WASTEWATER MANAGEMENT STUDIES IN TEXTILE PROCESSING

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CERTIFICATE

Certify that the thesis entitled **"Wastewater Management Studies in Textile Processing"** which is submitted by **Mr. Harpreet Singh**, in fulfillment of the requirement for the award of degree of **Doctor of Philosophy** in the School of Energy and Environment, Thapar University, Patiala, is a record of candidate's own original and independent research work carried out by him under my supervision and guidance. The matter embodied in this thesis has not been submitted in part or full to any other university or institute for the award of any degree.

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DECLARATION

I hereby declare that the research work presented in this thesis entitled **"Wastewater Management Studies in Textile Processing"** submitted for the award of the degree of Doctor of Philosophy in the School of Energy and Environment, Thapar University, Patiala is an authenticated record of my own research work carried out under the supervision of Dr. Akepati Siva Reddy, Associate Professor (School of Energy & Environment) and refers other researcher's work are duly listed in the reference section.

The matter presented in this thesis has not previously been submitted in part or full to any other university or institution for the award of any degree in India or abroad.

(Harpreet Singh)

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LIST OF PUBLICATIONS

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ii. **Harpreet Singh** and Akepati Siva Reddy (2014). Recycling of textile dyebath wastewater using membrane processes. In Proceedings of Third International Conference on Recycling and Reuse of Materials (ICRM 2014) by IIUCNN, MG University, Kottayam, Kerala and Wroclaw University of Technology, Poland at Kottyam (Kerala) **India**, 11-13 April 2014; Full Paper in CD ROM.

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iv. **Harpreet Singh** and Akepati Siva Reddy (2018). “Textile dyebath decolourization using pressure driven membranes: an integrated sustainable approach” at International Conference on Sustainable Technologies for Intelligent Water Management , at Department of Water Resources Development and Management, Indian Institute of Technology, Roorkee, Uttarakhand, **India**.

ABSTRACT

The textile processing industry has the importance of its own, being one of the basic needs of society. Textile processing industries are water, chemical, and energy intensive industries concerned with the dyeing, printing and finishing of textiles using various dyes, dye auxiliaries, chemicals etc. These industries generate high quantity and highly polluting wastewaters having the non-exhausting auxiliary chemicals. Mixing of this wastewater with other textile processing wastewaters makes the wastewater treatment very difficult and costly, and compliance with the applicable effluent standards almost impossible. Further, this mixing reduces the recycle and reuse potential of the treated effluents. Segregation and handling of the dye bath dump separate from the other wastewaters has been considered as an appropriate solution to the problem in this study.

The objective of this research was to suggest the strategies for the wastewater management and to develop the treatment technology for textile processing industries. This was achieved through an extensive literature review and reconnaissance visits to textile processing industries. The study was conducted to perform the critical analysis of water and wastewater management practices of the industrial unit, and understanding the merits and limitations of the management practices currently in practice. A few selected streams of water and wastewater (depending on the need for the characterization) were sampled and analysed.

An integrated and multimedia approach, wherein due importance is given to the USEPA's hierarchy of waste management was followed for the conceptualization and development of the water and wastewater management model. The process modifications to conserve water, energy and chemicals and to minimize wastewater generation were outlined respectively with each type of the fabric, fiber and yarn processed in the respective processing industries. The environmental inputs/outputs (process water requirements, chemical consumption, water

consumption, steam consumption, wastewater generation etc.) was listed accordingly in this research. In-plant measures and strategies have been identified to have the potential to conserve water and minimize wastewater generation. This study presents and compared the actual scheme and the modifying scheme of the textile (Cotton, polyester and acrylic: - fabric, fiber and yarn) processing steps and evaluates the reduction in the water, steam, chemicals consumption and wastewater generation. The reduction in process water and the steam requirement for Industry-I was estimated to 73.6 % and 23.1 % respectively. The reduction in wastewater generation was 71.6 %. The reduction in process water and the steam requirement for Industry-II was estimated to 31.1 % and 3.05 % respectively. The reduction in wastewater generation was 31.5 %.

In the second part of study pre-treatment technologies was evaluated and developed for selected critical wastewater streams (sulphate rich wastewater, chloride rich wastewater and softener application wastewater). The coagulation and flocculation process was tried using factorial experimental design as per CCD and it was concluded that alum (500 mg/L) was the better option for achieving the color and turbidity removal efficiency of 89.6 % and 95.7 % respectively when pH was adjusted in between 5.5 to 6.0.

In the electrolytic treatment of sulfate-rich textile dyebath wastewater using RSM, four electrode combinations viz. Fe–Fe, Fe (Anode)–Al (Cathode), Al–Al, and SS–SS was tried. Iron electrodes were found superior to the aluminium electrodes. Best results of 74% COD removal and 95% colour removal were observed with iron electrodes at 12 volts for 15 minutes duration. Power consumption was 168 KWh/m^3. The chloride rich textile dyebath wastewater was treated efficiently with iron electrodes. At 12 V and 15 min. treatment time, the maximum removal efficiency of 98.8 % for color was observed with sludge generation rate of 22.7 g/L at the current density of 2598.98 A/m^2 with power consumption of 196 KWh/m^3. ANOVA model was significant with Fe-Fe electrodes and optimized process

conditions are 1 V and 8.2 min. to achieve 96.6 % color removal efficiency with only 0.46 g/L of sludge generated and TOC removal efficiency of 69.5 %.

The membrane processes (MF, UF and NF) was used to treat textile cotton dyebath wastewater rich in sulphate. The dyebath wastewater with high values of chemical oxygen demand (1573.5 mg/L) and total dissolved solids (~21 gpl) was first segregated from the dyeing processing as dyebath and treated separately using pressure driven membranes in the batch process. The chemical oxygen demand and color removal efficiencies were 97.6% and 98.9% respectively after Nano-filtration (NF) treatment. The 80% of the dissolved solutes were recovered in retentate feed of NF, which can be used in the reconstitution of dyebath. The effectiveness of the microfiltration and ultrafiltration membrane separation techniques in treating softener wastewater was also tried in this study. The Turbidity and Total suspended solids removal efficiencies were 77.8 % and 87.5 % in cotton softener application wastewater and 90.9 % and 80 % in polyester softener application wastewater respectively with MF and UF membrane processes. The outcome of this research can provide the comprehensive information regarding wastewater management and development of treatment technology in the textile processing industry.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

Abbreviations		**Word(s)**
ACF	-	Activated Carbon Filter
ANOVA	-	Analysis of Variance
AOX	-	Adsorbable Organic Halides
APCD	-	Air Pollution Control Device
APHA	-	American Public Health Association
ASP	-	Activated Sludge Process
BAF	-	Biological Aerated Filters
BAT	-	Best Available Techniques
BOD	-	Biological Oxygen Demand
C.I.	-	Color Index
CCD	-	Central Composite Design
COD	-	Chemical Oxygen Demand
CRWW	-	Chloride Rich Wastewater
CSAWW	-	Cotton Softener Application Wastewater
CW	-	Cooling Water
DC	-	Direct current
DG	-	Diesel Generator
DM	-	Demineralised Water
DSA	-	Dimensionally Stable Anode
EC	-	Electrocoagulation
EPI-DMA	-	Epichlorohydrin-Dimethylamine

ETP - Effluent Treatment Plant

F/M - Food to Microorganism ratio

FBR - Fluidized Bed Reactor

FD - Force Draft

FMT - Flash Mixing Tank

FY - Financial Year

GAC - Granular Activated Carbon

GAC-SBR - Granular Activated Carbon-Sequencing Batch Reactor

HRT - Hydraulic Retention Time

HRU - Heat Recovery Unit

HTHP - High Temperature High Pressure

ID - Induced Draft

LT - Low Tension

MBBR - Moving-Bed Biofilm Reactors

MEE - Multiple Effect Evaporator

MF - Microfiltration

NF - Nanofiltration

PC - Polyester-Cotton

PDMDAAC - Polyimethyldiallylammonium Chloride

PEI - Polyethyleneimine

PFC - Polyferric Chloride

PSAWW - Polyester Softener Application Wastewater

PSEB - Punjab State Electricity Board

PU-DSCM - Polyurethane-Dyeing Sludge Carbonaceous

Material

PVC - Polyvinyl Chloride

PVDF - Polyvinylidene Difluoride

RBC - Rotating Biological Contactor

RFD - Ready For Dyeing

RFT - Right-First-Time Approach

RO - Reverse Osmosis

RSM - Response Surface Methodology

RW - Recycled Wastewater

SBR - Sequencing Batch Reactor

SDB - Sludge Drying Beds

SEM - Scanning Electron Microscopy

SEP - Solar Evaporation Pond

SMBR - Submerged Membrane Bioreactor

SRT - Sludge Retention Time

SRWW - Sulphate Rich Wastewater

SS - Suspended Solids

TDS - Total Dissolved Solids

TE - Treated Effluent

TKN - Total Kjehldahl Nitrogen

TMP - Trans Membrane Pressure

TOC - Total Organic Carbon

TS - Total Solids

UASB - Up-flow Anaerobic Sludge Blanket Reactor

UF - Ultrafiltration

USD	-	United States Dollars
USEPA	-	United States Environmental Protection Agency
VRF	-	Volumic Reduction Factor
VSS	-	Volatile Suspended Solids
WPA	-	Water Pinch Analysis
ZLD	-	Zero Liquid Discharge

LIST OF UNITS

Units		**Word(s)**
%	-	Percent
µS/cm	-	Microsiemens per centimetre
A	-	Ampere
A/m^2	-	Ampere per square metre
cfm	-	Cubic feet per minute
g/Kg	-	Gram per kilogram
gpl	-	Gram per litre
kDa	-	Kilo daltons
Kg/Batch	-	Kilogram per batch
Kg/cm^2	-	Kilogram per square centimetre
Kg/day	-	Kilogram per day
kPa	-	Kilo pascal
kVA	-	Kilo-volt-ampere
KWh/m^3	-	Kilowatt hour per cubic meter
L/Kg	-	Litre per kilogram
lb/inch^2	-	Pound per square inch
LPM	-	Litre per minute
m^3	-	Cubic metre
m^3/day	-	Cubic metre per day
m^3/ton	-	Cubic meter per ton
mg/cc	-	Milligram per cubic centimetre
mg/L	-	Milligram per litre

mS/cm	-	Millisiemens per centimetre
NTU	-	Nephelometric turbidity units
^{o}C	-	Degree celsius
ppm	-	Parts per million
Pt. Co.	-	Platinum cobalt units
TPH	-	Ton per hour
V	-	Volt

CHAPTER 1

INTRODUCTION

It deals with the textile consumption as well as the concerns related with the textile processing industries in brief. It also includes the research problem, pollutants in wastewater, emphasizing on pollution prevention practices and the objectives of the present work.

1.1 BACKGROUND

Indian textile industry is one of the emerging as well as leading textile industries in the world, producing about 14% of world's share of textile fibres and yarns. It is projected to reach USD 226 billion by 2023 from USD 137 billion in 2016, exports will also increase to USD 82 billion by 2021 from USD 39.66 billion in 2016 (*Source- Ministry of textiles, Make in India, Technopak, TechSci Research*). As, India's population will touch 1.34 billion by the end 2019, as compared to 1.28 billion in 2015, it increases the textile consumption in the country. The fabric production increases from 52,665 million square meters in FY07 to 64,775 million square meters in FY17. The Fig.1.1 depicts the fabric production (million square meters) for cotton, non-cotton and blended fabrics.

Textile processing is water, chemical and energy intensive industries. The major concern for the wet processing industries is the rapid receding of ground water table which adversely affects the ecological balance. Textile processing industry is concerned with the dyeing and printing, and finishing of textiles (fibre/ yarn/fabric/garment). Dyes and chemicals (such as, sodium sulfate/sodium chloride, sodium hydroxide, sodium carbonate, sodium sulfite, sodium hydro-sulfite, acetic acid, hydrogen peroxide, etc.) and other substances (like leveling agents, wetting agents, anti-creasing agents, stabilizing agents, etc.) are extensively used in the textile processing and are major pollutants of wastewater.

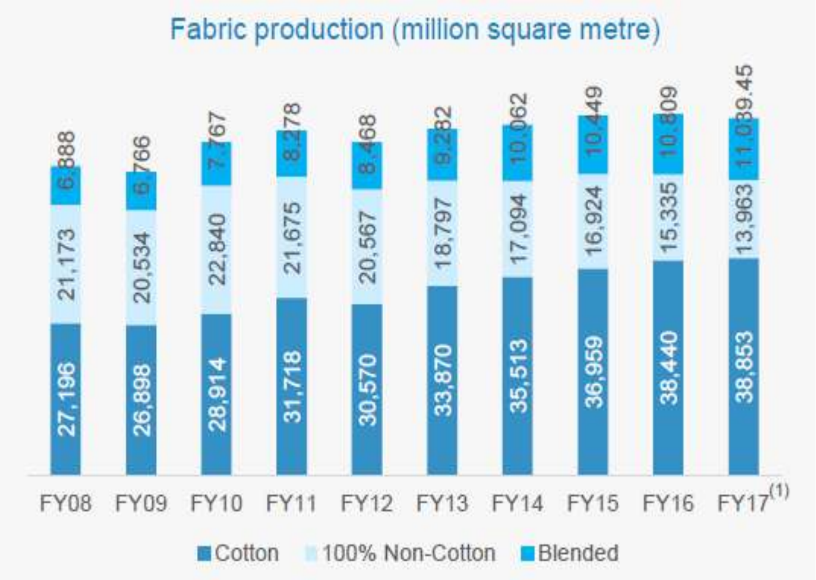


Fig. 1.1- Fabric production in million square meters, (1) FY 17 till March 2017

(Source: Ministry of Textiles, TechSci Research, 2017)

Textile processing involves a series of steps (Shamey and Shim, 2011). And, each of the steps involves filling water, dosing dyes and/or chemicals, heating to facilitate process reactions, cooling & washing, draining out the liquid and proceeding with the next step of processing. Requirements of cooling water and saturated steam are thus also quite high in the textile processing. Textile processing generates highly polluting wastewaters (Bisschops and Spanjers, 2003). Pollutants important in the textile processing wastewaters are high/low pH, high TDS levels, intense colour, BOD/COD, sulfides and sulfites, phenolic compounds, etc. Quantities of wastewater generated are also quite high (upto 120 L/kg of the textile processed and even more).

