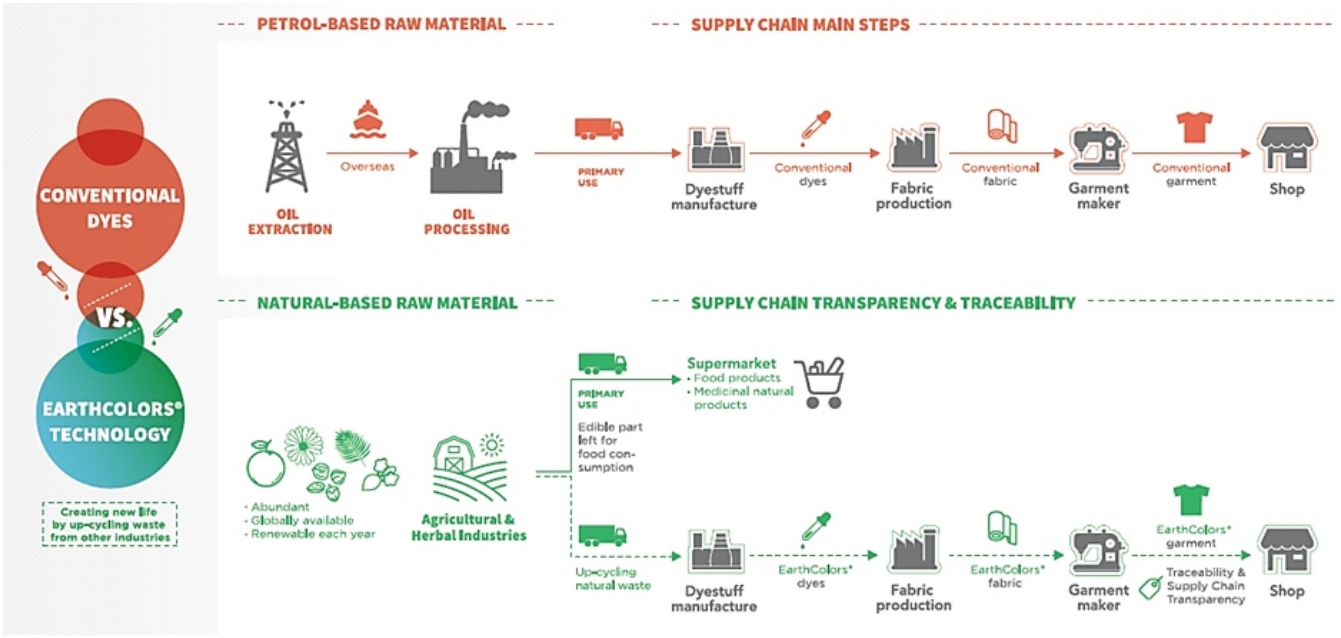


Figure 6.3 - Fully traceable biosynthetic dyes derived from natural waste products of the agriculture and herbal industries



Figure 6.4 - Start to End Process route for natural dye manufacturing

Source: Archroma

Description

Most textile dyes are synthetic, usually oil-based. Archroma has developed a line of sustainable dyes, called EarthColors, made from natural waste, including almond shells, bitter orange residues, rosemary waste, and beet residues. This collection now includes a dye made from cotton byproducts — for the first time, and cotton waste can be used to dye cotton.

Operational Details

As shown infigure 6.4, The cotton byproducts (burs, stems, and leaves) are ground into very fine particles. Caustic soda is added to the heated grounds, forming a paste that becomes the basis of the dye. Almost 100% of the cotton plant byproduct is used to create the dye, and no harmful chemical waste is produced. The Earth Colors cotton dye can be used to dye woven and knit fabrics and yarns. It is suitable for cellulosic-based fibres such as cotton, viscose, linen, bamboo, kapok, etc.

The natural colour of gin waste limits the range of shades. EarthColors® are available in a range of six dyes made from waste left over by the agricultural and herbal industry, covering a palette of natural shades.

EarthColors® dyes equal the fixation rate, fastness and overall performance of Archroma's existing range of sulfur dyes made from conventional petroleum-based raw materials.

Environmental Benefits

- Biodegradable Dyes
- Reduction in Waste generation

6.6 Alkali Clearable Disperse Dyes

Description

Disperse dyes with little water solubility are mostly used to colour hydrophobic fibres like polyester. Because of the limited solubility of dispersion dyes in water, some dye particles may stay on the fibre's surface after dyeing is complete, resulting in decreased colour fastness upon washing and rubbing. As a result, after dyeing, it is normal to use some clearing methods to remove the insoluble dye particles. Reduction clearing is a standard technique for polyester fabrics.

The dyed fabrics are exposed to a solution of sodium hydrosulfite (as reductant) and sodium hydroxide, breaking down scattered dye particles into minute water-soluble molecules.

However, the reduction clearing process causes severe water pollution because of the addition of chemicals. It increases the treatment difficulty of the effluents. Additionally, disperse dyes containing azo groups can also be cleaved to aromatic amines, and some of them might be toxic and carcinogenic.
Phthalimide-based alkali-clearable azo disperse dyes are applied to polyester and polyester/cotton blends. These dyes have an alkali-clearable property that enables alkaline treatment to be substituted for conventional reduction clearing. Therefore, by using these dyes, it is possible to avoid generating dyehouse effluents with high BOD values and carcinogenic aromatic amines that may, in some cases, be liberated by reduction clearing.

Operational Details

An alkali-clearable azo disperse dye containing a carboxylic ester moiety can be synthesised from carboxylic-containing azo acid dye as a reactant by chlorination and esterification with ethanol in high yield.

The defect of the traditional synthetic route of azo dyes, which could generate unwanted byproducts, can be avoided. The ester-containing, alkali-clearable dye could be applied to PET fabric and attain the same excellent wet colour fastnesses after alkali clearing treatment without the utilisation of reductants compared with that after reduction clearing treatment.

The ester-containing, disperse dye shows good alkali clear ability and results in little contamination to the environment due to the absence of reductants, as well as low toxicity and easy recycling of the hydrolysates.

Environmental Benefits

- Reduction in Wastewater load
- More Greener Process

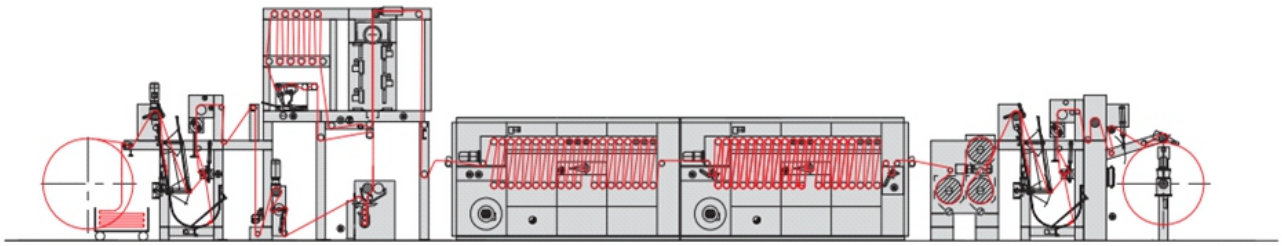


Figure 6.5 - Schematic of Econtrol Process

Source: A. Monforts Textilmaschinen GmbH & Co. KG

Description

With the trend towards smaller lot sizes per colour in continuous dyeing and the requirement for simple processes, the Econtrol® process for reactive dyestuffs was developed in the mid-nineties. It has now established itself with DyStar technology worldwide.

Operational Details

The Econtrol® process is a simple, quick and economical one-pass pad – dry – wash off continuous dyeing process with drying in a hot flue at 120°C-130° C and controlled humidity (25-30% by volume) to obtain fixation in 2 - 3 minutes.

However, complete fixation of reactive dyes is not possible in normal drying conditions because of the wet bulb temperature, which is a characteristic of all convection-based drying systems. It means that the temperature of the moist goods is far lower during drying than the surrounding temperature.
The exact temperature depends on the humidity of the air used to dry the goods. If humidity is 25 percent and the air temperature is 120^{0}C, the temperature on the surface of the goods is around 68^{0}C. If humidity is 30 percent, the temperature on the goods is around 71^{0}C. In normal drying processes, the temperature on the goods can drop to 50-55^{0}C.

The Econtrol process uses this physical fact to fix the reactive dye during drying. Three key variables – time, temperature and humidity – are used to ensure accurate control of the dyeing process in the Thermex® hotflue.

The exact temperature depends on the humidity of the air used to dry the goods. If humidity is 25 percent and the air temperature is 120^{0}C, the temperature on the surface of the goods is around 68^{0}C. If humidity is 30 percent, the temperature on the goods is around 71^{0}C. In normal drying processes, the temperature on the goods can drop to 50-55^{0}C.

The Econtrol process uses this physical fact to fix the reactive dye during drying. Three key variables – time, temperature and humidity – are used to ensure accurate control of the dyeing process in the Thermex® hotflue[3].

[3]*https://www.emerald.com/insight/content/doi/10.1108/prt.2006.12935eab.019/full/html*

Alkali and auxiliaries

Soda ash or soda ash/NaOH is usually used as the alkali system. To ensure optimum reliability, it is essential to dose the alkali and dye solutions separately.

Environmental benefits

- Reduction in Chemical Consumption
- Reduction in Energy Consumption

6.8 Use of casein-based printing binders

Description

Casein acid can be used as a printing binder as an alternative to the acrylic resins used in textile printing.

Operational Details

This technique provides an alternative to the acrylic resins used in textile printing (reducing the ecotoxicity of water effluents). Discharging printing waste allows for a simple biological purification, which may be converted into fertiliser. Since the product is bio-based and biodegradable, microorganisms can easily attack it. Therefore, it should be stored in temperature-controlled areas at 10 °C or below.

The casein acid binders are compatible with all existing textile printing pigments. They can be used in printing paste for ink-jet printing.

Environmental benefits

- Reduced consumption of chemicals.
- Reduced emissions to water.

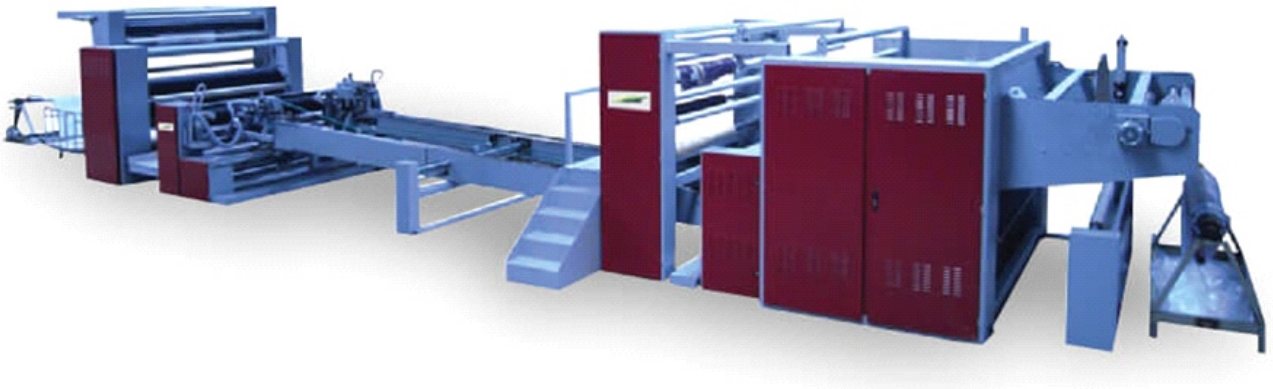


Figure 6.6: Schematic of cool transfer printing

Source: https://www.cottonworks.com/en/topics/fabric-technology/product-technologies/cooltrans/

Description

Traditional transfer printing applies a print pattern from one substrate, typically paper, to synthetic fabrics by applying heat and pressure. Cool transfer printing is a newer process that transfers a design from paper to fabric without heat. Due to high market interest, cool transfer printing technology has evolved to achieve high-quality digital printing on cotton fabrics.

Operational Details

Since cool transfer printing is new compared to other traditional printing methods, the cost and performance are roadblocks to widespread industry adoption. Some certain finishes and effects are not possible with this technology, such as glitter or other raised surface special effects. However, the production speeds, limited WEC footprint, strong colour fastness, and print quality make cool transfer printing an attractive option.

Cool transfer printing has many advantages. The process does not require any heat to transfer the design to the fabric and also uses less water, dye, and energy, proving to be an environmentally-friendly alternative to other printing methods. The speeds are comparable to rotary screen printing, reaching up to 40 yards per minute. Cool transfer printing enables high-quality, photo-realistic images printed on the fabric while maintaining cotton's soft hand-feel. New updates to this process have allowed designs to be printed on both sides of the fabric during a single pass by using a duplex printing machine.

Environmental Benefits

- Reduction in Greenhouse gas emissions
- Reduction in water and energy consumption



CHAPTER 07

CONCLUDING REMARKS & RECOMMENDATION FOR FUTURE WORK

The key milestones of the review process are summarized in below table.

Table 7.1 - Key milestones of the TXT BREF review process

Key milestone	Date
Appointment of Author	September 2016
TWG Formation	October 2016
TWG Sensitization Meeting	December 2016
Kick-off Meeting	January 2017
Selection of Reference Units	February 2017
Data collection	April 2017 – March 2018 Revised: May 2021 – July 2022
TWG meeting	September 2017
BREF Core Committee Meeting	December 2017
BREF Core Committee Meeting	February 2018
BREF Core Committee Meeting	October 2018
BREF of Gujarat 1 st Draft (Chapter 1 – 4)	August 2018
Commenting Period on 1 st Draft	September 2018 – February 2019
BREF Core Committee Meeting	February 2019
BREF Core Committee Meeting	April 2019
BREF Core Committee Meeting	July 2021
BREF of Gujarat 2 nd Draft (Chapter 1 – 4)	July 2021
Commenting Period on 2 nd Draft	July - August 2021
BREF Core Committee Meeting	August 2021
TWG Sensitization Meeting	October 2021
BREF of Gujarat 3 rd Draft (Chapter 1, 2, 3 and 4, Annexes 1 - 5)	March 2022
BREF Core Committee Meeting	April 2022
TWG Informal Meeting	April 2022
TWG meeting	April 2022
Data Collection Review by Expert	June – July 2022
BREF of Gujarat 4 th Draft	October 2022
Commenting Period for 4 th Draft	October – November 2022
Final TWG Meeting	November 2022
DFBARC Committee First (Introductory) Meeting	October 2023
DFBARC Committee Second Meeting	November 2023
DFBARC Committee Third and Fourth Meeting	December 2023

Gujarat Pollution Control Board (GPCB) with the support of Federal Environmental Agency (UBA) and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) has undertaken the preparation of BREF in Gujarat (India) Context as various aspects of industrial and technological development and environment problems are widely different as Europe and India are concerned.

The document is the first of its kind in India, and the Gujarat Cleaner Production Centre (GCPC) has penned down the whole document under the guidance of GCPB, UBA and GIZ.

The TWG constituted comprised representatives of government institutions, NGOs, Industry Experts, Machinery Manufacturers, Chemical Manufacturers and Industries Associations.

Table 7.2: Representative various institute and their role

Sr. No.	Representative	Role	Institution Type
1.	Gujarat Pollution Control Board, Head Office, "Paryavaran Bhavan", Gandhinagar.	Core Committee	Govt Institution
2.	Federal Environment Agency (Umweltbundesamt-UBA, Germany.	Core Committee	Govt Institution
3.	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, New Delhi.	Core Committee	Govt Institution
4.	Gujarat Cleaner Production Centre, Gandhinagar, Gujarat.	Core Committee and Author	Govt Institution
5.	Regional Office – Ahmedabad, Gujarat Pollution Control Board.	TWG Member	Govt Institution
6.	Regional Office – Ahmedabad-East , Gujarat Pollution Control Board.	TWG Member	Govt Institution
7.	Regional Office – Surat, Gujarat Pollution Control Board.	TWG Member	Govt Institution
8.	Regional Office - Jetpur, Gujarat Pollution Control Board.	TWG Member	Govt Institution
9.	Ahmedabad Hand Screen Printing Association, Ahmedabad.	TWG Member	Industries Association
10.	Pandesara Industries Association, Pandesara, Surat.	TWG Member	Industries Association
11.	Sachin Textile Processors Welfare Association, Sachin, Surat.	TWG Member	Industries Association
12.	South Gujarat Textile Processers Association (SGTPA), Surat.	TWG Member	Industries Association
13.	Palsana Enviro Protection Ltd. (PIA), Surat.	TWG Member	Industries Association
14.	New Palsana Industries Association, Palasana, Surat.	TWG Member	Industries Association
15.	Narol Textile Infrastructure and Enviro Management, Ahmedabad.	TWG Member	Industries Association
16.	Jetpur Dyeing and Printing Association; Jetpur.	TWG Member	Industries Association
17.	Colourtex Pvt. Ltd., Surat.	TWG Member	Chemical Supplier
18.	Arvind Limited, Santej Unit, Ahmedabad.	TWG Member	Industry Expert
19.	Paryavaran Mitra, Ahmedabad.	TWG Member	NGO
20.	Atul Ltd, Valsad.	TWG Member	Chemical Supplier

21.	Prism Textile Machinery Pvt. Ltd., Ahmedabad.	TWG Member	Machinery Supplier
22.	Kiri industries, Ahmedabad.	TWG Member	Chemical Supplier
23.	Jay Chemical Industry, Ahmedabad.	TWG Member	Chemical Supplier

As the representatives of institutions have changed over time, it was important to continuously engage TWG members about the BREF process to gain active participation. For this purpose, the Author and GPCB organized two sensitization meetings and one informal TWG meeting to ensure a seamless flow of information throughout the group.

During the BREF process, a total of Thirty-three plants were visited in three clusters for data collection. The plant details can be found in Chapter 3.

Due to the COVID-19 pandemic, the BREF process was delayed for nearly two years, from 2020 to 2021, due to the lockdown, stringent travel restrictions, and social distancing measures.

As a result, the author had to gather data twice for each of the three clusters because the time gap was so considerable. It was advantageous to the document because the data acquired from the new data collection were more comprehensive and useful for finalizing the BAT.

Since it was the author's first time drafting such a document, multiple versions were drafted and updated before the core committee approved the final version.

Sources of information

The main sources of information for the drawing BREF process were:

- Scientific and technical literature;
- Filled-in questionnaires from operators of textile industry plants;
- Additional information from the TWG members;
- Inputs from industry experts;
- Information gathered from site visits;

Degree of consensus reached during the information exchange

At the Final TWG Meeting that took place on November 2023, a high degree of consensus was reached on most of the BAT conclusions.

DFBARC Committee

The Draft Final BREF Assessment and Review Committee (DFBARC) is tasked with meticulously assessing and reviewing the Draft Final BREF document. Composed of three environmental engineering experts with a strong understanding of Best Available Techniques (BAT), the DFBARC committee members are:

- Prof. P.B. Jhala, Retired Senior Deputy Director, Ahmedabad Textile Industry's Research Association (ATIRA).
- Dr. S. D. Wadekar, Technical Director, M/s. Kumar Industries, GIDC, Naroda.
- Prof. Huma Syed, Associate Professor, Environmental Engineering Department, L. D. College of Engineering, Ahmedabad.

The committee's initial meeting provided an overview of the BREF concept and its necessity to the experts. Subsequent meetings delved deeper, facilitating a comprehensive discussion of all BREF chapters and annexures incorporating valuable committee feedback. These insightful comments have now been integrated into the documents.

Disclaimer

This document is published by the Gujarat Pollution Control Board (GPCB) as a reference document for the textile sector in Gujarat. The BREF is not a legal document and does not create any new obligations on the textile industry. The document is based on the best available information and data collected from various sources, including literature review, site visits, stakeholder consultations and expert opinions. The document does not necessarily reflect the official views or policies of the GPCB or any other authority. The document is intended to provide guidance and information for improving the environmental performance of the textile sector in Gujarat, but it does not impose any legal obligations or liabilities on the GPCB or any other party. The GPCB does not guarantee the accuracy, completeness or suitability of the information and data contained in this document for any specific purpose. The GPCB reserves the right to revise or update this document at time as mentioned in Guidance Document.



A.

TEXTILE AUXILIARIES

Introduction

The textile industry uses natural and/or man-made (semisynthetic and synthetic) textile fibres and filaments as its primary raw materials. These are subjected to various mechanical processes to convert them into yarns and further into woven or knitted fabrics. Occasionally, these processes are aided by the physical deposition of certain chemicals in the fibre assembly to facilitate mechanical processing and/or protect the fibre from getting damaged during such processing. Coning oils, anti-static compositions and sizing ingredients fall under this chemical group. Generally, after the fabric is made (it is known as grey cloth at this stage), all chemicals are removed from the fabric since these chemicals interfere with the subsequent processes (bleaching, dyeing, printing, finishing etc.) involving physical and/or chemical processes. Thus, in the entire process of converting fibres into the finished fabric, ready to be introduced onto the consumer market, a wide variety of chemicals, variously known as textile auxiliaries, textile chemicals, textile process chemicals, textile auxiliary products, speciality chemicals, etc., are used.

The textile auxiliaries may be divided into essentially three groups, as shown in figure a.1:

- Surface-active compounds
- Non-surface active compounds
- Water-insoluble solids or water-immiscible liquids, dispersed or emulsified in water with the help of dispersing agents or emulsifiers.

Textile auxiliaries can also be classified based on the textile processes as mentioned below:

- **Spinning Assistants:** Cotton spray oils, coning oils, anti-static agents, lubricating agents etc.
- **Sizing Agents:** Adhesives, lubricants, softeners, preservatives etc.
- **Desizing Agents:** Mineral acids and enzymes
- **Scouring and Bleaching Aids:** Wetting agents, detergents, emulsifying agents, mild oxidising agents, sequestering agents, rapid wetting agents, mercerising wetting agents, stain removers, etc.
- **Dyeing Assistants:** Levelling agents, retarding agents, dispersing agents, carriers, after treating agents, dye fixing agents, stripping agents, rubbing fastners improves, detergents, sequestering agents etc.
- **Printing Aids:** Thickeners, wetting agents, solution aids, hygroscopic agents, binders and fixers (in pigment printing), catalysts, discharging and resisting agents, complexing agents, mild oxidising agents, carriers and swelling agents, defoaming agents, emulsifying agents, dye fixing agents, detergents, sequestering agents, etc.

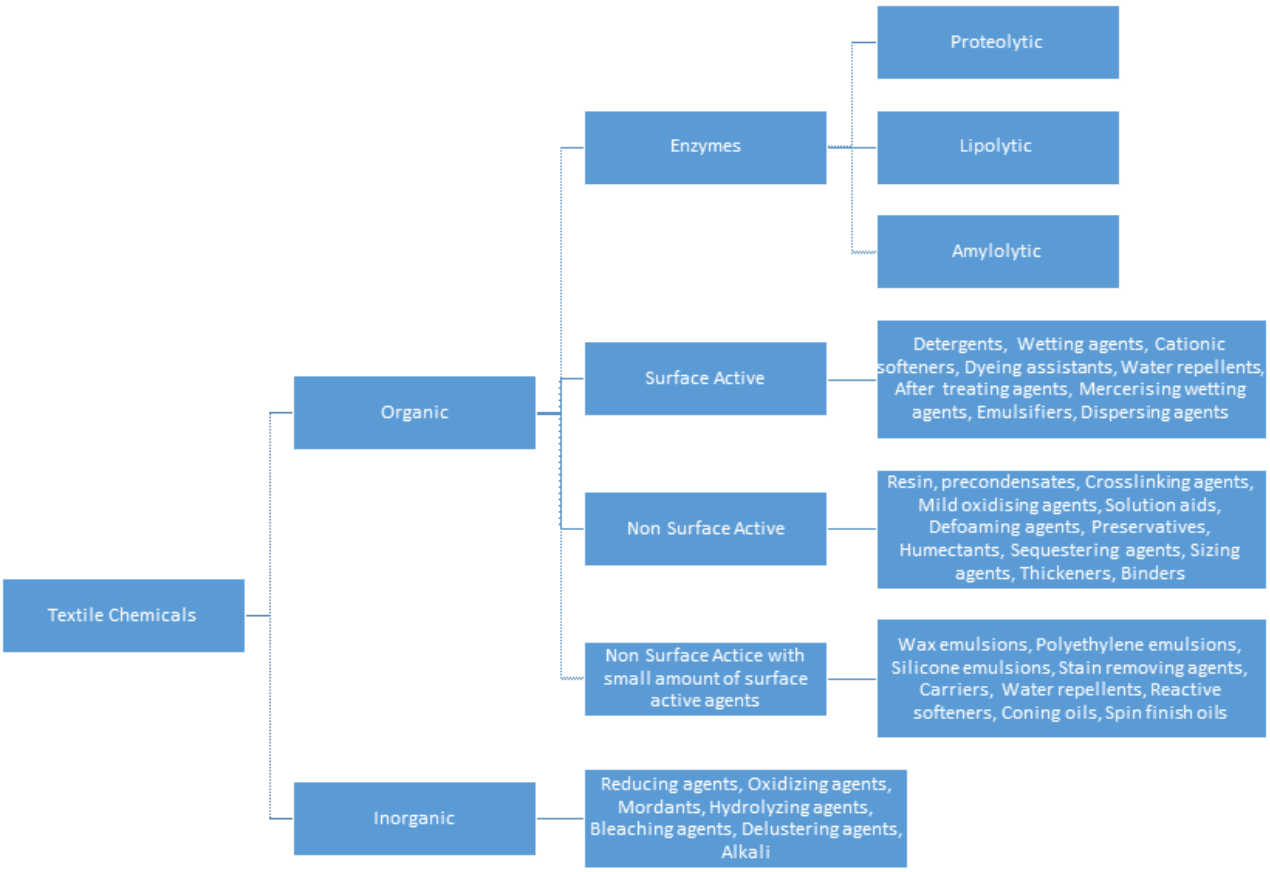


Figure a.1: Classification of Textile Auxiliaries

Surfactants

SURFace **ACT**ive **A**ge**NT**' - **SURFACTANT** (are also known as amphiphiles or tensides) are compounds that lower the surface tension between two liquids, between a gas and a liquid, or between a liquid and a solid.

The reason for dedicating a section to these compounds is that they are used in the textile industry for many different purposes (e.g. lubricants, antistatics, wetting agents, etc.). Elaborating them in a common section avoids repetitions in other parts of this annexe.

Surfactants can be the essential active substance in a textile auxiliary or can be used as additives in formulating auxiliaries, dyes, printing pastes, coating pastes (e.g. dispersing agents in dyestuffs, emulsifiers in preparation agents, etc.).

A surfactant molecule consists of two structures: polar (hydrophilic, lipophobic or oleophobic) head groups and non-polar (hydrophobic, lipophilic or oleophilic) tail groups. The hydrophilic group makes the surfactant soluble in polar solvents such as water. The hydrophobic group makes the surfactant soluble in non-polar solvents and oil.

Classification of Surfactants

The most accepted and scientifically sound classification of surfactants is based on their dissociation in water. Surfactants are classified into four broad categories: anionic, cationic, amphoteric and nonionic.

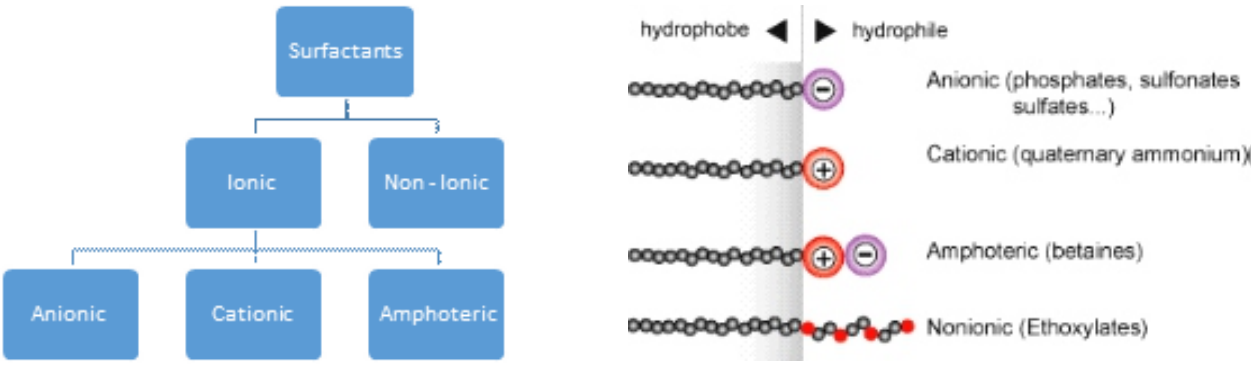


Figure a.2 : Representation of different types of surfactant molecules

Anionic Surfactants: It gives rise to a negatively charged surfactant ion (hence anionic) and a positively charged counter ion upon dissolution in water. A negatively charged hydrophilic polar group characterises anionic surfactants. These surfactants are organic substances. When these surfactants are dissolved in water, negatively charged particles, i.e. anions, are created[1].

Moreover, important types of anionic surfactants are carboxylates, sulphonates, sulphates and phosphates. Examples like alcohol ethoxy sulphates, alkanol amides sulphates, sulphated/sulphonated vegetable oils, naphthalene sulphonates, lignin sulphonates, alkyl ether phosphates, etc are widely used for the textile industry.

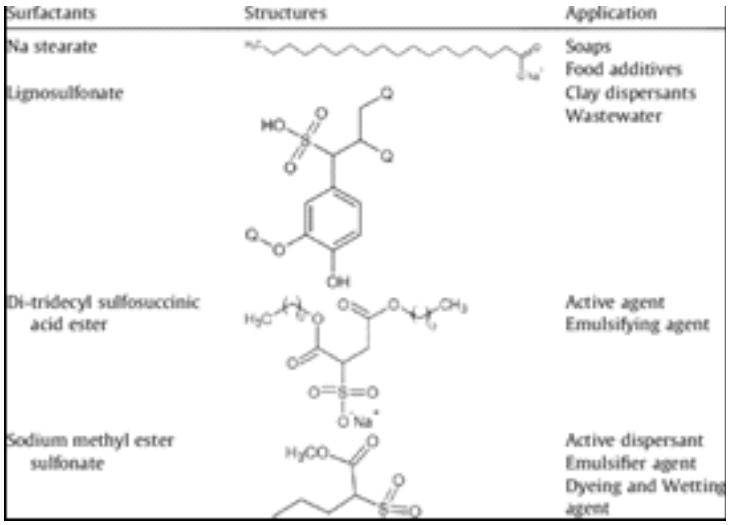


Figure a.3:structure of various types of anionic surfactants

[1] J. Beringer, J. Kurz, In Handbook Of Medical Textiles, 2011

Highly biodegradable linear alcohol surfactants (e.g. alkyl benzene sulphonates, fatty alkyl sulphates, etc.) have proven to be efficient wetting and scouring agents for use in all phases of textile wet processing. Also, they are widely used as dispersants for vat, sulphur and disperse dyes.

Anionic surfactants have several advantages: they are good oil emulsifiers and dye dispersants. They are excellent wetting agents and are not expensive. In turn, they generate high foam levels, and sulphate surfactants can be sensitive to calcium and magnesium.

Cationic Surfactants

They yield a positively charged surfactant ion (hence cationic) and a negatively charged counter ion upon dissolution in water. Cationic surfactants first became important when Domagk recognised the commercial potential of their bacteriostatic properties in 1935. These surfactants are generally more expensive than anionics because of the high-pressure hydrogenation reaction to be carried out during their synthesis.

The positive charge makes them useful in anti-static products, like fabric softeners. Additionally, the positive nature of cationic surfactants has an interesting function of disrupting the bacteria cell membrane; hence they can be used as antimicrobial agents. Examples of some common cationic surfactants include alkyl ammonium chlorides. But along with the limited application, these surfactants also have the highest toxicity.

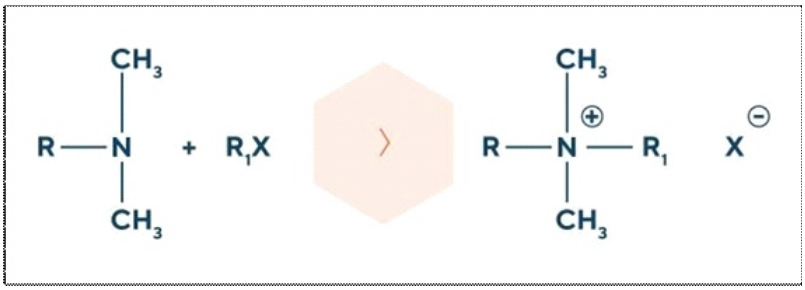


Figure a.4 :structure of cationic surfactants

Cationic surfactants have a relatively limited role in textile processing except as levelling agents in acrylic dyeing with cationic dyes; alkyl dimethyl ammonium chloride is a typical example. Alkyl dimethyl ammonium chloride is produced by benzylation of fatty amines such as cocoamine, lauryl amine, etc., under controlled conditions.

[2]Alwadani, Nora & Fatehi, Pedram. (2018). Synthetic And Lignin Based Surfactants: Challenges And Opportunities. 1. Carbon Resources Conversion. 1. 10.1016/J.Crcon.2018.07.006

[3]Dorugade, V.A.. (2009). Surfactants In Textile Processing. Colourage. 56. 39-46.

[4]Https://Www.Ipcol.Com/Blog/An-Easy-Guide-To-Understanding-Surfactants/

Amphoteric or Zwitterionic

When a single surfactant molecule exhibits both anionic and cationic dissociations, it is called amphoteric or zwitterionic. This is the case of synthetic products like betaines or sulfobetaine and natural substances such as amino acids and phospholipids.

Amphoteric surface-active agents are agents that ionise and produce large segments carrying both anionic and cationic ions (Called zwitter ions) when dissolved in water. For example, amino carboxylic acids in which amino and carboxylic groups are present at the ends of the molecular chain are dissolved in water to give the zwitter ions. Figure a.5.: structure of Amphoteric surfactants

Amphoteric surfactants are not widely used in the textile industry. A few instances where the compounds are used in the industry are Cocoampho carboxy propionate (CPP) as a mild scouring agent for wool and silk and finishing textiles with zwitterionic polymers like sulfobetaine which is shown in figure a.5. Other than these compounds, imidazoline modifies fatty amino ethylates, which are also used for reductive cleaning of the polyester fabric. They possess a good emulsifying and dissolving capacity. These are also opted because of their property of being less toxic.

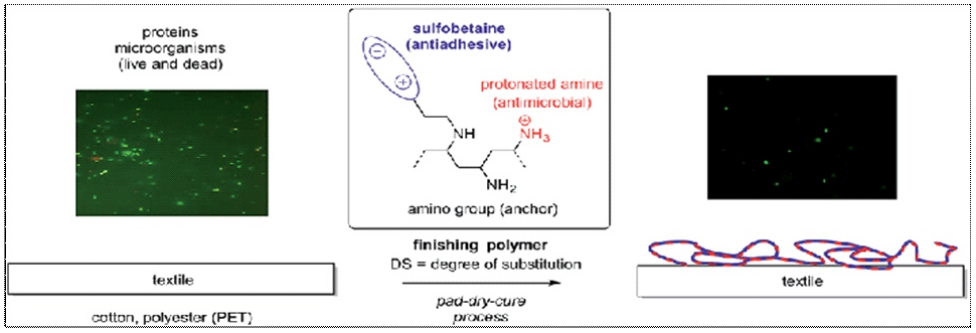


Figure a.5 :structure of cationic surfactants

The main advantage of this type is that they can be used in alkaline and acidic mediums and in combination with cationic or anionic surfactants.

Nonionic Surfactants

Nonionic Surfactants are characterised by hydrophilic head groups that do not ionise appreciably in water. Examples include polyoxyethylenated alkyl phenols, alcohol ethoxylates, alkylphenol ethoxylates, and alkanol amides. According to their different structures, nonionic surfactants can be divided into two categories:

[5] Timma, Lisa & Lewald, Laura-Isabell & Gier, Franziska & Homey, Lisa & Neyer, Christian & Nickisch-Hartfiel, Anna & Gutmann, Jochen & Oberthür, Markus. (2019). Nonfouling Textiles With Tunable Antimicrobial Activity Based On A Zwitterionic Polyamine Finish. Rsc Advances. 9. 9783-9791. 10.1039/C8ra09975h.
[6] Thiele, Björn. (2005). Surfactants. 10.1201/9781420027983.Ch30.

- Aliphatic alcohol polyoxyethylene ether and
- Alkylphenol polyoxyethylene ether[6].

It is used in textile processing because of the aliphatic molecule's strong emulsifying, degreasing, solubilising and low foaming properties. In comparison, the alkyl molecules are often used as emulsifiers, levelling and scouring agents. Moreover, the hydrophilic behaviour of nonionic surfactants is caused by polymerised glycol ether or glucose units (as shown in figure a.6). They are almost exclusively synthesised by the addition of ethylene oxide propylene oxide to alkylphenols (AP), fatty alcohols, fatty acids, or fatty acid amides.