Textile processing industries find treatment of its wastewaters in compliance with the applicable discharge standards, quite difficult and costly. Treatment especially for TDS removal has become a major challenge to the industry. The main environmental concern of the textile industry is the amount of water used. Textile industry every year releases more than 0.2 million of tons of salts in the environment. More than 7000 different compounds and additives are used for the preparation of the textile materials, and up to 1 kg of these substances are used for each kilogram of fabric processed (Hessel, 2007).

Discharge of textile processing wastewater is proving quite damaging to the environment. In the face of this, regulatory agencies are demanding the industry to go for zero effluent discharge and sometimes pressing them to close down the textile processing operations. Further, establishment of new industrial units and expansion of the existing units are very much discouraged.

Wastewater management in the textile processing industries may have to give emphasis on source reduction and pollution prevention plans/practices by conceptualization and development of a water and wastewater management model making water reuse more prevalent.

1.2 STUDY AREA AND RESEARCH PROBLEM

Ludhiana (30.91°N 75.85°E), Manchester of India, is one of the textile hub, was chosen as study area to undertake this research. The Textile industries in Ludhiana use natural fibres (cotton, silk, jute and wool), artificial fibres (polyester, viscose, nylon and acrylic) and blended fibres (polyester-cotton) for making yarns and fabrics. These industries therefore, produces various types of garments like- Shirts, trousers, socks, shawls, t-shirts, track suits, jersey, under-garments, jeans, turbans, bed-sheets, curtains, baby-dresses, mufflers, jackets etc. In manufacturing and processing the same, different environmental concerns are associated, as these undergo various wet and dry textile processes. Raw water, steam, chemicals consumption and generation of wastewater, sludge gives more emphasis on pollution prevention and water/wastewater management at point of source.

Textile industries generate at least three types of wastewaters: core textile process wastewaters; wastewaters from supporting processes and activities (process water, soft water, DM water plants; cooling water systems, boilers and steam systems, etc.), and wastewater from domestic water use in the amenities. Some of the wastewaters generated have recycle-reuse and resource and by-product recovery potentials. Such wastewater can be segregated and reused (either directly or after needed pre-treatment) or resources and by-products can be recovered from them. However, nothing much is reported on the segregation and recycling and reuse of textile processing industry wastewaters.

Typical points of attention includes the following-

- Wastewater segregation
- Recycle and reuse of high- volume wastewater
- Treatment processes for hard to treat wastewaters
- Environmental concerns associated with machinery
- Optimizing housekeeping techniques

Wasteful use of water, immense heating and cooling requirements, generation of immense quantities of wastewater has also been the problems associated with the textile processing industry. Small scale batch operations are also contributing to the problems being faced. Development of the effective strategies for wastewater treatment and management that identifies and considers the above mentioned key problems has been the research problem of this Ph.D. work.

1.3 SIGNIFICANCE AND OBJECTIVES OF THE RESEARCH

1.3.1 Significance in Research Area

In the light of the research problem, the approach following the combination of various wastewater management key elements focussing various types of medium like-raw water, wastewater, dyebath, cooling water, steam, thermic fluid etc (integrated multimedia waste management) in the textile (cotton, polyester and acrylic) processing industry is proposed here under the Ph.D. program. USEPA's waste management hierarchy, (Jeremy and O'Brien, 2008) wherein extra emphasis will be on waste minimization through source reduction and through recycling and reuse of wastes, water conservation and consistent and cost-effective compliance with the applicable effluent standards have also been focused. The present study helps in conceptualization and development of the water and wastewater management model for textile processing industries. Efforts were also made to keep the conceptualized/developed model very generic and implementable in any textile processing industrial unit.

1.3.2 Gap in the Research Area

End-of-pipe treatment approach has been used for the management of wastewater in textile processing industry. This approach has not been very successful. Wastewater generation rate continues to remain high. Treatment of color has not been proving cost effective. TDS in the wastewater has also continued to remain a major challenge. Adopting an integrated multimedia approach for waste management though felt very essential has been rarely adopted.

Pollution prevention approach with emphasis on USEPA's waste hierarchy is widely believed as quite appropriate. But the approach has been rarely adopted by textile processing industry. Potential for source reduction and for waste minimization through waste recycling and reuse and recovery of resources from wastes have not been sufficiently studied. And, wherever studied, the efforts have been sporadic and mostly involved membrane processes for the recovery and reuse of treated wastewater. High working pressures, significant energy consumption, high costs of membrane, relatively shorter membrane life, limit the use of these techniques in the dye-house effluent management.

Washing and rinsing operations are the major wastewater generating operations in textile processing. Still optimization of these operations with the objective of waste minimization has not been taken seriously (Moore and Ausley, 2004; Kant, 2012). Biological decolourisation of wastewater has been a very active area of research. But, the stability of the microorganisms involved is doubtful, specially, in the presence of high concentrations of salt and frequent changes of the combination of dyes used in the dyeing process.

Treatment methodologies for textile industry wastewaters are sufficiently mature and well developed, but not very cost effective in removing the pollutants. Treatment is extremely expensive and associated with generation of large amount of secondary wastes such as ETP sludge. Segregation of the key contributing waste streams and handling them separately from the bulk wastewaters are believed to make wastewater treatment both feasible and cost effective. However, this segregation of critical waste streams and their separate treatment has not been clearly attempted (Holkar *et al*. 2016; Carmen and Daniela, 2012).

1.3.3 Objectives of the Research Work

Keeping in the mind, the gaps in the research area, objectives are as follows:

- To suggest strategies for the wastewater management
- To develop technologies for a few selected wastewater streams

1.4 ORGANIZATION OF THE THESIS

The thesis consists of five chapters:

Chapter 1 describes the research background, major concerns of textile processing industries, research problem, significance and objectives of the research.

Chapter 2 reviews the existing literature on textile dyeing process, wastewater generated, its treatment and disposal, strategies and approaches for wastewater management in textile processing, also identifies the gaps in the previous studies in context to the present research.

Chapter 3 details the materials used and methodologies adopted to achieve the objectives of the research work.

Chapter 4 presents the results for the environmental analysis, activities and processing of the textile industries. Strategies for the wastewater management were listed. A few selected streams of water and wastewater (depending on the need for the characterization) were sampled and the samples were analysed. The schematic process and material flow diagrams were developed for the water treatment and supply systems, boilers and steam supply (and condensate recovery) systems, cooling towers and circulating cooling water systems and wastewaters collection, treatment and disposal systems. The cotton textile dyebath effluents based on the moderating salts used were categorised into Chloride rich cotton dyebath effluents and Sulphate rich cotton dyebath effluents. Samples of the cotton dye bath effluents were collected and analyzed. The chloride rich cotton textile dye bath effluents were evaluated using coagulation-flocculation-settling and electroflocculation treatment technologies, and in case of sulphate rich effluents electroflocculation and membrane processes were used as pre-treatment technology. The treatment strategy was presented for the SRWW and CRWW. Experimental results obtained were presented and wastewater management model was conceptualized and developed in this chapter.

Chapter 5 summarizes and concludes the findings of the study.

References cited in the thesis are placed at the end.

CHAPTER 2

LITERATURE REVIEW

This chapter reviews the literature on the textile dyeing process including pre-treatment, the machinery and equipments used, wastewater, the treatment technologies and disposal, wastewater management in processing industries.

Review of literature has been carried out on the following aspects

- Textile dyeing process
- Wastewaters from textile processing
- Treatment and disposal of textile industry wastewaters
- Strategies and approaches for wastewater management
- Wastewater management hierarchy studies in textile processing industry

Sources surveyed: The literature review was carried out from sources like research papers published in peer reviewed journals, technical manuals published by USEPA and some related handbooks.

2.1. TEXTILE DYEING PROCESS

Prior to the actual dyeing the textile is usually subjected to certain pretreatment processes, such as, desizing, scouring, bleaching, mercerizing, carbonizing and fulling/milling (Bisschops and Spanjers, 2003). The dyed textile is often subjected to certain post-dye processes like mercerizing, softener and builder application, finishing etc.

2.1.1 Pre-treatment processes

During sizing, fibre is covered with a layer of polymer (Starch, carboxymethyl-starch, carboxymethyl-cellulose, polyvinylalcohols) in order to ensure that it withstands the mechanical stress during weaving. After weaving, prior to the processing, the size is removed through desizing through application of either acids or enzymes. Soaking in acid or enzyme results in the conversion of insoluble starch into soluble sugars or dextrins (Porter, *et al*. 1972; Holker, *et al.* 2016).

Scouring is a cleaning process and it involves removal of impurities like lubricants, water soluble sizes, dirt, oils and other natural materials from the fiber/yarn/fabric. Here, the textile is boiled in alkaline solution (NaOH) to saponify natural oils. Then surfactants are used to emulsify and suspend non-saponifiable impurities. Procedures, chemicals, temperature and time specifications for scouring vary with the type of textile (Kirsch, *et al*. 1979; Chatha, *et al.* 2017).

Bleaching involves chemical elimination of unwanted color from the textile. Several types of chemicals (bleaching agents), such as, hydrogen peroxide, sodium hypochlorite, sodium chlorite and sulphurous acid, are used in the bleaching process. For bleaching, first the textile is soaked with bleaching agents and then temperature is raised to recommended level. The bleached textile is then thoroughly washed and dried (Diehl, 1981; Farrell, *et al.* 2016; Yu, *et al.* 2017).

Mercerizing is a chemical process. It is used for cotton and cotton/polyester textiles to increase dyeability, luster and strength, and to improve appearance. The fabric is treated under tension with caustic solution, and then the textile is made caustic free by several washes with hot water (Johnston, *et al*. 1985; Zahid, *et al.* 2017).

Carbonizing is meant to remove grass bits, leaf particles and other cellulosic impurities from woollen textile (Wang *et al.* 2016). The woollen textile is passed through sulphuric acid bath and padded for carbonizing (Moyer, 1967).

Fulling/Milling is used for shrinking of woollen fabrics and thus making them denser. The process is carried out with hot solutions of soda ash or sulphuric acid in the presence of detergents and in conjunction with mechanical agitation (Chapin, 1961; Mojsov, 2017).

2.1.2 Textile dyeing

Dyeing is colouring of textiles (fibre/yarn/fabric/garment) by chemical or physical binding of dyes. Various types of dyes and processes are used in the textile dyeing which depends upon the type of textile being dyed and the end-product desired (Chequer, *et al.* 2013).

In batch dyeing, the textile is loaded into a dyeing machine to bring contact with a solution of dyes and several other auxiliary chemicals, and dye under controlled dyebath conditions (mainly temperature). Builder materials, like melanine or urea-formaldehyde resins, which impart crease resistance, and stabilizing agents, that improve softness are often applied to cellulosic fabrics during dyeing. Surfactants, like, alcohol ethoxylates, tertiary thiol ethoxylate, alkylbenzene sulphonates, cationic gemini surfactants, etc., are also applied during dyeing for lubricity and antistatic properties. The dyed textile is then washed (hot and cold with and without soap) and neutralized. Schoeberl, *et al.* (2004) reported the typical range of Dyes (15-50 g/Kg), Auxiliaries (45-150 g/Kg) and basic chemicals (50-280 g/Kg) from fiber finishing textile mill.

Woven fabric is mostly dyed on continuous dyeing ranges, whereas the Knitted fabric is mostly dyed in batch dyeing machines (knitted fabric reportedly cannot withstand the tension of the continuous dyeing range).

2.1.3 Textile printing

Textile printing involves application of dyes/pigments in the form of thick paste (using a variety of machinery and techniques) on the fabric or garment for colours and patterns, fixation of the applied dyestuff and washing off the excess and loosely held dye stuff (Clarke, 2013). The major types of printing are direct, warp, discharge, resist, jet and heat transfer printing. In the direct printing, smaller rollers containing the color are brought into contact with the spread and stretched fabric. In the warp printing, patterns are placed on the warp yarn prior to weaving. In discharge printing, which is usually done on garments, a special preparation ("discharge ink”) is used to remove color, and even replace color for obtaining the desired pattern. In resist printing, the patterns are applied by preventing color from penetrating certain areas during piece dyeing. Jet printing applies dye to fabric in continuous streams using applicator jets (Stempien, *et al.* 2015). In heat-transfer printing, the pattern is first printed onto a paper substrate, and then paper is positioned against the fabric and subjected to heat for the transfer of dyes to fabric through sublimation.

2.1.4 Post dyeing and finishing processes

Textile finishing is important especially in cotton and synthetic production for improving appearance and texture of the fabric after dyeing (Vigo, 2013). Softeners (polyethylene glycol, polyethylene oxide, reactive silicone, paraffin wax, etc.), abrasion-resistant finishes, etc. are added to the fabric for enhancing the ability to resist abrasion and tearing (Wahle, 2002). Other finishes include photo-protective agents, antioxidants, oil and water repellents, antistatic treatments, biological protectants and flame retardants. These chemical finishes are applied using padding machines the fabric is passed through finishing solution in between two padding rolls.

2.1.5 Machinery and equipment used in textile processing

Textile processing encompasses different stages, and specialized machinery and equipment may be used at each of the stages. Dyeing can be done at any stage of the manufacturing process (at fibre, yarn, fabric and garment stages).