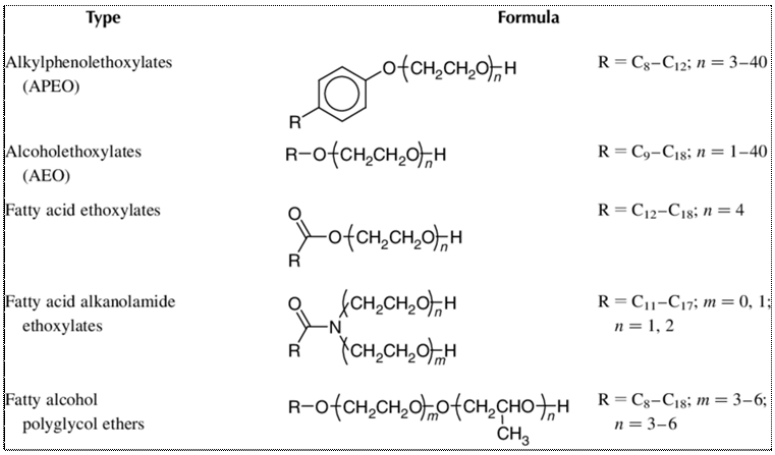


Figure a.6 :structure of hydrophilic behaviour of nonionic surfactants

Some examples of commonly used nonionic surfactants are fatty alcohol ethoxylates, fatty amines ethoxylates, fatty acids ethoxylates, triglyceride ethoxylates, alkylphenol ethoxylates, and ethylene oxide/propylene oxide adducts. Out of all the molecules, few surfactants are easily degradable, like ethoxylated fatty alcohols, acids and triglycerides; however, ethylene oxide/propylene oxide adducts, fatty amines and alkylphenol ethoxylates (APEO) are few ones tough to biodegrade and also challenging to eliminate because of its good solubility in water.

During degradation, each time the ethoxy phenol molecule gets removed, it transforms into corresponding alkyl phenol. These alkyl molecules get bioaccumulated because of their poor degradability. Notably, nonyl- or octylphenol ethoxylates (NPEOs) are more toxic than their precursors, i.e. alkylphenol (APs). Mostly, NPEO (nonylphenol ethoxylates) and OPEO (octyl phenol ethoxylates) forms of alkylphenol ethoxylates (APEO) are used in the textile industry. They possess lower biodegradability and eliminability, damaging aquatic species' reproduction by disrupting the endocrine system. Even with highly effective effluent treatment systems, which allow only trivial amounts of APEO or their metabolites to enter the aquatic environment, concerns arise from the resultant sludge. Unless these sludge are subject to treatments such as incineration or pyrolysis, capable of destroying the organic material, the APEO or their metabolites may enter surface water or ground waters in run-off from composting, spreading of treated or untreated sludge on agricultural land, or in leachate from landfill.

Several countries have already placed restrictions on the use of NPE. Moreover, these surfactants are on the "Priority Hazardous Substances" list targeted for priority regulatory action under the Water Framework Directive.

[7] Jardak K, Drogui P, Daghrir R (2016) Surfactants In Aquatic And Terrestrial Environment: Occurrence, Behavior, And Treatment Processes. Environ Sci Pollut Res 23:3195–3216.

Sizing

During the weaving process, the warp threads are subjected to a certain amount of friction as they move forward through the eyes of the healds and between the teeth of the reed. The friction during the vertical separation of the yarns to make the space or shed through which the shuttle passes is also there. Reinforcement and lubrication of the warp yarns are needed before it goes into the loom. This process is known as sizing.

Sizing materials are adhesive liquids that penetrate yarn pores forming a film on the outer diameter of the yarn. The size fills the pores and thus reduces absorption of subsequently applied adhesives or coatings. The size creates smooth surfaces by laying down projecting fibers and creates sufficient strength to resist the strains of weaving by fastening the fibers together. After applying the size, however, the yarn must remain flexible enough to be woven. An ideal size will eliminate loom warp stops and, at the same time, add to the overall quality of the fabric. An effective size formula must impart several basic characteristics to a yarn to reduce warp breaks during weaving. Also, a size recipe depends not only on the nature of warp yarns, but also on weaving conditions.

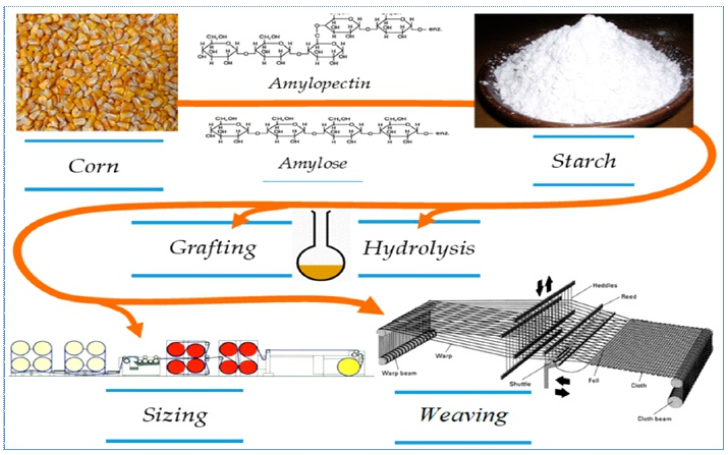


Figure a.7 : Sizing preparation

The sizing material must be an emollient adhesive substance, preferably with film forming properties. The chief adhesive substances are gums, starches and glues. The softening and lubricating material is generally an oily or fatty substance such as glycerol, olive oil, etc. Hygroscopic substances such as glycol are also added to counteract any tendency to undue dryness of the sized yarns. Finally, an antiseptic substance is added to prevent mildew formation during storage. Zinc chloride, phenol or salicylanilide are used. The sizing preparation should be readily removed before the bleaching and dyeing of the cloth.

Starch, modified starch, natural gums carboxy methyl cellulose, tamarind Rernel powder are used as main ingredients of sizes for cotton. For synthetic fibres the usual size material is polyvinyl alcohol and acrylic polymers with other chemicals.

[8] Rick A. Porterjames M. Self, Https://Patents.Google.Com/Patent/Us5397483a/En

They can be divided into two main groups

- Macromolecular natural products and their derivatives:
  - ◊ Starches and starch derivatives,
  - ◊ Industrial Gum

- Synthetic Polymers:
  - ◊ Poly(vinyl alcohol),
  - ◊ Poly(meth)acrylates,
  - ◊ Polyester condensates, and
  - ◊ Polyvinyl compounds

Starch

Starch is a carbohydrate and is widely available in plants. Starch is obtained and extracted economically from maise, cassava, potato, wheat etc. Starches from different sources have different physical and chemical properties.

Starch is a high polymeric carbohydrate composed of glucopyranose units joined by alpha glucoside linkages. The approximate formula can be written as $(C_6H_{10}O_5)_n$ where n can be from a few hundred to a few million. Starch occurs in white granules usually made up of amylose (linear polymer) and amylopectin (branched). Each starch has a characteristic gelatinisation range. The granules' size varies from 3 to 30 microns from cereals and 20 to 100 microns from tubers. The granules gelatinise in water when the temperature is raised to 60-70°C.

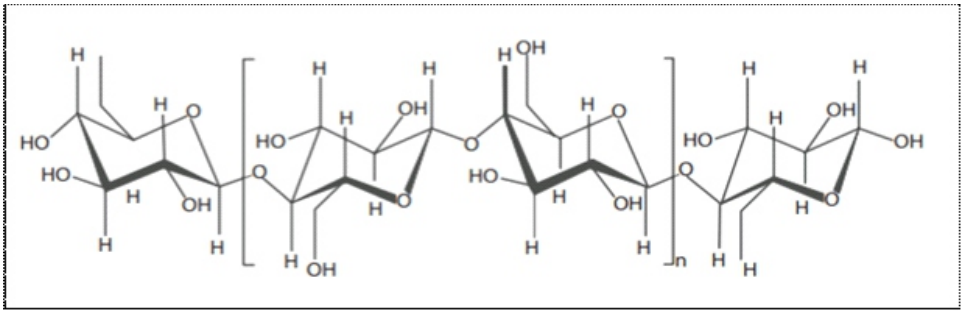


Figure a.8 :structure of cellulose unit of cotton

Hence, an adhesive material for sizing cotton should have the following characteristics:

- Starches and starch derivatives,
- Industrial Gum
- Ease of removal

[9]https://www.polyestermfg.com/what-is-the-best-sizing-chemical-for-textile/

Starch is completely biologically removed, but it is only sparingly soluble in water; the action of animal or vegetable enzymes is needed. These enzymes decompose the starch into water-soluble sugars, then are removed by washing before scouring. As a result, starch cannot be recycled and is responsible for most of the COD load in finishing effluents. Moreover, compared with other sizing agents, starch must be applied at about twice the rate of carboxymethyl cellulose because of the poorer sizing effect, leading to a higher COD in the wastewater.

The modification of natural starches reduces or even eliminates all deficiencies of natural starches. Starch modification reduces retrogradation, paste gelling tendencies and gel syneresis, improves paste clarity and gloss, as well as paste and gel texture. In this way, starch adhesion is improved, and a protective film is formed around the thread, which is extremely important for hydrophobic synthetic fibres.

Modified Starch

Starch derivatives include dextrins, starch esters and starch ethers. They are increasingly replacing natural starches, as their tendency to retrograde is considerably reduced.

The most commonly used starch derivatives are the esters with phosphoric acid (phosphate starches) and acetic acid (acetyl starches). These can be, to a great extent, biologically reduced.Carboxymethyl Starch Whereas commonly used ethers are the hydroxyethyl, hydroxypropyl and carboxymethyl starches. In comparison, ethers-based starches are more difficult to biodegrade. However, the great variety of possible chemical modifications makes it possible to produce good slashing agents, virtually completely biodegradable.

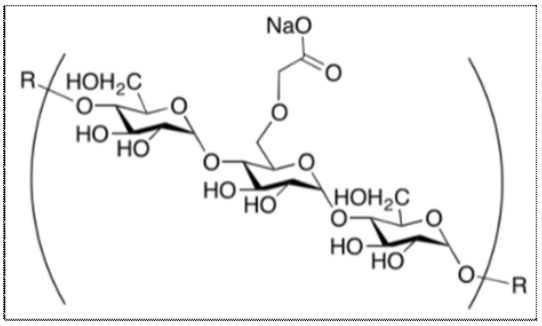


Figure a.9 :structure of carboxymethyl starches

Like natural starch, both the starch derivatives when applied leads to higher COD in the effluents.

Industrial Gums

Several naturally occurring gums are used as sizing agents. Because they are expensive, they are usually added to starch-based sizes to improve their properties. These gums are gum Arabic, gum guar, locust bean gum, tamarind kernel powder etc.

[09] https://www.polyestermfg.com/what-is-the-best-sizing-chemical-for-textile/

[10] Textiles Auxiliaries And Chemicals With Processes & Formulations by EIRI Consultants and Engineers

Gum Arabic

Gum Arabic is obtained as exudes from the Aeacia. There are five hundred different varieties of Aeacia.. Gum production starts by creating would on the bark of the tree. It is a neutral or slightly acidic salt of a complex polysaccharide. Gum Arabic dissolves in hot or cold water forming a clear mucilaginous solution. It is used as a sizing component and in printing and finishing formulations.

Guar gum is obtained from the seeds of Cyamopsis tetragonolobus. The active constituent is galactomannan. Guar is plenty available in India as a cultivated vegetable for human and animal consumption. For textile, the gums or ethoxylated and propoxylated gums are used as size components and printing pastes.

Locust bean gum is obtained from locust beam botanically called Ceratonia siliqua or Caroband and are found only in the Mediterranean coastal areas. There are four grades of locust bean gums top high, normal high, industrial and technical. The pods are collected, crushed and kibbled. The gum and its derivatives are used as sizing agent addition and also as a thickener in printing paste. It is also used to impart body and smooth touch to the fabric.

Tamarind kernel powder is obtained from tamarind trees widely grown in India. The creamy white powder contains mainly polysaccharides and fibre, fat and salts. The pulp of the print is used as acidulent in food. The seed kernel powder is used for sizing. The seeds are decorticated and powdered.

Sodium carboxymethyl cellulose was first used to substitute for natural gums, but new markets based on its properties have since been developed. Sodium carboxymethylcellulose, a water-soluble cellulose ether with the ability to suspend solids in and control the viscosity of aqueous solutions and form strong, tough films, has accounted for the rapid growth of its use in the industry since 1947. Sodium carboxymethyl cellulose has received considerable attention in the textile industry because of its ready solubility and excellent film-forming characteristics. It has been advantageous as a warp size for yarns and filaments. Sodium carboxymethylcellulose has replaced starch in many warp sizing operations because of its marked advantage in weaving efficiency and in reducing stream pollution at the finishing mill. Other advantages have also been realised, such as reduced shedding on the loom, elimination of the need for desizing enzymes, and lowered water and steam consumption.

This cellulose ether has also been used successfully as a thickener for textile printing pastes for many years. It is not sensitive to acids or alkalies within the pH range of these pastes and can be used with various dyes. It dissolves readily in hot and cold water, which facilitates formula preparation and gum removal after printing. Because viscosity can be closely controlled, sharper prints can be obtained at higher machine speeds.

Synthetic Sizing

Polyvinyl alcohol (PVA)

Vinyl alcohol is a polymer monomer called Poly Vinyl Alcohol (PVA), a synthetic resin. PVA can produce a stronger yarn with more excellent elongation and lower stiffness. However, PVA tends to be relatively more expensive than other sizing agents because it is a petroleum-based product. Although lower than starch or carboxymethyl cellulose, PVA's BOD and COD values can be high. PVA is often used in combination with starch.

Since the monomeric vinyl alcohol does not exist, poly(vinyl alcohol) is produced by hydrolysis (vinyl acetate).

The parameters that determine sizing properties are the degree of polymerisation and the degree of hydrolysis. There are two grades: the partly hydrolysed grade with a degree of hydrolysis of ca. 88 % and the fully hydrolysed grade with a degree of hydrolysis of ca. 98 %.

Partially hydrolysed PVA grades are preferred as sizing agents because they show maximum water solubility and adhere strongly to non-polar fibres such as PES. In addition to these conventional poly(vinyl alcohol) grades, copolymers with methyl methacrylate or co-monomers with carboxyl groups are also used as sizing agents.

The degree of polymerisation and hydrolysis lead to significant differences in biodegradability between the individual types of polyvinyl alcohols. PVA is not acutely toxic to micro-organisms and does not inhibit nitrification. It can be quantitatively eliminated by biological degradation after adaptation of the sludge. Given such adaptation, PVA can be classified as having good bioeliminability. The conditions for a 90 % reduction are relatively high concentrations (20 mg/l), temperature above 18 °C and a regular load over a long period (in wintertime and in the holiday period, problems can occur) [7, UBA, 1994].

Polyvinyl alcohol (PVA)

Poly(meth)acrylates show considerable variation in chemical structure (the building blocks can be: acrylic acid, acrylic esters, acrylamide, acrylonitrile, methacrylic acid) and therefore have an extensive range of applications. Hydrophilic monomers like methacrylic acid and its salts and acrylamide give good adhesion to polar fibres and easy removal by washing. Hydrophobic monomers such as the acrylic esters increase the elasticity of the sizing film and improve the ease of removal from wastewater.

Poly(methacrylates) cannot be reduced biologically, not even after a period of adaptation. Hydrophilic products cannot even be eliminated from the aqueous phase because they behave as hydrophilic polyelectrolytes.

An improvement is represented by poly(methacrylates) based on esters. In this case, thanks to the presence of hydrophobic groups, the poly(methacrylates) can be 90 % bio-eliminated by adsorption onto sludge after a residence time of 6 – 9 hours (which in practice is secured many times over) [18, VITO, 1998]. However, it is important to point out that the bio-elimination curve raises several questions about the elimination mechanisms (the elimination mechanisms are not clear).

Polyesters

Polyesters are generally condensates of aromatic dicarboxylic acids with diols (e.g. ethylene glycol, diethylene glycol) and sulphonated aromatic dicarboxylic acids (the latter provide solubility or dispersability in water, they are mainly added to improve dyeability).

Their biodegradability is bad, but they show a certain degree of bioelimination [77, EURATEX, 2000]. They are mainly used for sizing flat filament yarns. They are also found as co- components in sizing agents for staple fibres made of polyester blends.

Table a.1 : Amounts of sizing agents applied on different types of substrates

Textile substrate	Load (g /kg warp yarn) [1]	Explanations
Staple fibres		
CO & CO/PES	80 - 200	As sizing agents, starch and starch derivates, very often in combination with PVA, CMC or polyacrylates are applied. The ratio of starch/starch derivates to synthetic sizing agents is generally 3:1 and 1:1 for air-jet weaving machines. The loads depend mainly on the density of warp yarns, and the kind of sizing agent (for starch/starch derivates is significantly higher (150 – 200 g/kg).
CV	40 - 120	The load is 60 g/kg on average. Usually, combinations of all available sizing agents are applied, e.g. polyacrylates in combination with CMC and/or starch derivates
WO	0 - 20 [2]	A woven fabric consisting of wool is usually produced with twisted yarn, so the warp yarns do not need to be sized for the weaving process. In the case of simple yarns (in practice not very significant), up to 200 g/kg starch/starch derivate (80 %) in combination with synthetic sizing agents are applied.
Filament yarns		
PES	40 - 60	For 90 % of PES flat yarns, polyester sizing agents (which can be dispersed) are applied; the rest is sized with modified PVA and polyacrylates.
	80 - 120	This is the load for texturised yarns; about 80 g/kg for polyester sizing agents, about 120 g/kg for PVA and about 100 g/kg for polyacrylates
PA	20 - 50	Polyacrylic acid is used as sizing agent; 50 g/kg is applied for very thin fabric only
CV	15 - 30	Mostly for linings for which polyacrylates are used as sizing agents
CA	15 - 60	Polyacrylates and polyvinyl acetate are applied

Typical wastewater pollutants resulting from sizing agents include biological oxygen demand (BOD), chemical oxygen demand (COD), and aquatic toxicity

Knowing the loads of sizing agents on the different substrates, the calculation/estimation of organic loads as BOD_5 and COD is possible, provided that specific BOD_5 and COD values are available. These values are given in Table a.2.

Table a.2 :Specific COD and BOD5 values for the most common sizing agents

Kind of sizing agent	Specific COD-value (mg O2/g)	Specific BOD5-value (mg O2/g)
Starch	900 – 1000 *1	500 – 600
CMC	800 – 1000 *1	50 – 90
PVA	c. 1700 *1	30 – 80 *2
Polyacrylates	900 – 1650	< 50
Galactomannans	1000 – 1150 *1	400
PES-dispersions	1450 – 1700	< 50
Protein sizing agents	1200	700 – 800
Protein sizing agents	1200	700 – 800
Source: [179, UBA, 2001] Notes: *1 Considering the usual moisture content of commodity *2 For non-adapted "inocula"		

Desizing

The size applied to the warp yarns must be removed before scouring and bleaching the fabrics. These chemicals otherwise hamper the subsequent operations on textile fabrics. The process of removing size from the cloth is termed desizing.

Desizing can be done using acids, alkalis, enzymes, hypochlorites and sodium bromite. Enzymes are most commonly used for desizing. The enzymes convert starch into soluble products, which are then removed by washing with water. To accelerate wetting penetration, wetting agents are incorporated in the desizing bath. The selection of appropriate wetting agents incorporated in the desizing is important. The efficiency of desizing would depend upon the type and quantity of size used, temperature, pH, treatment time, and water quality.

Nonionic ethylene oxide condensates are better suited as wetting agents in desizing.

Sodium bromite oxidises starch rapidly into alkali products which are removed by the subsequent scouring operation. The rate of desizing with sodium bromite is very rapid.

Enzymes can remove starch sizes. As a general rule, nonionic surfactants do not harm enzymes, whereas anionics have a widely variable effect. Hydrocarbon solvents such as xylene ar alsoe used to facilitate the removal of waxy components of the size. Common solvents do not have an adverse effect on enzymes, but the emulsifier used should be selected appropriately. Fabrics should be desized at pH 7.

Scouring

The textile auxiliaries used in scouring must be stable to hard water and alkaline conditions. It should have good wetting power and be capable of emulsifying the impurities and maintaining them in the dispersed state over a wide range of temperatures scouring and washing. Alkyl derivatives of naphthalene sulphonic acids, fatty alcohol sulphates, fatty acid amides, phosphate esters and nonionic ethylene oxide condensates are scouring auxiliaries. The absorbency of caustic boiled cotton is much better when nonionic octylphenol ethylene oxide condensate is used as a surfactant compared to fatty alcohol sulphate or soap. A nonionic product with 12 ethylene oxide units was found to give the best result. Phosphate ester surfactants are good scouring auxiliaries because they have excellent compatibility with alkali. Bleeding of colour due to the formation of the leu covat dye can be prevented by a mild oxidant such as m nitrobenzene sulphonic acid.

Scouring of synthetic fibres uses mild detergents. Synthetic surface-active agents are used extensively. Nonionic and anionic detergents are suitable for scouring synthetic fibres.

Bleaching

The cleaning of cotton cloth from the coloured impurities is known as bleaching. The purpose of bleaching is to make the fabric amendable for subsequent processes of colouration and finishing. Bleaching is carried out after a gamut of operations performed in one or the other sequence depending upon the situation. Each operation is essential and is carefully carried out to obtain satisfactory and consistent results. Bleaching is usually carried out with oxidising agents to oxidise the coloured impurities. The usual bleaching agents are sodium hypochlorite, hydrogen peroxide, sodium peroxide, salts of peracids like sodium perborate etc. Wetting agents like nonionic, cationic, or anionic surfactants are used during peroxide bleach. Stain removers like surfactants, trichloroethylene, and perchloroethylenes are also used.

[11] *Textiles Auxiliaries And Chemicals With Processes & Formulations by EIRI Consultants and Engineers*

Mercerising

Mercerisation of cotton material is carried out to improve its strength, lustre and dye adsorption. Cotton's rapid and uniform wetting by sodium hydroxide is necessary for successful mercerisation. The grey fabric is treated with 52-54º Tw sodium hydroxide, stretched and washed in this process.

Ordinary wetting agents used in scouring are unsuitable as wetting agents in mercerising liquors, and special wetting agents effective under these conditions have been developed. A mercerising auxiliary has high stability in concentrated alkali and good wetting power. It is readily removable from the fabric by a simple washing treatment.

Generally, there are two types: cresylic and non-cresylic mercerising wetting agents to be used in mercerising liquors. Phenolic compounds such as cresylic acid form the basis of most commercial preparations.

Mixtures of ortho-, meta-, and para-cresols (cresylic acids), are not soluble in water but dissolve in a strong caustic soda solution. These are found to be stable wetting agents in this solution. Their wetting power is considerably improved by incorporating certain other additives like ethyl alcohol, polyhydric alcohols having C18 chain, butanol, 2-ethyl hexanol, polyethene glycol etc. Some are not miscible with water but dissolve in a caustic soda solution.

A product obtained by distilling pine oil as a fraction between turpentine and rosin has excellent wetting, penetrating and emulsifying properties. It is dispersible in mercerising liquors and improves their penetration power to give mercerised cotton more even dyeing properties. This fraction may be used together with cresols, which assist the dispersion of the pine oil distillate.

Cresylic wetting agents have a strong phenolic odour and are known coloured liquids. Noncresylic wetting agents include sulphated lower aliphatic alcohols such as hexyl or alcohols. These mercerising wetting agents are free from phenolic odour and foamless.

Piononic acid as a mercerising auxiliary is as effective as a cresylic acid. Mercerising auxiliaries based on substituted diethylene glycol sodium sulphates in conjunction with sparingly soluble alcohol and solution promoter of cellosolve type is a good mercerising wetting agent.

Special wetting agents suitable for adding to mercerising liquors, which are sulphoxide compounds, conform to the general formulae given below. Typical compounds are n-octyl-bid-(beta-hydroxyethyl)-sulphonium sulphate, n-octyl-(beta-hydroxyethyl)-sulphoxides, n-nonyl-(beta-hydroxyethyl)-sulphoxides and n-hexyldiethyl-sulphoxonium chloride. These chemicals are more efficient than the cresylic type of wetting agents. Because of their good solubility in caustic liquor, the mercerising liquor has no clouding effect.

Mixtures of alkyl sulphonic acid having on an average one sulphonic acid group for 7 carbon atoms, alkyl dialkanolamine of general formula R-N [$(CnH_{2n}O)mH$]2 in which R represents an alkyl radical of C2 to C5 n is either 2 or 3 and m is 1 or 2 and an ester of phosphoric acid with alcohol having 4-8 carbon atoms are nonfoaming type and dissolve easily in mercerising liquor, giving clear solution. They are more efficient than conventional wetting agents.

Dyeing

Dyeing is the production of coloured fabrics. Various dyestuffs are available, and each class of dyes has a different application method. Chemicals (auxiliaries) are used in the dying process to obtain a satisfactory dyeing process. The auxiliaries used in dyeing are:

- Wetting and penetrating agents
- Dispersing agents
- Levelling agents
- Sequestering agents
- Antifoaming agents
- Accelerators
- Migration inhibitor
- Dye fixing agents
- After washing agents
- Stripping agents

Wetting Agents

Surfactants are added to the dye bath to ensure the penetration of dye liquor into the yarns and fabrics. Sulphated fatty alcohol, sulphated oil and anionic surfactants like sulphonic acids are used.

Dispersing Agents

Dispersing agents are also surfactants used for uniform dye dispersion. These are mainly used in disperse and vat dyes. Sulphated fatty alcohol, alkyl aryl sulphonates, sulphated fatty acid amides are used.

Levelling Agents

Levelling agents are uniformly added in the dye bath due to the yarns or fabrics. Ionic surfactants like alkyl aryl sulphonates, fatty alcohol sulphates, fatty amide sulphonates are used. Nonionic surfactants are used for direct dyes, cationic surfactants and nonionic surfactants are used in vat dyeing. In the case of dyeing of acrylics, retarding agents like cationic and anionic surfactants are used as retarders. No ionic surfactants are used in polyester/blends dyeing as a levelling agent.

Table a.3 : Possible surfactant components compatible with respective dyes and fibres

Fibre	Dye	Possible components
Cellulose fibres	Vat dyes	Fatty alcohol ethoxylates Fatty amines ethoxylates Polyamide amines Polyvinylpyrrolidones
	Direct dyes	Non-ionic surfactants such as ethoxylated fatty alcohols, fatty amines, fatty acids, alkylphenols or propylene oxide polymers Anionic surfactants such as fatty alcohol sulphates and alkyl aryl sulphatesPolyvinylpyrrolidone
Wool	Acid, metal complex and reactive dyes	Ethoxylated fatty amines Quaternary ammonium compounds Bisulphate anion (HSO_4)$^-$ Other non-ionic surfactants such as ethoxylated fatty alcohols, fatty acids, alkylphenol and fatty mercaptans may
Polyamide	Acid and metal	Anionic, cationic and non-ionic surfactants used for wool Condensation products of aromatic sulphonic acids, alkyl
	Disperse dyes	Non-ionic surfactants
Polyester	Disperse dyes (at HT conditions)	Ethoxylated castor oil, stearic acid, alkylphenols Mixtures of alcohols, esters or ketones of medium chain length with emulsifying systems Hazardous carriers were used in the past as levelling agents, today they are no longer used in high-temperature dyeing
Polyacrylonitrile	Basic dyes	Quaternary ammonium salts with C_{12}-C_{14} fatty alkyl side chains (also known as retarders) Quaternary ammonium salts with aromatic ring systems

Sequestering Agents

Sequestering agents are chemicals that complex heavy metals and do not allow these heavy metals to react with fibre or dyes. EDTA, NTA are common sequestering agents.

Antifoaming Agents

Antifoaming agents are used in the dye bath to prevent foaming of the bath, which affects dyeing adversely. The best antifoaming agents are silicone polymers such as dimethyl polysiloxane with a viscosity of 100-500 centiposie at 25°C. Polyamino alkyl-substituted hydrocarbons are based on organo poly siloxanes and are as effective agents.

Carriers

Carriers are used in the dyeing of synthetics, particularly polyesters with disperse dyes. It imbibes deep shades on polyester and blended fabrics. O phenyl phenol, monochloro o phenyl phenol, p phenyl phenol, diphenyl, monomethyl naphthalene, trichloro benzene, dimethyl terephthalate, methyl salicylate etc. are good carriers.

Migration inhibitor

Migration inhibitorss affect uniform fabric dyeing by preventing dye molecules and liquor migration during the drying operation. Good migration inhibitors are sodium alginate nonionic polyelectrolytes, carboxymethyl cellulose, ethoxylated and propoxylated guar gums.

Dye fixing agents

Dye fixing agents permanently fix the dye on the yarns and fabric so that their fastness properties are adequately manifested. Usually, cationic surfactants are used as dye-fixing agents.

Stripping agents

Stripping agents are used for dye removal from badly dyed cloth produced by faulty dyeing. Quartery ammonium compounds with long-chain alkyl are effective. Polyvinyl pyrrolidone based agents are used for stripping vat sulphur and direct dyes. Cetyl trimethyl ammonium bromide is efficient in stripping azoic dyes. These are usually effective in the presence of oxidising or reducing agents. Nonionic surfactants with caustic soda and hydrosulphite are formed useful.

Sulphoxylate of formaldehyde polyvinyl pyrrolidone in the presence of acetic strips disperse dyes from nylon. 1-20% diphenyl with 3- 5% zinc sulphoxylate and 5% acetic acid at boiling temperature strips colour from polyester.

PRINTING

Printing is a process to decorate textile fabrics with colours and colour motifs. Textile printing may be considered a specialised dyeing process. It is a controlled application of dyes and pigments to exactly defined locations on the fabric, leaving the rest essentially unaffected.

There are three primary printing methods: direct printing, resist printing and discharge printing.

- In the direct printing method, a paste of dyes and auxiliary chemicals are directly fixed on the fabric by a pattern block or silkscreen.
- In resist printing, the fabric is printed in two steps. In the first step, the pattern or design is printed on a white fabric with a chemical (wax-like resinous substance) that will prevent or resist the penetration of dyes. In second step, the fabric is dyed by piece dyeing method.
- In discharge printing, Fabrics are generally dyed in a solid colour; before printing, the design is applied by screen or roller with a chemical (sodium sulphoxylate formaldehyde, a reducing agent). This reducing agent destroys the printed portion's colour, and the white background appears in the printed area.

There are three primary printing methods: direct printing, resist printing and discharge printing.

- Thickeners,
- Wetting agents,
- Dispersing agents,
- Antifoaming agents,
- Hygroscopic agents,
- Reducing and oxidising agents,
- Binders,
- After washing agents and;
- Miscellaneous auxiliaries.

Thickeners

Starch and natural gums like locust bean, senegal, arabic, karaya, guar bean are used commonly. Modified starches like British gums dextrin, sodium alginate, and sodium carboxy methyl cellulose are also used with satisfactory results. Kerosene, and water emulsions with non ionic surfactants are also used. These chemicals act as vehicles for carrying the dyes onto the cloth to prevent the colour spread on the fabric beyond the desired limit.

Wetting Agents

These are usually various surfactants compatible with other auxiliaries used for a specific printing

formulation. These have already been discussed earlier.

Dispersing Agents

Dispersing agents used are diethylene glycol, thio diglycol, sodium benzyl sulphanilate, and nonionic surfactants to prevent the agglomeration of dye particles.

Antifoaming Agents

Antifoaming agents are the same used for the dye bath. They are usually siloxanes. Hygroscopic agents used are glycerine, diethylene glycol etc.

Oxidising and Reducing Agents

Oxidising and reducing agents are sodium chlorate, chromate, dichromate, nitrate, ferrocyanide hydrosulphite, bisulphite, glucose and stannous and ferrous salts.

Carriers

Carriers are the same chemicals used for dyeing with disperse dyes and have already been discussed earlier.

Binders

Binders are film-forming polymers that play essential roles in achieving optimum properties. Pigments have no affinity for textile materials. So, pigment particles are stuck on the fabric's surface. Binders are those adhesive-type coating forming polymeric materials that stick pigment particles on fiber/fabric surfaces. Binders are white, milk-like liquids that form a thin invisible film on the fabric surface during curing. Under this film, pigment particles remain stuck. So a binder is a crucial and essential ingredient in pigment dyeing and printing.

Binders with a particle size range of 0.05 to 2 microns are usually available. These contain about 6% by weight of reactive groups for cross-linking binder to textile. The reaction involved is as below:

Binder-CH_2-OR + HO-textile = Binder-O-textile + HOR

[where R is H or CH_3]

Crosslinking increases the rubbing washing and drycleaning fastness properties but affects the fabric's handle.

Types of the binder:

The binder can be classified according to many aspects. Some are mentioned below:

- According to origin: According to origin, there are two types of binder,
  - ◊ Natural binder- glue, gelatin etc.
  - ◊ Synthetic binder- TROL, SLN, IG, Acramin binders etc.

- According to chemical groups: According to the chemical group present in the binder, there are two types of binder, those are:
  - ◊ IG Binders: Emulsion copolymer of vinyl acetate and butyl acrylate with modified urea-formaldehyde.
  - ◊ Ag Binders: They are made by emulsion copolymerisation of olefinic unsaturated monomers in an aqueous medium. These monomers include:
    - › Acrylic acid ester (butyl or ethyl acrylate)
    - › Styrene
    - › Acrylonitrile
    - › Vinyl chloride
    - › Asymmetric dichloroethane
    - › Vinyl acetate
    - › Diolifine such as butadiene

After Washing

The binder can be classified according to many aspects. Some are mentioned below:

Textile Finishing Chemicals for Chemical Finishes / Wet Finishes

In such finishing types, acids, alkalis, bleaches, detergents, softeners, resins and other chemical substances cause a reaction and produce permanent changes in fibre, yarn or fabric. These finishes are generally permanent in nature.

Shape Retention Finishes

It is an essential property of a garment to retain its shape. Apparel products must retain their shape and pleats the same even after wearing washings and dry cleaning. Such types of finishing are called "Durable Press / Wrinkle Free / Wrinkle Resistant and Permanent Press".

Resins like Dimethylol Dihydroxy Ethylene Urea (DMDHEU) – Modified glyoxal based Poly Carboxylic Acid derived (Recent development) are generally used in the Durable Press finishes.

There are two types of processes for the application of Durable Press Finish.

- Pre- Cured Process
- Post – Cured Process

Both the processes are described in detail,

Pre-cured process of Durable Press

Application Procedure

- Treat the fabric with resin and dry it.
- Cure the fabric in the curing chamber to form cross-linking between molecular chains
- Cut and sew the products and press

General Advantages and Disadvantages are given below.

Advantages

- Smooth fabric
- Dimensionally stable
- Lowest cost

Disadvantages

- No permanent creases
- Puckered seams
- Strength loss
- Abrasion sensitive

Such finishes are used for shirting, draperies and other items that do not require pleating (Curtains, Bedsheets). They can also be used to shape garments like (pants with a center crease). These finishes are commonly given in Cotton / Polyester blends.

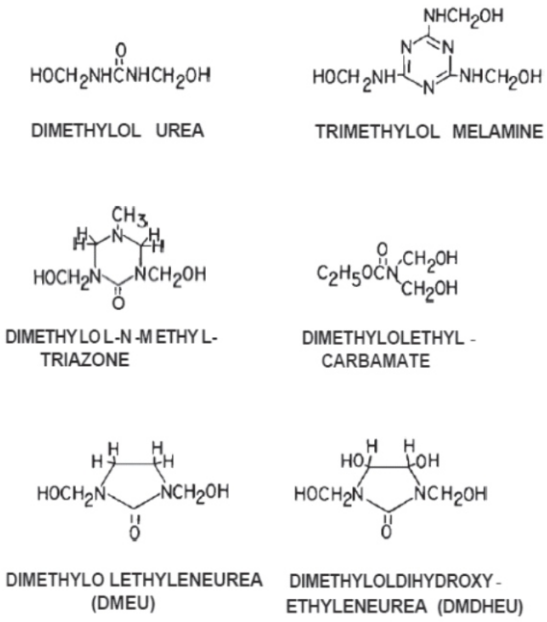


Figure a.10 : Resin for shape retention finishes

Such garments are pressed with high-temperature pressing equipment (Hot Head Pressers) to heat set the Polyester component.

Post Cured Process

- Treat the fabric with resin and dry it.
- Cure the fabric in the curing chamber to form cross-linking between molecular chains
- Cut and sew the products and press

The advantages and disadvantages of the post-cured process are given below.

Advantages

- Post cured durable press finishes are Dimensionally stable
- Crease retention Properties of the durable press finishes are excellent
- Post cured durable press finishes fabrics shows Minimum Seam Puckering

Disadvantages

- Higher cost of production of post-cure durable finish.
- Sometimes Post Cure Durable Finish May set prematurely
- Over finished areas of the Post Cure Durable Finish also increase the cost of the fabric.

- Such finishes are commonly used for Polyester/Cotton and Polyester/Viscose blends. The main reason for using polyester blends is to compensate for loss of strength and Abrasion resistance due to resin treatment on cellulose materials.
- it is a Durable finish and generally lasts for 40 – 50 laundering.

If a Durable Press Finish is given to 100% Cotton fabrics, then specially constructed fabric and modified techniques are required to reduce the resin-induced loss, abrasion resistance and tensile strength. For this purpose, long-staple cotton with tightly twisted yarns and compact construction (more yarns per inch) is required. it provides a Semi durable effect lasting for 15 – 20 laundering cycles.

Advantages

- Post cured durable press finishes are Dimensionally stable
- Crease retention Properties of the durable press finishes are excellent
- Post cured durable press finishes fabrics shows Minimum Seam Puckering

Disadvantages

- Higher cost of production of post-cure durable finish.
- Sometimes Post Cure Durable Finish May set prematurely
- Over finished areas of the Post Cure Durable Finish also increase the cost of the fabric.
- Such finishes are commonly used for Polyester/Cotton and Polyester/Viscose blends. The main reason for using polyester blends is to compensate for loss of strength and Abrasion resistance due to resin treatment on cellulose materials
- It is a Durable finish and generally lasts for 40 – 50 laundering.

Soil Release / Stain Proof / Stain Repellent Finishes

This type of finish improves the soil's resistance during the day-to-day use of the fabric, provides easy releasing of soil during the washing operations, and prevents the soil from redepositing on the fabric and retaining whiteness or the fabric's original colour. The Soil Release Finish reduces the degree of soiling of the fabrics by:

- Repelling the soil
- Preventing the formation of bond between soil and fabric
- The following chemicals are commonly used and applied by pad system
    - ◊ Silicone - Durable
    - ◊ Pyridinium - Durable

- ◊ Fluoro Carbon - Durable
- ◊ Fluoro Carbon / Pyridinium - Durable - Water / Oil borne
- ◊ Wax and metallic salt - Semi durable

Mainly applied for P/C, P/V blends and resin treated fabrics. These finishes helps to improve wet ability – during laundering for easy removal of soils by action of detergents/ agitation.

Water Repellent / Water Proof Finishes

Water repellency depends on surface tension and fabric penetrability. Water repellent fabric resists wetting, but air/moisture can penetrate. It is achieved by a combination of fabric structure and finishes.

Commonly used chemicals are:

- Paraffin Wax -> Spray
- Paraffin Wax with Al or Cr Salt -> Spray
- Pyridinum Salt -> Pad > Dry > Bake
- Reactive Silicon Resins -> Pad > Dry > Bake
- Fluoro Carbon Emulsion -> Pad > Dry > Bake

These chemicals fill the gaps between yarns in the fabric.

The performance of repellency depends upon the nature of the fabric and soap/detergents used in cleaning.

Water Proof Breathable Laminated Fabric

The laminated fabric consists of extremely thin laminate (0.001 inches) made from Teflon (Poly Tetra Fluroethylene). The Laminate sheet contains over one billion extremely fine holes per inch. It provides a waterproof yet breathable fabric. Laminate can be applied on to woven/knitted fabric.

Anti Microbial Finishes

This finish prevents the growth of bacteria and odour-causing germs, prevents decay and damage from perspiration, controls the spread of disease and reduces the risk of infection following injury. This finish is generally applied in intimate apparel, body-fit garments, jogging and exercise clothing, sportswear, shoe linings, hospital linen and carpets.

Chemicals Used Are:

1. Quaternary Ammonium Compounds
2. Zirconium Peroxides and N-halamines

This finish prevents the growth of bacteria and odour-causing germs, prevents decay and damage from perspiration, controls the spread of disease and reduces the risk of infection following injury. This finish is generally applied in intimate apparel, body-fit garments, jogging and exercise clothing, sportswear, shoe linings, hospital linen and carpets.

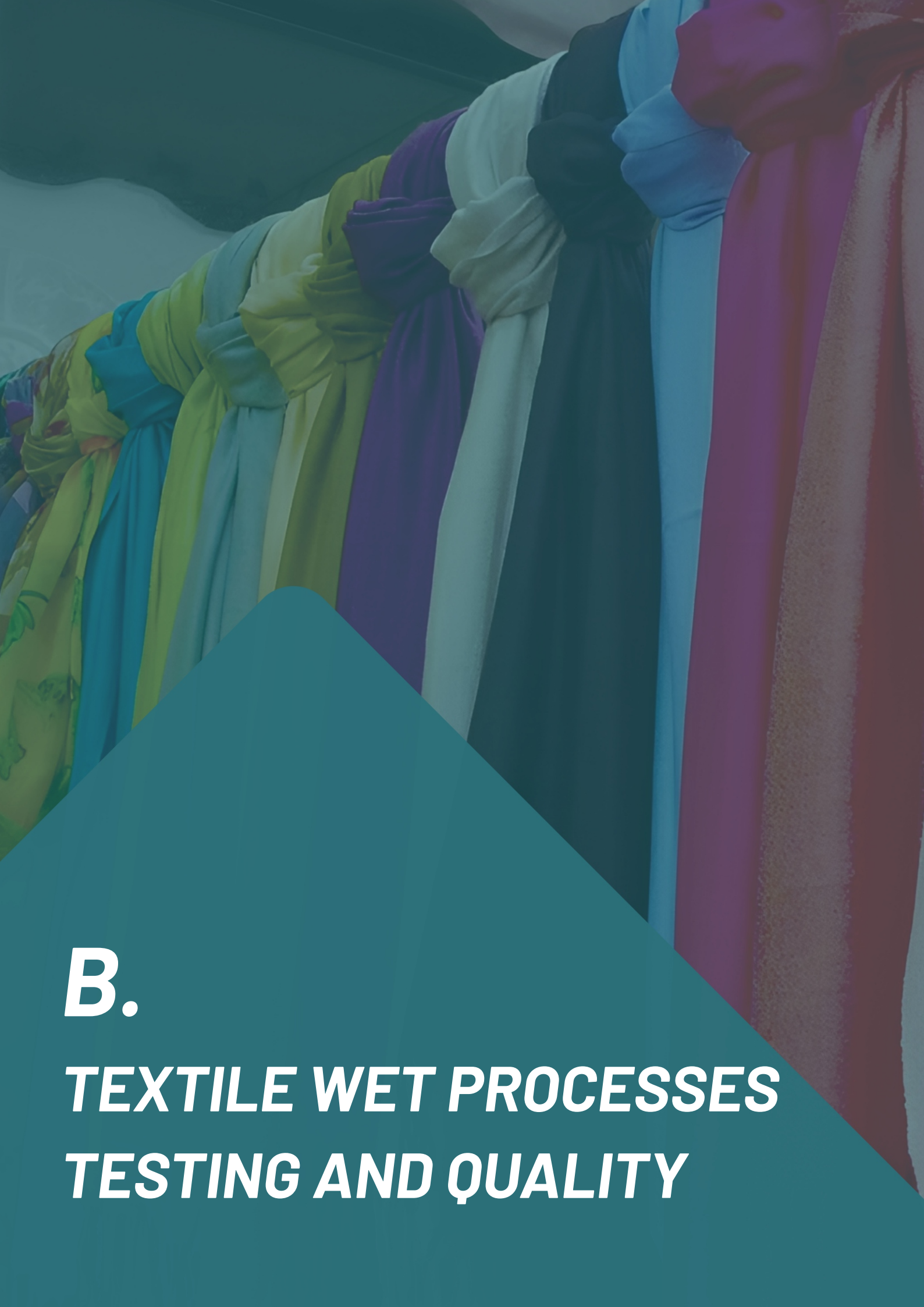
Insect & Moth Control Finishes

The Chemical finish Permethrin is applied at the scouring or dyeing stage. This finish is mainly applied for Wool and Wool Blends. It is a Semi Durable Finish => 15 – 20 launderings.

The prime requirement of a mothproofing agent is that it is toxic to moths and beetles that attack wool. Still, it must not be toxic to humans at concentration levels used for mothproofing.

Durable Flame Retardant

Durable flame retardant is a chemical finish that reacts with or is physically held on the fabric's surface or within the fibre. These finishes must withstand laundering and other cleaning procedures throughout the expected life of the fabric. Durable flame retardants are generally organic compounds containing phosphorus, nitrogen and/or halogen (chlorine or bromine) or a combination of these in the chemical structure. Durable flame retardant finishes are applied to a fabric by a pad-dry-cure process. The finish formulation usually contains the flame retardant chemical, softener, resin binder, cross-linking agent, and catalyst.



B.

TEXTILE WET PROCESSES TESTING AND QUALITY

Textile Testing

The quality of a product or process is checked before it is put into large-scale usage. The quality of the product, its performance, and its reliability are the key factors while testing is performed. Testing can be defined as the methods or protocols adopted to verify/determine the properties of a product. It can be divided primarily into two types: routine process testing and quality assurance testing. Routine testing helps to streamline the daily process. Quality assurance testing helps the process or product establish credibility in the long run. Testing can also be defined as the procedures adopted to determine a product's suitability and quality.

Importance of Textile Testing

Standards of control should be maintained to reduce waste, minimize price, and so on. Faulty machine parts or improper maintenance of the machines can be easily detected with the help of textile testing. Improved, less costly, and faster protocols can be developed by industries with the aid of testing. The efficiency and quality of the product can also be enhanced with the help of regular and periodic testing. Customer satisfaction and loyalty can also be won by producing according to customer specifications in good time. In short, testing is an essential pivot to the whole textile product supply chain.
Production monitoring involves testing production line samples, termed "quality control." Its purpose is to sustain specific, definite properties of the end product within acceptable tolerance limits as per the agreement between the producer and the consumer. A product that does not meet the already agreed specification or the required quality is termed a "fail."[1]

Grey Fabric

After receiving grey fabric in the Raw Material Section, it is inspected using a grey fabric inspection machine. During this inspection, defects such as knots, broken and loose warp ends, and broken weft ends are removed. In the case of holes, either it is mended, or the fabric is cut off, depending on the position of the hole and its severity. Inspecting and grading fabric quality is one of the important functions of quality control in the grey or finished state. The grading of fabric is a difficult task, taking two primary considerations: the frequency and the seriousness of defects.



Figure b1.1 Inspection machine at Reference Unit

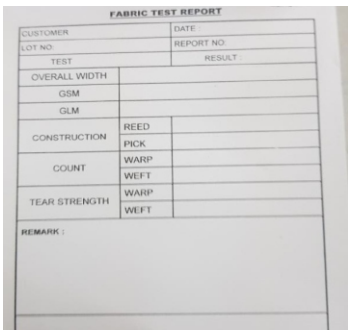


Figure b.2 Test Report Card Sample

[1] Advanced Textile Testing Techniques

Objectives and purposes of grey fabric inspection:

- To check the thickness and GSM of the fabric
- To identify the fabric faults
- To ensure the fabric quantity
- To ensure the fabric produced is of the required quality.
- To identify the looms or knitting machines producing defects and take corrective action.
- To prevent losses after cutting the fabric for making a garment because of fabric defects.
- Classify the products according to their different qualities based on the demands of the buyer/market or client.

Grey fabric inspection process:

- The inspector is given special instructions, if any, by writing on the job card by the supervisor.
- Check the details of fabric received and conforming before taking them for checking.
- Clean the inspection table and the surroundings before the start of the work.
- Check the fabric weight and compare it with the 'should be weight' as per design. If the weight differs from the norms, rechecking shall be done, and the concerned persons shall be given the alarm to decide.
- Set the length counter after the fabric end reaches the inspection area.
- Switch on lights both below the table and above the table.
- Check the back and face side of the fabric first and then inspect the goods for visible defects as per the required standards, for e.g. four points system.
- Mark the defects with a sticker at the defect location or with a marker (sticker, tag etc.) at the selvedge edge.
- Inform the supervisor regarding the materials checked and take instructions for further checking. If damages are found, the counting of defects is not done, and the in-charge is informed to decide.
- Keep the inspected fabric roll on the fabric stand and put the tag.

Detection of size on the fabric surface

The fastest method to detect sizes on fabric surfaces is staining of the size with the corresponding colour reactants. However, these tests are only possible if the reactant does not stain the fibre material itself. Staining tests usually only react to certain components or final groups within the size of the molecule. Some sizes that may seem different have equal or at least similar components. They can only be distinguished through a combination of different detections. Basic dyestuffs e.g., react with anionic groups in polyacrylate, polyester and polyvinyl acetate sizes. These size types, mainly applied on PES and PA fibres, can only be distinguished through different detection methods. Detecting sizes directly on the fabric surface is carried out by dripping on different reactants. The detections on the fabric surface described ought to generally serve as preliminary tests for the size detection in the aqueous extract.

The following table b.1 summarises the sizes and the corresponding detections. A detailed description of the detection reactions and the implementation is given on the following pages.

Table b.1: Staining sizes and the corresponding detections

Sizing Agent	Color Reactant	Detected Color
Starch and starch derivatives	Iodine/Potassium iodide	Blue/violet
	Iodine/ Potassium iodide	Brown
	Chromic acid/NaOH	Brown
Polyester (PES)	Mixed indicator 5	Blue with orange edge
Polyvinyl alcohol (PVA)	Iodine/Boric acid	Blue/grey
	Mixed indicator 5	Brown to blue/grey
	Benzacryl Red GRL 100%	Red
Polyvinyl acetate (PVAc)	Mixed indicator 5	Green to brown
	Iodine/boric acid	Blue/grey
	Benzacryl Red GRL 100%	Slightly red
Polyacrylate (PAC)	Mixed indicator 5	Blue with orange edge
	Benzacryl Red GRL 100%	Red
Acrylic acid	Mixed indicator 5	Blue with orange edge
	Benzacryl Red GRL 100%	Red
Polyester (PES)	Mixed indicator 5	Blue with orange edge

Desizing:

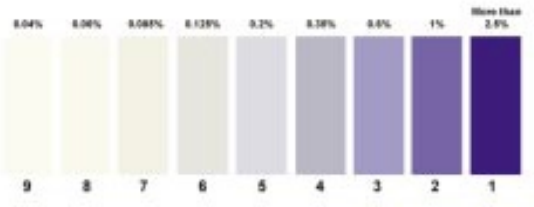
Weight loss method:

While desizing, starch is removed from the fabric. Hence, the material undergoes weight loss after the process is over. The more the weight loss, the better the desizing enzyme's efficiency. Weight loss can be calculated in terms of % weight loss as follows:

% Weight Loss = [(Initial GSM – Final GSM) / (Initial GSM)] X 100

Tegewa scale method

The scale consists of colours ranging from violet to white, as given.



Reagent Preparation :

Take potassium iodide [10gm of KI (100%)] in 100ml of water; then add 0.6358gm of iodine (100%); stir well until iodine is completely dissolved in the KI solution. After this, add 800ml of ethanol. Then by adding water, the volume should be raised to 1000ml.

Method of Testing:

Put one or two drops of the above solution on a fabric. Rub it gently and then assess the colour change as per the Tegewa scale. Before testing, the fabric should be cold, and there should not be any residual alkalinity in it.

Assessment:

No colour change = No starch is present
Pale blue to bluish violet = Presence of starch size or a blend of starch + synthetic size
Brown = Presence of modified starch or a blend of starch/PVA size

Scouring

Drop test method

The properly scoured fabric should wet out faster and be more water-absorbent. This test method is used to measure fabric wetting. A water drop is placed on the fabric, and the time it takes for the drop to penetrate the fabric is recorded. The faster the wetting time, the more absorbent the fabric is.

Principle of the test:

A drop of water is allowed to fall from a fixed height onto the taut surface of a test specimen. The time required for the specular reflection of the water drop to disappear is measured and recorded as wetting time.

Procedure:

Conduct the test in a standard atmosphere as defined above. Mount the cloth (or smoothed-out, thick portion of yarn) in the embroidery hoop so that the surface is free of wrinkles but without distorting the material's structure. Place the hoop about 10+1mm (0.375in) below the tip of the burette, and allow one drop of distilled or deionized water at 21+30C (70+50F) to fall on the cloth.

Using a stopwatch, measure the time required, up to 60 secs maximum, for the surface of the liquid to lose its specular reflectance. This point is determined by having the hoop between the observer and a source of light - such as a window or laboratory spotlight - at such an angle that the specular reflectance

of light from the surface of the flattened drop can be seen. As the drop is gradually absorbed, the area of this tiny mirror diminishes into a dull wet spot. The watch is stopped at this instant, and the elapsed time is recorded. When the wetting time exceeds 60 secs, 60+ secs should be recorded.

Calculations and evaluation:

Average the five 'time' readings. The shorter the average time, the more absorbent the textile is. Five seconds or less is generally considered to represent adequate absorbency.

Bleaching

Fluidity of dispersions of cellulose from bleached cotton fabric

Purpose and scope: The fluidity of dispersion of bleached cellulose cotton fibres in cuprammonium hydroxide or cupriethylene diamine is a sensitive measure of the dehydration of the cellulose resulting from the action of acids, alkalis, zoxidizing or reducing agents. Therefore, it helps to determine the completeness of the bleaching treatment to which the cloth has been subjected and the effect of the chemical treatments on the tensile strength of the fabric.

Principle:

The length of the chain of cellulose molecules is decreased when treated with acid, alkali, zoxidizing or reducing agents, etc. The severity of the treatment determines the extent of the shortening of the cellulose chain and the fluidity, or ease of flow, of dispersion of the cellulose in the solvents.

Procedure:

Weigh to the nearest 0.1 mg sufficient sample to give a 0.5% cellulose solution in cuprammonium solvent. it is determined as follows

$$W = \frac{0.94 \times V \times 0.5}{100 - M}$$

W = Weight of sample required
V = volume of liquid in the dissolving tube For Internal TWG discussion only

M = Moisture content (2% for desiccated samples)
0.94 = Density of the cuprammonium solution

Transfer the samples from the weighing dish or watch glass to the glass-dissolving bottle containing the stainless balls.

Add the standard cuprammonium solution in the following manner: with the stopcock of the T-tube closed, open the pinchcock and allow the solution to flow out. When the flow becomes sluggish, owing to the drop in pressure of the gas in the bottle, pass a brisk stream of nitrogen gas through the horizontal arm of the T-tube to expel the air, and then open the stopcock to allow nitrogen to be drawn into the bottle.

Fill the tube to one-fourth the volume and then wet out the specimen in the tube by stirring or shaking. Fill the tube completely with the solution so that no air is entrapped when the stopper is inserted. Rotate the tube at approximately 30 rpm using a suitable mechanical device for 16 hours. As light affects the solution, this should be done either in a dark room or on a device designed to exclude light.

Place the tube in a water bath at 25+0.50C, allowing it to come to an equilibrium temperature. After reaching equilibrium, remove it from the bath, unstop it, and fill the viscosimeter, which is mounted in a glass jacket, in the water bath. The efflux time between marks on the viscosimeter is then measured accurately to the nearest 0.2 secs. Take the average obtained with duplicate specimens as the apparent fluidity.

Calculation:

Calculate the apparent fluidity of the dispersion from the following formula:

$$F = \frac{C}{0.95(t - {}^{K}/_{T})}$$

where:
F = Apparent fluidity in rhes
t = Time of efflux
0.95 = Density of the cuprammonium solution
C and K = Instrumental constants

Reflectance, blue and whiteness of bleached fabrics are the main tests to determine bleaching effectiveness.

Purpose and scope:

This test method provides procedures for measuring the whiteness of textiles. Whiteness, as measured by this test method, indicates how white the textile appears to an average viewer. The formulae for calculation of whiteness are those recommended by the Commission Internationale de l'éclairage (CIE) whiteness formula. Because reflectance is affected by the nature of the surface of the textiles, comparisons can be made only between samples of the same type of textile.

Principle:

Many textile impurities absorb short-wavelength light; resulting in a yellowish appearance to observers. The whiteness is calculated from formulae based on the CIE chromaticity coordinates. The CIE tristimulus values are measured using a reflectance spectrophotometer or colourimeter.

Therefore, a measurement of whiteness may indicate the degree to which a textile is free from impurities. The presence of blueing components or FWAs in the textiles may also be determined using the whiteness measurement.

Procedure:

Operate the colour measuring instrument according to the manufacturer's instructions for standardization and measurement.

Periodically measure a standard tile to determine if the instrument has drifted and requires re-standardization. Before proceeding with the colour measurements, determine whether or not a fabric contains FWA by viewing a sample in a dark room under ultraviolet light. A fabric that contains FWA shows fluoresce under UV light. To determine the whiteness of optically brightened materials, the spectral power distribution of the light source is to approach that of CIE illuminant D65 from 330-700nm. Consult instrument manufacturers for suitable equipment. Determine the measured values of the sample after folding it until it is opaque. In positioning the sample over the instrument aperture, ensure that the measured area is free of creases or markings. Take at least four measurements for each fabric sample. Make two measurements on each side of the fabric, the fabric being moved and rotated 900 between measurements on the same side.

Fabrics with a pronounced face, such as corduroys and other pile fabrics, make all measurements on the face. If the fabric surface is unusually variable, more than four measurements might be required to characterize the variable sample. In this case, make equal measurements on each side in each direction.

Calculation:

Average the measurement values taken for each test sample.

Mercerization:

Barium activity number test

Purpose and scope:

This test method provides a method for determining the presence of mercerization in dyed and undyed cotton yarns and fabrics. In addition, the test indicates the completeness of the reaction between the

cotton and mercerization bath.

Principle:

Carefully scoured specimens of the cotton to be tested and unmercerized cotton are immersed in separate baths of barium hydroxide solution for a definite time period. The aliquot portion of each soaking bath and fresh barium hydroxide solution are then titrated with hydrochloric acid. The ratio of the barium hydroxide absorbed by the mercerized specimen to that absorbed by the unmercerized specimen multiplied by 100 gives the barium activity number.

Testing:

Take a minimum of 5gm of each sample of the unmercerized standards and scour it. Weigh 2gm of each scoured sample and the scoured standard cotton into dry 250ml flasks equipped with stoppers (Ground glass stoppers are recommended). Add 30ml of 0.25N barium hydroxide to each test specimen flask and two empty flasks for blank determinations. Stopper each flask immediately upon adding the barium hydroxide and store them for at least 2 hours in a water bath at 20-250C (68-770F) (room temperature). Shake the flasks at frequent intervals. After 2 hours, transfer 10ml of solution from each container, including the blanks and titrate with 0.1N hydrochloric acid, using phenolphthalein as an indicator.

Calculations:

Using titration figures, determine the ratio of barium hydroxide absorbed by a mercerized specimen to that absorbed by the unmercerized standard. Multiply this ratio by 100 to obtain the barium activity number. Barium activity number of unknown sample is:

$$\frac{\text{(B.R of Blank – B.R of unknown sample)}}{\text{(B.R Blank – B.R of unmercerised sample)}} \quad X \quad 100$$

Transmission of Dispersion Dyes

To check transmission of disperse dye.

1. Reagent: DMF (Dimethyl Formamide)

2. Apparatus / Equipments :

- Weighing balance
- Beakers
- Glass rod
- Volumetric flask

- Spectrophotometer

3. Procedure:-

Calibration for Disperse Dye :-

- Calibrate the spectrophotometer using DMF.

Dilution :-

- Prepare 1 gpl dispersing agent (Setamol WS) solution.
- Take 0.2 g of dye in a beaker & make up to 100 ml volume using a volumetric flask with the above stock solution.
- Carry out 0.5 ml solution from the above prepared dye solution.
- Make the final volume to 25 ml using a volumetric flask with DMF.
- Use this solution for transmission.
- Measure the transmission on standard wavelength (as per max value) of above solution in the spectrophotometer.

4. Evaluation:-

- Report values on standard wavelength as current vs proposed using a spectrophotometer.
- +/- 3 % strength is acceptable.

Parameter	Current Dye sample	Proposed Dye Sample
DL		
Da		
Db		
Dc		
Dh		
DE		
Strength		

Transmission of Reactive/Acid/Basic dyes

1. Reagent : - Distilled Water

2. Apparatus / Equipments : -

- Weighing balance
- Beakers
- Glass rod
- Volumetric flask
- Spectrophotometer

3. Procedure:-

Calibration for Reactive Dye :-

- Calibrate the spectrophotometer using Distilled water.

Dilution :-

- Take 0.1 to 0.125 g of dye in a beaker.
- Make 100 ml total volume using a volumetric flask with distilled water.
- Take out 2 ml of the above solution in a fresh beaker.
- Make up the total volume to 100 ml using a volumetric flask.
- Use this solution for transmission.
- Measure the transmission on standard wavelength (as per λ max value) of the above solution in the spectrophotometer.
  (For Basic Dye, use Glacial Acetic Acid 40% in dissolution)

4. Evaluation :-

- Measure the values on standard wavelength as current vs proposed using a spectrophotometer.
- +/- 3 % strength is acceptable.

Parameter	Current Dye sample	Proposed Dye Sample
DL		
Da		
Db		
Dc		
Dh		
DE		
Strength		

Soaping Effect

To determine the effect of soaping on shade.

1. Apparatus / Equipments : -

- Beaker
- Glass rod
- IR dyeing machine
- Computer Color Matching (CCM) Machine

2. Procedure:

- Take about 2.5 gm of pre-dyed substrate with respective depth.
- Then, take 0.25 and 1.0 gpl dosages of a particular soaping agent.
- And treated the substrate at 900C for 20 mins in IR dyeing machine.
- Then, take out the material and give hot wash-cold wash-Air dry.
- After air dry, assess the material by Computer Color Matching (CCM) Machine.

3. Evaluation:

- Evaluate the sample by measuring on CCM and visual observation.

Dispersion Stability of Disperse Dye

To check the Dispersion stability of Disperse Dye.

1. Apparatus / Equipments :

- Filter papers: Whatman filter paper no. 40
- Beakers-500 ml
- Weighing Balance
- Filter Residue scale
- Magnetic Stirrer
- Graduated Cylinder- 250 ml

2. Procedure:

- Prepare 10 gpl of dispersion of the given dye and 1 gpl of dispersing agent.
- Adjust pH 4.5 – 5.0.
- The dispersions are heated above 90 o C.
- At above the temp. pipette out 1 ml of the dye solution and dropped on a filter paper.

- The drops are allowed to dry out and inspected visually.

3. Evalution:-

Good dispersion stability: No dark spot with uniform spreading of dyes on filter paper.

Grades :-

- Minimum
- Poor
- Moderate
- Fairly Good
- Good
- Very Good ter air dry, assess the material by Computer Color Matching (CCM) Machine.
- Excellent
- Maximum

Detergency of Surfactant & Soap by EMPA 101

To determine the washing properties of detergent as well as wetting agents.

1. Reagents:

- Soda ash
- Caustic Soda

2. Apparatus / Equipments:

- Glass beaker
- Water bath
- Glass rod
- EMPA (101) Fabric

3. Procedure:

- Take 2 gm of substrate.
- Give treatment as per below Recipe :

Recipe : 1)
2 gpl detergent/wetting agent
3 gpl Soda ash

Recipe : 2)
2 gpl detergent/wetting agent
3 gpl caustic soda

Carry out Blank, also.

Give treatment as per the parameters below

- M:LR 1:50
- Enter the fabric in a bath at 60 0C.
- Temp. : 95 0C
- Time : 15 mins
- Hot wash (2 cycles) of 80 0C / 10 min >> Cold wash >> Air Dry for 10-15 mins >> Iron the treated substrate >> Assessment.

4. Evaluation:-

- Observe the bath's appearance and note the result as Heavy Tint / Medium / Very Less / No Tint.
- Assess the treated substrate using Spectrophotometer.
- Compare the Whiteness as Current vs Proposed.

Description	Current	Proposed		
	Bath Tint	Whiteness	Bath Tint	Whiteness
Recipe : 1				
Recipe : 2				
Control				

Levelling Property of Disperse dye

To check the Levelling Property of Disperse Dye.

1. Reagent: Acetic acid

2. Apparatus / Equipments : -

- IR Lab dyeing Machine
- Beakers
- Glass rod

3. Procedure:-

- Take pre-dyed Polyester fabric (1% depth) with a dye under test. An equal size of the same undyed fabric is blank dyed together at 130oC for 45 mins.
- The dye migrates from the dyed fabric to undyed fabric is assessed.

4. Evaluation:-

The dye migrate from dyed to the undyed fabric is noted and evaluated using 5-1 Scale.

Scale :-

- Very Good
- Good
- Average
- Fair
- Very Poor

By visual observation -

- If more dyes are migrated, then the levelling property is good.
- If less dyes is migrated – then levelling property is bad.

Chemicals

Acetic Acid (CH_3COOH) Testing Process

Recipe:

- Caustic soda (NaOH)..... 4.0% solution
- Phenolphthalein ($C_{20}H_{14}O4$).....0.1% solution
- Acetic Acid (CH_3COOH).....6.0 gm + 94ml Water

Testing Procedure:

- Acetic acid solution (10ml) and phenolphthalein-as indicator (3 drops) are taken in a glass flask.
- Caustic Soda is poured from the burette into the flask drop by drop until the solution color turns pink.
- Burette reading is taken.

Calculation:

Burette reading x 10 = Purity %

Caustic Soda (NaOH) Testing Process

Recipe:

- Hydrochloric acid (HCl).....3.75 gm+ 100ml water = 0.45N HCl
- Phenolphthalein ($C_{20}H_{14}O_4$).....0.1% solution
- Caustic soda (NaOH).....2.0% solution
- Water .....49.0 ml

Testing Procedure:

- Caustic soda (1.0 ml) and Phenolphthalein- As Indicator (1 drop) are taken in a glass flask.
- Water (49.0 ml) added to the solution.
- Hydrochloric Acid is poured from the burette into the flask drop by drop until the solution color turns pink.
- Burette reading is taken.

Calculation:

(Burette Reading x 0.45N x 0.04 x 100) / NaOH Weight = %Purity

Formic Acid (HCOOH) Testing Process

Recipe:

- Caustic soda (NaOH).....4.0% solution
- Phenolphthalein ($C_{20}H_{14}O_4$).....0.1% solution
- Hydrochloric acid (HCl).....3.75 gm+ 100ml water = 0.45N HCl

Testing Procedure:

- Formic acid (10ml) and Phenolphthalein- As Indicator (3 drops) are taken in a glass flask.
- Caustic Soda is kept pouring from burette into the flask drop by drop until the solution color turns into pink.
- Burette reading is taken.

Calculation:

Burette reading x 10= Purity %

Hydrochloric Acid (HCl) Testing Process

Recipe:

- Caustic soda (NaOH).....0.4% solution
- Phenolphthalein ($C_{20}H_{14}O_4$).....0.1% solution
- Hydrochloric acid (HCl).....1.0 gm + 100ml Water

Testing Procedure:

- Hydrochloric acid (25ml) and Phenolphthalein- As Indicator (3 drops) are taken in a glass flask.
- Caustic Soda is poured from the burette into the flask drop by drop until the solution color turns pink.
- Burette reading is taken.

Calculation:

(BURETTE READING X 0.1N X 0.365 X 400) / HYDROCHLORIC ACID WEIGHT = %Purity

Hydrogen Peroxide (H_2O_2) Testing Process

Recipe:

- Hydrogen Peroxide (H_2O_2).....0.12% solution
- Sulphuric Acid (H_2SO_4).....20% solution
- Potassium Permanganate ($KMnO_4$).....1.0 gm + 100ml Water

Testing Procedure:

- Hydrogen Peroxide (50ml or 0.06gm) and Sulphuric acid (10ml or 2gm) are taken in a glass flask.
- Potassium Permanganate is poured from the burette into the flask drop by drop until the solution color turns pink.
- Burette reading is taken.

Calculation:

[Burette Reading X 0.17 (Constant)] / Hydrogen Peroxide weight = %Purity

Soda Ash (Na2C03) Testing Process

Recipe:

- Sulphuric Acid (H_2SO_4).....0.49 gm + 99.51 ml water
- Soda Ash (Na_2Co_3).....0.53% solution
- Methyl Orange .....0.1% solution

Testing Procedure:

- Soda Ash (10ml) and Methyl Orange – As Indicator (3 drops) are taken in a glass flask.
- Sulphuric Acid is poured from the burette into the flask drop by drop until the solution color turns pink.
- Burette reading is taken

Calculation:

Burette reading x 10= Purity %

Sodium Hydrosulphite

Estimation of Strength / % Purity of Sodium hydrosulphite.

(Key's)	
Formula	$Na_2S_2O_4$
Mole. Wt.	174
Equi. Wt.	43.5

1. Appearance: White or grayish-white solid powder.

2. Solubility: Soluble in cold water. Slightly soluble in alcohol.

3. Reagents:

- Neutralized Formaldehyde solution (37%)
- Phenolphthalein indicator
- N/10 NaOH
- N/10 Iodine solution
- Starch indicator

4. Apparatus / Equipments:

- Weighing bottle
- Volumetric flask - 500 ml
- Volumetric pipette - 10 ml
- Conical flask

5. Procedure:

Neutralised Formaldehyde solution (37%) - 15 ml HCHO + one drop of phenolphthalein indicator + N/10 NaOH until Pink colour formed

2 g of the sample is accurately weighed in a weighing bottle and dissolved into above 15ml of neutralized formaldehyde solution (37%) and allowed to stand for 5 min.

Dilute it up to 500 ml with deionized water in a volumetric flask. Take 10 ml of this solution in a conical flask, add 1 ml starch indicator, and then titrate against N/10 Iodine solution until blue.

1 ml (N/10) I2 = 0.0435 g $Na_2S_2O_4$

Calculation:-

$$\% \text{ Purity } \frac{\text{Burette Reading x 0.0435 x 100 x 500 x N of Iodine}}{\text{Weight of Sample x 10 x 0.1}}$$

6. Evaluation:-

- % Purity of Sodium Hydrosulphite is_____.

Table b.2 - List of Test parameter and their testing standards

No	Test Parameters	Testing Standards	Testing Instruments
1.	pH (of aqueous extract Fab.)	IS-1390 ISO-3071	pH Meter
2.	Fiber Identification	IS-667	-
3.	Total size content	IS-199	-
4.	Scouring loss	IS-1383	-
5.	Barium activity number	IS-1689	-

6.	Wax/Oil content	IS-199	-
7.	Cupraammonium fludity	IS-244	-
8.	Wettability (Absorbency) of cotton	IS-2349	-
9.	Water soluble matter	IS-3456	-
10.	Nitrogen content	Kjeldahl Method	-
11.	Identification of class of dyes	IS-4472	-
12.	Analysis of wetting agent (Wetting power)	IS-5785	-
13.	Active content in detergent	IS-4955	-
14.	Analysis of sodium chloride	IS-797	-
15.	Analysis of sulphuric acid	IS-266	-
16.	Purity of sodium hydrosulphite	IS-1919	-
17.	Electrical current flows	-	Conductivity Meter
18.	Turbidity	-	Turbidity meter
19.	Colour fastness of textiles	-	Rotary Crock Meter
20.	Colourfastness of fabrics	-	Sublimation Tester
21.	Colourfastness (Washing, dry cleaning & dyeing)	-	Launder-o- Meter
22.	To measure heat released or absorbed during a combustion	-	Bomb Calorimeter
23.	Fluid viscosity	-	Brookfield Viscometer
24.	Flammability	-	Flammability Tester
25.	Colour deterioration	-	Fastness Tester



C.

DYES, PIGMENTS AND INKS

Colorants can be either dyes or pigments. Dyes are soluble, coloured organic compounds that are usually applied to textiles from a solution in water. They are designed to bond strongly to the polymer molecules that make up the textile fibre.

Pigments are insoluble compounds used in paints, printing inks, ceramics and plastics. They are applied by using dispersion in a suitable medium. Most pigments used are also organic compounds.

The Color Index (C.I.), published by the Society of Dyers and Colourists (United Kingdom) in cooperation with the American Association of Textile Chemists and Colorists (AATC), provides a detailed classification of commercial dyes and pigments by generic name and chemical constitution. This sourcebook also gives useful information on technical performance, physical properties, and application areas.

Commercial Naming of Dyes and Pigments

The brand name of a particular dye class distinguishes between those originating from different manufacturers. Brand names also contain designatory letters because not all dyes of the same basic colour are exactly the same shade. Colours with a yellowish tint, such as yellowish-red, bear the letter G (German gelb = yellow). Similarly, those with a reddish tinge will be identified by R (rot = red) and those with a blue tinge by B (blau = blue). The designatory letters are sometimes preceded by a number indicating the deviation's intensity from the main colour. So, for example, a dye with the designatory letters Red 6B can be expected to be a considerably bluer shade of red than one labelled Red 2B.[1]

Strength and Physical Form of Colorants

The dye powders sold by manufacturers may contain only about 30% colouring matter. When dyes are synthesised, their batch strength is much higher than the strength at which they are sold. During the final stage of manufacture, the dye batch is adjusted to a standard strength by mixing the dye powder with a diluent, usually a neutral electrolyte. In some cases, such as with vat and disperse dyes, the dilution to standard strength is also achieved using dispersing agents. A proportion of a second or even a third colour component may be added to ensure the shade matches other batches of the same dye. Dyes are marketed in various physical forms – fine powders, grains, pastes or liquids. The different forms are prepared not only for the convenience of handling but also for safety. During the handling and weighing of fine powders, for example, a dust of the powder can form in the atmosphere, thereby creating a hazardous working environment. For this reason, de-dusting agents are often added to fine dye powders, but grains are often a preferred choice of physical form, even though they are bulkier to transport. An important consideration about the physical form is the ease with which the dye will dissolve in water or, in the case of disperse and vat dyes, disperse in water to form a consistent dispersion.