Yarn dyeing is mostly done by any of the following three methods: skein/hank (cabinet dyeing), package (top dyeing) and beam dyeing (Ingamells, 1993). For large, bulky or delicate yarns, skein/hank dyeing is preferred. For dense, small and highly twisted yarns, package dyeing machine is preferred. In package dyeing, the yarn is wound onto perforated tubes and stacked on perforated rods and placed in pressurized tanks. In beam dyeing, yarn in open width is rolled onto perforated beam and the dye liquor is allowed to circulate through the perforations in the beam. The computational fluid dynamics study was performed by Karst, *et al.* (2004) which suggests placing the collars at 30% distance of winding height in beam dyeing machine under each side of fabric for uniformly distribution of dye.

Winch, jet and jig dyeing machines are used for the fabric. Woollen fabrics and occasionally cotton fabric are mostly dyed on winches. Many versions of jet dyeing machines (long tube and short tube jet dyeing machines, u-tube jet dyeing machines and soft-flow machines) are in use mostly for knitted polyester, polyester-cotton and cotton fabric dyeing. Jig dyeing machines are preferred for woven cotton fabric. Woven fabric is also dyed on continuous dyeing ranges.

Paddle dyeing machine is usually used for garment dyeing. The paddle circulates both the bath and garments in a perforated central island and the chemicals, water and steam for heat are added. Dyeing machines can also classified into two types: rope dyeing and open width dyeing machines. In the rope dyeing machines (e.g. Jet and winch dyeing machines), the fabric is transported through the machine in a loosely collapsed rope like form (Ozturk *et al.*

2016). In open width dyeing machines (jigs, padding, and continuous processing and dyeing machines), the fabric is maintained, all the time, in a flat and open condition.

Hydro-extractor is used to reduce the moisture content of the wet processed fabric/yarn for ease of drying. Here fabric/yarn is loaded in a well and closed from top, then with the help of a motor the loaded well is spinned for the centrifugal separation of liquid from fabric/yarn. In case of woven fabric, the fabric is passed through press rolls and then dried on drying ranges.

After hydro-dewatering, the fabric may be dried on a pole drier. In case of garments and yarn/fiber tumbler driers are used for drying. In case of the processed fiber cones drying is carried out in IR cone driers.

2.2. WASTEWATERS FROM TEXTILE PROCESSING

Textile processing involves a multitude of steps. Each of the steps usually involves taking the textile, water and chemicals in a processing machine, heating and holding the machine contents at desired temperature for desired duration for the processing to get completed, cooling to desired temperature, draining out the liquid as wastewater and then moving to the next step of processing. Hot or cold washing; with soap or without soap washing; neutralization (of the textile usually with acidic) and washing; etc., may also come as intervening steps during the textile processing. Even in these steps, the machine with the textile is filled with water and, after the washing or the neutralization-washing, the water is drained out as wastewater.

In case of the processing on continuous processing ranges, the textile is processed in a series of tanks (each representing a process step or a part of the process step). The tanks where processing is taking place, addition of water, processing chemicals, etc., and heating/cooling, of the contents will be taking place. The textile being processed while moving out of the tank will be dragging and carrying forward the processing chemical solutions to the next tank/tanks where rinsing/washing and/or neutralization-rinsing of the textile occurs. The rinse neutralization/rinse/wash tanks will be continuously overflowing and generating wastewaters.

Wastewaters generated by textile processing industry can be categorized as residual processing chemical solutions/liquors dumped from the processing machines and rinse/wash wastewaters. Many of the process liquor dumps are high strength, hard to treat wastewaters. These may contain dyes, salts, neutralizing organic acids, metals, phenols, surfactants, toxic organic compounds, etc. Rinse/wash waters are also contaminated by many of these contaminants but their concentrations are much lower. Use of hazardous/toxic materials for non-process applications also generates wastewaters. The constituents and the wastewater characteristics from various textile processing steps are showed in Fig. 2.1.

A survey conducted by Visvanathan, *et al*. (2000) in Thailand textile industries has shown 116-140 m^3/ton of fabric processed. For man-made fibers the wastewater generation was reported at 2.7- 27.4 m^3/ton. Main constituents of the textile industry wastewaters have been identified in the Manual of practice on “Industrial wastewater management, treatment and disposal”, 2008 (Water Environment Federation), as BOD, COD, Oil and Grease, pH, color, chromium, copper, zinc and sulphides. In addition to these, coarse suspended solids (lint, flock, fibers and yarns) have also been reported as present in the wastewaters. Analysis of articles for the parameters used in the monitoring of textile wastewaters by Bisschops and Spanjers (2003) have identified the following additional parameters: TDS, TOC, total phosphorus, TKN, conductivity, chloride, surfactants, alkalinity, sulfate, hardness, VSS, total solids, turbidity and AOX.

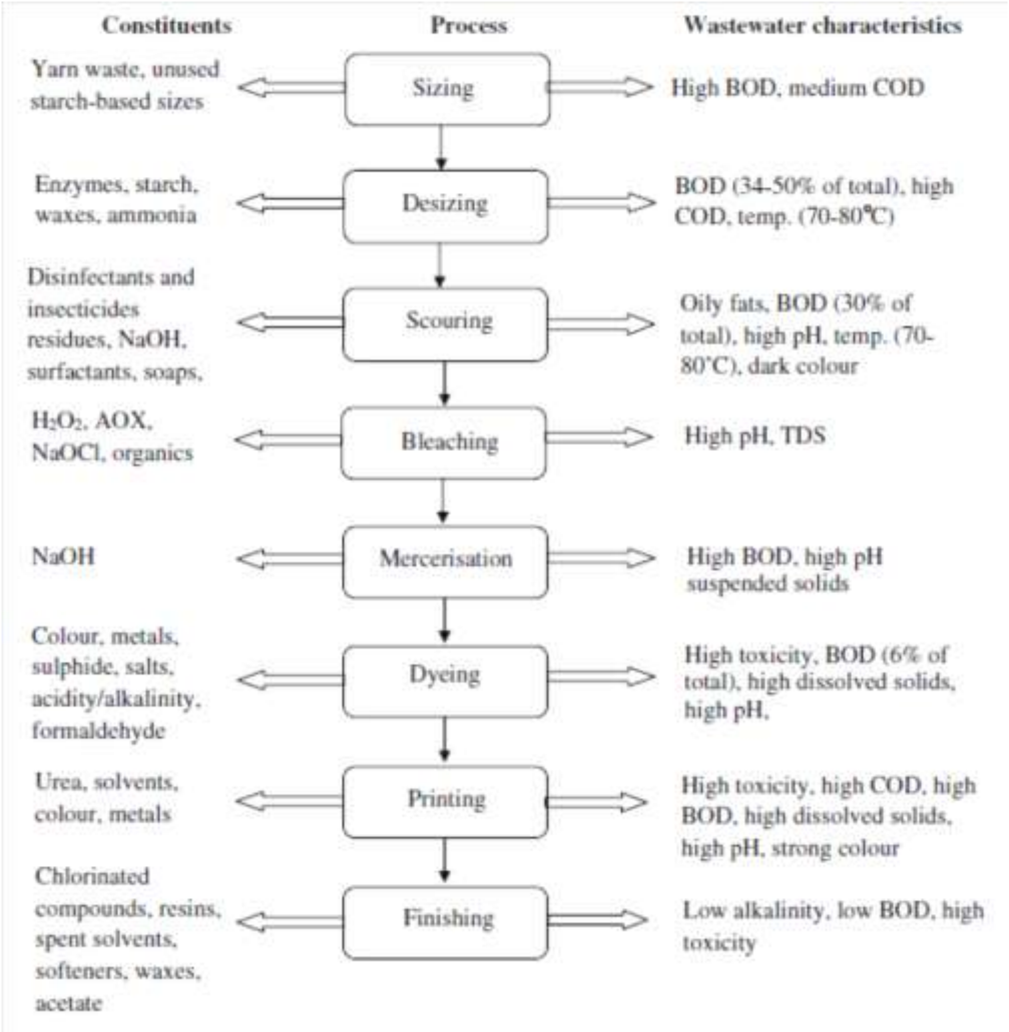


Fig. 2.1- The constituents and wastewater characteristics from various textile processing steps (Verma, *et al.*, 2012)

Correia, *et al.* (1994) reported the characteristics of wastewaters generated from different textile wet processing steps. Please see the details in Table 2.1. Volume of wastewaters generated from textile printing has been reported as quite low but often strong and may contain toxics. According to Kabdasli (2000), printing wastewaters have high COD (785 - 49170 mg/l), TKN (30 - 1765 mg/l), NH_3 (20 - 368 mg N/l), TSS (125 - 9500 mg/l) and pH (7.38 - 8.45). Adeniyi (2004) used mathematical models for predicting quantities of wastewaters and concentrations of pollutants discharged from textile industries. pH, alkalinity, iron, chromium, manganese, total dissolved solids, chloride, copper and zinc were used as parameters in the predictions through modeling.

Table 2.1- Characteristics of wastewaters generated from different textile wet processing steps

S.No.	Process	pH	BOD (mg/l)	TS (mg/l)	Water Usage (l/kg)
1	Desizing	---	1700-5200	16000-32000	3-9
2	Scouring	10-13	50-2900	7600-17400	26-43
3	Bleaching	8.5-9.6	90-1700	2300-14400	3-124
4	Mercerizing	5.5-9.5	45-65	600-1900	232-308
5	Dyeing	5-10	11-1800	500-14100	8-300

Results obtained were comparable with the experimental values (the percentage of deviation was between 0.16% and 1.52%). In a study by Soares, *et al.* 2017, the COD of polyester, cotton and polyester-cotton blend wastewater comes out to be 2530 mg/l, 1112 mg/l, 1450 mg/l respectively whereas, chloride content was 42 mg/l, 1900 mg/l and 1470 mg/l respectively. The effect of untreated textile wastewater (COD- 1129 mg/l, turbidity- 91 FTU, TDS- 4831 mg/l) onto soil carbon mineralization was investigated by Roohi, *et al.* 2016. The rinsing wastewater from pad batch machine having COD (186 mg/l), conductivity (568µS/cm) and color (2150 Pt.Co unit) treated with advance oxidation process was investigated by Güyer, *et al.* (2016). The alkaline wastewater having COD- 42 mg/l, color- 992 Pt. Co. Unit, Turbidity- 113 NTU was collected from a textile finishing industry located in the Yazd, Iran and treated using $FeCl_3$ –induced crude extract resulting in 89 % COD removal by Ramavandi and Farjadfard (2014). The effluent characteristics from a denim wet processing industry were presented in Table 2.2.

Table 2.2 Effluent characteristics from denim wet processing, garment washing and fabric dyeing (Ntuli, et al 2009)

Parameters (mg/L)	**Wet Processing Operations**		
	Denim wet Processing	**Garment Wash**	**Fabric Dyeing**
COD	10980	6470	14480
SS	625	95	221
Total Alkalinity	85	1585	3275
Chloride	680	4	11900
Sulphate	70	30	140
Phosphates	13	2	32

2.3. TREATMENT AND DISPOSAL OF TEXTILE INDUSTRY WASTEWATERS

Treatment of textile industry wastewaters is needed for complying with the applicable effluent standards and for making the wastewater compatible for disposal. Treatment may often be meant for making the treated effluent fit for reuse in the industry as process water in place of the raw water. The effluent standards prescribed in India (Standards for emission or discharge of environmental pollutants, Schedule – I, *The Environment (Protection) Rules, 1986*) indicate that the wastewaters should treated for the parameters pH, TSS, BOD_3 at 27^oC, oil & grease, bioassay, total Cr, sulfide, phenolic compounds, sodium absorption ratio, and residual chlorine. Limits are also specified for the quantity of effluent discharged (100, 250 and 80 L/kg product for composite cotton textile industry, composite woolen textile industry and textile processing industry respectively). Adverse environmental impacts from the disposal of the textile processing industry wastewaters indicate that the treatment should concentrate mainly on suspended solids, color, pH, temperature, heavy metals like chromium, sulfides, phenolic compounds, BOD, and toxicity. Disposal through recycling and reuse of the treated effluent may have to emphasize on the removal of TDS, chlorides and turbidity (and even the microbial count).

Treatment of textile processing industry wastewaters includes preliminary treatment (screening, equalization, grit removal, oil separation, etc.), primary (physicochemical) treatment, secondary (biological) treatment and tertiary (physicochemical and biological) treatment.

2.3.1 Primary treatment

Primary treatment mostly includes neutralization, precipitation, coagulation, flocculation and settling. Textile processing industry wastewaters are mostly alkaline in nature and contaminated with (toxic) dyes and colored. Suspended and colloidal solids concentrations are not very high in these waters. Primary treatment is most often concerned with the adjustment of pH and with the removal of colour. In quite a few cases, the strategy followed is adjust pH in the primary treatment, remove biodegradable organic matter during secondary treatment and go for colour removal during tertiary treatment.

Acid or alkali is added for the neutralization of the wastewaters. If colour is also to be removed, chemical precipitation, by alum, ferrous sulfate, ferric sulfate, ferric chloride, magnesium chloride, etc., in the presence of enough alkalinity and even dissolved oxygen, flocculation and settling is followed.

Alum as coagulant was used in the studies by Kumar, *et al.* (2008) and Golab, *et al.* (2005) to remove color from textile wastewater. $FeCl_3$ was used as coagulating agent in treatment of textile effluents in a study by Ali, *et al.* (2006). Patel and Vashi (2010) carried out the textile wastewater treatment by using activated charcoal as adsorbent and Alum, Ferric sulphate, Ferrous sulphate (more competent) as coagulant achieving more than 80 % of COD and

Color removal efficiency. Polysep3000 was found more suitable as compared with $Al_2(SO_4)_3$ and $FeCl_3$ for sludge production in a study by Aboulhassan *et al.* (2005) and tannic substances were used as natural flocculant. Chemical coagulation using Ferric chloride, alum, lime and calcium carbonate was used in treatment of textile wastewater in laboratory reactor by Altinbas *et al.* (1995). Composite flocculants (Fe-III flocculants and polydimethyldiallylammonium chloride - PDMDAAC) was compared and found more efficient in color removal than ferric chloride ($FeCl_3$), polyferric chloride (PFC) in a study by Wang *et al.* (2007). Coagulation followed by sedimentation by using lime and ferrous sulphate was studied by Abo-Elela *et al.* (1988). Inorganic coagulants ($FeCl_3.6H_2O$, Levafloc R and Colfloc 3915) and Polymeric flocculants were used to treat dye wastewater in a study by Koprivanac *et al.* (1993). Chen *et al.* (2010) investigated the color removal and floc aggregation in treatment of synthetic reactive red 24 and disperse yellow 201 wastewater by applying poly-ferric chloride dosing followed by organic polymeric coagulant-epichlorohydrin‑dimethylamine dual dosing (PFC/EPI‑DMA), this achieved higher color removal for synthetic disperse yellow wastewater.

Gao, *et al*. (2007) compared color removal from reactive and disperse dye wastewaters by different coagulants and found $MgCl_2/Ca(OH)_2$ as superior to $MgCl_2/NaOH$, $Al_2(SO_4)_3$, PAC and $FeSO_4/Ca(OH)_2$. Use of magnesium chloride for the removal of color has been reported by Tan (2000). $MgCl_2$ was reported to remove 90% of the color at 11 pH and COD and suspended solids were removed by 88% and 95% respectively. Lime and ferrous sulfate were used by Georgiou *et al.* (2003) for the colour removal from textile wastewater. Lime alone when used, removed color by 70–90% and COD by 50–60%. Treatment with ferrous sulfate and lime was found equally effective but 9.0±0.5 pH have to be maintained (pH was adjusted with lime). Alum and ferric chloride were used by Mo, *et al*. (2007), for the pretreatment of synthetic dyeing wastewater (composed of direct red dye, poly-vinyl alcohol, NaCl and

Na_2SO_4), and reported 90% removal under optimum conditions. Chu (2001) studied removal of dyes from textile dying wastewater through recycling the generated alum sludge and reported that it was a good way for removing especially hydrophobic dye. It also reduced the fresh alum dosage (to 2/3rd). However, for hydrophilic dyes, this method may not be appropriate. Bidhendi *et al*. (2007) select, $FeSO_4$ as optimum coagulant in color removal (because of its low dose requirement, maximum decolourization and minimum settled sludge volume) in comparison with Lime, $FeCl_3$ and $MgCl_2$. Birjandi *et al.* (2013) examine the efficiency of alum and PACl with C-PAM using CCD under response surface methodology and get 92% turbidity reduction and 97% COD removal.

2.3.2 Biological treatment

Secondary or biological treatment of textile wastewaters is meant mainly to remove BOD and also colour. Bacteria, fungi and algae have been tried in the biological treatment of the wastewaters especially for the colour removal. *Vibrio logei* and *Pseudomonas nitroreducens* (Adedayo, *et al*. 2004); *Proteus vulgaris* (Saratale, *et al*. 2011); *Bacillus sp.* (Dawkar, *et al*. 2010); *Shewanella putrefaciens* (Khalid, *et al*. 2008); Bacterial consortium consists of two isolates (BF1, BF2), both Gram negative cocci., and *Pseudomonas putida* (Senan and Abraham, 2004); *Streptomycetes* BW 130 (Zhou and Zimmermann, 1993); *Clostridium bifermentans* (Joe, *et al*. 2008); *Aeromonas hydrophila* (Chen, *et al*. 2003); *Pseudomonas sp*. SUK 1 (Kalyani, *et al*. 2008); *Exiguobacterium sp.* RD 3 (Dhanve, *et al*. 2008); *Pseudomonas aeroginosa* (Jadhav, *et al*. 2010); *Bacillus subtilis*, *Pseudomonas cepacia*, and *Pseudomonas stutzeri* (Yatome, *et al*. 1991); *Escherichia coli* (Chang, *et al*. 2000); SKB II Bacterial consortium consist of *Bacillus sp*. (Tony, *et al*. 2009); *Klebsiella pneumoniae* RS-13 (Wong, *et al*. 1996); *Halomonas variabilis* (Balamurugan, *et al*. 2011); *Chlorella pyrenoidosa* (Pathak, *et al.* 2015); *Bjerkandera adusta* and *Pleurotus eryngii* (Heinfling, *et al.*1997); *Nizamuddina zanardini* (Esmaeli, *et al.* 2013); *Enterobacter agglomerans*

(Moutaouakkil, *et al.* 2004); *Irpex lacteus* (Novotny, *et al.* 2011); *Aeromonas hydrophila, Klebsiella pneumoniae, Enterobacter cancerogenus, Proteus hauseri, Acinetobacter johnsonii* (Zhang, *et al.* 2010) etc. has been studied for the decolourization of textile wastewater.

White-rot basidiomycetes, *Phanerochaete chrysosporium* have been widely studied for their ability to degrade synthetic dyes (Fu and Viraraghavan, 2001; Reddy and Mathew, 2008; Tatarko and bumpus, 1998; Young and Yu, 1997; Pasti-grigsby, *et al*. 1992, etc.). Decolorization of *Trichoderma harzianum* WL1 laccase for synthetic dyes (Rhodamine 6G, Erioglaucine and Trypan blue) was evaluated by Sadhasivam, *et al*. (2009). *Aspergillus niger* (Fu and Viraraghavan, 2002; Khalaf, 2008); *Aspergillus fumigates* XC6 (Jin, *et al*. 2007); *Aspergillus lentulus* (Kaushik and Malik, 2013); *P. chrysosporium* K3 and *P. cinnabarinus* PB (Diwaniyan, et al. 2010); *Coriolus versicolor* (Knapp and Newby, 1999); *Myrothecum verrucaria* (Brahimi-Horn, *et al*. 1992); *Trametes versicolor* (Wong and Yu, 1999), *Aspergillus versicolor* (Tastan, *et al.* 2010) etc. were also found capable of dye decolorization.

Microalga, *Chlamydomonas sp.* (Khataee, *et al*. 2009); *Chlorella vulgaris* (Lim, *et al*. 2010); *Caulerpa lentillifera* (Marungrueng, *et al*. 2006); *Caulerpa scalpelliformis* (Aravindhan, *et al*. 2007), etc. are also able to remove dyes from textile wastewater. *Spirogyra sp.* (fresh water green algae) exhibited maximum dye removal efficiency of 85%, at pH 3, temperature 30^0C and 8 g/l (w/v) biomass conc., after 18 h contact time (Khalaf, 2008). In another study, biological decolourisation of two azo dye effluents (direct and reactive dye) were investigated using Spirogyra sp (Mohan *et al.* 2004).

SBR was used by Abu-Ghunmia, *et al*. (2006) for the biodegradation of textile wastewater and observed 55% (at 20-30 hr HRT) and 62 % (at 45- 50 HRT) COD removal, 8- 48 %

dissolved solids removal, and 0.4 - 28 % suspended solids removal. Lourenco, *et al*. (2001) also used SBR to study color removal from textile effluent, containing Remazol Brilliant Violet 5R and Remazol Black B dyes, and achieved 90% color removal (at 15 days SRT) and 75% color removal (at 20 days SRT) for Violet and black dyes respectively. In another study by Lourenco *et al.* (2006), the author performs the kinetic study of reactive azo dye decolorization in anaerobic and aerobic sequencing batch reactors. Coagulation/flocculation followed by sequential batch reactor (SBR) process was investigated by El-gohary and Tawfik (2009) and reported 68%, 76% and 61% removal of COD, BOD and TSS respectively. Granular Activated Carbon-Sequencing Batch Reactor (GAC-SBR) system was studied by Sirianuntapiboon, *et al*. (2007) for the treatment of textile wastewater containing direct dyes and achieved 76%, 86%, 84% and 68% removal of color, COD, BOD and TKN respectively. Niren and Jigisha (2011) investigated the performance of the laboratory scale UF hollow fibre submerged membrane bioreactor (SMBR) system for treatment of synthetic textile wastewater containing disperse red dye. In a paper by Szpyrkowicz, *et al.*(1999), the submerged aerobic filtration pilot plant was described to treat textile wastewater with 92.3% COD removal efficiency, this process also consumes less space than traditional aerobic activated sludge treatment. Pasukphun and Vinitnantharat (2003) used immobilized-cell sequencing batch reactor (SBR) with activated carbon, plastic and steel slag as supporting media to treat wastewater containing reactive azo dye Procion Red H-E7B. SBR was also used by Vives *et al.* (2003) to remove organic carbon from textile wastewater.

Kornaros and Lyberatos (2006) used trickling filters (attached growth aerobic systems) for the treatment of textile wastewater and achieved 60 – 70 % COD removal efficiency. Goyal, *et al*. (2010) studied performance of Rotating Biological Contactor (RBC) system for colour and COD removal from textile industry wastewater and reported up to 90±5% colour removal and 95±3% COD removal under optimum operating conditions. Chang, *et al*. (2002) applied Biological Aerated Filters (BAF) to treat textile wastewater.

Anaerobic treatment in UASB was carried out by Gnanapragasam, *et al*. (2010) and reported 96% and 93% removal of COD and colour at 24 h HRT. Cosmo balls were used by Ahmed, *et al*. (2007) as growth media for microorganisms in anaerobic reactor to get 84.62% and 98.9% removal of ammonical nitrogen and volatile suspended solid (VSS) respectively. Anaerobic treatment of cotton textile wastewater in a fluidized bed reactor (FBR) was investigated by Sen and Demirer (2003) and reported removal of COD, BOD_5 and color by 82%, 94% and 59%, respectively. Delée *et al.* (1998) treated the effluent with high organic load in desizing and scouring operations with anaerobic bioreactor. Textile sludge was subjected to mesophilic anaerobic treatment by Asia *et al.* (2006) resulting 89% of BOD and COD reduction each. Georgiou and Aivasidis (2006) tried fluidized-bed loop reactor and immobilized anaerobic bacteria to transform non-biodegradable azo-reactive dyes to the degradable aromatic amines. Decolourization on anthraquinone dyes was investigated with anaerobic granular sludge under 30^oC and 55 ^oC by Santos *et al*. (2005). A six phase anaerobic/aerobic sequencing laboratory scale batch reactor was developed by Shaw *et al.* (2002) to treat a synthetic textile effluent containing Remazol Black, an azo dye.

Two stage reactor system consisted of an anaerobic fixed-film fluidized bed reactor followed by an aerobic suspended growth activated sludge reactor was used by Fitzgerald and Bishop, (1995) for decolorizing Acid Orange 10, Acid Red 14, and Acid Red 18 dyes. 90% dye decolorization for the two red dyes and 65% decolorization for Acid Orange 10 were reported in the first stage. But, very little additional decolorization was observed in the second stage. Same has been the observation even for the COD (85% in the first stage and very little removal in the second stage).

In a study by An, *et al*. (1996), three dye solutions, (C.I. Acid Yellow 17, C.I. Basic Blue 3, and C.I. Basic Red 2) were treated first in a UASB reactor then in a semi-continuous aerobic activated sludge tank. The authors obtained COD and color removals of 83% and 90% respectively. In another sequential system consisting of an anaerobic packed column and a conventional activated sludge unit, decolorisation efficiency of 85% and COD removal efficiency of 90% was obtained (Kapdan, *et al*. 2003). Biological decolorization of textile dyestuff Reactive Orange 16 in fed-batch reactor under anaerobic condition by using facultative anaerobic bacterial consortium was investigated by Kapdan and Oztekin (2003).

Cactaceae Nopalea cochenillifera cell cultures and intact plants (cladodes) transform various toxic textile dyes, including Red HE7B into less phytotoxic, non-hazardous metabolites (Adki, *et al.* 2012). The potential of burhead (*Echinodorus cordifolius* L.) for the treatment of textile wastewater in constructed wetland has also been investigated by Noonpui and Thiravetyan (2011). Brassica juncea, Sorghum vulgare, and Phaseolus mungo of different agronomic consequence were showed textile effluent decolorization up to 79, 57, and 53%, respectively (Ghodake, *et al*. 2009).

2.3.3 Tertiary (advanced) treatment

Textile wastewaters have been subjected to tertiary or advanced treatment processes mainly for the removal of residual colour, for reducing the dissolved salt levels and for the further polishing of the treated secondary effluents. Treatment processes tried included adsorption, oxidation, photocatalytic oxidation, electrochemical processes and membrane processes.

2.3.3.1 Adsorption

Adsorption was used when the dyes were found recalcitrant to biological breakdown. Activated carbon was tried in sorption of acid dyes from effluent by Choy *et al.* (1999).

Adsorption using Granular Activated Carbon (GAC) was tried by Hassani, *et al*. (2008) to decolorize Acidic red, Direct red and Reactive red dyes and reported color reductions of 90%, 88% and 43% in 30, 60 and 120 min respectively. Activated carbon from municipal sewage sludge was tried by Reddy *et al.* (2006) to remove reactive dyes from dyeing effluent. For increasing the adsorption rate of activated carbon it was doped with TiO_2 in the study by Foo and Hameed (2010). Saw dust and coal based activated carbons were used in treatment of complex remazol dye effluent by Vijayaraghavan *et al.* (2009). Adsorption of turquoise blue QG reactive dye on commercial activated carbon in batch reactor was studied by Schimmel *et al*. (2010).

Mixed dye wastewater was efficiently adsorbed on decrystallised chitosan by Trung, *et al*. (2003). Decolorisation reached 90% within 10 minutes at pH 4.5 to 8.1. The adsorbent was regenerated by 2M H_2SO_4 and reused more than 10 times. The adsorption capacity of nanochitosan emulsion was found to be higher than normal chitosan with Acid Orange 10 (AO10), Acid Orange 12 (AO12), Acid Red 18 (AR18) and Acid Red 73 (AR73) in a study by cheung *et al.* (2009).