[1] An Introduction to Textile Coloration: Principles and Practice by Roger H. Wardman Storage[2].

Dyes are also sold in liquid form, but the challenge for the manufacturers is stability over long storage periods. Water-soluble dyes may aggregate in solution (see Section 6.3) and the aggregates precipitate. Similarly when disperse dyes are sold in liquid form as concentrated dispersions, the dispersion may break down during prolonged storage.[2]

Dyes

Textile dyes can be classified according to their chemical composition (azo, anthraquinone, sulphur, triphenylmethane, indigoid, phthalocyanine, etc.) or according to their application class.

At the industrial level, the second method is preferred.

Table: c.1 Classification of dyes according to chemical composition

Sr. No	Dye	Fibre
1.	Acid	Wool and other protein fibers, polyamides
2.	Basic	Acrylic
3.	Direct	Cotton, linen, viscose
4.	Disperse	Polyesters, polyamides, ethanoates
5.	Metal-complex	Wool and other protein fibers, polyamides
6.	Naphthol dyes (azoic)	Cotton, viscose, cellulose acetate, linen
7.	Reactive	Cotton, linen, viscose, wool, silk
8.	Sulfur	Cotton, linen
9.	Vat	Cotton, linen, viscose

Acid dyes

Applicability

These dyes are sodium salts of sulphonic acid that have very good affinity to wool and silk fibre under an acidic medium. These dyes are available in the form of salts and are water soluble. These dyes are applied in an acid medium by exhaust method. Acid dyes are mainly used for dyeing of wool and silk. However, acrylic, nylon and spandex can also be dyed with acid dyes with excellent fastness properties.

[2] *An Introduction to Textile Coloration: Principles and Practice by Roger H. Wardman*

Properties

An acid dye produces a complete range of colors except bright red and greenish blue. However, some bright colors tend to bleed while others have good colorfastness to light, dry cleaning and crocking. Few of the Acid dye have poor fastness to washing.

Chemical characteristics and general application conditions

Acid dyes are azo (the largest group), anthraquinone, triphenylmethane, and Cu phthalocyanine chromophoric systems made water-soluble by the introduction of up to four sulphonate groups.

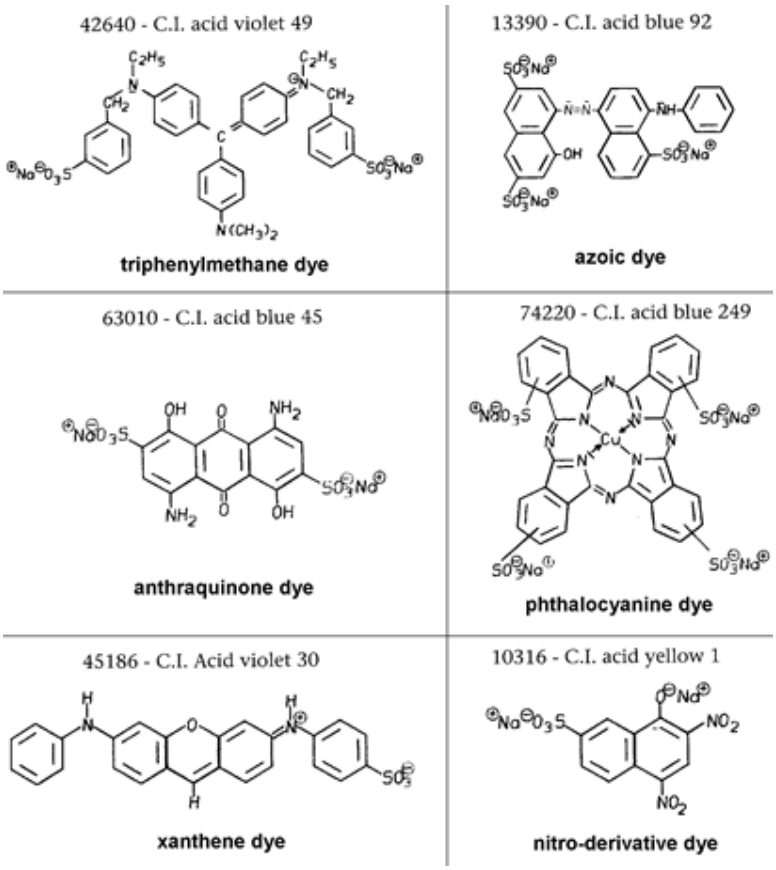


Figure c.1: Examples of acid dyes

Their interaction with the fibre is based partly on ionic bonds between sulphonate anions and the ammonium groups of the fibre, as shown below for wool and polyamyde, at different pH conditions.



Moreover, the fibre/dye interaction is based n secondary bonds such as Van der Waals forces. Secondary bonds are established in particular in the case of higher molecular weight dyes, which form aggregates with high affinity for the fibre.

Acid dyes are classified by their dyeing behaviour and wet-fastness properties rather than chemical composition; hence, the generic term acid dyes includes several individual dye classes. The arbitrary classification normally adopted, in order of increasing fastness is:

- Level-dyeing or equalising acid dyes
- Fast acid, half-milling or perspiration-fast dyes
- Acid milling dyes
- Supermilling dyes.

Level-dyeing or equalising dyes are subdivided into monosulphonated (mainly for PA) and disulphonated (mainly for wool). Due to their poor affinity for fibre, they all have very good levelling properties. Their wet-fastness is, however, sometimes poor, limiting their use to pale/medium shades.

Fast acid dyes (half-milling dyes or perspiration-fast dyes) are only used for PA. They are generally mono-sulphonated and exhibit superior fastness properties to level-dyeing acid dyes while retaining some migration properties. The shade range available in this class is not as wide as that of the levelling or milling dyes and they ,tend only to be used when alternatives would have poorer fastness properties.

Acid milling dyes are so named because they have a degree of fastness to the wet treatments employed when milling (mild felting) woollen fabrics. The class is further subdivided to include supermilling dyes, which have good wet-fastness properties arising from long alkyl side-chains attached to the chromophore. Due to their high molecular weight, milling dyes have a good affinity for the fibre and do not migrate well at the boil. Milling dyes are used mainly for wool for those applications where good wet-fastness is required, for example, in the dyeing of loose fibre, which will receive a further wet treatment during hank scouring.

Depending on their class, acid dyes are applied under pH conditions that vary from strongly acidic to more neutral ones (3 – 7.5). For low-affinity dyes it is necessary to increase the level of cationisation of the fibre (by acidification) in order to improve dye uptake. Conversely, dyes with higher molecular weight and high affinity would adsorb too rapidly on the fibre if applied under such strongly acidic conditions.

The most common chemicals and auxiliaries applied when dyeing with acid dyes are:

- Sodium sulphate (for level-dyeing and fast acid dyes), sodium acetate and ammonium sulphate (for acid milling dyes)
- pH regulators: acetic, formic and sulphuric acid, but also (typically for PA in the carpet sector) NaOH, NH_3 salts, phosphoric acid salts and higher (hydroxy) carboxylates

- Levelling agents, mainly cationic compounds such as ethoxylated fatty amines.

The most common chemicals and auxiliaries applied when printing with acid dyes are:

- Thickening agents
- Solubilising agents such as urea, thiourea, thiodiglycol, glycerine
- Acid donors: ammonium sulphate, tartrate or oxalate
- Antifoaming agents (e.g. silicone oils, organic and inorganic esters) and "printing oils" (mainly mineral oils)
- After-treatment agents such as formaldehyde condensates with aromatic sulphonic acids.

Environmental issues

The environmental properties of acid dyes are assessed under the following parameters.

Note: The following table does not consider the environmental issues related to chemicals and auxiliaries employed in the dyeing process.

Table c.2: Overview of the ecological properties of acid dyes

Parameters of concern	**Comments**
Bio-eliminability	-
Organic halogens (AOX)	-
Eco-toxicity	Acid dyes are in general not toxic. However, two dyes (Acid orange 156 and Acid orange 165) have been classified as toxic by ETAD. Acid Violet 17(triphenylmethane dye) is reported to have an allergenic effect
Heavy metals	-
Aromatic amines	-
Unfixed colourant	Degrees of fixation in batch dyeing are found to be in the range of 85 - 93 % for monosulphonated dyes and in the range of 85 - 98 % for di- and tri-sulphonated dyes
Effluent contamination by additives in the dye formulation	-

Basic (cationic) dyes

Applicability

These dyes are mainly used for dyeing of acrylic and mod acrylics materials. Apart from these, basic dyes can also be used for effectively dyeing of wool and silk but with poor fastness properties. It can also be used for dyeing of nylon. Some variety of polyester can also be dyed with Basic class of dyes.

Properties

A basic dye produces complete range of bright color with Good color fastness to light, washing, perspiration and crocking for acrylic and mod acrylic.

Chemical characteristics and general application conditions

Cationic dyes contain a quaternary amino group which can be an integral part (more common) or not of the conjugated system. Sometimes a positively-charged atom of oxygen or sulphur can be found instead of nitrogen.

Ionic bonds are formed between the cation in the dye and the anionic site on the fibre.

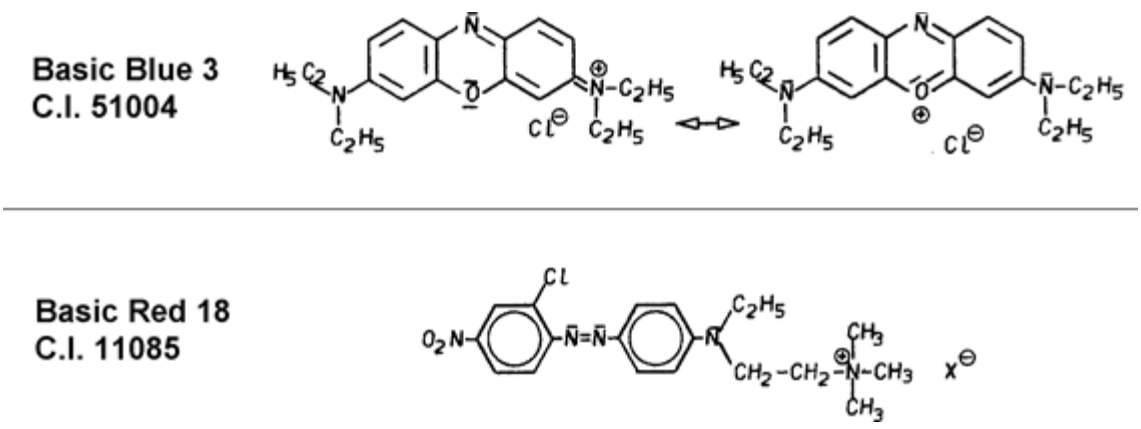


Figure c.2: Examples of typical basic dyes

Cationic dyes are slightly soluble in water, while they show higher solubility in acetic acid, ethanol, ether and other organic solvents. In dyeing processes, they are applied in weak acid conditions. Basic dyes are strongly bound to the fibre and do not migrate easily. In order to achieve level dyeing, specific levelling auxiliaries, (also called retarders) are normally employed (unless a pH controlled absorption process is used). The most important group of retarders is represented by quaternary ammonium compounds with long alkyl side-chains (cationic retarders). Electrolytes and anionic condensation products between formaldehyde and naphthalenesulphonic acid may also be found.

Environmental issues

Many basic dyes exhibit high aquatic toxicity but, when applied properly, they show fixation degrees close to 100 %. Problems are more often attributable to improper handling procedures, spill clean-up and other upsets [11, US EPA, 1995].

The following dyestuffs have been classified as toxic by ETAD:

- Basic Blue 3, 7, 81
- Basic Red 12
- Basic Violet 16
- Basic Yellow 21.

Direct (substantive) dyes

Applicability

These dyes are easy to apply and can be applied directly on the fabric without pre-treatment. Dye fixing agents are not required to fix this category of dye. These dyes are widely used on cellulosic fibres and are used for dyeing cotton, rayon, linen, jute, silk and polyamide fibres.

Properties

These dyes are derived from a formulation of Benzedrine salts. These are water soluble dyes and the least expensive ones. Direct dyes are having a wide range of colours and shades. The fabric dyed with direct dyes generally does not have bright colours. Among the bright colours, only bright greens are available but are more expensive than any other colour.

These dyes have good colour fastness to perspiration and dry cleaning. The light fastness of these dyes varies widely from poor to very good.

Some direct dyes are metalised with copper to increase their light fastness. In other cases, copper salts are applied after treatment to improve light and wash fastness. These dyes have poor fastness to washing and crocking. The majority of the direct dyes are used as background colours for discharge printing.

Chemical characteristics and general application conditions

Direct dyes (substantive dyes) can be azo compounds, stilbenes, oxazines, or phthalocyanines. They always contain solubilising groups (mainly sulphonic acid groups, but carboxylic and hydroxyl groups can also be found) that ionise in aqueous solution.

Direct dyes are characterised by long planar molecular structures that allow these molecules to align with the flat cellulose macromolecules, the dye molecules being held in place mainly through Van der

Waals forces and hydrogen bonds.

Direct dyes may require the use of the following chemicals and auxiliaries for satisfactory dyeing:

- Electrolytes, usually sodium chloride or sodium sulphate. Their function is to favour the aggregation of dye ions on the fibre
- Wetting and dispersing agents: mixtures of non-ionic and anionic surfactants are used for this aim
- After-treatment agents: they are used to improve wet-fastness properties. So-called fixative cationic agents are the most commonly used. They are usually quaternary ammonium compounds with long hydrocarbon chains. Formaldehyde condensation products with amines, polynuclear aromatic phenols, cyanamide or dicyandiamide may also be used for this purpose.

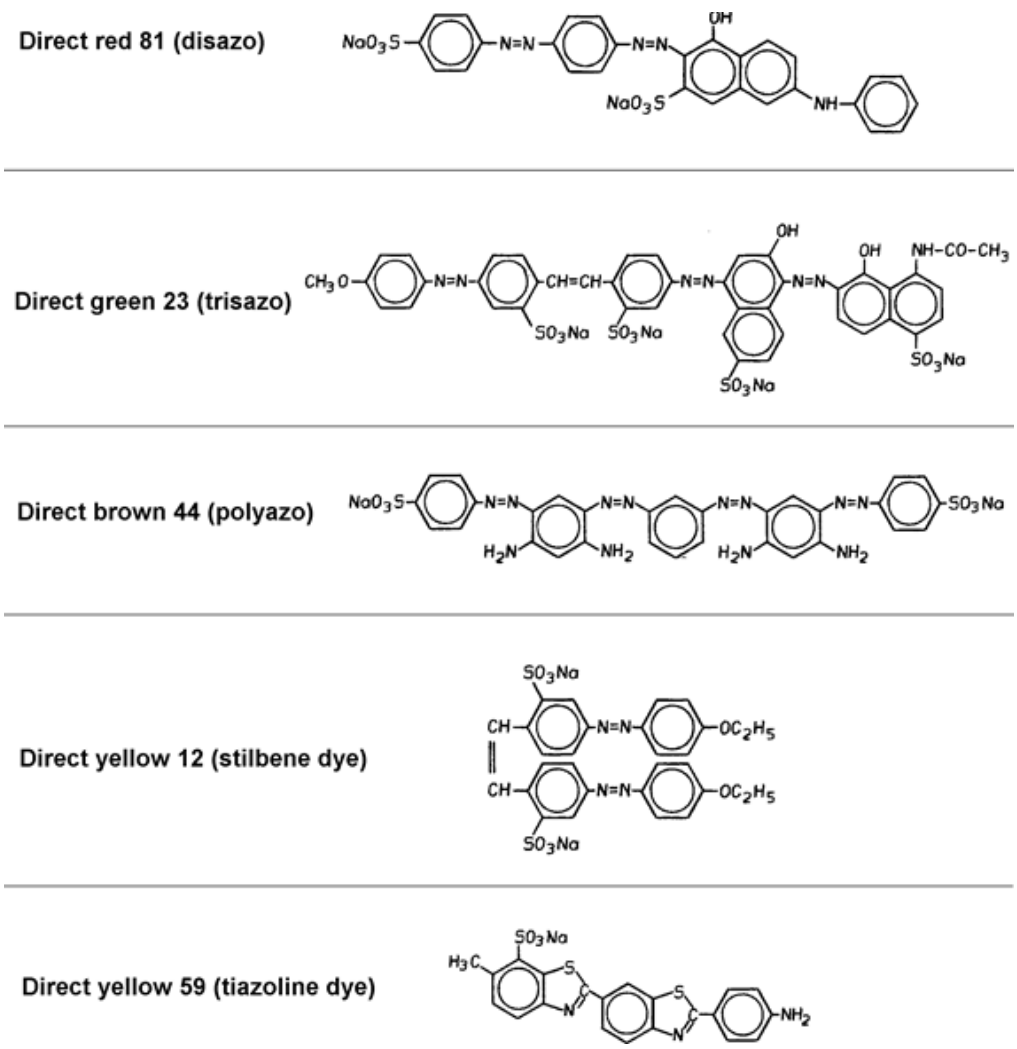


Figure c.3: Examples of typical direct dyes

Environmental Issues

The environmental properties of direct dyes are assessed under the following parameters.
Note: Table C.3 does not consider the environmental issues related to chemicals and auxiliaries employed in the dyeing process because these issues are dealt with in a specific annex.

Table c.3: Overview of the ecological properties of direct dyes

Parameters of concern	Comments
Bio-eliminability	-
Organic halogens (AOX)	-
Eco-toxicity	Direct Orange 62 has been classified as toxic by ETAD
Heavy metals	-
Aromatic amines	The main emphasis of research for direct dyes was actually on the replacement of possibly carcinogenic benzidine dyes [186, Ullmann's, 2000]
Unfixed colourant	Degree of fixation in batch dyeing processes ranges from 64 - 96 % [77, EURATEX, 2000] (70 - 95 % according to [11, US EPA, 1995])
Effluent contamination by additives in the dye formulation	-

Disperse dyes

Applicability

These dyes were originally developed for the dyeing of cellulose acetate, but nowadays, they are used to dye nylon, cellulose triacetate, acrylic, and mainly polyester. These dyes are also used for heat transfer printing.

Properties

Disperse dyes produces very good range of shades except dark blue and black. These dyes are having good -excellent fastness to perspiration, crocking and dry cleaning and Fair-Good fastness to light and washing. When these dyes are used on acetate, they exhibit poor fastness to light and are subject to gas fading.

Chemical characteristics and general application conditions

Disperse dyes are characterised by the absence of solubilising groups and low molecular weight. From a chemical point of view, more than 50 % of disperse dyes are simple azo compounds, about 25 % are anthraquinones, and the rest are methine, nitro and naphthoquinone dyes.

The dye-fibre affinity is the result of different types of interactions:

- Hydrogen bonds
- Dipole-dipole interactions
- Van der Waals forces.

Disperse dyes have hydrogen atoms in their molecule, capable of forming hydrogen bonds with oxygen and nitrogen atoms on the fibre.Dipole-dipole interactions result from the dye molecules' asymmetrical structure, making electrostatic interactions between dipoles on the dye molecules and polarised bonds on the fibre possible.

Van der Waals forces take effect when the molecules of the fibre and colourant are aligned and close to each other. These forces are very important in polyester fibres because they can take effect between the aromatic groups of the fibre and those of the colourant.

Disperse dyes are supplied as powder and liquid products. Powder dyes contain 40 – 60 % of dispersing agents, while in liquid formulations, the content of these substances is in the range of 10 – 30 %. Formaldehyde condensation products and lignosulphonate are widely used for this purpose.

Dyeing with disperse dyes may require the use of the following chemicals and auxiliaries:

- Dispersants: although all disperse dyes already have a high content of dispersants, they are further added to the dyeing liquor and in the final washing step
- Carriers: for some fibres, dyeing with disperse dyes at temperatures below 100 ºC requires carriers. it is the case with polyester, which needs the assistance of carriers to enable an even penetration of disperse dyes below boiling temperature. Because of environmental problems associated with these substances, polyester is preferably dyed under pressure at a temperature >100 ºC without carriers. However, carrier dyeing is still important for polyester-wool blends, as wool must not be submitted to wet treatment at temperatures significantly above 100 ºC
- Thickeners: polyacrylates or alginates are usually added to the dye liquor in padding processes. Their function is to prevent migration of the dye liquor on the surface during drying
- Reducing agents (mainly sodium hydrosulphite): They are added to the solution with alkali in the final washing step.

Disperse dyes are widely used not only for dyeing but also for printing synthetic fibres.

Environmental issues

The environmental properties of disperse dyes are assessed under the following parameters.

Note: Table C.4 does not consider the environmental issues related to chemicals and auxiliaries employed in the dyeing process because these issues are dealt with in a specific annex.

Table c.4: Overview of the ecological properties of disperse dyes

Parameters of concern	Comments
Bio-eliminability	Owing to their low water-solubility, they are largely eliminated by absorption on activated sludge in the waste water treatment plant.
Organic halogens (AO_x)	Some disperse dyes can contain organic halogens, but they are not expected to be found in the effluent after waste water treatment (because they are easily eliminated by absorption on the activated sludge) (see also Section 2.7.8.1)
Toxicology	The following disperse dyes potentially have an allergenic effect: Disperse Red 1, 11, 17, 15; Disperse Blue 1, 3, 7, 26, 35, 102, 124; Disperse Orange 1, 3, 76; Disperse Yellow 1, 9, 39, 49, 54, 64.
Heavy metals	
Aromatic amines	These dyes are still offered by some Far East dealers and manufacturers [294, ETAD, 2001]
Unfixed colourant	The level of fixation is in the range of 88 - 99 % for continuous dyeing and 91 - 99 % for printing.
Effluent contamination by additives in the dye formulation	Conventional dispersants (formaldehyde condensation compounds, lignosulphonates, etc.) are poorly biodegradable (<30 % according to [186, Ullmann's, 2000], ca. 15 % according to [18, VITO, 1998]). Some dyes are formulated with more readily eliminable dispersants (albeit not suitable for all formulations).

Metal-complex dyes

Applicability

Metal-complex dyes (also called pre-metallised dyes) have a great affinity for protein fibres. Among metal-complex dyes, 1:2 metal-complex dyes are also suitable for polyamide fibres.

More than 65 % of wool is dyed with chrome dyes (see next section) or metal-complex dyes today, and about 30 % of PA is dyed with 1:2 metal-complex dyes.

Properties

Light-fastness is excellent while washing fastness is not as good as with chrome dyes (particularly in darker shades).

Chemical characteristics and general application conditions

Metal-complex dyes may be broadly divided into two classes, 1:1 metal-complexes, in which one dye molecule is co-ordinated with one metal atom and 1:2 metal complexes, in which one metal atom is co-ordinated with two dye molecules. The dye molecule will typically be a monoazo structure containing additional groups such as hydroxyl, carboxyl or amino groups, capable of forming strong co-ordination complexes with transition metal ions, typically chromium, cobalt, nickel and copper. Note that phthalocyanine dyes cannot be classified as metal-complex dyes.

Typical examples of pre-metallised dyes are shown in Figure c.4 and Figure c.5

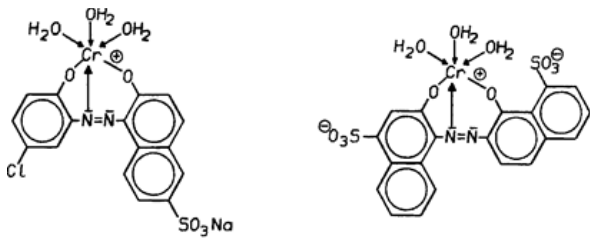


Figure c.4: Examples of molecular structures typical of 1.1 metal-complex dyes

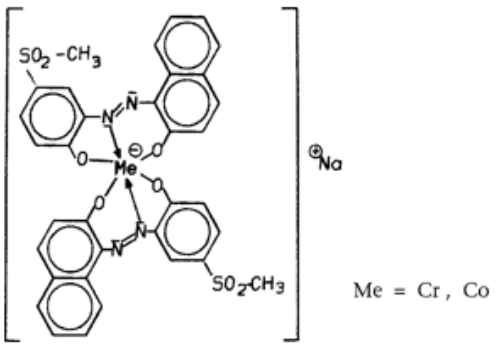


Figure c.5: Molecular structure typical of 1.2 metal-complex dyes

Metal-complex dyes do not represent a specific application dye class. Metal-complex dyes belong to many application classes of dyes (i.e. they can be found, for example, among acid, direct and reactive dyes). When used in dyeing processes, metal-complex dyes are applied in pH conditions regulated by the user class and the fibre type (wool, polyamide, etc.). The pH levels for wool range from strongly acidic (1.8 - 4 for 1:1 metal-complex dyes) to moderately acidic neutral (4 - 7 for 1:2 metal-complex dyes). For polyamide fibres, higher pH conditions are becoming more and more common.

1:1 metal-complex dyes exhibit excellent level dyeing and penetration characteristics and can cover irregularities in the substrate. Their light and wet-fastness properties are good even in deep shades. They are particularly suitable for yarn and for piece dyeing of carbonised wool.

1:2 Metal-complex dyes are used for both wool and polyamide. They form the most important group in this class and may be divided into two sub-groups:

Weakly polar 1:2 complexes are solubilised by the inherent anionicity of the complex or contain non-ionic, hydrophilic substituents such as methylsulphone (-SO2CH3). These dyes exhibit excellent fastness to light and wet treatments and excellent penetration properties.

Strongly polar 1:2 complexes – solubilised by one or more sulphonic or carboxylic acid residues, these dyes possess lower levelling power than the weakly polar dyes mentioned above but superior wet-fastness properties and are generally suitable for use in those applications where mordant dyes are used. This second group is also more suitable for dyeing polyamide fibres.

Dyeing with metal-complex dyes may require the use of the following chemicals and auxiliaries:
pH regulators: sulphuric, formic, acetic acid
electrolytes: sodium sulphate, ammonium acetate and sulphate

levelling agents: mixtures of anionic and non-ionic surfactants (these auxiliaries are not needed when using pH controlled adsorption dyeing techniques).

Environmental issues

The environmental properties of metal-complex dyes are assessed under the following parameters.

Note: Table C.5 does not consider the environmental issues related to chemicals and auxiliaries employed in the dyeing process because these issues are dealt with in a specific annex.

Table c.5: Overview of the ecological properties of metal complex dyes

Parameters of concern	Comments
Bio-eliminability	Great differences from dye to dye (bio- eliminability can be <50
Organic halogens (AOX)	Some products contain organic halogens: AOX in waste water, therefore depends on the eliminability of the dyes concerned (see also Section 2.7.8.1)
Eco-toxicity	
Heavy metals	Metals can be found in the effluent due to unfixed dye. However, Cr III and the other transition metals used in metal-complex dyes are an integral part of the chromophore (see also Section 2.7.8.1"heavy metals")
Aromatic amines	
Unfixed colourant	The degree of fixation ranges from moderate to excellent (from 85 to 98 % and greater in some cases)
Effluent contamination by additives in the dye formulation	Inorganic salts are present in the preparation of powder dyes. These salts, however, do not present any ecological or toxicological problems

Mordant dyes (chrome dyes)

Applicability

Mordant dyes are effectively used for dyeing wool & silk, where maximum wet fastness is required. They are practically no longer used for polyamide fibres or printing. However, acrylic, nylon, and spandex can also be dyed with mordent dyes.

Properties

Mordent dyes have excellent fastness to perspiration and washing. Good fastness to light and dry cleaning and very good fastness to crocking. Thanks to their good levelling properties and very good wet-fastness after chroming, chrome dyes are used principally to obtain dark shades (greens, blues and blacks) at moderate cost. There are disadvantages, however, in their use: long dyeing times, difficulties with shading, the risk of chemical damage to the fibre during chroming and the potential release of chromium in waste water.

Chemical characteristics and general application conditions

The Colour Index classifies these colourants as mordant dyes, but chromium has become the almost universally used mordant and the class is commonly referred to as chrome dyes.

From a chemical point of view they can be regarded as acid dyestuffs that contain suitable functional groups capable of forming metal complexes with chrome. They do not contain chrome in their molecule, which is instead added as dichromate or chromate salt to allow dye fixation.

Interaction with the fibre is established through ionic bonds formed between the anionic groups of the colourant and ammonium cations available on the fibre. In addition, chromium acts as a link between dye and fibre. it gives rise to a very strong bond, which is reflected in the excellent fastness obtained. shows the ionic and coordination bonds in the case of wool.

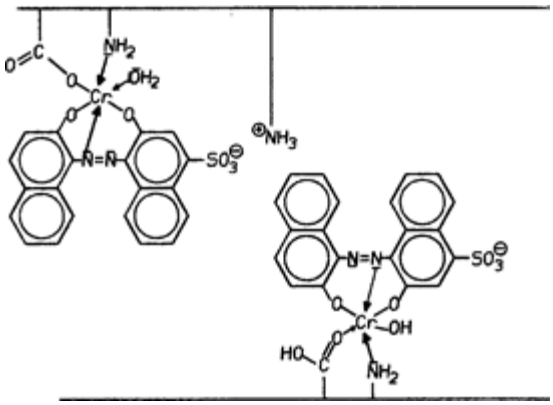


Figure c.6: Representation of possible ionic and coordination bonds between wool and chrome dyes
Source: [69, Corbani, 1994]

The use of chrome dyes in dyeing processes requires the use of the following chemicals and auxiliaries:

- Potassium and dichromate or chromate
- Formic or acetic acid as pH regulators
- Other organic acids such as tartaric and lactic acid. They are used to enhance the degree of conversion of Cr VI to Cr III
- Sodium or ammonium sulphate.

Environmental issues

The environmental properties of chrome dyes are assessed under the following parameters.

Note: Table c.6 does not consider the environmental issues related to chemicals and auxiliaries employed in the dyeing process because these issues are dealt with in a specific annex.

Table c.6: Overview of the ecological properties of chrome dyes

Parameters of concern	Comments
Bio-eliminability	-
Organic halogens (AO_x)	-
Eco-toxicity	-
Heavy metals	Chromium present in the final colourant is not contained in the molecule, being instead added as dichromate, or chromate salt during the dyeing process to allow dye fixation (see also Section 2.7.8.1)
Aromatic amines	-
Unfixed colourant	-
Effluent contamination by additives in the dye formulation	-

Naphthol dyes (azoic dyes developed on the fibre)

Applicability

Azoic dyes, also known as naphthol dyes, are used for cellulosic fibres (particularly cotton), but may also be applied to viscose, cellulose acetate, linen and sometimes polyester.

Properties

Azoic Dyes are derived from aryl amides organic compounds. These chemical compounds can not be used directly as dyes. However, the dyes are formed inside the fibre by reacting primary amines with napthols under controlled conditions. Hence, these dyes are also called ingrain dyes. The azo group is generally present in this dyes class, also called Azo dyes. These dyes are also insoluble in water, producing a full range of red, orange, and brilliant yellow colours along with maroons, scarlet, deep blacks and burgundies. Azoic dyes lack green and bright blue colours.

Chemical characteristics and general application conditions

From a chemical point of view, naphtol dyes are very similar to azo dyes, the main difference being the absence of sulphonic solubilising groups.

They are made up of two chemically reactive compounds applied to the fabric in a two-stage process. The insoluble dye is synthesised directly in the fibre as the result of the coupling reaction between a diazotised base (developing agent) and a coupling component.

The coupling components are usually derivatives of the anilides of the 2-hydroxy-3-naphthoic acid (also called naphthol AS). These naphthols are available in powder form or in liquid form (in this case, the solution also contains caustic soda, the naphthol concentration ranges between 30 % and 60 %).

Developing agents can be derivatives of aniline, toluidine, orto and meta anisidine, diphenylamine. They are available as:

- Free bases (fast colour bases)
- Liquid bases (these formulations are aqueous dispersions of the aromatic amines, they are safer and simpler to apply than solid bases)
- Fast colour salts (these are already diazotised diazonium compounds marketed in stabilised forms and do not need to be diazotised before use in dyeing: some examples are given in figure C.7).

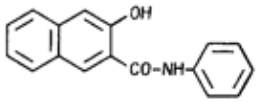
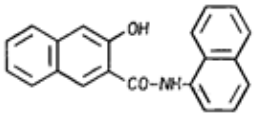
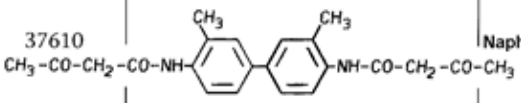
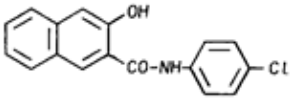
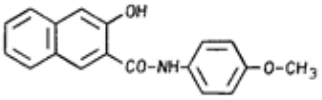
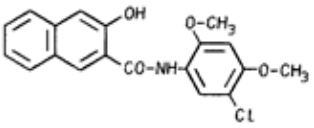
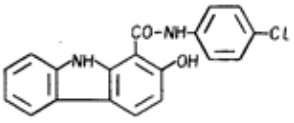
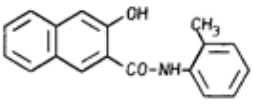
Colour Index III ed.		Formula	Name of the commercial product
Coupling component n°	Chemical composition n°		
2	37505		Naphthol AS (P,L)
4	37560		Naphthol AS-BO (P,L)
5	37610		Naphthol AS-G (P)
10	37510		Naphthol AS-E (P)
11	37535		Naphthol AS-RL (P)
12	37550		Naphthol AS-ITR (P,L)
15	37600		Naphthol AS-LB (P,L)
18	37520		Naphthol AS-D (P,L)

Figure c.7: Examples of typical coupling components for naphthol dyes

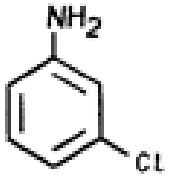
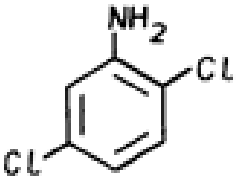
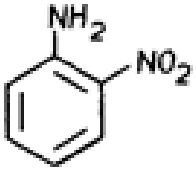
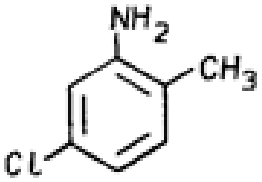
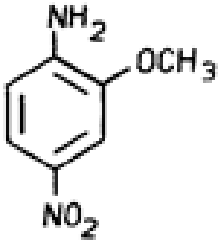
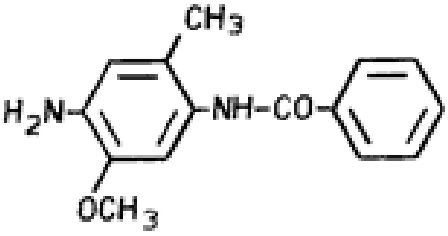
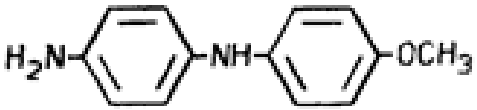
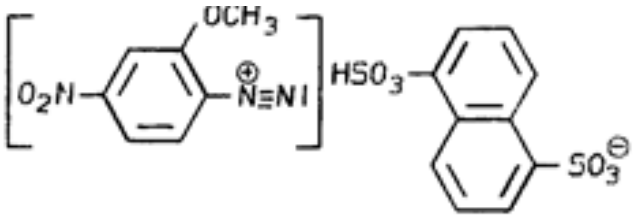
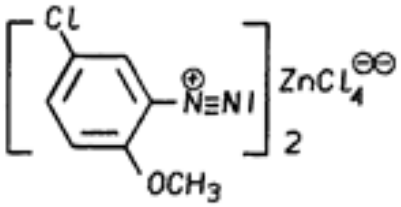
Colour Index		Formula
Diazo component n°	Chemical composition n°	
2	37005	
3	37010	
6	37025	
32	37090	
5	37125	
41	37165	
35	37255	

Figure c.8: Examples of typical developing agents (fast colour base) for naphthol dyes

C.I. Azoic Diazo component 5
stabilised as salt with
1,5 naphthalene disulphonic acid



C.I. Azoic Diazo component 10
stabilised as salt with
zinc chloride



C.I. Azoic Diazo component 34
stabilised as salt with
borontetrafluoride

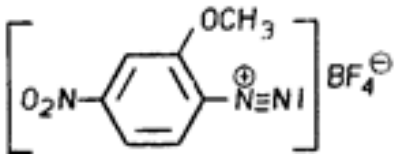


Figure c.9: Examples of typical fast colour salts

The application of azoic colourants involves several steps:

- Preparation of the naphtholate solution: naphthol is converted to the naphtholate form to be able to couple with the diazonium salt
- Application of the naphtholate to the fibre
- Preparation of the diazotised base: to make the coupling reaction possible, the base must first be diazotised in the cold, using sodium nitrite and hydrochloric acid (this step can be avoided when using fast colour salts)
- Formation of the azoic dye into the fibre.

Environmental issues

The environmental properties of naphthol dyes are assessed under the following parameters. However, does not consider the environmental issues related to chemicals and auxiliaries employed in the dyeing process because these issues are dealt with in a specific annexe.

Table c.7: Overview of the ecological properties of naphthol dyes

Parameters of concern	Comments
Bio-eliminability	-
Organic halogens (AOX)	-
Eco-toxicity	-
Heavy metals	-
Aromatic amines	Developing agents are all diazotisable amines or diamines or substituted anilines, toluidines, anisidines, azobenzenes or diphenylamines. Some of these amines and in particular, p- nitroaniline, chloroaniline and ß-naphtilamine are on the 1980 USEPA priority lists as harmful pollutants, and their use is forbidden.
Unfixed colourant	The degree of fixation in continuous dyeing processes ranges between 76 and 89 % and between 80 and 91 % in printing processes
Effluent contamination by dispersants and additives in the dye	-

Reactive dyes

Applicability

These dyes are primarily used for cotton and other cellulose fibre at an alkaline pH of 9-12. However, these dyes can also be used for wool, silk and polyamide fibres in weak acidic dye baths.

Properties

Reactive dyes are water-soluble dyes which are anionic. Since these dyes react with fibres and make a covalent bond with the fibre, they are called Reactive dyes. These dyes can be classified as hot brand reactive dyes and cold brand dyes.

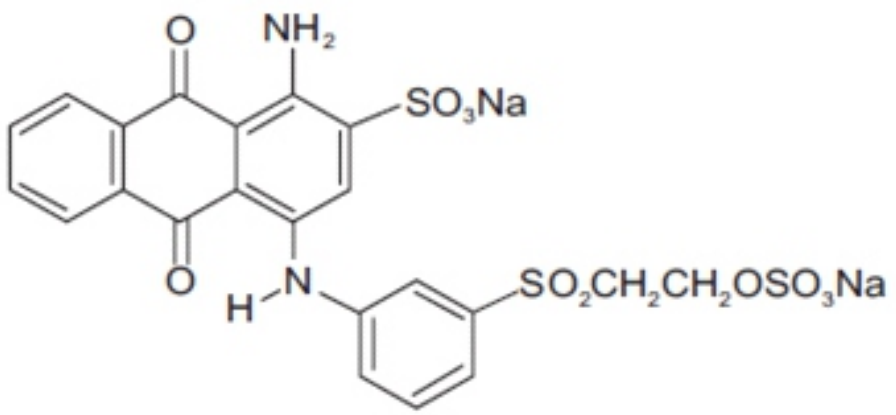
Procion (Triazine type)-H is a hot type of reactive dye. It reacts with cellulose in the presence of sodium carbonate at the temperature range of 75-90°C. Procion-C is a cold type of reactive dye that reacts at room temperature in the presence of sodium carbonate.
The range of available reactive dyes is comprehensive and enables many dyeing techniques to be used.

Chemical characteristics

Reactive dyes are unique because they contain specific chemical groups capable of forming covalent links with the textile substrate.

The energy required to break this bond is similar to that required to degrade the substrate itself, thus accounting for the high wet-fastness of these dyes.

The structure of Reactive Blue, one of the most important reactive dyestuffs in terms of volumes consumed, is illustrated in



CI Reactive Blue – 19

Figure c.10: Structure of reactive dye

The chemical structure of reactive dyes can be schematically represented by the following formula: Col-B-R, where:

- Col is the chromophore that is in general constituted by mono-azoic, anthraquinone, phthalocyanine and metal-complex compounds
- B is the linking group between the chromophore and the reactive group
- R represents the reactive group (anchor system with the leaving group). The anchor systems are characterised by their reactivity. They are classified as hot, warm or cold dyers based on this.

Some typical examples of reactive systems for cellulose and wool or polyamide fibres are reported in the following tables.

Table c.8: Typical anchor systems *for cellulose fibres*

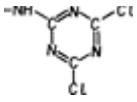
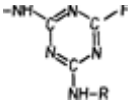
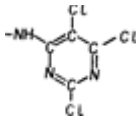
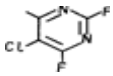
Anchor system	Denomination	Commercial name
	Dichloro-s-triazine (cold dyer)	Procion MX
	Amino-fluoro-s-triazine (warm dyer)	Cibacron F
	Trichloro-pyrimidine (hot dyer)	Cibacron T-E Dimaren X, Z
-SO2-CH2-CH2-O-SO3Na	Beta-sulphate-ethyl-sulphone (warm dyer)	Remazol

Table c.9: Typical anchor systems for wool and polyamide fibres

Anchor system	Denomination	Commercial name
	2,4-difluoro 5-chloro pyrimidine	Verofix Drimalan F
-SO2-CH2-CH2-O-SO3Na	Beta-sulphate-ethyl-sulphone	Remazolan
-SO2-NH-CH2-CH2-O-SO3H	Sulphate-ethyl sulphonamide	Levafix
-NHCO-CBr=CH2	Bromoacrylamide	Lanasol

The reactive groups of the colourant react with the amino groups of the fibre in the case of protein and polyamide fibres and with the hydroxyl groups in the case of cellulose.

In both cases, two reaction mechanisms are possible depending on the anchor system: a nucleophilic substitution mechanism or a nucleophilic addition mechanism.

An important issue to consider when dealing with reactive dyes is the fact that two competing reactions are always involved in the colouring process:

alcoholysis: dye + fibre → dye fixed on the fibre

hydrolysis: dye + water → hydrolysed dye washed away after dyeing (undesired reaction)

The resulting hydrolysed dye's characteristics are that it is no longer a reactive substance and is therefore discharged in the effluent. This fact has important consequences, especially in the case of cellulose fibres. In fact, the alkaline conditions in which reactive dyes react with cellulose fibres increase the hydrolysis reaction rate.

Dyeing cellulose fibres with reactive dyes may imply the use of the following chemicals and auxiliaries:

- Alkali (sodium carbonate, bicarbonate and caustic soda)
- Salt (mainly sodium chloride and sulphate)
- Urea may be added to the padding liquor in continuous processes in the one-bath method (see also Section 4.5.2.6 for alternative techniques)
- Sodium silicate may be added in the cold pad-batch method).

Reactive dyes are applied to wool or polyamide fibres under different conditions. In the case of wool and polyamide fibres, the reactivity of the amino groups is considerably higher than that of hydroxyl groups in cellulose.

Levelling properties are often achieved with the use of speciality amphoteric levelling agents.

Reactive dyes are generally applied at pH values of between 4.5 and 7, depending on the depth of shade, in the presence of ammonium sulphate and the specialised levelling agents mentioned above.

Moderately reactive dyes are generally employed (mainly mochlorotriazine systems). Highly reactive sulphoethyl sulphones are also sometimes used.

Printing with reactive dyes requires the use of:

- Thickening agents (mainly polyacrylates in combination with alginates)
- Urea
- Alkali (e.g. sodium carbonate and bicarbonate)
- Oxidising agents (mainly benzenesulphonic acid derivatives) are used to prevent reducing more sensitive dyes during steaming.

Environmental issues

Poor dye fixation has been a long-standing problem with reactive dyes, particularly in batch dyeing of cellulose fibres, where a significant amount of salt is normally added to improve dye exhaustion (and therefore also dye fixation). On the other hand, shade reproducibility and level dyeing were the majorobstacles in "right-first-time" production using the most efficient dyes (high exhaustion and fixation rate).

Research and development has been faced with several objectives, all of which have been or are in the process of being successfully achieved. These include:

- Increasing the robustness of individual dyes and dye combinations (trichromatic systems)
- Enhancing reproducibility of trichromatic combinations used in most commonly applied dyeing processes
- Reducing salt consumption and/or unused dye in the effluent
- Improving fastness properties (e.g. light fastness, fastness to repeated laundering).

With sophisticated molecular engineering techniques, it has been possible to design reactive dyes (e.g. bifunctional dyes and low-salt reactive dyes) with considerably higher performances than traditional reactive dyes.

The environmental properties of reactive dyes are assessed in The table does not consider the environmental issues related to chemicals (e.g. salt) and auxiliaries employed in the dyeing process because these issues are dealt with in a specific annex.

Table c.10: Overview of the ecological properties of reactive dyes

Parameters of concern	Comments
Bio-eliminability	Because both unfixed reactive dye and its hydrolysed form are readily soluble they are difficult to eliminate in biological waste water treatment plants
Organic halogens (AOX)	Many reactive dyes contain organic halogens. However, a distinction has to be made between halogens bonded to the chromophore and halogens bonded to the anchor group (see Section 2.7.8.1 for more detailed discussion).
Eco-toxicity	-
Heavy metals	Heavy metals can be present both as impurities from the production process (limits have been set by ETAD) and as an integral part of the chromophore. The latter concerns phthalocyanine dyes, which are still widely used especially for blue and turquoise shades (substitutes have not yet been found) (see also Section 2.7.8.1)
Aromatic amines	-
Unfixed colourant	Fixation rate can be poor (1) (see also discussion in Section 2.7.8). Efforts have been made to increase the level of fixation. Some reactive dyes can reach >95 % of fixation even for cellulosic fibres (see Sections 4.5.2.2 and 4.5.2.4 for recent developments)

Effluent contamination by dispersants and additives already in the dye	-
Notes: [1] [77, EURATEX, 2000] Fixation degree for: cotton batch dyeing: 55 - 80 % wool batch dyeing: 90 - 97 % printing (general): 60 %	

Sulphur dyes

Applicability

Sulphur dyes are mainly used for cotton and viscose substrates. They are occasionally used for dyeing silk. They may also be used for dyeing cellulose and synthetic fibres blends, including polyamides and polyesters. Besides black shades, sulphur dyes play almost no part in textile printing.

Properties

Sulfur dyes are relatively easy to dye cellulosic fibre with good-to-excellent washes and light fastness at a low cost. It produces a complete range of colours in "dull shades" and gives poor light fastness in pastel shades. These dyes are mainly used for dyeing black, brown, navy blue or olive in medium to dark shades. Some yellows and blues shades are also available, but only one red and a green dye.

Sometimes, these dyes are also used for improving the wash fastness of the Direct dyed fabric called topping.

Sulfur dyes have good fastness to light, washing, dry cleaning and perspiration. However, these dyes have poor fastness to chlorine bleach. Sulfur dyed materials can not be stored for longer periods at higher than normal room temperature because in the presence of moisture , It tends to oxidise and form sulfuric acids. This acid causes tendering to cellulose fabric. Due to this tendering process, sometimes the fabric's colour also changes and becomes dull. This colour change is called the bronziness of the shade.

Chemical characteristics and general application conditions

Sulphur dyes comprise high molecular weight compounds obtained by the reaction of sulphur or sulphides with amines and phenols. Many colourants contain sulphur in their molecule, but only dyestuffs that become soluble in water after reaction with sodium sulphide under alkaline conditions can be called sulphur dyes.
The exact chemical structure is not always known because these are mixtures of molecules of a high level of complexity. Amino derivatives, nitrobenzenes, nitro and aminobiphenyls, substituted phenols,

substituted naphthalenes, condensed aromatic compounds, indophenols, azines, oxazine, thiazol, azine and thiazine rings can be part of these compounds. Sulphur dyes contain sulphur as an integral part of the chromophore and polysulphide side chains.

As has already been mentioned, sulphur dyes are insoluble in water. Still, after reduction under alkaline conditions, they are converted into the leuco-form, which is water-soluble and has a high affinity for fibre. After absorption into the fibre, they are oxidised and converted to their original insoluble state.

Sulphur dyes are available in various modifications, which are classified under the following names:

- Sulphur dyes are available as amorphous powders or dispersible pigments. Amorphous powders are insoluble or partially soluble in water. They are brought into solution by boiling with sodium sulphide and water. Dispersible pigments can be used in this form for pad dyeing in the presence of a dispersing agent. They can contain a certain amount of reducing agent already in the formulation. This case is called "partly reduced pigments".
- Leuco-sulphur dyes (ready-for-use dyes) are available in liquid form and already contain the reducing agent required for dyeing. Therefore they must simply be diluted with water before application. Low-sulphide types are also available on the market
- Water-soluble sulphur dyes are available in the form of Bunte salts (Col-S-SO_3Na) obtained by treating the dye in its insoluble form (Col-S-S-Col) with sodium hydrosulphite. They can be dissolved in hot water, but they do not have an affinity for fibre. Adding an alkali and the reducing agent makes them substantive for the fibre.

Sodium sulphide and sodium hydrogen sulphide are generally used as reducing agents to bring into solution the dye (unless ready-for-use sulphur dyes are applied). Binary systems made of glucose and sodium dithionite (hydrosulphite) or thiourea dioxide are also used as alternative reducing agents.

In all processes, the dye is finally fixed on the substrate by oxidation. Nowadays, hydrogen peroxide or halogen-containing compounds such as bromate, iodate and chlorite are the most commonly used oxidising agents.

Apart from those mentioned above reducing and oxidising agents, additional chemicals and auxiliaries required when dyeing with sulphur dyes are:

- Alkali (mainly caustic soda)
- Salt (sodium chloride and sulphate)
- Dispersing agents: usually they are naphthalene sulphonic acid-formaldehyde condensates, lignin sulphonates and sulphonated oils
- Complexing agents: EDTA and polyphosphates are used in some cases to prevent negative effects due to the presence of alkaline-earth ions.

Environmental issues

The environmental properties of sulphur dyes are assessed under the following parameters. However, does not consider the environmental issues related to chemicals and auxiliaries employed in the dyeing process because these issues are dealt with in a specific annex.

Table c.11: Overview of the ecological properties of sulphur dyes

Parameters of concern	Comments
Bio-eliminability	Most sulphur dyes are water-insoluble after oxidation and therefore they can largely be eliminated by adsorption on the activated sludge in the waste water treatment plant
Organic halogens (AOX)	-
Eco-toxicity	-
Heavy metals	-
Aromatic amines	-
Unfixed colourant	Degree of fixation ranges between 60 and 90 % in continuous dyeing and 65 - 95 % in printing [77, EURATEX, 2000]
Effluent contamination by additives in the dye formulation	Poorly biodegradable dispersants are present. New formaldehyde condensation products with higher elimination (>70 %) are already available (see Section 4.5.1.1)

Vat dyes

Applicability

Vat dyes are often used in dyeing and printing cotton and cellulose fibres. They can also be applied for dyeing polyamide and polyester blends with cellulose fibres.

Properties

Vat dyes have excellent fastness properties when properly selected. They are often used for fabrics subjected to severe washing and bleaching conditions (towelling, industrial and military uniforms, etc.). The range of colours is wide, but shades are generally dull.

Chemical characteristics and general application conditions

From a chemical point of view, vat dyes can be distinguished into two groups: indigoid vat dyes and anthraquinoid dyes. Indigo dyes are almost exclusively used for dyeing warp yarn in the production of blue denim.

Like sulphur dyes, vat dyes are normally insoluble in water, but they become water-soluble and substantive for the fibre after reduction in alkaline conditions (vatting). They are then converted again to the original insoluble form by oxidation and in this way they remain fixed into the fibre.

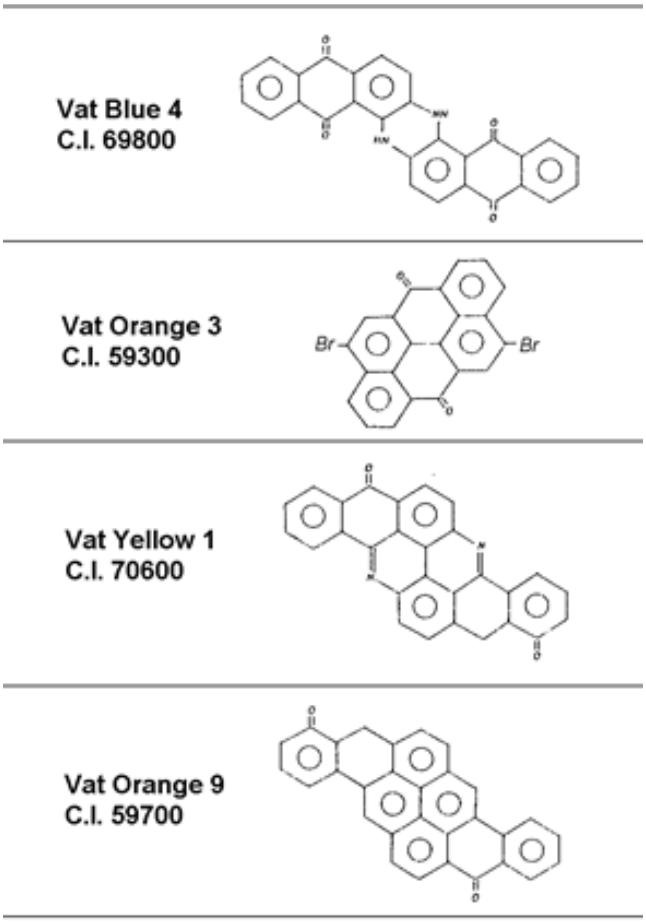


Figure c.11: Examples of typical vat dyes

Vat dyes are preparations that consist of a vattable coloured pigment and a dispersing agent (mainly formaldehyde condensation products and lignosulphonates). They are generally supplied in powder, granules and paste form.

A wide range of different techniques are used in colouring processes with vat dyes. Nevertheless, all processes involve three steps:

- Vatting
- Oxidation
- After-treatment.

The step in which the reduction of the dyestuff into its leuco-form takes place is called vatting. Vat dyes are generally more difficult to reduce than sulphur dyes. Various reducing agents are used. Sodium dithionite (hydrosulphite) is still the most widely employed, although it has some limits. Sodium dithionite is consumed by reduction of the dye and also by reaction with atmospheric oxygen. Therefore, an excess of reducing agent has to be used and various techniques have been proposed to

reduce these losses. In addition, sodium dithionite cannot be used for high-temperature or pad-steam dyeing processes because over-reduction can occur with sensitive dyes. In these application conditions and also for printing, sulphoxylic acid derivatives are normally preferred.

Thiourea dioxide is also sometimes used as a reducing agent, but a risk of over-reduction exists as its reduction potential is much higher than that of hydrosulphite. Furthermore, the oxidation products of thiourea dioxide contribute to nitrogen and sulphur contamination of waste water.

Following increasing environmental pressures, biodegradable sulphur-free organic reducing agents such as hydroxyacetone are now available. Their reducing effect, however, is weaker than that of hydrosulphite, so they cannot replace it in all applications. Nevertheless, hydroxyacetone can be used in combination with hydrosulphite, thus reducing the sulphite load in the effluent to a certain extent.

After absorption by the fibre, the dye in its soluble leuco-form is converted to the original pigment by oxidation. This process is carried out during wet treatment (washing) by adding oxidants such as hydrogen peroxide, perborate or 3-nitrobenzene sulphonic acid to the liquor.

The final step consists of after-treating the material in weakly alkaline liquor with a detergent at boiling temperature. This soap treatment is aimed at removing pigment particles and allows the crystallisation of amorphous dye particles, giving the material the final shade and the fastness properties typical of vat dyes.

Vat dyeing conditions can vary widely in terms of temperature and the amount of salt and alkali required, depending on the nature of the dye applied. Vat dyes are therefore divided into the following groups, according to their affinity for the fibre and the amount of alkali required for dyeing:

IK dyes (I = Indanthren, K = cold) have low affinity. They are dyed at 20 – 30°C and require little alkali and salt to increase dye absorption

IW dyes (W = warm) have a higher affinity, and they are dyed at 40 – 45 °C with more alkali and little or no salt

IN dyes (N = normal) are highly substantive, applied at 60°C, and require much alkali but no salt addition.

The following chemicals and auxiliaries may be found in dyeing processes:

- Sodium dithionite, thiourea dioxide and sulphoxilic acid derivatives as reducing agents
- Caustic soda
- Sodium sulphate
- Polyacrylates and alginates as anti-migration agents in padding processes
- Formaldehyde condensation products with naphthalene sulphonic acid and lignin sulphonates as dispersing agents
- Surfactants (including ethoxylated fatty amines) and other components such as betaines, poly

alkylamines, and polyvinylpyrrolidone as levelling agents
- Hydrogen peroxide, perborate, 3-nitrobenzene sulphonic acid as oxidant
- Soap.

The following chemicals and auxiliaries may be found in printing processes:

- Thickening agents (starch esters with seed flour derivatives)
- Reducing agents: various chemicals are used depending on the printing method (all-in or two-phase process), dye selected and steaming conditions. Sulphoxylic acid derivatives are the most common, but hydrosulphite can also be used (in the two-phase process when very short steaming time is required)
- Alkali: potassium carbonate, sodium carbonate, sodium hydroxide
- Oxidising agents (the same used for dyeing)
- Soap.

Environmental issues

The environmental properties of vat dyes are assessed under the following parameters.

Note: Table c.12 does not consider the environmental issues related to chemicals and auxiliaries employed in the dyeing process because these issues are dealt with in a specific annex.

Table c.12: Overview of the ecological properties of vat dyes

Parameters of	Comments
Bio-eliminability	Vat dyes can be regarded as highly eliminable due to the fact that they are water-insoluble and therefore largely adsorbed on the activated sludge in the waste water treatment plant.
Organic halogens (AOX)	-
Eco-toxicity	Since they are sparingly soluble they are not bio- available [64, BASF,
Heavy metals	Vat dyes contain heavy metal impurities (Cu, Fe, Mn, Ba and Pb) due to their production process (in some cases it is still difficult to keep these limits below the ETAD standards) [64, BASF, 1994]
Aromatic amines	-
Unfixed colourant	Vat dyes show high exhaustion levels (70 - 95 % in continuous dyeing processes and 70 - 80 % in printing)

Effluent contamination by additives in the dye formulation	Dispersants are present in the dye formulation. As they are water-soluble and poorly degradable, they are found in the waste water. New formaldehyde condensation products with higher elimination (>70 %) are already available and more readily eliminable substitutes are being developed [186, Ullmann's, 2000] (see Section 4.5.1.1)

Pigments

Pigments are insoluble colouring matter mostly of mineral origin with no fibre affinity. They are fixed onto the textile substrate with a binding agent in the required pattern. It has only a chromophore group but no auxochrome group. So, it has no affinity for fibre. They are applied by using dispersion in a suitable medium. Generally, pigment retains its particulate or crystalline form essentially during application.[3]

Properties of pigments:

- It is insoluble in liquids but can be mechanically dispersed in the medium.
- Pigments have no direct affinity towards fibre, so the binder is used as a binding agent in pigment colouration, which sticks the pigment particle on the fibre surface.
- Pigments apply to all kinds of fibres.
- No after-treatment is required after the colouration process. Only drying and curing are required.
- The rubbing fastness of pigment colouration is poor, but water wash and light fastness are very good.
- Pigments can produce a wide range of bright shades.

In pigments, auxochrome groups are absent.

The primary difference between dye and pigment is that a dye has three parts-

- Chromophore, which is responsible for colour.
- Auxochrome, which is responsible for dye properties
- Chromogen, which holds the above two together.

But pigment has two parts:-

- Chromophore, i.e. colour bearing part.
- Chromogen.

[3] *http://textileengg.blogspot.com/2015/12/pigments.html*

Classification of pigments:-

There are mainly two types of pigments, as described in figure C.12:

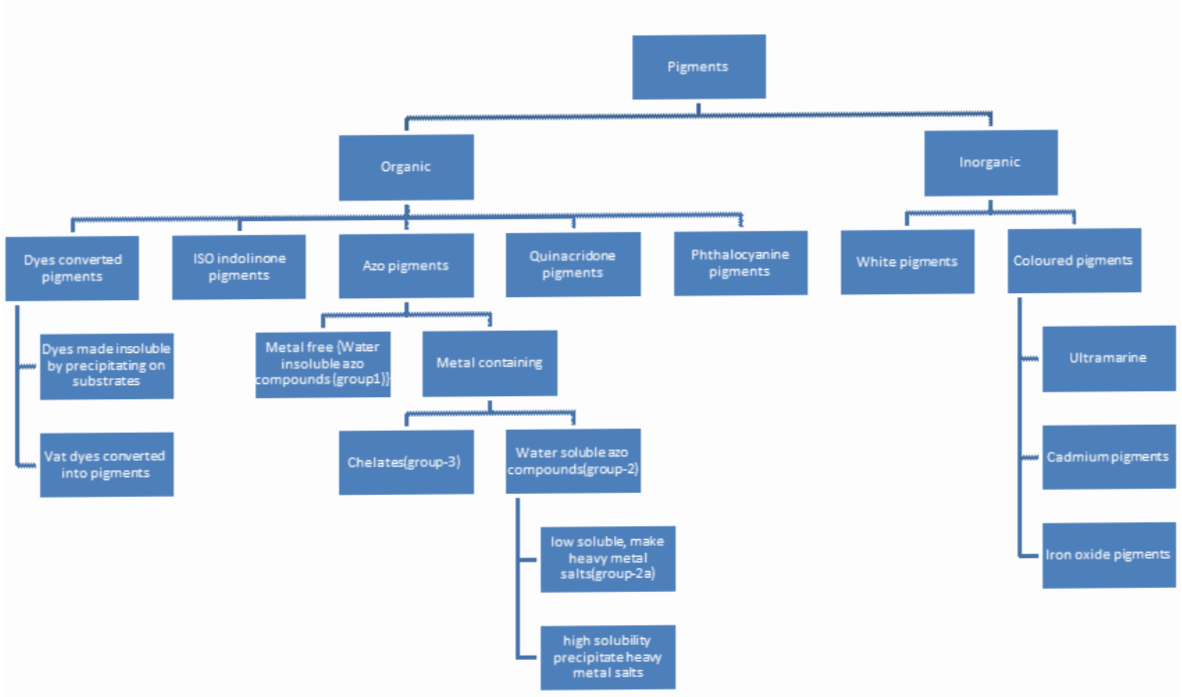


Figure c.12: Classification of Pigmants

Pigments are widely used in printing processes (pigment printing).

Print system components

There are three basic requirements for print paste system:

- Pigments
- Binder
- Thickener & Auxiliaries

Where in pigment dyeing and printing binder is a very important and essential ingredient.

Digital Inks

There are five types of inks used for digital textile printing , and we can summarise them as follows[4]:

1. **Reactive:** they are used on natural or artificial fabrics of plant origin (cotton and viscose), more rarely also on silk
2. **Acids:** used on natural fabrics of animal origin (silk, wool) or synthetic (nylon) with characteristics similar to animal fibres

https://www.cibitex.it/types-of-ink-for-digital-textile-printing/

3. **Disperse:** used mainly on synthetic fibres
4. **Pigments:** they can be used on natural and artificial fibres
5. **Dye Sublimation:** this type of ink can only be used on synthetic fibres

Table c.13: Types of inks used for digital printing

Ink chemistry	Ink type	Fibre	Pre and post-treatment	Market application
Acid	Aqueous	Protein and nylon	Pre-treatment – steaming fixation – washing	Apparel / Fashion
Disperse	Dispersion	Polyester and synthetic fibres	Pre-treatment – steaming or heat fixation – washing	Apparel / Fashion / Automotive / Home textile
Pigment	Dispersion	Cellulosic and synthetic fibres	Pre-treatment – fixation	Home textile / DTG / Low quality Apparel
Reactive	Aqueous	Mainly cellulosic and protein	Pre-treatment – steaming fixation – washing	Apparel / Fashion
Sublimation	Dispersion	Polyester	Fixation with heat transfer	Signage / Sportswear

Reactive inks

Reactive inks are the most commonly used inks in the textile industry nowadays. Reactive inks are very popular, especially among digital textile printers. The ideal application of reactive inks is printing on cotton. However, reactive inks can also be used when printing on silk and wool.

Two great advantages of using reactive inks for textile printing are the high-quality colours and the high wash fastness. The best colour quality is reached when using reactive inks to print on cotton or viscose. When printing on silk or wool the colors can become less bright and intense. However, especially for top-level fashion brands, the high wash fastness is an important advantage of reactive inks. A high wash fastness means textiles can be washed often without losing its color.

Acid inks

Acid inks are known for its vibrant colors, even when printing on materials which do not retain colors very easily. For that reason, acids inks are often used for printing wool and silk. With acid inks, you get a high level of color brilliance when printing on these type of materials. Besides wool and silk, acid inks are regularly used for printing swim clothing, which is often made of lycra. First of all because of its high color brilliance, but also because acid inks have a high tolerance for chlorine and salt water.

Disperse inks

Disperse inks are the most commonly used inks in conventional printing on polyester fabrics. With disperse printing, the ink is sprayed directly on the textile after which it is being steamed and washed. The steaming process opens up the fibers allowing the ink to fully penetrate the textile. After the steaming process, the fiber closes again and the colors are locked into the material. This results in a very high color brilliance and a high wash fastness. Nowadays, disperse ink are the most commonly used inks in conventional textile printing.

The last couple of years, polyester has become more and more popular within the fashion industry, which means there was a high demand for fast printing with disperse inks on this fabric. A problem, since experience showed that disperse inks do not work very well when printing with high-speed printers. Therefore many textile printers that want to print polyesters digital went to sublimation printing through paper transfer.

Sublimation inks

When digital textile printing became more and more popular, a new type of printing emerged within the digital textile industry: transfer printing or sublimation printing. Sublimation printing means that you print the sublimation ink onto a piece of paper after which you put this paper with the fabric in a calander and under high temperature and pressure the ink changes from liquid to gas (sublimates). This gas easily penetrates the polyester fibers. The colours are locked into the fabric after removing the pressure and lowering the temperature.

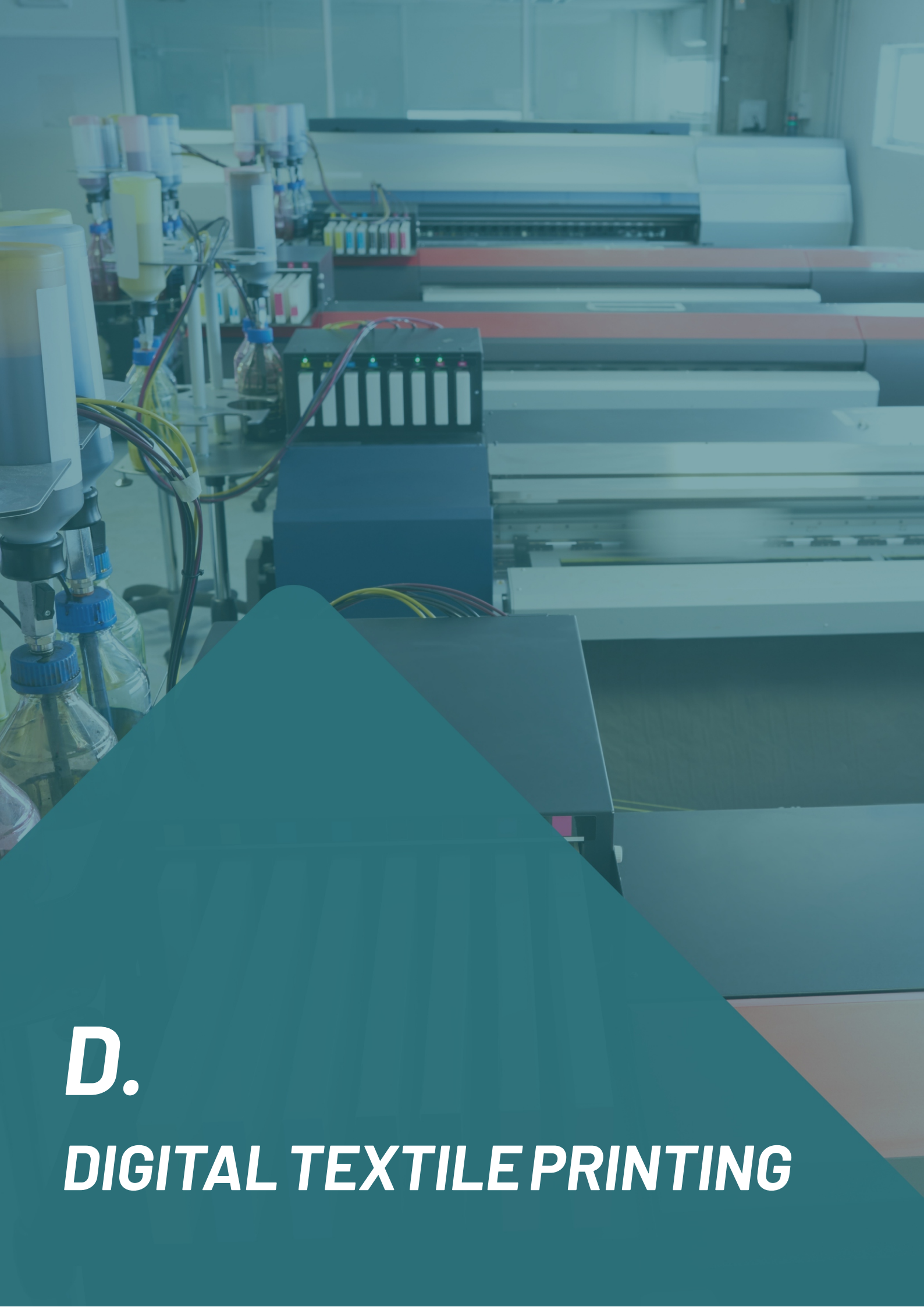
An advantage of using sublimation inks is that you do not need to steam and wash the textile after printing. For this reason, this technique is less environmentally damaging, easier and cheaper than other printing methods. On top of that, sublimation ink can be used for digital printing , which means you can print large quantities faster.

Recently, textile printers have successfully printed directly to the polyester fabric with the same sublimation inks. It requires a more expensive printer as a belt system to hold the fabric is needed, but it saves the paper costs and you still do not need to steam and wash. In general, sublimation printing on polyester results in somewhat lower fastness than printing with direct disperse inks. But in the fast fashion world, that is an acceptable compromise for sustainability (no need to steam and wash).

Pigment inks

While around 50% of all fabrics in conventional printing are printed with pigment inks, it is logical that many customers ask for 'digital pigment printing'. In fact, they are looking for an easy process with acceptable colour and a very low price. In digital, all those advantages cannot (yet) be realised.

To achieve a somewhat acceptable color yield, a pre-treatment is needed, making the process more complicated. Because the pigment particles need to be very small to go through an inkjet head, the process to achieve those small particles makes the inks more expensive than reactive inks. Still, the risk of clogging heads remains considerably larger as the pigment particles like to stick to everything. Therefore, digital pigment applications are restricted to very small niche markets where other solutions cannot help (f.i. a 50% cotton 50% polyester fabric).



D.

DIGITAL TEXTILE PRINTING

Digital Textile Printing (DTP) is the most modern textile printing technique. This technique prints textile material without using any block or, engraved roller, or screen but with better prominence of images. There is a lot of flexibility in working. The colours can easily change within a few seconds if they do not match the sample.

When looked at from a bird-view, the digital textile printing process has many similarities with that of conventional textile printing. The work process includes fabric inspection, pre-treatment, printing, post-treatment, and final inspection.

The flow of the digital textile printing process is concise compared with the rotary screen printing. But, printing costs are very high compared to other textile printing methods. So, this process is not yet accepted as an option for mass production. This technique is generally used to produce samples for the new designs and for designer costumes. But in recent years, garment and textile printing facilities are preferring in-house digital textile printing to reduce the sampling lead time. The digital textile printing technique can be used for woven and knitted fabrics. In this The subsection specifies which materials are suitable for digital printing and which are not.

Fabric

Cotton is a natural fibre that is widely used for clothing because of its high moisture control, comfort, and durability, especially within the fashion industry. A digital textile printing machine can print on cotton. Most digital printers use reactive inks to obtain the highest quality in cotton fabric since this type of ink provides the highest wash fastness for prints on cotton.

Viscose Another natural fibre that is widely used in the fashion industry is viscose. Printing on viscose with a digital printer is possible. As with cotton printing, it gives the best results when printing on viscose with reactive ink.

Wool Printing on wool with a digital textile printer is possible. Wool can be printed with reactive ink (when high fastness is a priority) or acid inks (if colour gamut is a priority). As wool is naturally quite "hairy" - meaning it has a lot of loose threads sticking out - the print heads have to be positioned as far away from the substrate as possible. Woollen yarn is five times as thick as the diameter of the nozzle in the print head and can, therefore, severely damage the print head. For this reason, it is crucial to choose a digital printer that enables to position the print heads at a considerable distance from the substrate.

Silk Another natural fibre that is suitable for digital textile printing is silk. Silk can be printed with reactive ink (when high-fastness is a priority) or acid inks (if colour gamut is a priority).

Polyamide Lycra

Polyamide Lycra is a type of fabric that is mainly used for swimwear. Printing on polyamide Lycra with a digital printer is possible and can best be done with acid inks. The highest colour brilliance, wash fastness, and saltwater and chlorine resistance can be obtained using acid inks.