Bottom ash of municipal solid waste incinerator was used by Gupta, *et al*. (2005a) for the removal of alizarin yellow, fast green and methyl violet dyes from textile wastewater. Optimum contact time was found to be 4 h, and the maximum adsorption was observed at pH 5.5 to 8.0. Bottom ash from power plant with de-oiled soya was employed for removal and recovery of Quinoline yellow dye in a study by Gupta, *et al.* (2005b). Ash produced from palm oil factory was reported to have potential as a low cost adsorbent for the removal of dyes from effluents (Isa, *et al*. 2007).

Silica surface (modified by using silane coupling agents with the amino functional group) was tried by Krysztafkiewicz, *et al*. (2002) for the adsorption of organic dyes. Syloid 244 silica was employed to remove C.I. Reactive Blue 19 in a study by Andrzejewska, *et al.* (2007). Adsorption of organic dyes was tried on the aminosilane modified TiO_2 surface by Andrzejewska, *et al.* (2004). Alumina was also studied for the removal of dyes (Adak et al., 2005, 2006)

Diatomaceous earth was found capable of adsorbing methylene blue, reactive black and yellow dyes by (Al-Ghouti, *et al*. 2003). Maximum adsorption capacity was reached after 48 h of contact. Spent bleaching earth from an edible oil refinery was used for removal of basic dyes from aqueous solutions (Mana, *et al.* 2007). Various other types of adsorbents, such as, saw dust (Batzias and Sidiras, 2007), coal fly ash (Janos, *et al.* 2003), powdered waste sludge (Ozmihci and kargi, 2006), maize cob (El-Geundi and Aly, 1992), soy meal hull (Arami, *et al.* 2007), waste red mud (Namasivayam and Arasi, 1997), hazelnut shell (Ferrero, 2007), banana pith (Namasivayam, *et al*. 1998), hen feathers (Gupta, *et al.* 2006), coir pith (Kadirvelu, 1994), orange peel (Sivaraj, *et al.* 2001), jackfruit peel (Hameed, 2009), garlic peel (Hameed and Ahmad, 2009), pomelo peel (Hameed, *et al.* 2008), baggase (Kaushik, *et al*. 2009), date seed (Yakubu, *et al.* 2008) etc., have also been tried on textile wastewater for the dye removal/decolorization by adsorption.

The combination of coagulation and adsorption (using alum and ferric chloride as coagulants and granular activated carbon (GAC) as adsorbent) was tried by Guendy (2010) for the acid red dye removal. Application of coagulation before adsorption was found most effective in removing the color. Use of alum enhanced the removal from 71% to 97.7%, and use of $FeCl_3$ enhanced the removal from 53.7 % to 98.9%.

2.3.3.2 Oxidation

Various oxidants (Hydrogen Peroxide, Sodium Hypochlorite, Calcium Hypochlorite, Potassium Dichromate and Calcium Dichromate) were compared by Aslam, *et al*. (2004) and reported that calcium hypochlorite as the suitable oxidant. It reduced COD up to 69% (at 100^{o}C and at 1440 min. contact time).

Decolorization and degradation of an anthraquinone dye (C.I. Reactive Blue 19) by ozonation was tried at laboratory scale in a cylindrical batch reactor by Tehrani-Bagha, *et al*. (2010). 55% COD and 17% TOC reductions were reported at 800 mg/L dye concentration for 90 min. ozonation. Barredo-damas, *et al*. (2005) studied the influence of preozonation on coagulation-flocculation treatment of textile wastewater. The preozonation enhanced the COD and turbidity removal to 57% and 95% from 36% and 74% respectively. Ozonation-Biological Aerated Filter process was tried by Wang, *et al*. (2008) on the textile washing wastewater with COD about 80 mg/L, color 16 degree and turbidity about 8 NTU. At the ozone dose of 30-45 mg/L with the Biological Aerated Filter with 3-4 hour HRT, treated effluent with COD less than 30 mg/L, color 2 degree and turbidity less than 1NTU resulted.

Amin, *et al*. (2008) studied Advanced Oxidation Process (AOP) based on H_2O_2/UV system for the treatment of textile wastewater. In the study, UV intensity and dye concentration were varied and obtained 90.69% decolorisation with H_2O_2 dose of 10 cm^3 (3.9 wt %). Increase of UV power from 18 to 54 W had further increased the decolourization efficiency to 100%. Treatment of two wastewater streams containing direct dyes, Black 22 and Blue 199 (difficult to treat among the azo dyes), by Ozone alone, by UV/H_2O_2 and by sequential ozone and UV/ H_2O_2 was tried by Huang, *et al*., (1994). Sequential treatment by ozone and UV/H_2O_2 gave the best results (decolorization and TOC reduction). The degradation of the Disperse Red 354 azo dye in water was investigated by Neamtu, *et al.* (2004) in laboratory-scale experiments, using ozonation, Fenton, UV/H_2O_2, and photo-Fenton.

Heterogeneous catalytic Fenton system was used for dye removal by Soon and Hameed (2010). Fenton (H_2O_2 and Fe^{2+}), Fenton-like (H_2O_2 and Fe^{3+}), Photo-Fenton and Photo-

Fenton-like treatment methods were compared by Abo-farha (2010) for the removal of two acid dyes, C.I. Acid Orange 8 and C.I. Acid red 17. The results indicated that the utilization of UV irradiation with Fenton and Fenton like reagent increased the degree of degradation of both the dyes.

2.3.3.3 Electrocoagulation

Treatment of textile wastewaters by electrocoagulation, using iron and aluminium electrodes, was investigated by Kobya, *et al*. (2003). Iron electrode was reported as superior to the aluminium electrodes. COD and turbidity removals with Al electrodes were 65% and 98% respectively. With iron electrodes the removals were 77% and 98% respectively. Dimensionally stable anode (DSA) against steel cathode was investigated by Vaghela, *et al*. (2005). In a thin electrochemical flow reactor, at different current densities, flow rates and dilutions, 94-99% decolourization was achieved with azo dye effluents. Ti/RuO_2, Ti/Pt and Ti/Pt/Ir electrodes were investigated by Naumcjyk, *et al*. (1996) for the treatment of textile wastewater with high Cl^- ion concentration. After 60 min. of electrolysis, at 6 A/dm^2, 85–92% COD reduction was reported. In a study by Raju *et al.* (2009), electrocoagulation with mild steel as anode was performed followed by electro-oxidation with graphite and $RuO_2/IrO_2/TaO_2$ coated titanium as electrodes. Aluminium electrodes was used for the treatment of synthetic textile wastewater containing a disperse red dye and was compared with chemical coagulation using $FeCl_3$, $Al_2(SO_4)_3$ by Merzouk *et al.* (2011). In an experimental study by Secula *et al.* (2011), a batch stirred electrocoagulation reactor was used for removal of indigo carmine dye using steel electrodes. Aluminium electrodes were used in a study by Can *et al*. (2006) in the electrolytic cell in which a known amount of concentrated solution of polyaluminum chloride or alum was added, which enhances the COD removal efficiency. In the work by Aoudj *et al.* (2010), electrocoagulation was applied to solution containing direct red 81 using Aluminium electrodes. Another study by

Phalakornkule *et al.* (2010) investigated the color removal efficiency from synthetic textile wastewater containing Reactive Blue 140 and Disperse Red 1 (Initial dye concentration of 100mg/L) using iron and aluminium electrodes. The Energy consumption was in the order of 1 kWh/m^3 achieving >95% of color removal for both the dyes. Sengil and Ozacar (2009) investigated the decolourization (98.8 %) from synthetic wastewater containing Reactive Black 5 using iron electrodes consuming 4.96 kWh/Kg dye of electric energy. Iron as anode and stainless steel as cathode was used by Patel *et al.* (2011) to treat the floor-wash wastewater containing Reactive Black 5 in presence of Na_2SO_4 and NaCl. At current densities of 4.5, 6, and 7.5 mA/cm^2 the 90% of initial 25 mg/L of RB5 was removed. Mahmoud *et al.* (2013) studied removal of methylene blue dye using electromagnetic field during electrocoagulation with iron electrodes and the optimum values for current density was 8 mA/cm^2 with optimum electrolysis time of 10-20 min. The textile wastewater was treated with iron and aluminium electrodes and operating costs was calculated in another study by Bayramoglu *et al.* (2004). Mondal *et al.* (2013) studied the treatment of textile printing dyebath effluent using aluminium electrode in batch mode whereas full factorial central composite design was used for optimizing responses. Kabdasli *et al.* (2009) investigated the treatment of simulated reactive dyebath wastewater and effects of dye auxiliaries using aluminium and steel electrodes. The performance of a continuous EC process was investigated by Merzouk *et al.* (2009) for decolorization and COD removal of a synthetic textile wastewater using aluminum electrodes. Akbal and Kuleyin (2011) studied the decolorization of Levafix Brilliant Blue E-B using aluminium and iron electrodes. Color removal efficiency of 99% was obtained at current density of 100 A/m^2, initial pH of 5.5, electrolyte concentration of 5 mM, and electrolysis time of 20 min. The decolourization of Reactive yellow 135 solution and treatment with aluminium electrodes were studied by Yuksel *et al.* (2012). Yuksel *et al.* (2013) again studied the decolourization of Reactive

Orange 84 by EC with SS and Fe electrodes resulting in 89.7% of COD, 90.3% of turbidity, 91.2% of TOC and 94.1% of TSS removal efficiencies as well as 2.43 kWh/m^3 of energy and 0.05 kg/m^3 of electrode consumptions, 1.061 kg/m^3 of sludge generation, and 0.62 \$/m^3 of operating cost. Ghalib (2010) investigated the treatment of direct blue dye using aluminium electrode in a bench scale electrochemical system. In a study by Mondal *et al.* (2012) the dyebath effluent was treated in batch EC reactor using stainless steel electrodes, RSM was employed and at the optimized condition, 99.8% color removal and 91.7% COD removal was observed with energy consumption of 7.71 kWh/kg of COD removed. Fongsatitkul *et al.* (2006) studied the treatment of sulphur dye wastewater using steel electrodes, observing 63% to 80% for COD, 81% to 96% for TSS, and 93% to 99% for color removal rates. Wang *et al.* (2011) investigated the electrolytic treatment of textile wastewater using mild steel as anode and stainless steel as cathode which results into the 75.45% of COD and 84.62% of colour removal efficiencies. Szpyrkowicz (2005), performed the EC in a reactor having the mixture of Disperse Yellow 126, Disperse Red 74 and Disperse Blue 139 using aluminium as anode and stainless steel as cathode. Arslan-Alaton *et al.* (2009) applied central composite design for optimization of wastewater containing CI Acid Blue 193 using iron electrodes. Cerqueira *et al.* (2009) works on textile wastewater treatment with EF using iron electrodes resulting in 61 % COD removal, 95% color removal and 96% of turbidity removal efficiencies with current density of 125 A/m^2 and 10 minutes treatment time. Patil, *et al*. (2010) tried photo-catalysis with TiO_2 powder (anatase form) and ZnO as catalysts for the degradation of textile dyeing and printing wastewater. Catalytic performance of ZnO was found more effective. A photocatalyst, methylene blue immobilized resin dowex-11, was tested by Meena, *et al*., (2009) for the degradation of model dyes, Ponceau S and Sudan IV, and observed 99% removal efficiency (after 3 h at pH 9).

2.3.3.4 Membrane Filtration

Nanofiltration of dyeing wastewater (with Direct red and Direct yellow) through polyamide (NFPA) membrane was tried by Mo, *et al*. (2008) and achieved almost 100% removal of the dyes. In another study, nanofiltration, with the membrane NFT-50, was evaluated by Petrinic, *et al*. (2008) and reported 99.4 to 99.9 % color removal. The study by Sahinkaya et al. (2008) using nanofiltration in combination with activated sludge treatment was showing promising results as the wastewater meets the reuse criteria for denim textile wastewater. Tang and Chen in 2002, uses crossflow nanofiltration to recover NaCl at low pressures upto 500 kPa to obtain high quality reuse water from textile wastewater. Ellouze, et al. (2012), investigated the nanofiltration as a post treatment process after Coagulation–flocculation (CF) on combined wastewater from textile processes facing the difficulty to treat salts concentration more than 9 gpl. The micro-filtration was also used as pre-treatment option in place of CF which leads to higher COD removal efficiency. The polyamide-imide hollow fiber nanofiltration membrane was evaluated by Ong et al. (2014) in various operating conditions such as feed temperature (25, 40, 50, 70 °C), solute concentration (100, 500, 1000 ppm) and pH (3, 7, 10) resulted in more than 90% rejections. Lv, et al. (2010), fabricated a photocatalytic nanofiltration membrane by depositing polydopamine (PDA)/polyethyleneimine (PEI) intermediate layer on an ultrafiltration membrane followed β-FeOOH nanorods (photocatalytic active) mineralization which shows great potential in treatment of textile dye wastewater. The decolourization of Reactive Blue 19 and Acid Black 172 ionic dyes by nanofiltration was studied by Farhadian, et al. (2015) using response surface methodology and achieve 95 % color removal efficiency. Nanofiltration was used after chemical pre-treatment (pH of 8, $FeSO_4$ of 600 mg/L) for woollen textile wastewater (Turbidity >40 NTU and COD >1500 mg/L) by Hassanzadeh, et al. (2017). RSM was also employed for achieving 98% of turbidity and COD removal efficiency. Makertihartha, et al. (2017) investigates the graphene and its derivatives based membranes as novel materials in dyes removal processes. The UH004, Microdyn-Nadir ultrafiltration membrane was used by Lin, *et al.* (2016) to remove four different types of dyes (direct red 80, direct red 23, congo red and reactive blue 2) and Na_2SO_4 from the textile wastewater. This membrane yielded greater than 98.9% rejection for all of the dyes at 4 bar pressure and 60 gpl Na_2SO_4. In a study, by Lin *et al.* (2015) the Sepro NF 6 and NF 2A, Ultura, nanofiltration membranes were used in treatment of synthetic solutions containing dyes and NaCl. The catechol/PEI600 co-deposited NF membrane was used efficiently in removal of dyes, salts and heavy metal ions with textile wastewater treatment by Xu, *et al*. (2016). The pilot plant installed and studied by Marucci *et al.* (2001) used sand filtration and ultrafiltration (innovative module designed on flat membranes operating under vacuum) as pre-treatments for spiral wound nanofiltration or reverse osmosis to verify the possibility of reusing the textile wastewater. The performance of hybrid membrane photocatalytic reactor (flat polyethersulfone membrane module submerged into a ZnO or TiO_2 slurry) was investigated by Doruk *et al.* (2016) in textile wastewater treatment. Color and COD removal efficiency of 100% and 30–55% was achieved at 6 h hydraulic retention time.