Polyester Over the last couple of years, polyester has become an increasingly popular fabric within the fashion industry. Direct disperse is the most commonly used for printing on polyester, but there is another solution for digital textile printers. Due to a more manageable process, industries have switched to sublimation printing on paper instead of direct printing on polyester fabric with sublimation inks. Direct sublimation requires a more complex printer than paper sublimation since a belt system to hold the fabric is needed, but it saves paper costs. Overall, general sublimation printing on polyester results in lower fastness than printing with direct disperse inks. In the fashion industry, that is nowadays an acceptable compromise for sustainability.

Digital Textile Printing Method

The fabric is selected and pre-treated, where it passes through the printer and then steamed, washed and dried. But instead of pressing the different pre-mixed colours of dye on the fabric through rotary screens, each having their pattern engraved, the digital textile printer uses a printable image (design) of a graphical data file. It reads the correct colour information by using a LAB or RGB system. It then prints the desired colour onto the fabric with minuscule ink droplets.
Digital textile printing ensures high-quality designs and enables a fast production rate. However, because the print heads are close to the fabric, some materials cannot be used for digital printing. Fabrics that, for example, have quite some loose threads can come in contact with the print heads and cause damage.

The digital textile printing method:

- Direct to Fabric (DTF)
- Direct to Garment (DTG)

Direct to Fabric (DTF)

The printing is performed directly on a roll of fabric. Depending on the type of fabric, the following inks are used for printing (as shown in Table d.1). Please refer to Annex 3 of Dyes, Pigments and inks for further details on inks:

Table d.1 Ink types and Applications

Ink Type	Suitable	Applications	Pro/Contra
Pigments	All types of substrates, including blends	• Signage • Flags • Apparel (mainly DTG) • Home textiles	Pro • No post washing required • UV resistance • Fits all types of substrates • No or limited pre-/post-treatment Cons • Touch & feel issues • Colourfastness

				• Ink Cost • Ink Consumption (2 - 2.5 times > reactive ink)
Dyes	Reactive	Cellulosics, linen (polyamide, silk)	• Apparel • Home textiles	Pro • Fastness • Runnability • Colour gamut • Ink cost Cons • Substrate pre-/post-treatment
	Acid	Polyamide, silk, wool	• Apparel • Home textiles	Pro • Fastness • Runnability (direct or transfer) • Colour gamut Cons • Substrate pre-/post-treatment
	Disperse	Polyester, polyester/cotton blends	• Signage • Flags • Apparel • Home textiles	Pro • Fastness • Runnability (direct or transfer) • Colour gamut • Ink cost Cons • Substrate pre-/post-treatment • High share of PES needed for the blend
Source: Gherzi research				

Direct to Garment (DTG)

DTG printing is printing on textiles and garments using specialised or modified inkjet technology. Direct to Garment (DTG) printmaking is the best use of the newest print technology with smaller droplet sizes, more precise placement and ever clearer images printing onto light and dark t-shirts.

The following applications under DTG covered:

- T-shirts
- Shirts
- Jeans

The steps involved in the digital textile printing work based on the type of fabric is explained in brief in following subsection:

For Natural Fabrics (Cotton / Viscose / Silk / Wool):

Inspection of Fabric: The goods are well inspected for all kinds of physical damage. During this process, the quantity received is checked against the quantity received from the client. Any unusual damage and shortage are reported to the client at this stage.

Pre-Treatment: After the physical inspection, the fabric is sent for Coating / Padding. During this process, the fabric treats with chemicals through the special recipe of chemicals that help in colour absorbency and print stability and drains out during washing with colour fixed to the fabric. This process is essential for all fabrics printed with Reactive dyes.

Printing: The next stage after pre-treatment is printing this fabric through inkjet digital print process through high-quality, high-speed machines with output in dried fabric well-batched rolls.

Post–Treatment: After printing, the colour fixation process is carried out through steam & temperature through high-speed loop agers, resulting in high consistency and quality output. After that, the steamed fabric goes under the washing process to eliminate chemicals from the fabric and get the colour proper fixed to the fabric.

Final inspection: The goods are well inspected for quality standards as per requirement. The final meterage is done at this stage.

For Polyester Fabrics:

Inspection of Fabric: The goods are well inspected for physical damage. During this process, the quantity received is checked against the quantity received from the client. Any unusual damage and shortage are reported to the client at this stage.

Printing: For printing polyester fabric, generally, the sublimation print technique is used to print specially treated paper using the inkjet paper printer. The ink used in this process is Sublimation ink.

Heat Transfer: The Printed paper is fed into the heat transfer machine along with the fabric to perform print transfer from paper to polyester fabric. To transfer, hot press roller machines are used.

Final inspection: The goods are well inspected for quality standards as per requirement. The final meterage is done at this stage.

[1]http://texindia.in/digital-textile-printing-services/digital-textile-printing/index.html

Pre-Treatment Process

Pre-treatment for fabric substrates in inkjet printing is much more complicated than conventional dyeing and printing. After the common pre-treatment processes, including singing, desizing, scouring, bleaching and/or mercerisation, padding with thickener is essential for the fabric to be directly printed via inkjet.

The thickener, acting as the printing paste in conventional printing to prevent dye migration, is not present in the printing ink but is padded onto the fabric prior to inkjet printing. Even though thickener in inkjet printing will bring some problems in practical production, such as instability of printing ink, clogging of jet nozzle, low printing speed, and some other less predictable problems, pre-treating fabric with thickener is a priority before it is printed with dye-based inks.

Figure d.1 shows the schematic difference of the shape of an ink drop landing on a fabric substrate. It is evident that the ink drop on non-pre-treated fabric shows much wicking, and the drop size extends beyond the treated substrate. For fabrics printed with an ink consisting of pigment, pre-treatment with thickener might be an option depending on the particular situation.

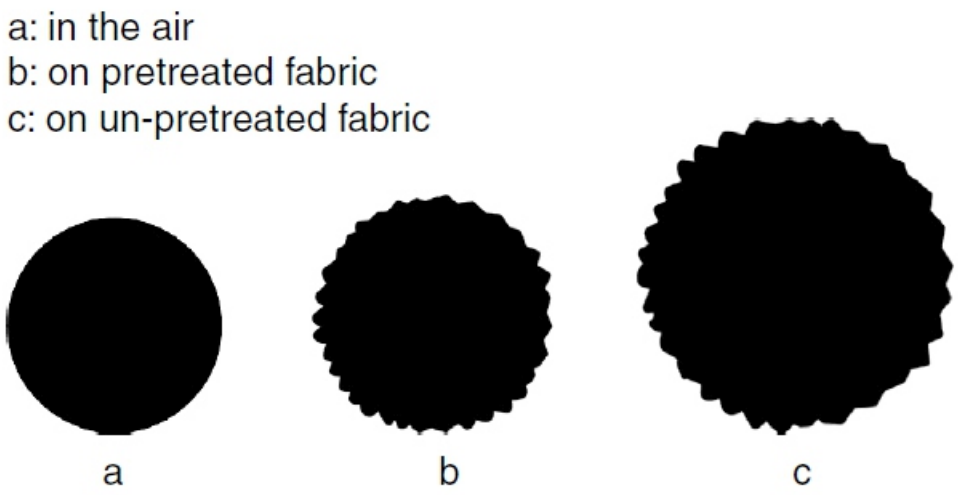


Figure d.1 Vertical view of the shape of ink drop

Because of its inexpensiveness, sodium alginate (medium viscosity) is the most common thickener adopted in pre-treatment to preserve the edge. To obtain good pre-treatment results, the thickener should exhibit the following properties:

- Excellent ability to hold water/moisture,
- Easy removal ability,
- Good fluidity,
- Good stability to pH, temperature, electrolyte and dyestuff.
- Outline sharpness of printed pattern.

The dose range of sodium alginate depends on the dye applied and the fabric specification to print. It holds moisture content to help dyes dissolve and enter into fibre during the steaming of printed fabric. It also modifies the flow property of printing ink. Excessive sodium alginate on the fabric would cause difficulties after treatment, such as in the wash-off process, while inadequate thickener could lead to poor definition of the printed pattern. If yellowing the background of printed fabric is not acceptable, a polyacrylic polymer is recommended to replace sodium alginate for a whiter and brighter background.

When preparing the pad bath, the formulation

- Should ensure the other ingredients are totally dissolved before adding thickener,
- Should eliminate impurities in pad bath,
- Should prepare the pad bath in use and is used shortly after preparation.

With the development of inkjet printing, specialised products, recipes, and processes are being developed by the printing ink manufacturers, facilitating the printing mills' obtaining optimum pre-treatment.

Once the fabric is pre-treated, it becomes much more hydrophilic. Consequently, the humidity of the storage condition for the pre-treated fabric has a profound effect on the moisture regain of the fabric. Controlling the moisture content to a proper level facilitates subsequent inkjet printing in terms of image definition and colour density. Printing on fabric with high moisture content results in poor absorption of jetting inks, and substrate retaining low humidity reduces colour density. The optimum moisture retention of the padded thickener on fabric depends on the pre-treated substrates and the applied jetting inks[2].

After-treatment Processes

After-treatment refers to the process required after inkjet printing. Curing is the only process required for pigment inkjet printing, and washing is not necessary. However, dye inkjet printing includes dyes fixation and subsequent wash-off. The printed fabric is gone through the streaming, washing, drying, and ironing. This is the most vulnerable process. Each fabric requires a different length and quantity of steam depending on several variables, including fabric type and length of fabric.

To fix the fabric, it must be steamed so that the printed ink can bond to the fabric's fibres.

The fabric needs to be washed to remove any excess ink after the steaming process, further fix the print and wash out the excess fixer, which has now done its job. The fabric is then dried and ironed with final quality control check.[3]

[2]*Process control in textile manufacturing, Edited by Abhijit Majumdar, Apurba Das, R. Alagirusamy and V. K. Kothari*
[3]Digital Printing On Fabric (https://www.hollyflower.com/digital-printing-on-fabric)
[4]Digital Textile Design Second Edition by MELANIE BOWLES AND CERI ISAAC

Printing technologies

Textile printing has developed from handcraft to high-speed, automatic processing of fabrics throughout the years. Innovative techniques have accelerated and improved the printing process, creating more and better possibilities for textile printers.

Currently, there are two different types of digital print technology. The first of these, electrostatic (also known as laser printing), only works with paper and is the technology used in colour copying machines and some office printers. The second method, inkjet printing, can be divided into continuous flow and drop on demand (DOD).

In turn, DOD technology has two subcategories: thermal and piezoelectric. Piezoelectric DOD inkjet technology is currently the primary method for the digital printing of textiles[4].

These innovations have contributed to creating the two main printing techniques used nowadays: single-pass and multi-pass digital textile printing.

As mentioned above, Inkjet technologies are typically classified into two large classes[5]:

- Continuous Ink Jet (CIJ)
- Drop-on-Demand Ink Jet (DOD).

Continuous Inkjet (CIJ)

In CIJ, the jet of ink generated by each nozzle breaks up into droplets shortly after exiting the nozzle. Without any other intervention, the breakup would occur randomly and result in droplets of variable sizes. This is usually corrected by providing a periodic excitation to the nozzle in the time domain that translates into a spatial perturbation in the fluid jet. The combination of the jet velocity and frequency of the excitation determines the droplet size, which can be controlled with very high accuracy.

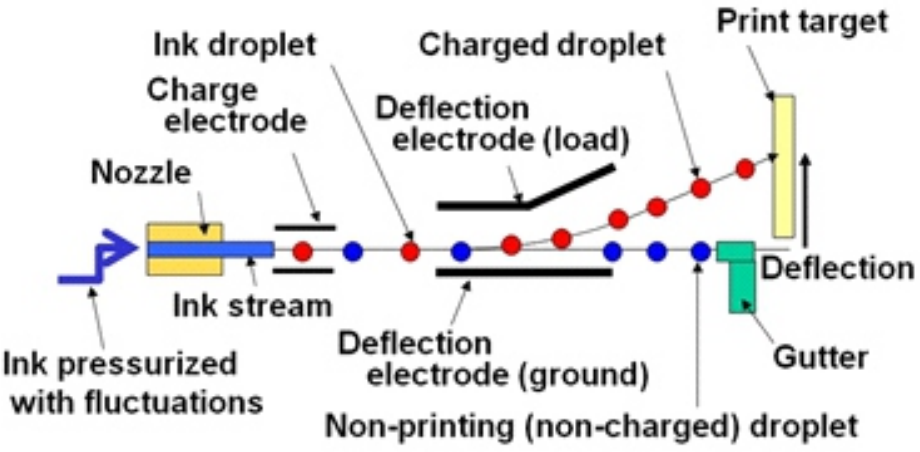


Figure d.2 Contiunous Inkjet Schematic

In the traditional CIJ approach, a piezoelectric transducer is coupled to the print head to provide the

periodic excitation. The oscillations are therefore mechanical. After leaving the nozzle, the drops are electrically charged by an amount that depends on the image to be printed. The drops then pass through an electric field to cause them to deflect. There are two ways of deflecting the drops in piezoelectric-driven CIJ. In the binary deflection method, the droplets are directed either to a single-pixel location in the medium or to the recirculating gutter. In the multiple-deflection method, the deflection is variable so that the drops can address several pixels. In CIJ, ink is squirted through nozzles at a constant speed by constant pressure. The Inkjet is unstable and breaks into droplets; as it leaves the nozzle, the drops go to the medium or are deflected to a gutter for recirculation depending on the image being printed. The deflection is usually achieved by electrically charging the drops and applying an electric field to control the trajectory. The name `continuous' originates in the fact that drops are ejected at all times.

Continuous Inkjet (CIJ) printing is an older technology. Its advantages include high drop velocity, permitting longer throw distances and faster throughput rates. Additionally, clogging is not usually a problem since the nozzle is in continuous use. CIJ printing Drawbacks includes a high degree of wasted ink due to recirculation and the need for solvent-based inks in CIJ printheads.

Drop-on-demand(DOD)

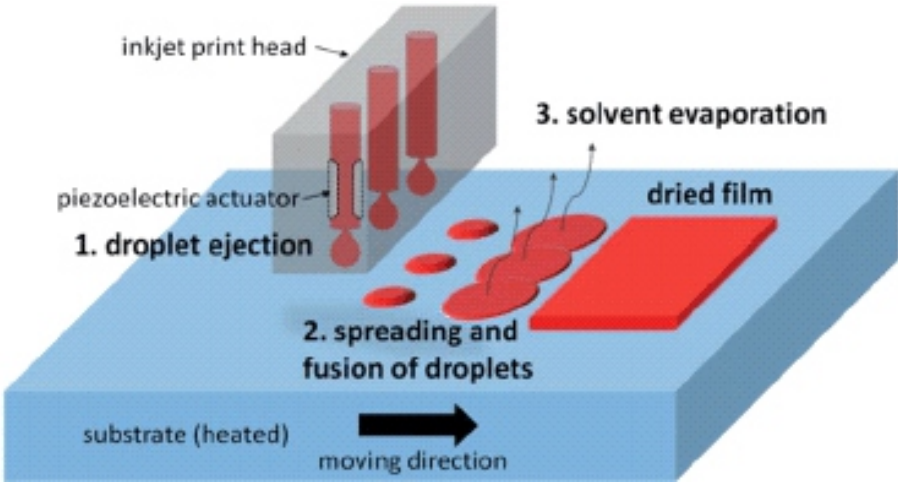


Figure d.3 Drop on Demand Schematic

Drops are shot out in the DOD ink stream just when expected to frame the picture. The two principal drop ejector components used to produce drops are piezoelectric ink fly (PIJ) and warm ink fly (TIJ). In PIJ, the volume of an ink chamber inside the spout is immediately decreased by a piezoelectric actuator, which crushes the ink bead out of the spout.

In TIJ, an electrical warmer situated inside every spout is utilised to raise the temperature of the ink to the point of air pocket nucleation. The uneven development of the vapour bubble pushes the ink outside the spout.

Drop-on-demand inkjet printing uses only enough ink to create the image, and drop-on-demand print heads can create gradients and greyscale effects at effective resolutions of 1200 dpi and higher. With

[5]https://www.onlineclothingstudy.com/2018/03/digital-textile-printing-technology-and.html

fast-curing UV-LED based inks, drop-on-demand inkjet printers can match the throughput rates of CIJ systems at a fraction of the unit cost.

Usually, single-pass inkjet printers use drop-on-demand print heads. drop-on-demand technology is sought after by the Ad specialty sector because it enables the vivid designs that promotional product printing demands.[6]

Printing Techniques

Multi-pass textile printing

It resembles the inkjet printer that you use at home or at the office to print your documents. Multi-pass textile printing means that the print heads – one or more for each colour – move from left to right over the substrate. After moving along the whole substrate, the fabric moves forward, and the heads start printing another horizontal lane. Still, this time they move from right to left. All these horizontal lanes together make up the whole design. The multi-pass printing advantage is that only a few print heads are needed to print designs on fabric (minimum one head per colour, minimum 4 colours).

While choosing multi-pass printing as a new textile printer, consider the print head's cost as they are quite expensive. It can minimise the investment. Nonetheless, a significant weak spot of digital printing is its high sensibility for errors, like when one nozzle gets clogged. No ink is printed on the substrate with that clogged nozzle, creating a white stripe in your design. On top of that, the lanes have to match up precisely to create a high-quality image. If the printer is not adjusted correctly, this can result in white stripes.

A way to solve this problem is to have the print heads create an overlap between the lanes. Instead of printing wide lanes with the same width as the printheads, which then repeatedly follow each other, you have the printer create an overlap of half of the width of the print heads. This technique is called two-pass printing. Although this technique reduces your printing speed, it also reduces the chance of mistakes being made. This 'trick' can be extended to 4 or even up to 16 passes.

Single-pass textile printing

A newer printing technique enables faster printing at a higher quality. The fast speed and high quality are due to the many print heads used for this technique. Instead of having a few print heads moving from left to right over the substrate, single-pass printing uses multiple print heads positioned along the whole width of the fabric, and they do not move. This enables faster printing since the fabric can run through the printing machine.

Two significant benefits of single-pass printing are the high production speed and the extreme sharpness. The whole image is printed in one stroke (hence the name single pass) to guarantee maximum sharpness in a single-pass printer. The image is built up in multiple layers in multi-pass

[6] **https://epsvt.com/what-is-drop-on-demand-printing**

printing, so sharp lines might become a bit fuzzier if the passes do not match up 100%.

A single-pass printer can print up to 60 linear meters per minute, whereas a multi-pass printer cannot produce more than six linear meters per minute (and this goes down with more passes). This enables printers to accelerate their production speed by at least 10 times.

As, there are no multiple strokes, a single-pass printer cannot mask white lines due to lost nozzles. This requires high reliability of the printheads combined with a very reliable ink.

Another disadvantage of single-pass printing is the high initial investment. Single-pass printing is more expensive than multi-pass textile printing because of the many print heads placed in the printing machine. Print heads are costly components, so the more print heads there are incorporated in the machine, the more expensive the machine is. Using single-pass printing, therefore, requires a large investment.

Environmental Impact

The first element to stand out when looking at a digital printer is the considerable advantage given by the possibility of producing what is needed in the necessary quantities and with the required variables, without wastes or batches lying in warehouses as they wait for a buyer

The following observations can be made while comparing digital printing and conventional printing[7]:

- Preparation of the printing machines is no longer necessary thanks to the interaction between computer and printer, with the consequent reduction of the process' economic and environmental costs;
- As the printing paste no longer needs to be prepared, the actions performed in the colour kitchen are avoided, as are the operations of washing the containers and equipment used in making and distribution of colour as the ink is already prepared in cartridges; consequently, water consumption is also avoided;
- By producing only the requested lots, the material waste is reduced;
- Colourants, thickeners, and auxiliaries are limited to the actual printed area, thus avoiding waste and reducing the emission of chemical substances into the environment.

Highly favourable results on the environmental impact of Inkjet as compared to traditional printing were cited in a recent study by Provost Ink Jet Consulting Ltd (Heimtextil 2016)[8].

- Emissions in water – 60%
- Water consumption – 69%
- Energy saving, up to 80%
- Reduction of the Carbon Footprint 40%

[7] Digital Printing And Sustainability by Epson Italia – For.Tex – F.lli Robustelli, November 2017
[8] Digital Printing And Sustainability by Epson Italia – For.Tex – F.lli Robustelli, November 2017



E.

WET PROCESSES: MACHINERY & TECHNIQUES

Loose fibre

Autoclave

Various types of machines are used for processing fibres in loose form. These include conical pan machines, pear-shaped machines and radial flow machines. They are used for all wet operations, that is, pretreatment, dyeing, application of finishing agents and washing.

In conical pan machines (Figure e.1), the fibre is packed into a removable fibre carrier, which is located on a central spigot at the base of the vessel. Liquor circulation is provided via this connection, by an external pump. Associated pipework allows liquor to be circulated either from the base of the pack or from the top.

Pear-shaped machines have a removable perforated base plate through which liquor is circulated via an impeller, returning to the dyeing vessel via a weir. Fibre is loaded directly into these machines and a further perforated plate is positioned on top. Liquor circulation packs the fibre into the base of the machine between the two plates. To unload the machine, crane removes both plates and the fibre is manually removed.

Radial flow machines are characterised by a fibre carrier equipped with a central perforated column from which liquor flows across the pack to the perforated walls of the carrier.

Loose fibre is typically packed into these machines manually. Capacity varies between 200 - 300 kg, with a working volume equivalent to between 7 and 10 litres per kg fibre. The low packing density in these machines allows liquor to circulate freely through the fibre pack at modest pressures, thus minimising mechanical damage to the fibre while ensuring level dyeing.

Closed steam coils heat the bath in the machine's base. In many cases, the level of automation on these machines is low and temperature may be controlled manually with a simple steam valve. In other cases, electro/pneumatic programmers or logic controllers may be installed to regulate time / temperature and control the direction of liquor circulation.

Autoclaves can be equipped for operation at higher pressure (this is not the case when they are used for dyeing wool fibres).

Autoclaves of all designs may be fitted with an external holding tank capable of accommodating at least the volume of the dyeing vessel. Such tanks are used to facilitate reuse of liquors in more than one dyeing. Occasionally more than one dyeing vessel may be connected to a common tank, allowing liquor to be shared between vessels.

The liquor ratio for loose fibre can vary between 1:4 to 1:12, depending on the type of machine, level of loading, type of fibre, etc.

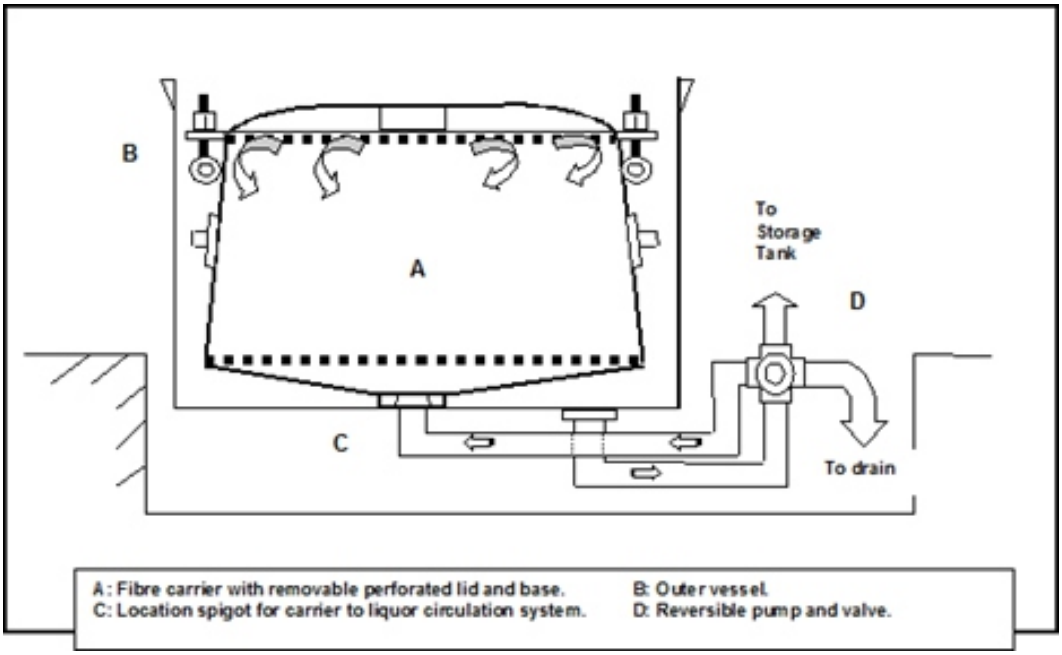


Figure e.1: Schematic layout of a conical pan loose fibre dyeing machine

Yarn

Yarn can be processed either in hank form or in package. Different machines are used depending on the method chosen. They are used for all wet operations: pretreatment, dyeing, application of finishing agents and washing.

Hank dyeing machines

Hank dyeing machines are mostly of the single stick (Hussong) design, in which hanks are hung from the underside of the dyeing vessel lid on removable sticks. (Figure 5.2) The lid is lowered vertically onto the dyeing vessel, which consists of a simple box with a perforated false bottom. Liquor is circulated by a reversible impeller located vertically in a weir chamber at one end of the machine. Heating is typically by closed steam coils beneath the false bottom and on smaller machines by live steam injection. Electro-mechanical or programmable logic controllers provide temperature control. These devices may also control/time the timing of chemical and dye additions and any required cooling cycles. Machine capacities vary from 10 kg sample machines to 1000 kg machines. These larger machines may be coupled in pairs with interconnecting pipework so that yarn loads of up to 4000 kg can be dyed while still retaining the flexibility to dye individual 1000 kg lots.

Variations of this design may utilise a horizontal circulation impeller passing through a sealing gland at the base of the weir chamber. Such machines invariably have a concave bottom, which is said to improve circulation and reduce fibre to liquor ratio by a small margin.

Liquor ratios from 1:15 to 1:25 are typical for these machines.



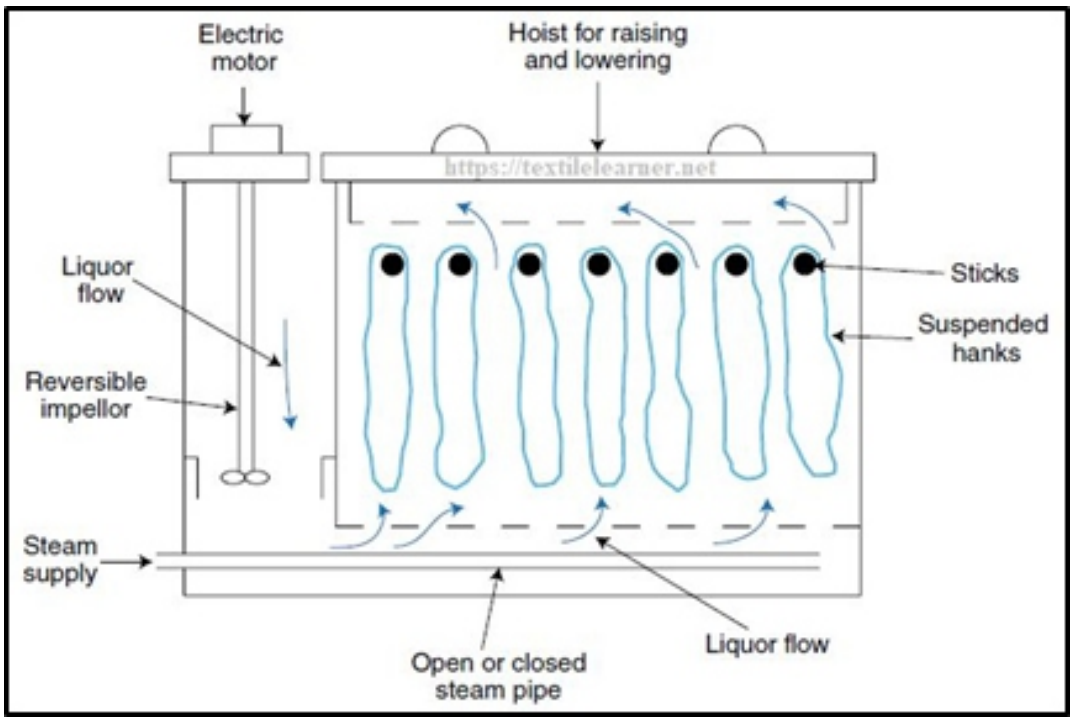


Figure: e.2: Schematic diagram of a Hussong type hank dying machine

---

Package dyeing machines

Three basic machine types may be used for package dyeing wool yarns: horizontal or vertical spindle machines or tube-type machines.

Horizontal spindle machines may be rectangular in design, similar to hank dyeing machines, but modified to take frames, onto which yarn packages are inserted horizontally, or alternatively may be a horizontal autoclave into which is wheeled the carrier containing the yarn packages. Both types operate with high flow rate pumps, which are necessary to give good dye liquor circulation. These machines are usually used for bulky yarns, wound onto soft packages, again to increase dye liquor penetration.

Vertical spindle machines are the most commonly used (see Figure e.3). The packages may be press packed onto vertical carrier spindles to increase payload, assist in dye liquor circulation and minimise liquor to fibre ratio.

Tube type machines consist of several vertical or horizontal tubes into which package carriers are inserted, the tubes forming individual dyeing vessels linked by common pipework and circulation pumps. These machines are more flexible than the above types because individual tubes can be blanked off to vary the overall load capacity of the machine.

Liquor ratios employed in package dyeing are close to 1:12 (typically from 1:8 to 1:15). Machines with capacities of up to 500 kg are used in dyeing carpet yarns, with the facility to link two or dyeing larger single batches. [32, ENco, 2001]

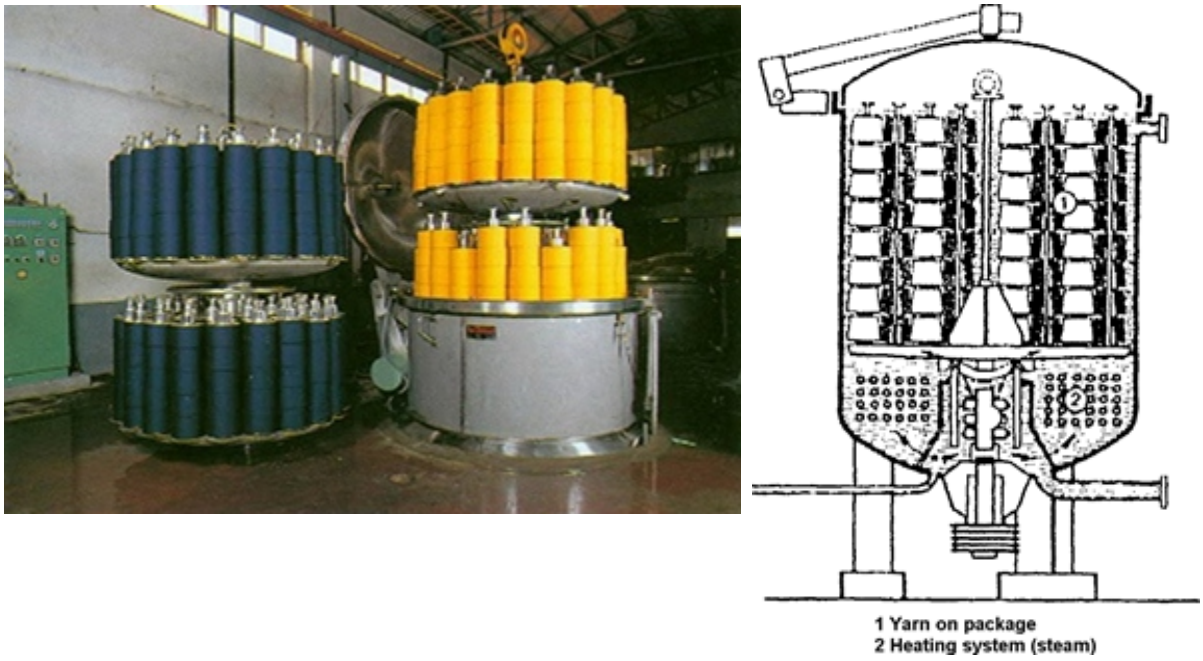


Figure e.3: Schematic layout of a package dyeing machine
Source: [, Ullmann's, 2000]

Fabric in rope form

Wet treatments on fabrics in rope form can be carried out in batch and continuous processes.

Batch processes

Winch beck

The common element in all winch beck machines is the winch mechanism used to move the fabric. The winch draws the fabric out of the bath via a guide roller and returns it in folds into the bath. In the conventional winch beck (see Figure e.4), the bath stands still, while the fabric is kept in circulation by a

reel positioned in the machine's upper part. In modern winches, both the bath and the fabric are kept in circulation, improving homogenisation and the liquor exchange with the fabric.

Greige goods are loaded into the winch either in rope form or in open width, which means that the winches must be 5 - 6 meters in width. The ends of the fabric piece to be dyed are sewn together to form endless loops over the rotating boom (winch).

Winch becks are primarily machines for dyeing, but for practical reasons, both preparation and dyeing are normally carried out in the same machine.

These machines are essentially operated at atmospheric pressure, although the development of synthetic fibres has led to pressurised machines (HT machines may reach 130 – 140 °C).

Winch beck is a very versatile machine that can be used for all fabric types. It is a prevalent technique for dyeing carpets (they are usually dyed in full width).

Typical bath ratios vary from 1:15 to 1:40 (typically 1:30 in the carpet sector) which makes this technique fairly expensive due to high water and energy consumption. However, recent technological developments have been made to improve its environmental performance.

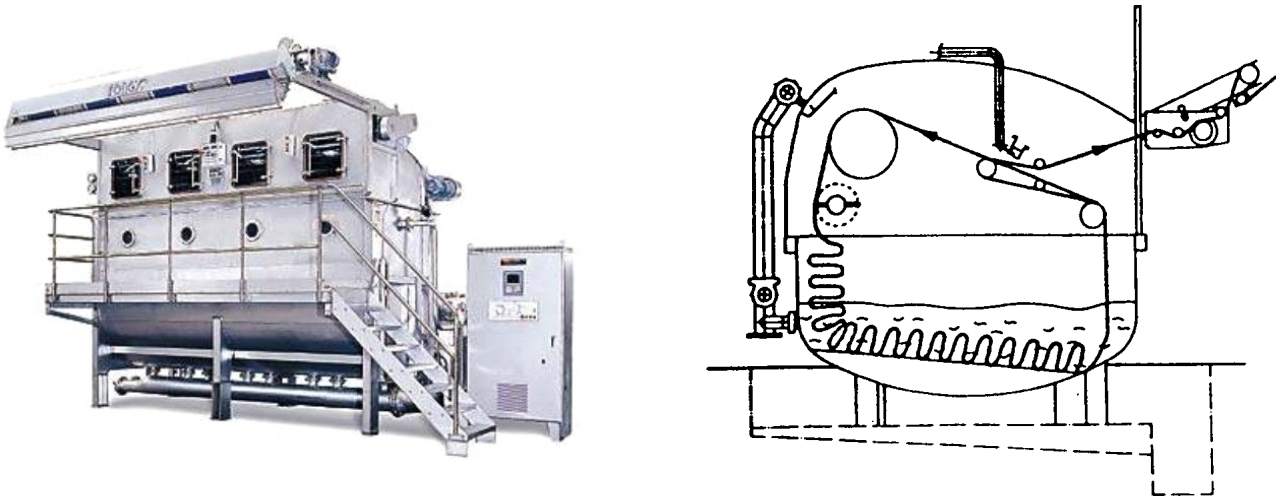


Figure e.4: Schematic representation of a winch beck dyeing machine
Source: [186, Ullmann's, 2000]

Jet

Jet machines (see Figure e.5) have been designed to eliminate some of the problems associated with using winch machines.

The reel is eliminated, and the fabric is placed in a closed tubular system. A jet of dye liquor is supplied through a venturi to transport the fabric through the tube. The turbulence created by the jet aids in dye penetration and prevents the fabric from touching the walls of the tube.

Since the fabric is frequently exposed to high liquor concentrations within the transport tube, relatively little dye bath is needed in the bottom of the vessel: just enough to ensure smooth movement from rear to front. : This machine's advantages are low water consumption and short treatment time (e.g., short dyeing time). Typical liquor ratios vary between 1:4 and 1:20, ranging from 1:4 to 1:10 for fabric and from 1:6 to 1:20 for carpet (lower values apply to synthetic fibres while higher values are typical for cotton) [GuT, 2001].

Jets can usually be operated at high temperatures, which makes them very suitable for dyeing polyester fibres. A disadvantage, however, is the high mechanical stress on the textile, caused by the speed difference between the bath and the fabric. For this reason, jets are not suitable for some delicate fabrics.

Depending on the shape of the fabric storage area (long shape machine or J-box compact machine), the type of nozzle and its position (above or below the bath level) various types of jets exist. Overflow, soft-flow and airflow dyeing machines can be regarded as developments of the conventional jet.

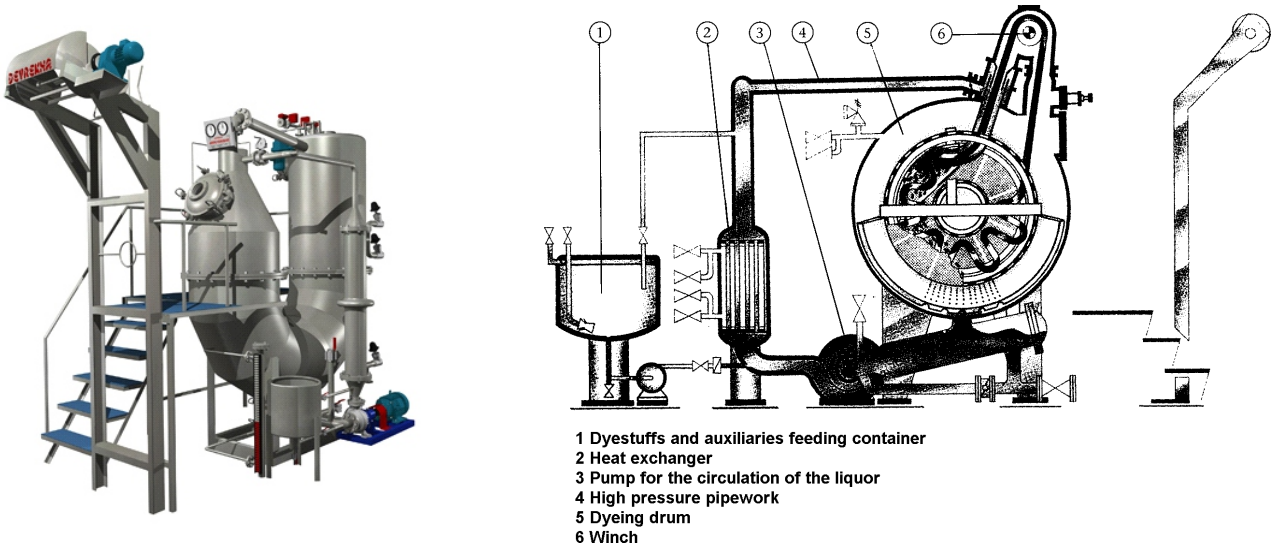


Figure e.5: Schematic representation of a jet dyeing machine
Source: [186, Ullmann's, 2000]

Overflow

Overflows (see Figure e.6) have been designed for delicate knitted and woven fabrics made of natural and synthetic fibres. They are also found in the carpet sector.

The main difference between jet and overflows machines remains in the fact that in jet machines, the fabric is transported by the bath flowing at high speed through the nozzle, while with overflows the fabric is transported by the gravitational force of the liquor overflow.

A winch (usually not motor driven) is located in the machine's upper part and the fabric hangs over it. A longer length of textile hangs from the exit side of the winch than from the inlet side. Gravitational forces pull the longer textile length downward more strongly than the shorter. The fabric is, therefore soaked in the bath without any tension (transportation is very gentle).

Different designs are available on the market; some can operate under pressure and consequently at higher temperatures.

Typical liquor ratios for overflows range between 1:12 and 1:20.

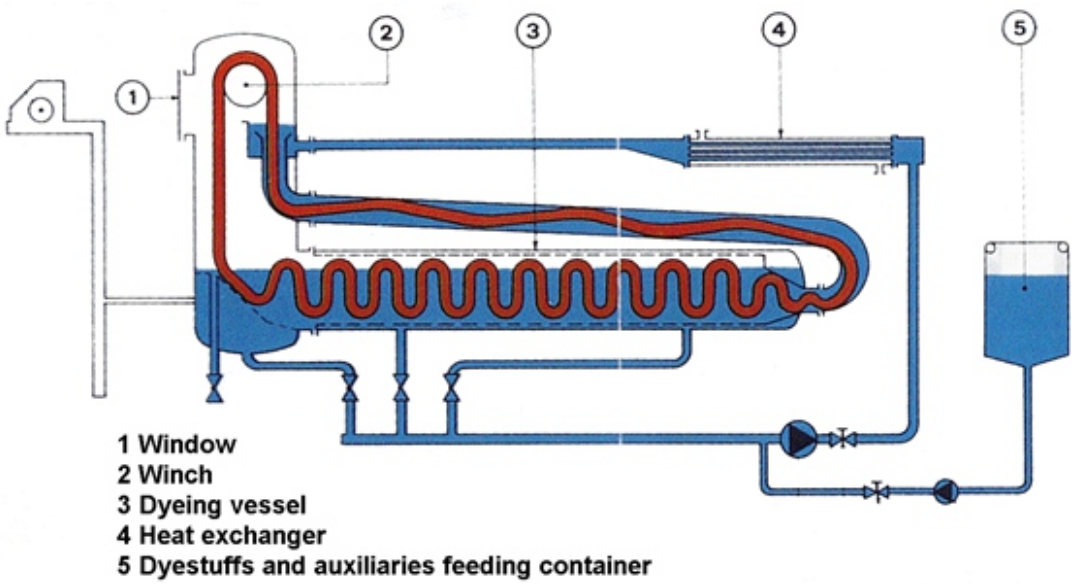


Figure e.6: Schematic representation of an overflow dyeing machine
Source: [69, Corbani, 1994]

Soft-flow

The so-called "soft-flow" machines use the same transport tube principle as overflow machines where the fabric is transported in a stream of dye liquor. However, while in overflow machines, the reel is not motor driven, in soft-flow equipment the reel and the jet work in constant harmony to remove the fabric from the front of the storage area, expose it briefly to a high concentration of liquor within the transport tube, then return it to the rear of the vessel. Soft flow machines are gentler on the fabric than conventional jet overflow machines.



Figure e.7: Soft flow machines

Airflow

The difference between air jets (see Figure e.8) and jet machines is that in the former, an air jet keeps the fabric in circulation instead of a water jet. The fabric passes into the storage area, which contains a very small amount of free liquor. As a result, water, energy and chemicals consumption can be reduced. The dye must be highly water- soluble because of the short liquor ratios achievable (from 1:2 to 1:5).

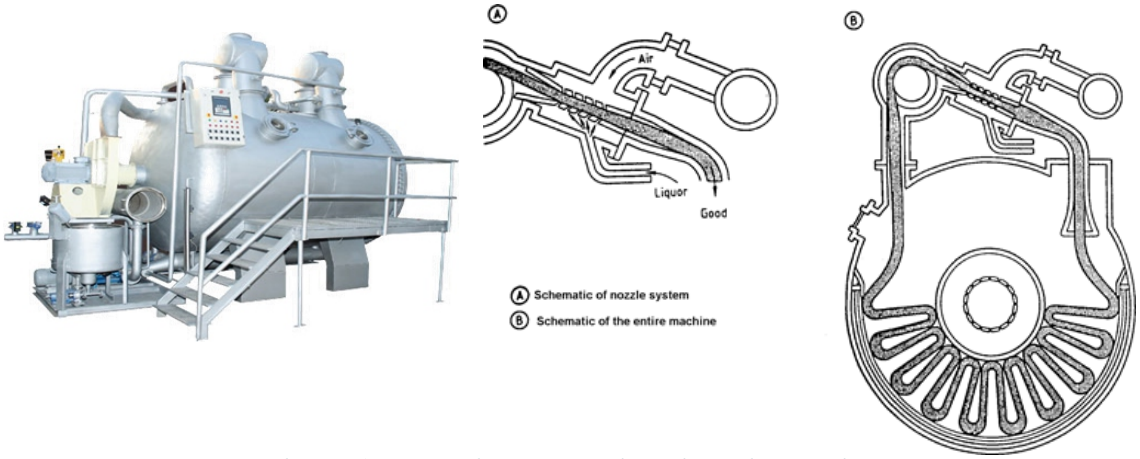


Figure e.8: Schematic representation of jet dyeing machine
Source: [186, Ullmann's, 2000]

Continuous processes

Machines for treatment in continuous processes of fabrics in rope form are essentially composed of the following parts:

- A padding device for impregnating the fabric in rope form
- A storage area for the fixation of the chemicals applied
- A washing machine for fabric in rope form.

The padding device comprises a long basin equipped with two or three rotating rollers at the inlet and another two at the outlet. The basin contains a concentrated solution of the chemicals and auxiliaries that have to be applied (desizing agents, bleaching agents, etc.). The fabric is pressed by the rotating rollers at the inlet to obtain a homogeneous absorption of the chemicals and eliminate air. The other two rollers only squeeze the fabric. After squeezing, the fabric retains only a relatively low amount of bath. As a result, high concentrations of the chemicals are needed, moreover, the solutions must be adequately stabilised to avoid unwanted oxidation reactions, etc.

The storage area (also called the reaction chamber) can have different shapes: one typical model is the J-Box. The J-Box is filled to 1/3 of its capacity with the treatment bath.

The main advantage of this technique is its high production capacity. On the other hand, there is the risk of longitudinal creases, which can negatively affect the dyeing process. As a result, this technique is mainly applied for white end-products for pretreatment operations (e.g. bleaching).

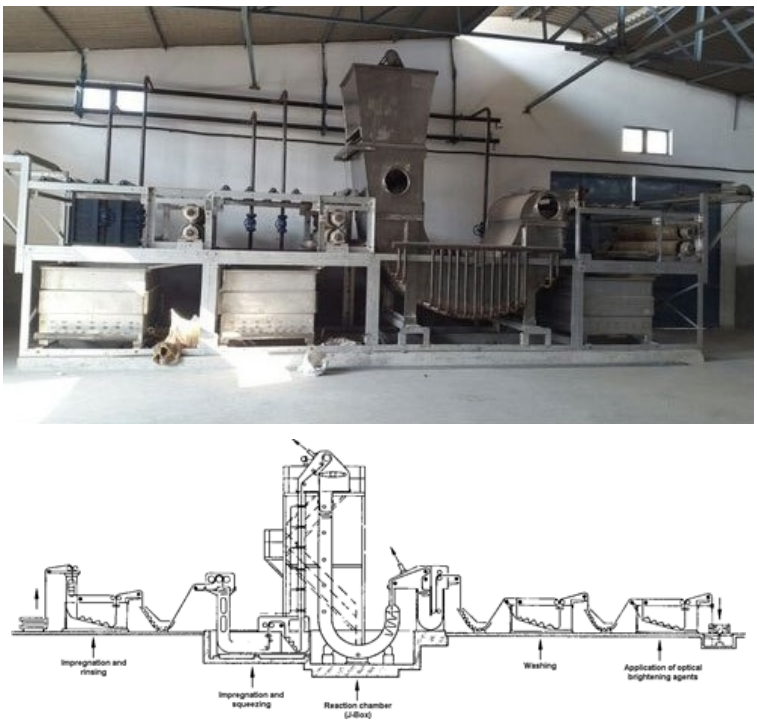


Figure e.9: Example of continuous process for knitted fabric in rope form
Source: Corbani, 1994]

Fabric in open-width

Batch processes

Beam

The fabric is wound in open-width on a perforated cylinder called a beam (see Figure e.10). The fabric is stationary, and the bath is pumped through the beam. The direction of the flow is normally from the inside to the outside of the roll of the textile.

The ends of the beam are covered with metal sheets before the fabric is wound on, to prevent a short circuit of the liquor.

Beams can operate both under pressure and at atmospheric pressure.

These machines are suitable for pretreatment operations like scouring and bleaching and for dyeing lightweight, wide and delicate goods. One disadvantage is the risk of non-homogeneous penetration of chemicals and aux

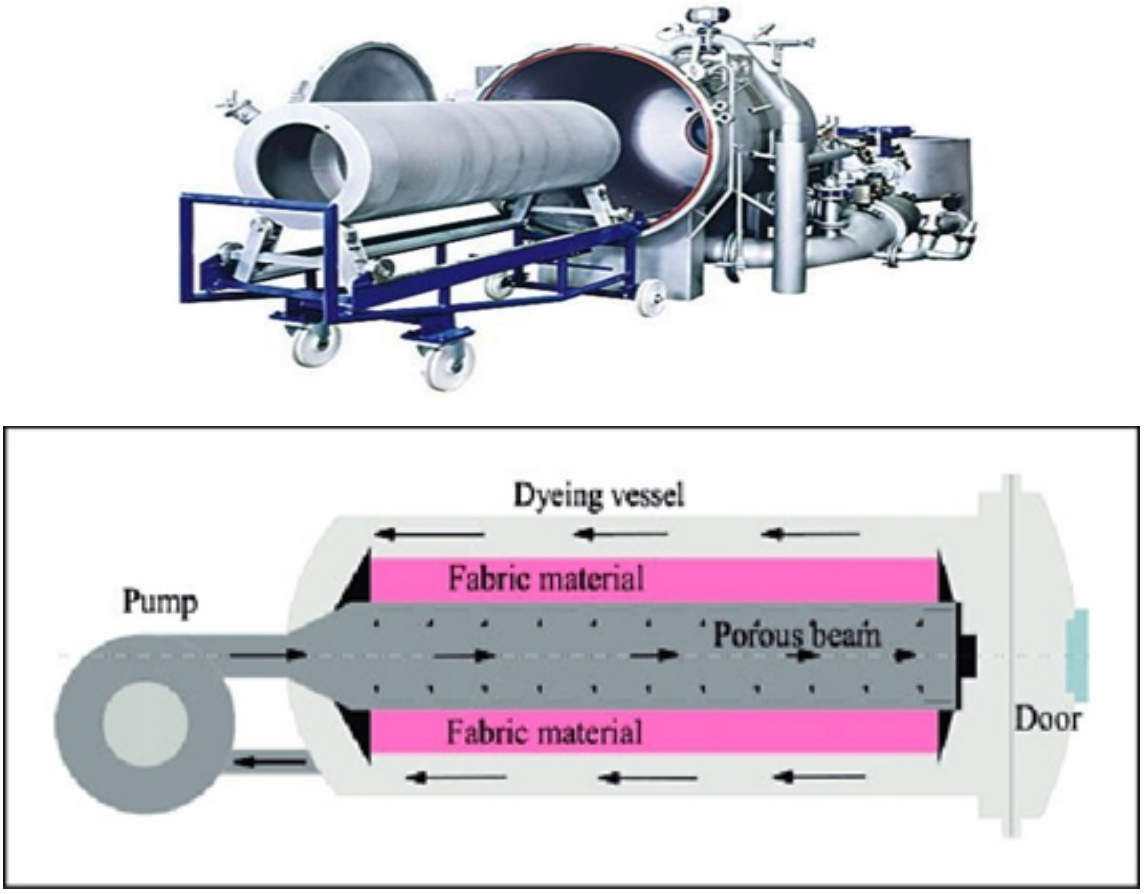


Figure e.10: Schematic representation of a beam dyeing machine

Jigger

A jigger (see) is composed of a trapezoidal tub containing the bath and two rolls on which the fabric is alternatively wound. The bath is stationary in this type of machine while the fabric is in motion. The fabric, initially wound on the first roll, flows through the bath and then is wound on the other one; the rotation is then reversed and the cycle continues. The fabric is led in its path by a few small guide rollers.

HT jiggers are also produced, allowing treatments at temperatures above 100 ºC. This type of machine is used not only for dyeing, but also for various wet treatments on fabrics in full width.
The main disadvantage of this system is the risk of non-homogeneity between the initial and final part of the roll. it is due to variations in feed speed and tension of the fabric or temperature and chemicals concentration in the bath during the treatment period. However, in modern jiggers, the tension of the fabric is kept constant during the whole process, thanks to special devices.

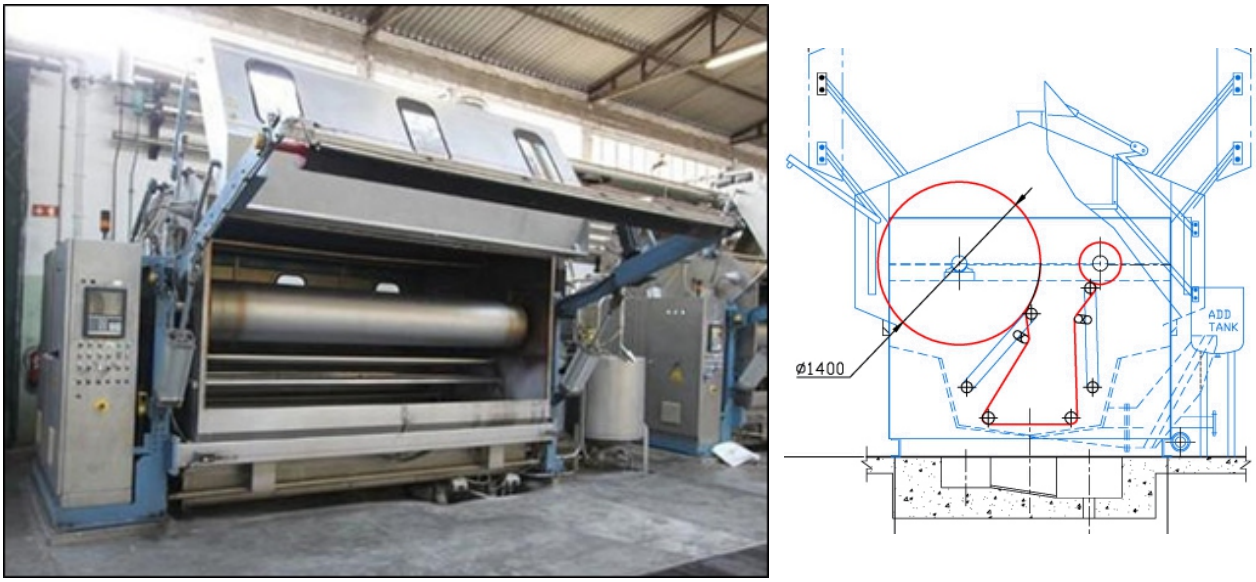


Figure e.11: Schematic representation of a jigger
Source: [https://www.thakoreexports.com/Super_Jumbo_Jigger_SJ_1000.html]

Semi-continuous and continuous processes

Some of the most widely used continuous and semi-continuous processes are:

- Pad-batch
- Pad-roll
- Pad-jig
- Pad-steam
- Pad-dry
- Thermosol

They are briefly described in the following sections.

Typical treatment steps in both semi-continuous and continuous processes are:

- Application of the dye or finishing agent either by impregnation (using a padding device) or by means of other types of application systems (see)
- Storage/fixation, which can be carried out in different ways depending on the process applied (e.g. dry heat, steam)
- Washing in continuous mode in open width.

Padding machines (foulards) are used to apply dyestuffs or other chemicals onto the fabric in open-width form. The fabric passes through the pad trough, picking up the liquor. After leaving the pad trough, the fabric is squeezed between rubber rolls. The amount of liquor picked up depends mainly on the pressure produced by the two rolls, the speed at which the fabric is transported and the type of substrate. The level in the trough is automatically maintained to compensate for liquor picked up by the fabric. The liquor is kept in circulation to avoid temperature and/or concentration differences.

Different designs of foulards exist: some examples are shown in Figure e.12.

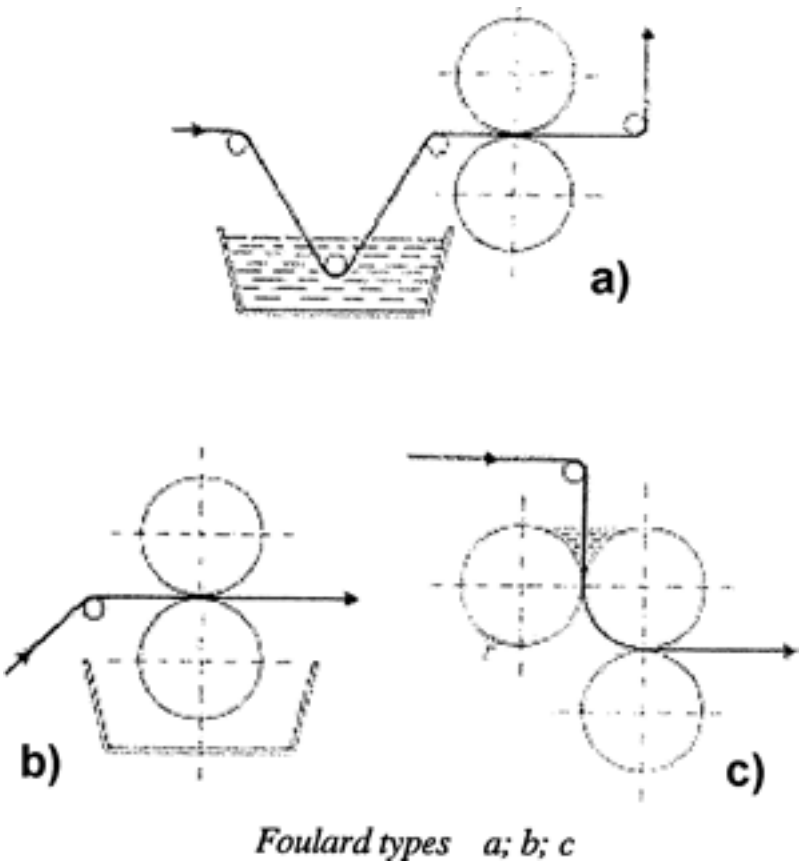


Figure e.12: Foulard types
Source: [18, VITO, 1998]

Padding is the most common application technique in textile finishing, but other application systems (see Figure e.13 below) are more common in the carpet industry. Due to their higher ecological performance, some are increasingly used in the textile finishing sector.

..

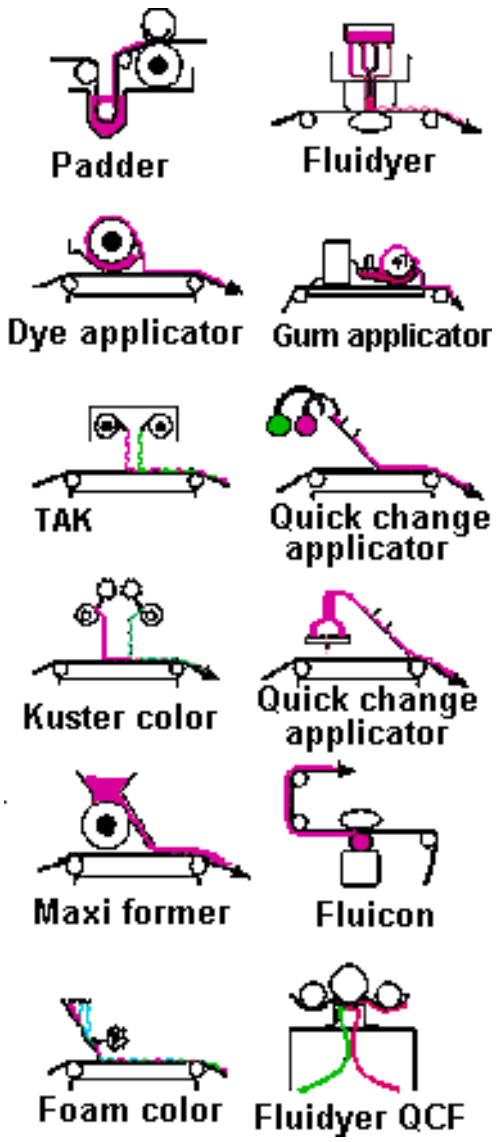


Figure e.13: Illustration of some of the most important dye/finish applicators

Pad-batch process (semi-continuous)

This process includes an impregnation step on a padding machine.

After being squeezed, the fabric is wound onto a roll and stored at room temperature. The roll is kept in slow rotation until the desired chemical processes (e.g. fixation of the dyestuffs, etc.) are complete. At the end the fabric is washed in an open-width washing machine.

This process is commonly used for pretreatment (e.g. desizing) and dyeing (mainly with direct and reactive dyes). It is characterised by low water and energy consumption (about 50 – 80 % less than conventional systems) and good repeatability.



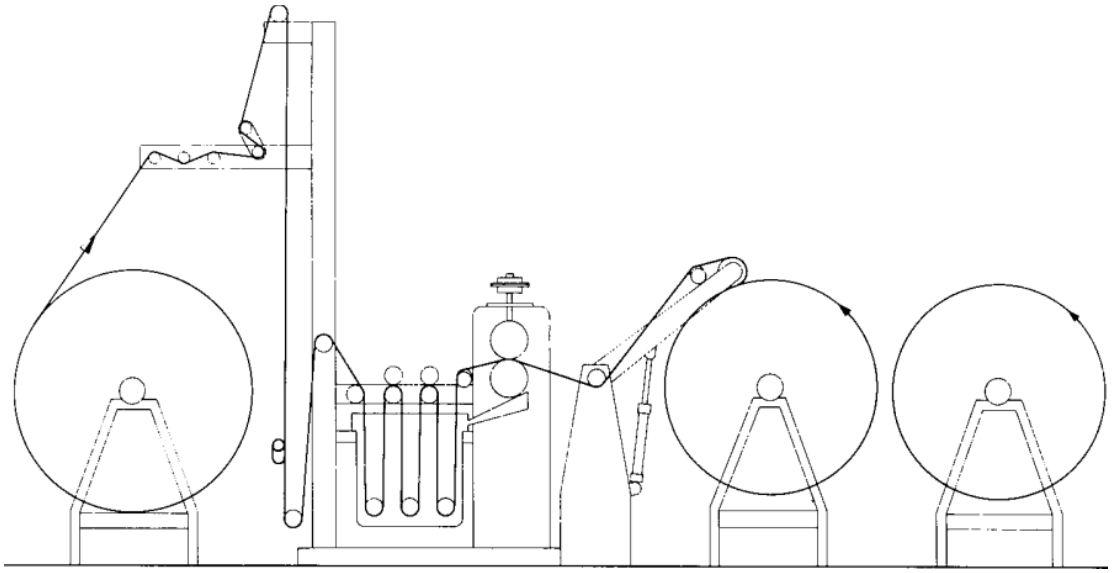


Figure e.14: Schematic layout of a pad-batch plant
Source: [69, Corbani, 1994]

Pad-roll process (semi-continuous)

This process is similar to pad-batch, but in this case the fabric, after padding, passes through an infrared oven. It is then rolled and kept in slow rotation in a hot steam chamber until fixation, or other chemical processes are complete. The fabric is then washed in an open-width washing machine.

Pad-jig process (semi-continuous)

This process is generally used as a dyeing technique, mainly for heavy-weight fabrics with direct and reactive dyes.

In this process, the fabric passes through a padding machine where it is impregnated with the dye bath, then the dyestuff is fixed on a jigger.

Sometimes the fabric can be dried in a hot-flue drier after padding, before entering the jigger.
The application of the dyestuff by padding allows for homogeneous dyeing and time saving when compared to traditional jigger dyeing processes.

Pad-steam process (continuous)

This technique is mainly used for scouring woven fabric and dyeing. It is particularly suitable for applying direct, vat, sulphur and reactive dyestuffs.

It includes the following steps:

- Impregnation by padding
- Steaming (at about 100 ºC)
- Additional impregnation of the fabric with developing agents (e.g. reducing agents in vat or sulphur dyeing)
- Washing and rinsing.

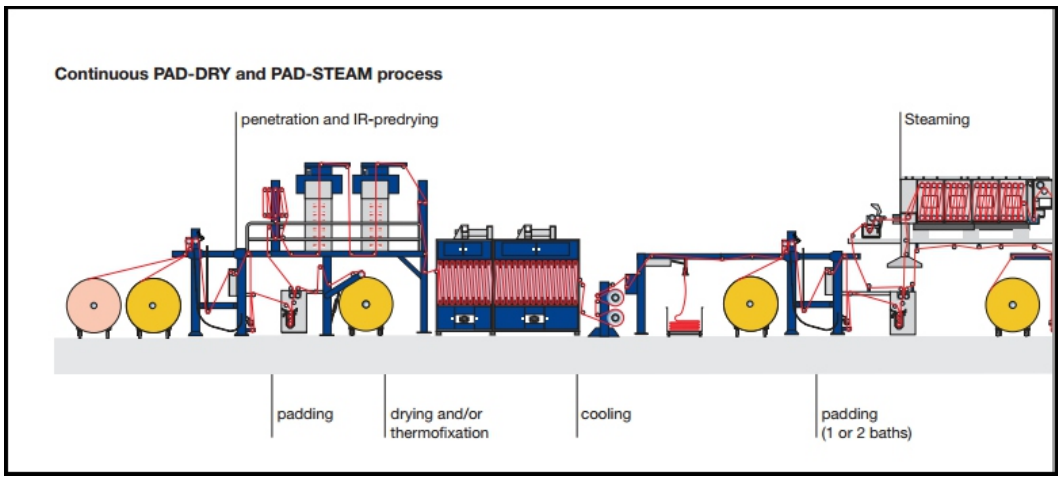


Figure e.15: Schematic representation of a PAD-DRY and PAD-STEAM plant (wet steam) for dyeing with vat dyes.

Pad-dry process (continuous)

This process includes the following steps:

- Impregnation by padding
- Intermediate drying (optional)
- Fixation in hot-flue
- Washing.

Thermosol process (continuous)

This process is specific for dyeing with disperse dyestuffs of polyester or cotton/polyester blends.

The process includes the following steps:

- Impregnation in the dyeing liquor
- Pre-drying in an infrared oven
- Drying in hot-flue
- Passage through a stenter frame for thermal fixation at 200 ºC of the disperse dyes to the PES.

An alkaline reductive after-treatment is then carried out or, in the case of cotton/polyester blends, the second dye is developed according to the procedure typical of its class, using in general pad-steam, pad-jig or pad-batch processes.

There are various methods of printing:

- Stencil Printing
- Hand Block Printing
- Hand Screen Printing
- Flat Bed Screen Printing
- Rotary Printing
- Digital or Inkjet Printing

Stencil Printing

This is the oldest method of printing in which designs are cut out from a sheet of metal or waterproof paper or plastic sheet or laminated sheet, and colours are applied by brushing or spraying on it.



Figure e.16: Stencil Printing

Advantages of Stencil Printing

- This is the simplest and most cost-effective method & does not require expensive equipment.
- Change in design is a rapid process and can be used to execute small orders.
- A great variety of graded colour effects can be achieved from one stencil by blending different colours on different parts of stencils with one single stroke of the brush.

Limitations of Stencil Printing

- Complete rings or circles, as well as unbroken lines, can not be printed by this method.
- The process is manual and laborious.
- This method is not suitable for large scale of production.

Block Printing

Block Printing is also an ancient and simplest method of printing in which the designs are engraved on the seasoned Teak wood. These blocks are then immersed into the oil for several weeks, making it water and chemical resistant.



Figure e.17: Block Printing

To print the correct block registration on the cloth, "Pitch Pins" are fixed around the side of the block, which prints tiny dots on the fabric. These pins are so arranged that they coincide with the pattern, and each impression joins up and makes the perfect print.

Advantages of Block Printing

- It is simple to operate and does not require expensive equipment.
- There is no limitation on the number of colours, and the reproduction of the design is effortless.
- The prints produced by this method have great decorative value and craftsmanship.

Limitations of Block Printing

- This is a slow process, and the cost of production is high.
- Making new blocks are time-consuming and difcult.
- It is somewhat difficult to join each impression of repeat perfectly each time.
- Due to weight and handling issues, printing with long blocks or wide repeats is impossible.
- It is difficult to produce fine lines by this method.

Hand Screen-Printing

Hand screen printing is the best method to print low yardage and samples of exclusive limited design quality. Screens are generally made of polyester fabric. Sometimes this fabric is also called bolting cloth because the fabric is tightened on a lightweight wooden frame. Large repeat sizes (up to 120") are possible in this type of printing.



Figure e.18: Hand Screen-Printing

Flat Bed Screen Printing

Flat-screen printing is the most versatile of all printing processes. This is the most widely used form of fabric printing. It can be used to print on various fibres (such as pure cotton, silk, pure synthetic or their blend), light or heavy fabrics (such woven, knitted, pile fabric, towel, etc.), and garments.

The raw flat-screen combines a frame and a piece of polyester fabric tightly stretched across the frame. Flat-screen printing consists of four elements: the screen, the image carrier, the squeegee and the colour paste as shown in fig. 5.19 The screen printing process uses a tightly stretched porous mesh over a frame made of metal.

Flat-screen printing is a semi-continuous and reciprocating process. Using a rubber squeegee, colour pastes are spread across the width of the screen frame and forced to pass through the pattern location only, producing a localised dyeing effect. The screen is first moved into position over the fabric, the squeegee is pressed against the mesh and drawn over the image area, and then the screen is lifted away from the fabric to complete the process1.

The printing quality is influenced by many factors, such as composition, size and form of fabric, angle, pressure, and squeegee speed.

[1] Process control in textile manufacturing, Edited by Abhijit Majumdar, Apurba Das, R. Alagirusamy and V. K. Kothari

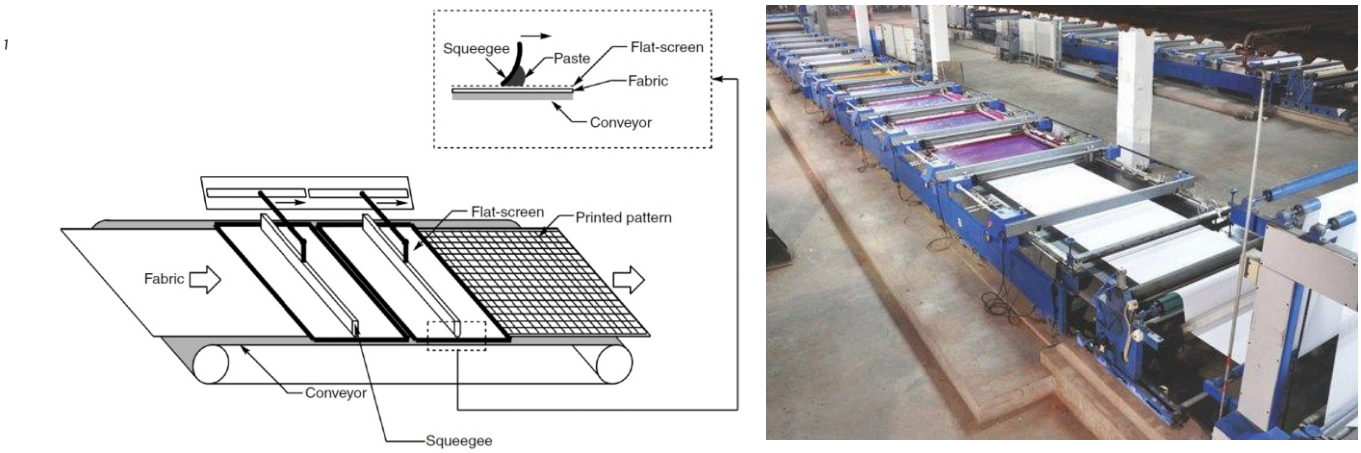


Figure e.19: Flat Bed Screen Printing

Important Features of Flat Bed Screen Printing

- Large repeat size (up to 60")is possible
- Better color denition than roller prints; and eual to hand screen printing.
- Adaptable to all woven & knits.
- Rapid changeover of designs possible.
- Best machine registration.

Limitations of Flat Bed Screen Printing

- Cost of screen preparation and special mountings are more costly than hand screen printing.
- Not adaptable to low yardage.
- Half-tone designs are not possible.
- Fine-line paisley prints are not possible to print.
- Lengthwise stripes are not possible to print.

Rotary Screen Printing

Rotary-screen printing can increase production rates by its continuous production process, compared with the semi-continuous process of the flat-screen printing method, and is more suitable for mass printing production.

Nowadays, rotary-screen printing has become the most widely applied technology in the entire printing industry. The screen is made in rotary form and usually made from stainless steel and nickel. Depending on design complexity and fabric construction, its typical speeds vary between 50–100 m/min.

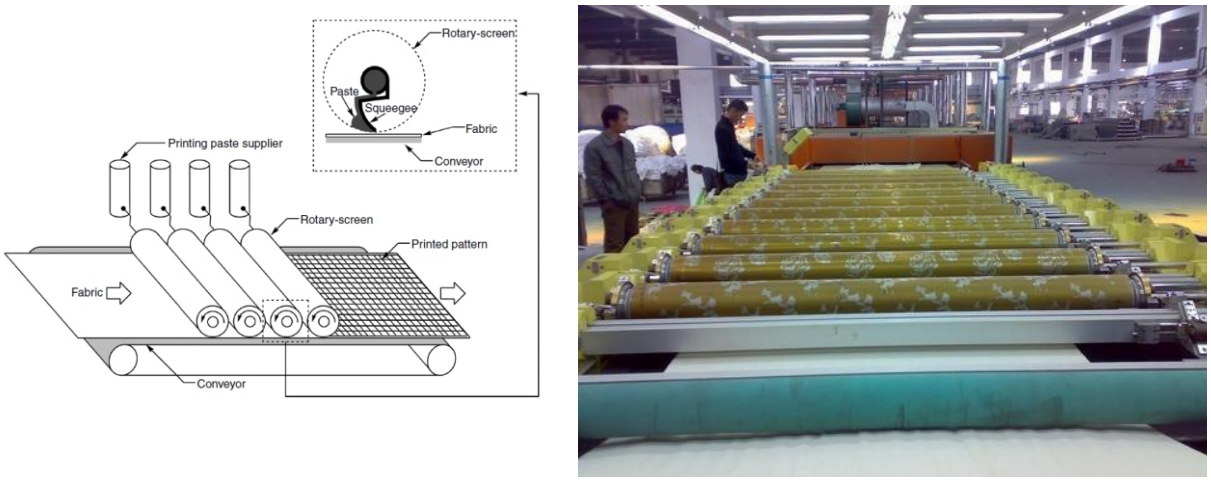


Figure e.20: Rotary Screen Printing

The basic operations of rotary-screen and flat-screen printing machines are very similar. An in-feed device, paste trough, rotating blanket (print table), dryer, and fixation equipment are used. The process involves initially feeding fabric onto the rubber blanket. As the fabric travels under the rotary screens, the screens turn with the fabric. Colour paste is continuously fed to the screen's interior through a pipe. As the screen rotates, the squeegee device pushes paste through the design areas of the screen onto the fabric.