Five different UF membranes (5 kDa PES (polyethersulfone), 5 kDa and 1 kDa RC (regenerated cellulose), 2 kDa TFC (thin film composite) and 3, 5 kDa polypiperazine-amide) were compared by Zaf, *et al.* (2017). TFC and polypiperazine-amide provides the highest color and TOC removals for reactive-dying wastewater. Aeration in a homogenization–decantation tank followed by Polyvinylidene difluoride (PVDF) ultrafiltration membrane process was used by Buscio, et al. (2015) in treatment of textile wastewater. Two tubular carbon microfiltration membranes was prepared by Ayadi, et al. (2016) using coal powder onto graphite supports (made from carbon powder of 25 µm and 44 µm) and studied the performance based on pore sizes. A same tubular carbon microfiltration membrane was prepared in a study by Tahri, et al. (2013) using mineral coal powder (100 μm-particle size) mixed with phenolic resin solution and organic additives and used in the treatment of textile wastewater with 100 % turbidity and color retention.

2.3.4 Combined Treatment Technologies

Activated sludge process and powdered activated carbon adsorption for organic and color removal from textile wastewaters was tried by Yeh, *et al*. (2002) and reported 88-98% COD removal. Park, *et al*. (2011) investigated a combined process consisting of Moving-Bed Biofilm Reactors (MBBRs) of Polyurethane-Dyeing Sludge Carbonaceous Material (PU-DSCM) foam inoculated with white-rot fungus, Phanerochaete chrysosporium, and Chemical coagulation with $FeCl_2$ or alum for the dyeing wastewater treatment. MBBR process removed COD and colour by 79% and 54% respectively. But, coagulation with alum followed by MBBR process increased the removal to 95.7% for COD and 73.4% for color.

Textile wastewater was treated by using SBR and fenton's reagent in a study by Fongsatitkul, *et al* (2004). Combination of ozonation before or after biological treatment achieve better COD removal efficiencies as compared to combination of chemical precipitation and ozonation as demonstrated in a study by Turan-Ertas in 2001. Granular activated carbon layer was provided at the bottom of the UASB reactor with combination of semi-continuous activated sludge reactor gives the stable performance with 98 and 95% of COD and Color removal efficiency respectively (Kuai *et al.* 1998).

To decompose toxic substances in textile dyeing wastewater the iron filling filtration was developed as pre-treatment with sequencing batch reactor (SBR) by Hao et al. (2000) which results in 85% COD and 90% BOD removal efficiency. Coagulation ($FeSO_4$, $FeCl_3$ and $MgCl_2$), Fenton oxidation (H_2O_2 and H_2O_2/Fe^{2+}) and Adsorption (Chitosan) processes was performed for treatment of simulated textile wastewater resulting in sludge disposal as major concern in a study by Yadav *et al.* (2013). In a study by Mazumder (2011), coagulation was conducted by alum, followed by oxidation with bleaching powder and adsorption with crushed burnt coal, resulting in 100% color removal and 95% of COD removal efficiencies.

2.4. STRATEGIES AND APPROACHES FOR WASTEWATER MANAGEMENT

Conventionally industrial wastewater management has been reactive, compliance based, end-of-the-pipe focused approach. It often involved treatment of one medium resulting in the contamination of another medium. This approach is considered unacceptable. Now it is clearer that end-of-the-pipe treatment alone cannot control the pollutant discharge. A market driven, proactive wastewater management approach is now replacing this conventional reactive approach. This new approach is based on a waste hierarchy that prioritizes solving of the problems of wastes as indicated in the following Table 2.3 (Water Environment Federation, 2008).

Table 2.3 Waste management hierarchy (ranked most favorable to least favorable)

S.No.	Management options	Definition
1	Source reduction	Any practice that reduces the amount of any hazardous substance entering any waste stream before recycling, treatment, or disposal.
2	In-process recycle	Un-reacted feedstock is separated and recycled to the process.
3	Onsite recycle	Waste from the initial process is converted into a commercial product in a second process performed onsite.
4	Offsite recycle	Waste from the initial process is collected and transferred to another facility, where it is converted into

		a commercial product.
5	Waste treatment	Waste is separated and treated to render it less hazardous.
6	Secure disposal	Waste is separated and sent to a secure site.
7	Direct release	Waste is separated from product and released to the environment.

Moving ahead of the market driven approach, now-a-days people talk about value driven approach for the waste management. Here the focus is on the environmentally sustainable products and processes and on the product stewardship. The product stewardship demands the management practices to make health, safety and environmental protection an integral part of designing, manufacturing, marketing, distributing, using, recycling, and disposing of products. Successful wastewater management at minimal cost demands full understanding of the production processes. In this new approach, waste-minimization is achieved through improving the plant operations, altering the process technologies, substituting the materials, reformulating products, and recycle, recover or reuse of wastes. Waste characterization is a baseline for any changes made to the production process.

2.5. WASTEWATER MANAGEMENT HIERARCHY STUDIES IN TEXTILE PROCESSING INDUSTRY

Wang and Smith (1994) presented the following four general approaches to wastewater minimization for textile processing industry:

1. Process change: Process changes can reduce the inherent demand for water

2. Water reuse: Wastewater can be reused directly in other water using operations when the level of previous contamination does not interfere with the water using operation.
3. Regeneration/reuse: Wastewater can be regenerated by partial or total treatment (filtration, pH adjustment, carbon adsorption, and other processes) to remove the contaminants that would otherwise prevent reuse and then can be reused in other water using operations
4. Regeneration/recycle: Wastewater can be regenerated to remove contaminants and then the water recycled

Manual on “Best Management Practices for Pollution Prevention in the Textile industry” of USEPA (1996), describes various pollution prevention approaches (equipment maintenance, chemical alternatives, chemical substitutions, etc.). This manual suggests use of counter current washing for multistage washing processes (continuous dyeing, printing, desizing, scouring and bleaching). It also advocates recovery and reuse of sodium hydroxide by ultrafiltration, RO and evaporative recovery methods.

Batch dyeing is dominant process occurring in most small and medium scale dyeing units, which is inefficient in the use of chemicals, energy and water. Most of these chemicals do not absorb into the fabric and increase the waste load of effluent. By reconstituting and reusing dyebath, the efficiency of batch dyeing can be increased, and the use of chemicals, water and energy can be reduced significantly. Babuna (2011) presented methodology for wastewater reuse in textile industry. Development of production flowcharts to illustrate every step of the production processes and showing especially the quantities of water inputs and wastewater discharges, and referring to the flowcharts to select some of the segregated effluent streams for characterization and evaluation, and for assessing their reuse are suggested. Erdogan (2004) evaluated feasibility of wastewater minimization by water conservation and wastewater reuse for wool finishing textile mill. He based his evaluation upon a detailed analysis on water use, process profile and wastewater characterization. He indicated a potential for 34% reduction in water consumption and 23% of wastewater recovery for reuse. Stopping the shower rinsing at a point where COD of the segregated wastewaters reach under 50 mg/L, reuse of the wastewater streams having COD lower than 650 mg/l, etc., were suggested for the water conservation. A systematic water networks design using water pinch analysis (WPA) was investigated by Ujang, *et al*. (2002), for minimizing the water usage and wastewater generation. WPA application was reported to reduce the operating costs by 16% and 50% through reuse and regeneration-reuse strategies respectively. Mass and energy balances (including steam distribution, steam utilization and condensate system) were produced and examined in a piece dyeing mill by Petek and Glavi, (1996). Implementation of several options for waste minimization, together with good housekeeping and regular maintenance, wastewater production was decreased by 21%, consumption of dyes by 24%, textile auxiliaries and chemicals consumption by 14 % and steam usage by 25%. Kocabus, *et al*. (2009) evaluated a few selected Best Available Techniques (BAT) in a denim manufacturing textile mill. Detailed mass balance calculations, installation of flow meters, counter-current rinsing, minimization of wash waters in the water softening plant, reuse of concentrate stream from reverse osmosis plant and compressor cooling waters, etc., provided 29.5% reduction in the total water consumption. In terms of Energy consumption, use of waste heat from wastewater streams (for heating up the wash water), heat insulation and maintenance etc., reduced energy consumption by 9%. Rott (2003) tried process integrated measures and production integrated measures in a textile industry.

The process integrated measures included optimization of washing and rinsing processes, optimization of H_2O_2 bleaching techniques, substitution of the dyes with small exhaustion and dyes with heavy metals and sulphide, and substitution of the textile auxiliaries that are not biodegradable. The production integrated measures included reuse of residual dye bath and rinsing wastewater from discontinuous bleaching process and recycling of mixed wastewater after treatment, etc. Process water recycling rates of approximately 95% were reached, and more than 90% of the used sizing agent was recovered. Waste heat recovery potential in a textile industry was assessed by Pulat, *et al*. (2009). Use of waste heat recovery systems (water-to-water shell and tube heat exchanger) and optimizing their working conditions were found effective. Payback period for these systems was found to be less than 6 months.

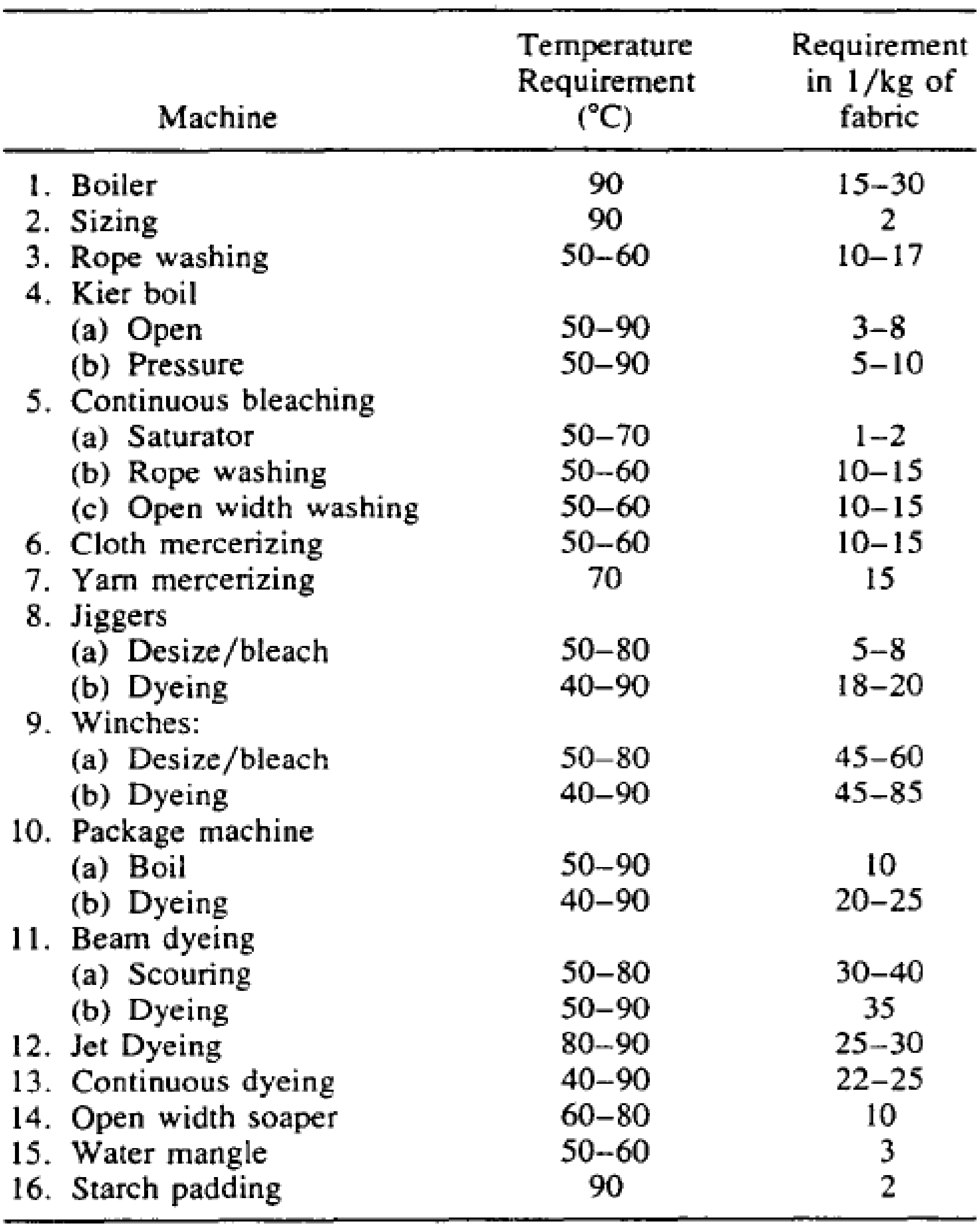
Process Integration and water pinch techniques were used by Wenzel and Knudsen, (2005) to identify the potentials for the reuse of water, energy and chemicals in a textile industry. Membrane filtration was successfully applied to the process water used in wet processing in both cotton and polyester dyeing. A pilot scale demonstration plant confirmed technical feasibility with payback periods of 1–3 years. With respect to energy consumption, the proportion of energy cost in total production cost is 5-10% (Kiran-Ciliz, 2003). The process heat requirements are satisfied by steam. The reduction in steam consumption hence reduces the consumption of energy requirements in processing industry.