The major disadvantage of rotary-screen printing is the high investment cost of the machine. As mentioned before, rotary-screen printing is most suitable for mass production but generally not profitable for small batch production because of the cumbersome clean-up process for this machine when changing colours or patterns.

Digital Printing

Inkjet printing of textiles is the method of direct printing of colourants onto fabric by a computer-controlled printer, which creates a digital image by propelling droplets of ink onto fabric. Therefore, this method is also called digital textile printing. That is, solutions or dispersions of dyes (or pigments) are sprayed on the detailed region of fabric as droplets from printing heads.



Figure e.21: Digital Printing

The printed fabrics then will be immediately steamed or cured for colourant fi xation, followed by rinsing and drying if dyestuff inks have been applied, similar to conventional printing.

An industrial textile inkjet printing machine is usually designed in roll-to roll or roll-to-folder form. The printing machine is fitted with a rubber blanket and an online dryer and features different entry/exit configurations.

A good inkjet machine should have such characteristics as high productivity (250 m^2/h or even higher), low ink consumption, suitability for a wide range of fabric (knitted, woven, non-woven, etc.) and a wide range of inks (acid, reactive, direct disperse, sublimated disperse and pigment), a wide range of printing width (1800, 2400, 3400 mm, etc.), high resolution (600 × 600 dpi), and high reliability (embedded printheads maintenance system, unlimited printhead lifetime), and printheads adjustable to media distance. Appropriate software is also necessary for an inkjet printer for image scanning, colour separation, and colour management.

Please refer to a separate annexure dedicated to digital textile printing for further information.



F.

Zero Discharge of Hazardous Compounds Materials Restricted Substance List (ZDHC MRSL)

Zero Discharge of Hazardous Compounds Materials Restricted Substance List (ZDHC MRSL)

This Annex is an extract from the Materials Restricted Substance Lists of ZDHC[1]

Category of chemicals	Additional information
Alkylphenol(AP) and Alkylphenol Ethoxylates (APEOs) including all isomers	APEOs can be used as or found in: detergents, scouring agents, spinning oils, wetting agents, softeners, emulsifier/dispersing agents for dyes and prints, impregnating agents, de- gumming for silk production, dyes and pigment preparations, polyester padding and down/feather fillings.
AntiMicrobials & Biocides	These substances have biocidal properties, making it useful for multiple preservation applications.
Chlorinated parafins	These are used occasionally as flame retardants in certain industries. In leather formulations, these are also used as fat liquoring agents.
Chlorobenzenes and Chlorotoluenes	Chlorobenzenes and chlorotoluenes (chlorinated aromatic hydrocarbons) can be used as carriers in the dyeing process of polyester or wool/polyester fibres. They can also be used as solvents.
Chlorophenols	Chlorophenols are polychlorinated compounds used as preservatives or pesticides. Pentachlorophenol (PCP) and tetrachlorophenol (TeCP) have been used in the past to prevent mould when storing/transporting raw hides and leather. They are now regulated and should not be used.
Dyes – Azo (forming restricted amines)	Azo dyes and pigments are colourants that incorporate one or several azo groups (-N=N-) bound with aromatic compounds. Thousands of azo dyes exist, but only those that degrade to form the listed cleavable amines are restricted. Azo dyes that release these amines are regulated and should no longer be used for the dyeing of textiles.
Dyes – Carcinogenic or equivalent concern	Most of these substances are regulated and should no longer be used for the dyeing of textiles.
Dyes – Disperse (Sensitising)	Disperse dyes are a class of water-insoluble dyes that penetrate the fibre system of synthetic or manufactured fibres and are held in place by physical forces without forming chemical bonds.

[1] ZDHC Manufacturing Restricted Substances List (ZDHC MRSL)

	Disperse dyes are used in synthetic fibre (e.g. polyester, acetate, polyamide). Restricted disperse dyes are suspected of causing allergic reactions and should no longer be used for dyeing of textiles.
Dyes – Navy Blue Colourant	Navy blue colourant is regulated and should no longer be used for the dyeing of textiles.
Flame retardants	Flame retardant chemicals are rarely used to meet flammability requirements in children's clothing and adult products. They should no longer be used in apparel and footwear. All halogenated flame retardants are banned from intentional use that means including but not exclusive the list below;
Glycols/Glycol Ethers	In apparel and footwear, glycols have a wide range of uses including as solvents for finishing/cleaning, printing agents, and dissolving/diluting fats, oils, and adhesives (e.g. in degreasing or cleaning operations).
Halogenated Solvents	In apparel and footwear, halogenated solvents are used as finishing/cleaning and printing agents, for dissolving/diluting fats, oils and adhesives (e.g. in degreasing or cleaning operations).
Organotin Compounds	Organotins are a class of chemicals combining tin and organics such as butyl and phenyl groups. Organotins are predominantly found in the environment as antifoulants in marine paints, but they can also be used as biocides (e.g. antibacterials), catalysts in plastic and glue production and heat stabilisers in plastics/rubber. In textiles and apparel, organotins are associated with plastics/rubber, inks, paints, metallic glitter, polyurethane products and heat transfer material.
Other/Miscellaneous Chemicals	These are other chemicals/substances/process with a usage ban.
Perfluorinated and Polyfluorinated Chemicals (PFCs)	Durable water, oil and stain repellent finishes based on long-chain PFC's are banned from intentional use. There are two methods of manufacture of PFCs referred to as electrofluorination and telomerisation. PFC's made by the electrofluorination method have by-products associated with them called perfluoroalkyl sulphonates with the most common being the C8 species Perfluorooctane sulphonate (PFOS). The deliberate use of any PFCs made by electrofluorination with a chain length of C6 or above is not permitted. The detection of any PFOS analogue as where the chain length is 6 units or longer will trigger a failure (i.e. PFHS and above). These types of PFCs are typically used in home textiles. PFC's made

	by the telomerisation method have by-products associated with them called perfluorocarboxylic acids with the most common being the C8 species perfluorooctanoic acid (PFOA). The deliberate use of any PFCs made by telomerisation with a chain length of C8 or above is restricted. ZDHC plans to further restrict the use of PFCs in future revisions and details can be found in the candidate list is not permitted. The detection of any PFOA analogue as where the chain length is 8 units or longer will trigger a failure (i.e. PFOA and above). These types of PFCs are typically used in clothing and footwear PFOA and PFOS may be present as unintended by-products in long-chain commercial water, oil and stain repellent agents. PFOA also may be in used in the production for polymers like polytetrafluoroethylene (PTFE).
Phthalates – including all other esters of ortho-phthalic acid	Esters of ortho-phthalic acid (phthalates) are a class of organic compounds commonly added to plastics to increase flexibility. They sometimes are used to facilitate moulding of plastic by decreasing its melting temperature. Phthalates can be found in: • Flexible plastic components (e.g. PVC) • Print pastes • Adhesives • Plastic buttons • Plastic sleevings • Polymeric coatings
Polycyclic Aromatic Hydrocarbons (PAHs)	Oil containing PAHs are added to rubber and plastics as a softener or extender and may be found in rubber, plastics, lacquers, and coatings. Within the footwear producing industry, PAHs are often found in the outsoles of footwear and in printing pastes for screen prints. PAHs can be present as impurities in carbon black dyestuffs.
Total Heavy Metals	In the list below the formulation limit for As, Cd, Hg, Pb and Cr VI apply to all types of formulation. Where there is a specific limit for pigments that that is different to the general limit this is shown in brackets. The formulation limits for Sb, Cr, Ba, Se, Sn, Ni, Cu, Co and Ag only apply to dye and/or pigment formulations. Any differences between limits for dyes and pigments are indicated in the formulation limit column. The limits for the heavy metals do not apply to colourants containing a listed metal as an inherent compositional part (e.g. metal-complex colorants, the double salts of certain cationic colourants or extenders like barium sulfate). When using any colourant with listed metals as an inherent compositional part, wet processors need to be aware of the need to comply with brand RSL limits with respect to extractable metals from dyed materials and they also need to be aware of the metal limits in the ZDHC wasterwater guidelines. Where RSL and/or wastewater issues are observed

[1]

	wet processors should discuss this with supply chain partners. For the listed exceptions, laboratory tests to determine separately metal contaminants that are not bound into a colourant (free metals) are under development. Although typically associated with leather tanning, chromium VI also may be used in the dyeing of wool (after the chroming process).
UV absorbers	These are frequently used in formulations to be stable to the influences of light and UV.
Volatile Organic Compounds (VOC)	These Volatile Organic Compounds (VOC) should not be used in textile auxiliary chemical preparations. They are associated with solvent-based processes like solvent-based polyurethane coatings and glues/adhesives. They should not be used for any kind of facility cleaning or spot cleaning.

Acronym	Full Phrase
BAT	Best Available Techniques
BREF	BAT REFERENCE DOCUMENT
UBA	Umweltbundesamt
TWG	Technical Working Group
SGTPA	South Gujarat Textile Processers Association
PIA	Palsana Industries Association
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
NGO	Non-Governmental Organization
MoEF&CC	Ministry of Environment, Forest and Climate Change
OE	Open End
FBC	Fluidized Bed
CETP	Common Effluent Treatment Plant
CPH	Cotton Processing House
PPH	Polyester Processing House
RO	Reverse Osmosis
CBR	Continuous Bleaching Range
VFD	Variable Frequency Drive
BAT-AELs	Air Emissions Levels associated with the best available techniques
EMS	Environmental Management System
CMS	Chemicals Management System
pH	Potential of Hydrogen
CPCB	Central Pollution Control Board
ISO	International Organization for Standardization
MSME	Micro, Small & Medium Enterprises
BAT-AEPLs	BAT - Associated Environmental Performance Levels
CRP	Caustic Recovery Plant
TIC	Toxic Industrial Chemical
CPB	Cold pad batch dyeing
COD	Chemical Oxygen Demand
BOD	Bio-Chemical Oxygen Demand

GDP	Gross Domestic Production (Gross Domestic Product)
USD	US Dollar
CAGR	Cumulative Annual Growth Rate
T & A	Textile and Apparel
MT	Million Tonnes
IBEF	India Brand Equity Foundation
DIPP	Department of Industrial Policy and Promotion
MoCI	Ministry of Commerce and Industry
UT	Union territory
BRAP	Business Reform Action Plan
ETPs	Effluent Treatment Plants
JDPA	Jetpur Dyeing and Printing Association
MLD	Million Litres Per Day
TERI	The Energy And Research Institute
SPCB	State Pollution Control Board
PCCs	Pollution Control Committees
CO/PES	Cotton /Polyester
gm/den	Gram per Denier
VOC	Volatile Organic Compound /Volatile Organic Carbon
PES	Polyester
PET	Polyethylene terephthalate
PBT	Polybutylene terephthalate
PTT	Polytrimethylene terephthalate
PA	Polyamide
PAC	Poly Acrylic fibres
PAN	Poly Acrylonitrile
PP	Polypropylene fibres
EL	Elastane
UV	Ultra violate
PU	Polyurethane
CU	Cupro
CV	Viscose

NAOH	Sodium Hydroxide
BISFA	Bureau International pour la Standardization des Fibres Artificielles
BCF	Bulk Continuous Filament
N/A	Not Available
AOX	Adsorbable organic halogens
EDTA	Ethylene diamine tetra acetic acid
TPA	Terephthalic acid
$MgCl_2$	Magnesium Chloride
$MgSio_2$	Magnesium Silicide
H_2O_2	Hydrogen Peroxide
OBA's	Optical Brightening Agents
PVA	Polyvinyl alcohols
PAA	Peracetic acid
PEs	Polyelectrolyte
CMC	Carboxy methyl cellulose
HEC	Hydroxy ethyl cellulose
CMS	Carboxy methyl starch
TOC	Total Organic Carbon
PTA	Purified Terephthalic Acid
MEG	Monoethylene Glycol
FCB	fluidized bed combustion (
NOx	Oxides of Nitrogen Oxides
SOx	Sulfur Oxides
AFBC	Atmospheric Fluidized Bed Combustion
PFBC	Pressurized Fluidized Bed Combustion
FD	Forced Draft
CFBC	Circulating Fluidized Bed Combustion
SO_2	Sulpur Dioxide
GCV	Gross calorific value
CO_2	Carbone Dioxide
H_2	Hydrogen

O_2	Oxygen
CO	Carbone Monoxide
TDS	Total Dissolved Solids
kCal	Kilo- Calorie
PM	Particulate Matter
STPs	Sewage Treatment Plants
CEMS	Continuous Emission Monitoring System
HF	Hydro Fluoric Acid
NH_3	Ammonia
NO	Nitrogen Oxide
NO_2	Nitrogen Dioxide
Cl_2	Chlorine
HCL	Hydro Chloric Acid
THC	Total Hydro Carbon
Hg	Mercury
DAS	Data Acquisition System
EN	European Nation
ESP	Electrostatic Precipitator
AC	Alternating Current
DC	Direct Current
NDIR	Non-Dispersive Infra- Red
IR GFC	Infra-red Gas Filter Correlation
UVDOAS	Ultraviolet Differential Optical Absorption Spectroscopy
NDUV	Non-Dispersive Ultraviolet Spectroscopy
FTIR	Fourier Transform Infrared Spectroscopy
SEIAA	State Environmental Impact Assessment Authority
PVC	Polyvinyl Chloride
F/M	Food-to-microorganism ratio
NTA	Nitrilotriacetate
WWTP	Wastewater Treatment Plant
PCU	Platinum Cobalt Units
Cr	Chromium

SAR	Sodium Absorption Ratio
$AlCl_3$	Poly aluminium chloride
MLSS	Mixed liquor suspended solids
MLVSS	Mixed liquor volatile suspended solids
VSS	Volatile Suspended Solids
TSS	Total Suspended Solids
SRT	Solids retention time
HRT	Hydraulic retention time
SBR	Sequencing batch reactor
MBR	Membrane biological reactor
RAS	Return activated sludge
WAS	Waste activated sludge
CSTR	Continuous-flow stirred tank reactor
PFR	plug-flow reactor
PEPL	Palsana Enviro Protection Ltd.
RBC	Rotating biological contactors
AOP	Advanced oxidation process
NTIEM	Narol Textile Infrastructure & Enviro Management
CFICASS	Continuous flow integral clarifier activated sludge system
CC&A	Consolidated Consent and Authorization
W2W	Waste to Wealth
DPH	Denim Processing House
GSM	Grams per square metre
ID Fan	Induced Draught Fan
OBA	Optical Brightening Agents
PDPS	Pad-Dry-Pad-Steam
INR	Indian Rupees
GMT	General Management techniques
MSS	Management System Standards
EIA	Environment Impact Assessment
IEMA	Institute of Environmental Management and Assessment
BSI	British Standards Institution

EMAS	Eco-Management and Audit Scheme
SMEs	Small and Medium-sized organisations
GRS	Global recycled Standard
RCS	Recycled Claim Standard
LEED	Leadership in Energy and Environment Design
GOTS	Global Organic Textile Standard
OEKO-TEX	International Association for Research and Testing in the Field of Textile and Leather Ecology
ZDHC	Zero Discharge of Hazardous Chemicals
OCS	Organic Content Standard
ROC	Regenerative Organic Certified™
MRSL	Manufacturing Restricted Substance List
STeP	Sustainable Textile Production
SRSL	Screening Restricted Substance List
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
CLP	Classification, Labelling and Packaging
BPR	Biocidal Products Regulation
PPP	Plant Protection Products
POPs	Persistent Organic Pollutants
PPPPU	Pressure Powered Package Pumping Unit
CHP	Combined heat and power
BPSTs	Backpressure steam turbines
LP	Pow-pressure
RVSS	Reduced voltage soft starters
kVA	KiloVolt Amperes
VDR	Vertical Drying Range
CMS	Chemicals Management System
PFAS	Per- and polyfluoroalkyl substance
ENES	Exchange Network on Exposure Scenarios
EUSES	European Union System for the Evaluation of Substances
AFIRM	Apparel and Footwear International RSL Management

GHS	Globally Harmonized System
SOP	Standard Operating Procedure
PPE	Personal Protective Equipment
SDS	Safety Data Sheet
CAS	Chemical Abstracts Service
GLM	Gram Per Linear Meter
APEO	Alkylphenol ethoxylates
NPE	Nonylphenol ethoxylates
AP/APEO	Ikylphenols and alkylphenol ethoxylates
AEs	Alcohol ethoxylates
EO	Ethoxylated
PPM	Parts Per Million
MFT	Monoflurotriazine
MCT	Monochlorotriazine
VS	Vinyl sulphone
OECD	Organisation for Economic Co-operative and Development
MGDA	Methylglycinediacetic acid
GLDA	L-glutamic acid N,N-diacetic acid
IDS	Iminodisuccinic acid
ATMP	Aminotris methylene phosphonic acid
DTPMP	Diethylenetriamine pentamethylene phosphonic acid
HEDP	Hydroxyl ethylidene-1,1-diphosphonic acid (
SURFACTANT	Surface Active Agent
CPP	Cocoampho carboxy propionate
NPEOs	Nonyl- or octylphenol ethoxylates
OPEO	Octyl phenol ethoxylates
DMDHEU	Dimethylol Dihydroxy Ethylene Urea
DMF	Dimethyl Formamide
CCM	Computer Colour Machine
C.I.	Color Index
DTF	Direct to Fabric
DTG	Direct to Garment

CIJ	Continuous Inkjet
DOD	Drop on Demand
DTP	Digital Textile Printing
RGB	Red, Green and Blue
ZDHC MRSL	Materials Restricted Substance List of Zero Discharge of Hazardous Compounds
PCP	Pentachlorophenol
TeCP	Tetrachlorophenol
PFCs	Perfluorinated and Polyfluorinated Chemicals
PFOS	Perfluorooctane sulphonate
PFOA	perfluorooctanoic acid
PTFE	Polytetrafluoroethylene
PAHs	Polycyclic Aromatic Hydrocarbons

1. TXT_BREF_2023_for_publishing ISSN 1831-9424_final_1_revised.pdf

2. INDUSTRY SCENARIO – Textile and Apparel Sector (HTTPS://WWW.INVESTINDIA.GOV.IN/SECTOR/TEXTILES-APPAREL)

3. Ministry of Textiles Annual Report 2020-21

4. Indian textile industry - An overview, Dr. M. Dhanabhakyam (2007) (https://www.fibre2fashion.com/industry-article/2363/indian-textile-industry-an-overview)

5. Indian Textile and Apparel Industrial Analysis (https://www.ibef.org/industry/indian-textiles-and-apparel-industry-analysis-presentation)

6. Textile Industry and market growth in India (https://www.ibef.org/industry/textiles.aspx)

7. "Top 5 textile and clothing manufacturing Indian states", - Apparel Resources 20-July-2018 (https://in.apparelresources.com/business-news/sourcing/top-5-textile-and-clothing-manufacturing-indian-states)

8. "Gujarat – Emerging the most ideal destination for textile investors", The Textile Magazine, 2017 (https://www.indiantextilemagazine.in/gujarat-emerging-the-most-ideal-destination-for-textile-investors/).

9. History Of Textile Industry In Ahmedabad (http://www.taiahd.com/history.html)

10. Indian Textile and Apparel Industry 2021 – AEPC,2021

11. "Surat textile industry still under subdued capacity utilization", 2019, (business standard-textile industry)

12. "Cluster Profile Jetpur Profile Industries" TERI, Sameeeksha (2015) http://www.sameeeksha.org/pdf/clusterprofile/Jetpur_Textiles_Gujarat.pdf

13. Connell, D.L. (1995). The environmental impact of the textiles industry.

14. Thangavel, Karthik & Duraisamy, Gopalakrishnan. (2014). Environmental Analysis of Textile Value Chain: An Overview.

15. C Parvathi, T Maruthavanan and C Prakash. (2009). Environmental impacts of textile industries

16. European Commission, Best Available Techniques Reference Document on the Textiles Industry, 2003

17. Chaitanna Sarkar & Muhammad Abdur Rashid,(2021) "Estimation of Scouring Effect on Cotton by Varying Concentration of Caustic Soda" (https://textilelearner.net/estimation-of-scouring-effect-on-cotton/)

18. Yarn (http://www.madehow.com/Volume-3/Yarn.html#ixzz77Mc4Lv5q)

19. Degani, O. Synergism between Cutinase and Pectinase in the Hydrolysis of Cotton Fibres' Cuticle. Catalysts 2021, 11, 84. https://doi.org/10.3390/ catal11010084

20. Sweety Shahinur, Mahbub Hasan, Qumrul Ahsan, Dilip Kumar Saha, Md. Saiful

Islam, "Characterization on the Properties of Jute Fibre at Different Portions",

International Journal of Polymer Science, vol. 2015, Article ID 262348, 6 pages,2015. https://doi.org/10.1155/2015/262348

21. Rana, Sohel & Pichandi, Subramani & Parveen, Shama & Fangueiro, Raul. (2014). Regenerated Cellulosic Fibres and Their Implications on Sustainability. 10.1007/978-981-287-065-0_8.

22. Textile Apex – a guide to textile and fabric (https://textileapex.blogspot.com/2020/02/fibre-vs-yarn-vs-fabric-finddifferences.html)

23. Marczak Daria, Lejcuś Krzysztof, Misiewicz Jakub, "Characteristics of biodegradable textiles used in environmental engineering: A comprehensive review", Journal of Cleaner Production, Volume 268, 2020.

24. Best Available Techniques (BAT) Reference Document for the Textiles Industry, Section 8.2.5 Knitting oils

25. Methods of Heat Setting in Textile Industry (https://textilelearner.net/methods-of-heat-setting-in-textile-industry/)

26. Best Available Techniques in Textile Industry by Dr. Harald Schönberger,Gottenheim and Dr. Thomas Schäfer EnviroTex GmbH, Augsburg, pg 46

27. Yaseen, D.A., Scholz, M. Textile dye wastewater characteristics and constituents of synthetic effluents: a critical review. Int. J. Environ. Sci. Technol. 16, 1193–1226 (2019)

28. Water and Chemical use in the Textile Dyeing and Finishing Industry (GG62 Guide) (http://www.envirowise.gov.uk/uk.html)

29. Textile knowledge Printing (http://textileengg.blogspot.com/2015/12/printing.html)

30. Fabric Printing Methods by Gozia Z Cotton bee(https://ctnbee.com/blog/en/fabric-printing-methods-printing-technology-choose/

31. Boruah, Sunita & Kalita, Binita. (2016). Utilization of natural printing paste for textile

application. ASIAN JOURNAL OF HOME SCIENCE. 11. 136-141.10.15740/HAS/AJHS/11.1/136-141.

32. Lin L, Zhu W, Zhang C, et al. Combination of wet fixation and drying treatments to improve dye fixation onto spray-dyed cotton fabric. Sci Rep. 2021;11(1):15403. Published 2021 Jul 28. doi:10.1038/s41598-021-94885-z

33. Impact of Textile in Environmental Issues and Environmental Legislation (Part I) By: Karthik T. and Gopalakrishnan D.

34. Water efficiency in Textile Processes by New Cloth market (https://www.fibre2fashion.com/industry-article/3406/water-efficiency-in-textile-processe)

35. W.D. Schindler, P.J. Hauser, "Finishes to improve colour fastness", Chemical Finishing of Textiles (2004)

36. Chemical Technology in the Pre-treatment Processes of Textiles by S.R. Karmakar

37. Scouring agent by NICCA(https://nctexchem.com/product/process/preparation/scouring/)

38. Pretreatment of Textile Substrates by Mathews Kolanjikombil

39. Bleaching of Blended fibres)(https://textilelearner.net/bleaching-of-blended-fibre-fabrics/)

40. 4 steps to improve your reactive dyeing with pH monitoring by first source worldwide.LLP (https://www.fsw.cc/ph-monitoring-improve-reactive-dyeing/)

41. Peavy et al., 1985

42. Su et al., 2012; Kim and van der Bruggen, 2010; Lu et al., 2009; Zodrow et al., 2007; Bae and Tak, 2005

43. Metcalf and Eddy, 2013

44. Textile Industry Effluent Treatment Techniques, Journal of Chemistry · July 2021

45. Management System Standards by ISO (https://www.iso.org/management-system-standards.html)

46. greenmark.co.uk

47. IEMA – Transforming the world to sustainability(https://www.iema.net/)

48. Environmental management systems for the textile industry : A case study (Indian Journal of Fibre A Textile Research Vol.26. March-June 2001. pp. 33-38)

49. Strategic Management and Business Policy Globalization, Innovation and Sustainability

50. Munksgaard, Jesper & Wier, Mette & Lenzen, Manfred & Dey, Christopher. (2005). Using Input-Output Analysis to Measure the Environmental Pressure of Consumption at Different Spatial Levels. Journal of Industrial Ecology. 9. 169 - 185.10.1162/1088198054084699.

51. Motor soft starter(https://en.wikipedia.org/wiki/Motor_soft_starter#cite_note-Siskind-1)

52.Continuous Dyeing Method by abu sayed (https://textileapex.blogspot.com/2015/02/continuous-dyeing-method.html#:~:text=It%20involves%20immersion%20of%20the,used%20in%20continuous%20dyeing%20process)

53. Pad-Steam Dyeing Process/Machine(https://textileinsight.blogspot.com/2014/08/pad-steam-dyeing-machineprocess.html)

54. Best Available Techniques in Textile Industry by Dr. Harald Schönberger and Dr. Thomas Schäfer

55. Alternative and Emerging Technologies for an Energy Efficient, Water Efficient, and Low Pollution Textile Industry by Ali Hasanbeigi

56. Ultrasonic system for continuous washing of textiles in liquid layers, Ultrasonics Sonochemistry 17(2010)234–238

58. J. Beringer, J. Kurz, In Handbook Of Medical Textiles, 2011

59. Alwadani, Nora & Fatehi, Pedram. (2018). Synthetic And Lignin Based Surfactants: Challenges And Opportunities. Carbon Resources Conversion. 1. 10.1016/J.Crcon.2018.07.006

60. Dorugade, V.A.. (2009). Surfactants In Textile Processing. Colourage. 56. 39-46.

61. An easy guide to understanding how surfactants works by international products (Https://Www.Ipcol.Com/Blog/An-Easy-Guide-To-Understanding-Surfactants/)

62. Timma, Lisa & Lewald, Laura-Isabell & Gier, Franziska & Homey, Lisa & Neyer, Christian & Nickisch-Hartfiel, Anna & Gutmann, Jochen & Oberthür, Markus. (2019). Nonfouling Textiles With Tunable Antimicrobial Activity Based On A Zwitterionic Polyamine Finish. Rsc Advances. 9. 9783-9791. 10.1039/C8ra09975h

63. Thiele, Björn. (2005). Surfactants. 10.1201/9781420027983.Ch30.

64. Jardak K, Drogui P, Daghrir R (2016) Surfactants In Aquatic And Terrestrial Environment: ccurrence, Behavior, And Treatment Processes. Environ Sci Pollut Res 23:3195–3216.

65. Thiele, Björn. (2005). Surfactants. 10.1201/9781420027983.Ch30.

66. Rick A. Porterjames M. Self, (Https://Patents.Google.Com/Patent/Us5397483a/En)

67. Best sizing chemical for textile (https://www.polyestermfg.com/what-is-the-best-sizing-chemical-for-textile/)

68. Textiles Auxiliaries And Chemicals With Processes & Formulations by EIRI Consultants and Engineers

69. Advanced Textile Testing Techniques

70. An Introduction to Textile Coloration: Principles and Practice by Roger H. Wardman

71. Pigments by Textile knowledge(http://textileengg.blogspot.com/2015/12/pigments.html)

72. Types of ink for digital textile printing by CIBITE (https://www.cibitex.it/types-of-ink-for-digital-textile-printing/)

73. Digital Textile Printing by TEX India enterprise private limited (http://texindia.in/digital-textile-printing-services/digital-textile-printing/index.html)

74. Process control in textile manufacturing, Edited by Abhijit Majumdar, Apurba Das,R.Alagirusamy and V. K. Kothari

75. Digital Printing On Fabric (https://www.hollyflower.com/digital-printing-on-fabric)

76. Digital Textile Design Second Edition by MELANIE BOWLES AND CERI ISAAC

77. Digital Textile Printing – The Technology and Production Processes by Prasanta Sarkar (https://www.onlineclothingstudy.com/2018/03/digital-textile-printing-technology-and.html)

78. Drop on Demand printing by Engineered Printing Solutions(https://epsvt.com/what-is-drop-on-demand-printing/)

79. Digital Printing And Sustainability by Epson Italia – For.Tex – F.lli Robustelli, November 2017

80. Process control in textile manufacturing, Edited by Abhijit Majumdar, Apurba Das, R. Alagirusamy and V. K. Kothari

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

giz Country Office New Delhi, 46, Paschimi Marg, Vasant Vihar, New Delhi 11 00 57 India



International Co-operation for the Textile BREF of Gujarat

For over 60 years, the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, has been working jointly with its partners to develop effective solutions that offer people better prospects and sustainably improve their living conditions.

The textile industry, a cornerstone of Gujarat's economic landscape, plays a pivotal role in the State's growth and prosperity. Recognising the importance and need of energy efficient and environment-friendly technologies in the textile sector, a Joint Declaration of Intent (JDI) was signed between the Gujarat Pollution Control Board (GPCB), Umweltbundesamt (UBA) and GIZ during the Vibrant Gujarat Summit 2013 to initiate the process of drafting the Best Available Techniques (BAT) Reference Document for the Textile Industry of Gujarat.

The Best Available Techniques (BAT) Reference Document for the textiles sector serves as a guide to the industry and likewise to the regulatory agencies for enhancing the environmental performance of the textiles industry in Gujarat. This collaborative effort of GPCB, UBA, and GIZ promotes the vision of environmentally sustainable practices within the textile industry. The collaboration highlights the effectiveness of combining local best practices with proven international processes, fostering a holistic approach to environmental management in Gujarat's textile sector.

We would like to express our sincere appreciation to the Gujarat Pollution Control Board (GPCB), Umweltbundesamt (UBA), the Gujarat Cleaner Production Centre (GCPC), the Technical Working Group (TWG) members and other key stakeholders involved in the collaborative endeavor to successfully bring out this Best Available Techniques (BAT) Reference Document for the textiles sector in Gujarat.

Mr. Raghu Babu Nukala
Programme Director
Best Available Techniques for Selected Industry Sectors
Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

January 2024

German Development Cooperation
Best Available Techniques for Selected Industry Sectors

Raghu Babu Nukala
Programme Director

1st Floor, B-5/1, Safdarjung Enclave
New Delhi-110029
India

T +91 11 4949 5353 Extn. 1160
F +91 11 4949 5391
nukala.raghu@giz.de

Your reference
Our reference BAT/
Date 05 January 2024

Deutsche Gesellschaft für
Internationale Zusammenarbeit (GIZ) GmbH

Registered offices
Bonn and Eschborn, Germany

Friedrich-Ebert-Allee 32 + 36
53113 Bonn, Germany
T +49 228 44 60-0
F +49 228 44 60-17 66

Dag-Hammarskjöld-Weg 1 - 5
65760 Eschborn, Germany
T +49 61 96 79-0
F +49 61 96 79-11 15

E info@giz.de
I www.giz.de

Registered at
Local court (Amtsgericht)
Bonn, Germany
Registration no. HRB 18384
Local court (Amtsgericht)
Frankfurt am Main, Germany
Registration no. HRB 12394

Chairman of the Supervisory Board
Jochen Flasbarth
State Secretary in the Federal Ministry for
Economic Cooperation and Development

Management Board
Thorsten Schäfer-Gümbel (Chair)
Ingrid-Gabriela Hoven (Vice-Chair)
Anna Sophie Herken

GPCB

D. M. Thaker
Member Secretary

Gujarat Pollution Control Board
"Paryavaran Bhavan", Sector-10-A
Gandhinagar - 382 010, Gujarat



Acknowledgement

The Best Available Techniques Reference Document (BREF) for the Textile sector of Gujarat is developed by the Gujarat Pollution Control Board (GPCB) with support of Gujarat Cleaner Production Centre (GCPC), German Federal Environment Agency (Umwelt bundesamt-UBA), and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.

This Textiles-BREF has been developed in accordance with the functions of the State Pollution Control Board under The Water (Prevention and Control of Pollution) Act, 1974, and The Air (Prevention and Control of Pollution) Act, 1981 as amended till date.

GCPC was appointed by GPCB as the author of this reference document (BREF). The GCPC team, led by Dr. Bharat Jain, Member Secretary, included Mr. Hiren Bhendwal, Sr. Project Engineer, Mr. Kashyap Arya, Assistant Project Engineer, and Ms. Anjali Pala, Assistant Project Engineer. The preparation of the document included conducting sensitization workshops, industry visits, data collection and analysis, writing, editing, and formatting of the entire document.

GIZ India's BAT Project, headed by Mr. Raghu Babu Nukala, Programme Director, supported the preparation of the document by providing technical inputs, and sharing knowledge and expertise on the participatory information exchange among stakeholders and the process-oriented approach adopted by GPCB. GIZ also engaged an international consultant, Dr. Harald Schoenberger, to provide technical support to GPCB and GCPC for data collection and analysis and identification of BATs.

Under the able guidance of Dr. Bettina Rechenberg; Ms. Almut Reichart, Ms. Brigitte Zietlow, senior officials from UBA contributed significantly to the internal discussions *and Technical Working Group (TWG) meetings and information exchange sessions*

E-mail : ms-gpcb@gujarat.gov.in., membersecretarygpcb@gmail.com
Tel. : (o) 079-23262703, Website : http//gpcb.gujarat.gov.in

for the development of this document; as well as supporting the GPCB throughout during the preparation of this document.

Representatives from Government organizations, textile industries, environmental non-governmental organizations and academia contributed valuable information towards the preparation of the BREF. This was predominantly accomplished through the representatives of the TWG appointed by GPCB.

The Gujarat Pollution Control Board (GPCB) team provided significant contributions and peer reviewed the reference document. Additionally, Mr. Niraj Shah – Environment Engineer and his team has also overall coordinated the preparation of the document.

I appreciate and acknowledge efforts of all who have been directly or indirectly has contributed for this BREF document first of its kind in the Country.

D. M. Thaker.

D. M. Thaker
Member Secretary

Dr. Bettina Rechenberg
General Director of Department of sustainable Production, sustainable Products and circular economy, UBA



Copyright: Susanne Kambor, Umweltbundesamt.

Acknowledgement

A high share of the industrial production for the European market takes place in India - which is connected with high environmental impacts. As an authority committed to the protection of people and environment, German Environment Agency (UBA) has a major interest to reduce these impacts.

Therefore, I am very pleased about the long-term cooperation on the introduction of technology-based environmental standards in the textile industry through a participatory exchange of information between authorities, affected industry and civil society.
We experienced a very fruitful long-term cooperation in the field of BAT and the enormous efforts of the Indian partners, the Gujarat Pollution Control Board (GPCB), the Gujarat Cleaner Production Center (GCPC) and all members of the Technical Working Group (TWG). As an exceptional result of the information exchange on BAT between all the stakeholders the Best Available Techniques Reference Document for the Textile Industry of Gujarat was developed. This document is the first of its kind for all over India. So, in the process for the national Textile BREF, Gujarat is a frontrunner. All federal states play a central role in the implementation of national and international environmental goals.

The development of the BREF was a complex consensus building process but it is worth it, because the intensive information exchange with stakeholders and focus on applicability will lead to higher acceptance and overall implementation of environmental standards.
The focus on integrated solutions will improve the efficiency of installations and also of product quality and therefore lead to better competitiveness of the textile industry.

We would like to express our great respect and appreciation for the efforts of all those who have contributed to this process. We are looking forward to continue our collaboration for the implementation of BAT and for new BREF processes for other relevant industrial sectors of Gujarat.



Dr. Bettina Rechenberg
General Director of Department of sustainable Production, sustainable Products and circular economy, UBA

In co-operation with:

On behalf of:

Federal Ministry
for the Environment, Nature Conservation,
Nuclear Safety and Consumer Protection

of the Federal Republic of Germany

ENVIRONMENTAL made PROTECTION in Germany

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Umwelt Bundesamt

RECYCLE GCPC REUSE



Gujarat Pollution Control Board

Paryavaran Bhavan, Sector-10A,
Gandhinagar-382010.
Phone : (079) 2323 2152
Website: https://gpcb.gujarat.gov.in/