Water consumption can be cut down by 87.5% in textile washing process by process integrated recycling of washing fluids with help of MBR, NF and UF (Schoeberl, *et al.* 2004). The hot water requirement and steam consumption in a textile mill was worked out by Gupta, (1989) and is showed in Table 2.4 and Table 2.5 respectively.

70% reduction in sulphide was achieved by replacing sulphur dyestuff with low sulphide content in a study for wet processing textile mill in turkey (Ozturk, *et al.* 2009). Dyeing and finishing wastewater was reclaimed by using two stage anaerobic-aerobic treatment, biological aerated filter process (BAF) and membrane technology (Lu, *et al.* 2010).

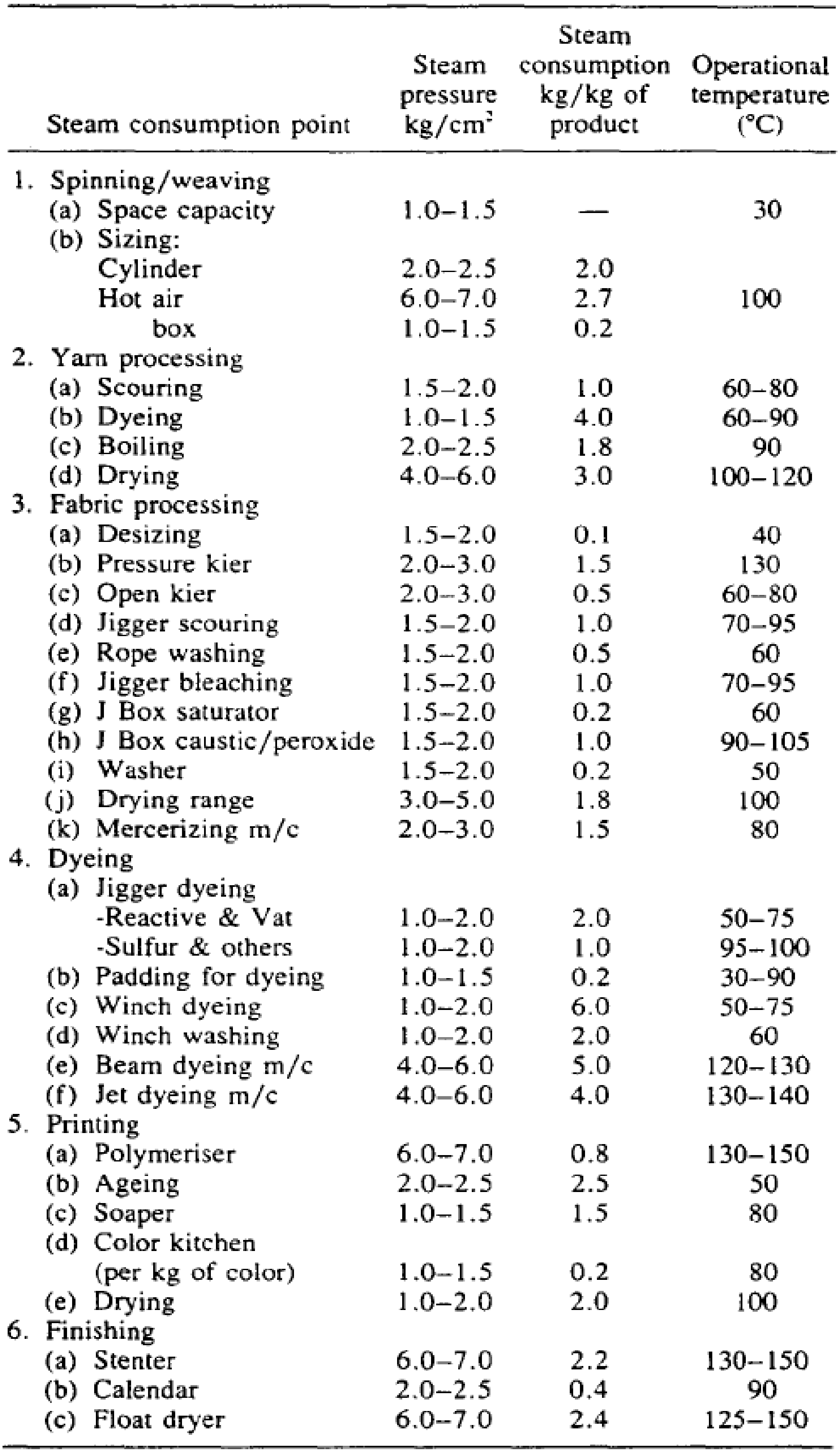
Reduction in wastewater generation was also achieved through process modification (Dipping time, temperature and weight ratio of desizing agent and fabric) in scouring process (Tanapongpipa, *et al.* 2008). 64% reduction in water consumption was obtained by reusing continuous washing water by applying modified water source diagram method (Souza, *et al.* 2010). Possibility of recycling reactive dyebath effluent after decolourization using ozone was also studied (Senthilkumar and Muthukumar, 2007).

Table 2.4 The hot water requirement in a textile mill (Gupta, 1989)



Machine	Temperature Requirement (°C)	Requirement in 1/kg of fabric
1. Boiler	90	15–30
2. Sizing	90	2
3. Rope washing	50–60	10–17
4. Kier boil		
(a) Open	50–90	3–8
(b) Pressure	50–90	5–10
5. Continuous bleaching		
(a) Saturator	50–70	1–2
(b) Rope washing	50–60	10–15
(c) Open width washing	50–60	10–15
6. Cloth mercerizing	50–60	10–15
7. Yarn mercerizing	70	15
8. Jiggers		
(a) Desize/bleach	50–80	5–8
(b) Dyeing	40–90	18–20
9. Winches:		
(a) Desize/bleach	50–80	45–60
(b) Dyeing	40–90	45–85
10. Package machine		
(a) Boil	50–90	10
(b) Dyeing	40–90	20–25
11. Beam dyeing		
(a) Scouring	50–80	30–40
(b) Dyeing	50–90	35
12. Jet Dyeing	80–90	25–30
13. Continuous dyeing	40–90	22–25
14. Open width soaper	60–80	10
15. Water mangle	50–60	3
16. Starch padding	90	2

Table 2.5 The steam consumption in a textile mill (Gupta, 1989)



Steam consumption point	Steam pressure kg/cm^2	Steam consumption kg/kg of product	Operational temperature (°C)
1. Spinning/weaving			
(a) Space capacity	1.0–1.5	—	30
(b) Sizing:			
Cylinder	2.0–2.5	2.0	
Hot air	6.0–7.0	2.7	100
box	1.0–1.5	0.2	
2. Yarn processing			
(a) Scouring	1.5–2.0	1.0	60–80
(b) Dyeing	1.0–1.5	4.0	60–90
(c) Boiling	2.0–2.5	1.8	90
(d) Drying	4.0–6.0	3.0	100–120
3. Fabric processing			
(a) Desizing	1.5–2.0	0.1	40
(b) Pressure kier	2.0–3.0	1.5	130
(c) Open kier	2.0–3.0	0.5	60–80
(d) Jigger scouring	1.5–2.0	1.0	70–95
(e) Rope washing	1.5–2.0	0.5	60
(f) Jigger bleaching	1.5–2.0	1.0	70–95
(g) J Box saturator	1.5–2.0	0.2	60
(h) J Box caustic/peroxide	1.5–2.0	1.0	90–105
(i) Washer	1.5–2.0	0.2	50
(j) Drying range	3.0–5.0	1.8	100
(k) Mercerizing m/c	2.0–3.0	1.5	80
4. Dyeing			
(a) Jigger dyeing			
-Reactive & Vat	1.0–2.0	2.0	50–75
-Sulfur & others	1.0–2.0	1.0	95–100
(b) Padding for dyeing	1.0–1.5	0.2	30–90
(c) Winch dyeing	1.0–2.0	6.0	50–75
(d) Winch washing	1.0–2.0	2.0	60
(e) Beam dyeing m/c	4.0–6.0	5.0	120–130
(f) Jet dyeing m/c	4.0–6.0	4.0	130–140
5. Printing			
(a) Polymeriser	6.0–7.0	0.8	130–150
(b) Ageing	2.0–2.5	2.5	50
(c) Soaper	1.0–1.5	1.5	80
(d) Color kitchen			
(per kg of color)	1.0–1.5	0.2	80
(e) Drying	1.0–2.0	2.0	100
6. Finishing			
(a) Stenter	6.0–7.0	2.2	130–150
(b) Calendar	2.0–2.5	0.4	90
(c) Float dryer	6.0–7.0	2.4	125–150

Process water was reclaimed by treatment of dyebath with activated carbon adsorption and subsequent rinses with nanofiltration and RO in reactive dyeing of cotton, the rinsing was reduced to 50% by using hot water (90^{o}C) throughout all rinsing baths (Wenzel, *et al.* 1996). An attempt was made to reduce water and chemical usage in removal of reactive dyes by reduction of wash off stages from five to three and replacing Na_2CO_3 with 98^{o}C water rinses which increases the COD and BOD_5 loads improving biodegradability of wastewater generated (Burkinshaw and Kabambe, 2009).

Reduction of organic mass and water consumption by 1.43% and 16.15% respectively were obtained by proposing simulation model for continuous washing process in a study (Ulson de Souza, *et al.* 2006). An algorithm for optimization of production schedule was proposed in a study which cuts production time by 10-15%, reduces freshwater consumption by 20-30% and reduces wastewater generation by 20% (Jiang, *et al*. 2010).

Dye reduction, soda ash minimization, acid substitution and their integration was investigated for pollution prevention of cotton-cone reactive dyeing (Ibrahim, *et al.* 2008). Chemical substitution was one of the cost effective way to reduce the concentration of pollutants in wastewater. In a study the ethanol was found suitable for replacing wetting, leveling and retarding agents in dyeing recipes for various types of yarns (Ferrero, *et al.* 2011). Wastewater can be reused directly but the pollutant concentration should not interfere with process or wastewater can be regenerated by partial treatment and then reused or wastewater can regenerate and then recycled (Wang and Smith, 1994). In a study Sodium oxalate was used as exhausting agent with reactive dyes in dyeing of cotton fabrics in place of Sodium chloride or sodium sulphate and dyebath having sodium oxalate shows better color removal also (Yu, *et al.* 2014). Sodium edate may also use as exhausting and fixing agent for reactive dyeing of cotton in a study by Ahmed (2005). Ranganathan, *et al.* (2007) segregated dye bath wastewaters from the wash waters and treated dye bath water by sand and nanofiltration

(NF). The resultant permeate was used in the dye bath preparation. Reject stream (about 20–30% of the inlet volume) of the filtration was sent to multiple effect evaporator (MEE)/solar evaporation pond (SEP) for further treatment and disposal. Wash waters were treated using a sequence of physicochemical and biological unit processes and passed into two stage reverse osmosis (RO) membrane system.

The permeate was reused as process water, while the rejects (about 15–20% of the inlet volume) were subjected either to nanofiltration for salt recovery or sent to the evaporators. Final reject from the nanofilter system was directed to the multiple effect evaporator. Amar, *et al*. (2009) investigated coupling of activated sludge treatment with either ultrafiltration-nanofiltration (NF) or reverse osmosis (RO) for the recycling and reuse of the wastewaters resulting from different baths of a denim fabric dyeing industry. NF allowed higher yield. At 9 bar, the TDS rejection reached 60% and hardness of the output water was <100 mg L^{-1} $CaCO_3$.

Ujal, *et al*. (2010) developed a membrane based treatment strategy for the possible recycling of rinsing wastewater from indigo dyeing of a denim manufacturing plant. Performances of three different nanofiltration membranes (NF 270, NF 90 and NF 99) and two different reverse osmosis membranes (HR 98 PP and CA 995 PE) were investigated on the first post-rinsing wastewater of indigo dyeing process. Dead-end microfiltration with a 5 mm filter was employed, ahead of the NF and RO membranes, for the removal of coarse particles and minimizing fouling problems. The permeate was found acceptable for reuse in terms of COD and color. NF 270 was found as the best in terms of permeate quality (conductivity, color and COD values were 4.3 mS/cm, 8 Pt-Co, and 87 mg/L respectively) and it had higher flux rates.

Membrane filtration was studied at pilot scale level by Dvarioniene, *et al*. (2003) on rinsing water from reactive cotton dyeing process. Overall removal efficiencies for COD, colour, and conductivity were found > 95% for NF membranes and > 97% for RO membranes. An attempt was made by Raghu, *et al.* (2008) to generate sodium hydroxide (98-99%) as a by-product during degradation of dye effluent, using a commercially available electrolytic divided cell (having Ti/RuO_2/IrO_2 as anode and stainless steel as cathode). Sodium hydroxide was found concentrating from 40 g/l to 210.28 g/l. The finishing is also the important processing step in the textile industry to achieve the desired fashion trends and designs. The finish of the fabrics can be completed by using mechanical processes (Sanforizing, Calendering, Sueding, Shearing, Raising/napping, Emery grinding, stone wash etc.) or by applying chemicals (Styrene, Polyvinylacetates, Polyacrylates, Polyurethanes, Paraffins, Fatty acid derivatives etc.). Softeners are the textile auxiliaries which have anti-static, moisture absorbency, hydrophilic and wrinkling resistance properties, therefore, are applied to the fabrics to achieve soft handle, smoothness, elasticity and comfort in wearing. The most common softeners based on their ionic character are- Non-ionic softeners (Polyglycol esters, Oxiethylates products, Paraffins and fats), Anionic softeners (Alkyl aryl sulphonates, sulphonated amides etc.), Cationic Softeners- Quaternary ammonium salts, amino amides, imidazolines etc. and Silicone softeners- polysiloxane derivatives- polydimethylsiloxanes, amino silicones etc. (Habereder and Bereck, 2002; Min *et al*, 2014).

Softeners are generally available as liquid dispersions with solid contents between 10-50% (Wahle and Falkowski, 2002). The silicone emulsions are differentiated into various types depending upon their particle sizes- macro (150-300nm), semi-micro (80-100 nm), micro (particle size below 40 nm) and nano (particle size <10nm). In a study by Choudhury et al. (2012) these silicone softeners with different particle sizes were applied on fabrics and it was confirmed that fabrics finished with nano silicone softeners were produced maximum softness followed by micro and macro finished fabrics. Many research works are focused on the evaluation of the physical, chemical and mechanical properties and effects of the softener application on the textiles (Parvinzadeh and Hajiraissi, 2008; Parvinzadeh, 2007; Chattopadhyay and Vyas, 2010; Sarioğlu and Çelik 2015). Ultrasonic waves lead to an efficient coating of the softener layer on the surface of the fiber which leads to lower load on the wastewater (Parvinzadeh *et al*. 2010). In another study by Nazari *et al.* (2013) nano titanium dioxide (NTO_p) acted as UV absorber when applied onto polyester fabric in the presence of polysiloxane (causes stabilization of NTO_p on polyester fabric surface). The characteristic of the wastewater from the finishing process in the textile industry varies abruptly. The wastewater from softener textile processing contains non-biodegradable silicone resins (Correia *et al*, 1994).The degradation of these aminosilicones and polydimethylsiloxanes polymers had been investigated in the literature (Teixeira *et al.* 2005; Stevens 1998; Carpenter *et al.* 1995; Singh *et al.* 2000; Lehmann *et al*. 1995). The property of softener is the resultant of free movement along its Si-O bonds. The methyl groups in the polymer chain can be replaced by the amino functional groups to increase the durability through various washing and rinsing steps. These amino groups tend to be a cationic species in the micro-emulsion form, results in the attraction with negatively charged fabric (Skinner *et al.* 1999).

The electrostatic charging between fabric/cotton/polyester (negative charge) and softener molecule (positive charge), makes the softeners to adhere them onto fabric. It is very critical to understand the environmental impact caused by silicones. The one of the important purpose of adding the softeners at the end of the washing process is to neutralise the very small amounts of detergents left in the textiles and thus prevent static electricity and also these softeners will in result was eliminated by subsequent washing and rinsing steps. The treatment of these softeners present in the finishing wastewaters became necessary.

CHAPTER 3

METHODOLOGY

This chapter deals with the materials used and methodologies adopted to achieve the objectives of the research work. It describes the work elements which elaborates the strategies for the wastewater management and includes the critical analysis, characterization, development of model, sampling and analytical techniques used. It also includes the description of instrumentation required and the selection as well as development of pre-treatment technologies for characterization and analysing sulphate rich dyebath wastewater, chloride rich dyebath wastewater and wastewater from softener application.

The study had the following two objectives:

- To suggest the strategies for the wastewater management
- To develop technologies for a few selected wastewater streams

Methodology followed for achieving the above two objectives is described in this chapter.

3.1 STRATEGIES FOR THE WASTEWATER MANAGEMENT

Towards the first objective two textile processing units, located in Ludhiana were studied. The industrial units were selected such that processing of cotton, polyester and acrylic textiles (fibre, yarn and fabric) are covered in the study. The study involved the following aspects:

1. Reconnaissance visit of the industrial units to understand the core and the support activities/ processes of the industrial units
2. Survey of the industrial units for the environmental analysis and for the understanding of the water and wastewater management practices

3. Characterization of different water and wastewater streams through water and wastewater sampling and analysis
4. Critical analysis of water and wastewater management practices of the industrial unit, and understanding the merits and limitations of the management practices currently in practice
5. Conceptualization and development of a water and wastewater management model for the textile processing industry.

3.1.1. Reconnaissance visit of the industrial units

The reconnaissance visit of the industrial units was mainly meant for understanding and comprehensively listing all the activities (core, support and peripheral) having environmental relevance, and for developing the process and material flow diagrams for all the key processes. During the visit, key infrastructure and facilities of the industrial units were identified. Further, through these visits, acquaintance and rapport with the industrial units' organization were developed. The acquaintance and rapport were felt required during the detailed survey.

3.1.2. Survey of the industrial units

The process and material flow diagrams developed from the reconnaissance visits were used as a help in the survey. And, the survey was done at the individual process step level mainly for the following purposes:

- Infrastructure and facilities available at the process step
- Understanding the process (including the process conditions) to the desired level of detail

- Identifying the points of water use (including steam and cooling water) and wastewater generation
- Understanding the water quality desired at the individual uses
- Understanding the mechanisms of generation of the wastewaters
- Quantification and characterization of the wastewaters generated
- Identification of opportunities and options for the wastewater’s strength and volume reduction
- Knowing about the recycling and reuse of wastewaters and about the potential for the wastewater recycling and reuse.

The survey included personal observations, interviews with the process personnel, review of secondary data, and sampling and analysis of selected process input and output streams. Chemicals, dyes and other material inputs and different waste outputs were also recorded during the survey of the process steps.

The survey also included the following

- water treatment and water supply system of the industrial units
- boilers and steam system, and steam condensate handling and management system
- cooling towers and circulating cooling water systems
- schemes of wastewater collection, handling and disposal
- effluent treatment plants and sewage treatment plants

3.1.3. Characterization of different water and wastewater streams

A few selected streams of water and wastewater (depending on the need for the characterization) were sampled and the samples were analysed in the laboratory for the selected parameters. The source from where the water and wastewater samples were collected, the mechanisms water and wastewater generation, anticipated contaminants in the water or wastewater samples, and also the prescribed effluent standards were used as the bases in the parameter selection. The parameters analyzed included pH, alkalinity (total and phenolphthalein), total dissolved solids (TDS), conductivity, sodium, chlorides, sulfates, phenolic compounds, colour, biochemical oxygen demand (BOD), chemical oxygen demand (COD), turbidity, surfactants, metals (Zn, Mg, Ca, Fe, Pb, Ni, Mn, As, Cr etc.) and total suspended solids (TSS). Standard methods and analytical techniques given in the APHA manual and/or prescribed IS standard methods were followed in the water and wastewater sampling and analysis. The sampling and analytical techniques used are shown in Table-3.1.

Table 3.1 Analytical techniques used in analysis of water and wastewater

S.No.	**Parameter**	**Technique**	**Instruments**	**References**
1	COD (Chemical oxygen demand)	Open Reflux Titrimetric method	Spectralab COD Digestor 2015 M	APHA 22nd Edn. 5220- B
2	Color	Direct reading spectrophotometer at 455nm	HACH DR/2000 Direct reading Spectrophotometer	IS: 3025 (Part 4)-1983,1st revision, Reaffirmed March,2012
3	Sludge generation rate	Gravimetric	Whatman filter paper No. 1, Analytical balance (AG135 Mettler Toledo)	APHA 22nd Edn. 2540-D
4	pH	Electrometric	LI 127, pH meter-Elico pvt. Ltd.	APHA 22nd Edn. 4500-H*B

5	Conductivity	Electrometric	Thermo Orion model 555 A	APHA 22nd Edn. 2510B
6	Turbidity	Nephelometric	Elico CL 52D Nephelometer	APHA 22nd Edn. 2130B
7	TDS	Gravimetric	Analytical balance (AG135 Mettler Toledo)	APHA 22nd Edn. 2540C
8	TSS	Gravimetric	Analytical balance (AG135 Mettler Toledo)	APHA 22nd Edn. 2540D
9	Sulphate	Gravimetric with Ignition of Residue	Muffle furnace (Abrostate E/101/D)	APHA 22nd Edn. 4500C
10	Total Alkalinity	Titrimetric	_____	APHA 22nd Edn. 2320B
11	Sodium	Flame Emission Photometric method	Flame Photometer ESICO model 1382	APHA 22nd Edn. 3500 Na B
12	Chloride	Argentometric	_____	IS:3025 (Part 32)- 1998, Reaffirmed May, 2009
13	Surfactants	Anionic surfactants as MBAS	UV-Vis Spectrophotometer Analytik jena specord 200	APHA 22nd Edn. 5540C
14	Phenols	Direct photometric	UV-Vis Spectrophotometer Analytik jena specord 200	APHA 22nd Edn. 5530D
15	Sulfide	Iodometric	____	APHA 22nd Edn. 4500F
16	Sulfite	Iodometric	____	APHA 22nd Edn. 4500B
17	Calcium	Direct Air-Acetylene Flame Method	Atomic absorption spectrophotometer GBC 932 AA	APHA 22nd Edn. 3111B
18	Magnesium	Direct Air-Acetylene Flame	Atomic absorption spectrophotometer	APHA 22nd Edn.

		Method	GBC 932 AA	3111B

3.1.4. Critical analysis of water and wastewater management practices of the industrial units

All the water use points (including the cooling water and the steam) and wastewater generation points (including the return cooling water and steam condensate) of the textile dyeing and finishing sections and of the utilities and services sections were identified and listed, and further, efforts were made to characterize and quantify these water and wastewater streams. And then, how the different water and wastewater streams are handled and managed (collection, conveyance, treatment and disposal including the segregation and mixing of the streams) was examined critically. On the basis of the analysis schematic process and material flow diagrams were developed for the following for the industrial units surveyed:

- water treatment and supply systems
- boilers and steam supply (and condensate recovery) systems
- cooling towers and circulating cooling water systems
- wastewaters collection, treatment and disposal systems

Remarks were then made against different water and wastewater streams and also against the above mentioned systems. The remarks made included the following:

- on the quality and quantity of the water being used vis-a-vis the quality and quantity requirements of the use in question
- opportunities and options available for changing the quality and quantity requirements of the water use in question

- opportunities and options available for the process and product changes at the water use in question
- quantity and characteristics of the wastewater streams generated at each of the points of generation
- opportunities and options available associated with the wastewater stream for the recycling and reuse of the wastewater stream, and for the resources and by-products recovery from the wastewater stream, for the segregation/mixing of the wastewater stream in question with the other wastewater streams and for the pre-treatment of the wastewater stream.

At the systems level the remarks may include comments on the technological, economical and practical feasibilities, system performance, cost-effectiveness, environmental soundness and energy conservation and efficiency were discussed under the remarks.

3.1.5. Conceptualization and development of water and wastewater management model for textile processing industry.

An integrated and multimedia approach, wherein due importance is given to the USEPA's hierarchy of waste management (the hierarchy of a. source reduction, b. resource recovery, recycling and reuse, c. treatment and d. disposal), was followed for the conceptualization and development of the water and wastewater management model. Further, the model conceptualized was supposed to satisfy the following conditions:

- zero effluent discharge and compliance with applicable environmental regulations
- water and energy conserving
- techno-economic and practical feasibility of implementation

The information and the data, collected from the industrial survey, from the environmental sampling and analysis and from the critical analysis of the water and wastewater management practices, had become very important input for the conceptualization and development of the water and wastewater management model. Efforts were also made to keep the conceptualized/developed model very generic and implementable in any textile processing industrial unit.

3.2 DEVELOPMENT OF PRE-TREATMENT/TREATMENT TECHNOLOGIES/ PROCESSES FOR A FEW SELECTED CRITICAL WASTEWATER STREAMS OF TEXTILE PROCESSING INDUSTRY

Pre-treatment technologies were developed for the following two wastewater streams:

- Cotton textile dye bath effluents
- Wastewater from the softener application on the finished/processed fabric

In case of the cotton dyebath effluents, the objective of the pre-treatment was to decolourize the effluent and to remove hardness from the effluent so as the treated effluent can be reused in the cotton textile dyeing process as a substitute for moderator salts like sodium sulphate and/or sodium chloride. In case of the softener application wastewater, the pre-treatment objective was to investigating the recovery of the softener chemical from the wastewater and reuse in the textile fabric finishing.

3.2.1 Pre-treatment of the cotton dye bath effluent

Development of a pre-treatment technology involved the following aspects of study:

- Characterization of the cotton dye bath effluents and deciding on the pre-treatment indicator parameters

- Identification of alternate treatment technologies that can be employed for the pre-treatment
- Evaluation of each of the identified treatment technologies for effectiveness and selection of an appropriate treatment technology
- Development of a treatment scheme or system for the wastewater pre-treatment

3.2.1.1 Characterization of the cotton dye bath effluents and finalizing the pre-treatment parameters

The cotton textile dyebath effluents based on the moderating salts used were categorised into Chloride rich cotton dyebath effluents and Sulphate rich cotton dyebath effluents. Samples of the cotton dye bath effluents were collected and analyzed for the parameters indicated in Table-3.1. The methods employed for the sampling and analysis are indicated in the Table-3.1.

Parameters had chosen included colour, COD, TDS, and sulphate (in case of sulphate rich dye effluents) or chloride (in case of chloride rich dye effluents).

3.2.1.2 Identification of pre-treatment technologies

From literature review, a list of the pre-treatment technologies than can be employed for the pre-treatment of textile dye bath effluents was prepared (see Table-3.2). After critically looking at the objective of the treatment, a few technologies (a maximum of 3 technologies) were selected for the evaluation studies purpose. The technologies selected are also indicated in the Table-3.2 in bold-phase. The technologies selected for evaluation in case of the chloride rich cotton textile dye bath effluents were coagulation-flocculation-settling and electroflocculation, and in case of sulphate rich effluents electroflocculation and membrane processes were selected.

Table-3.2: List of the technologies for the treatment of textile dyeing and finishing effluents

S. No.	Types of Technology	Various technologies
1	Adsorption	Activated carbon, Ion-exchange resins, Inorganic materials as adsorbent, Biomass, etc.
2	Oxidation	Electrochemical, Chlorination, Ozone/UV/H_2O_2, Fenton's reagent, **Electroflocculation**, etc.
3	Physico-chemical	**Coagulation-Flocculation-Settling**
4	Membrane Separation	**Micro-Filtration, Ultra-Filtration, Nano-Filtration,** Reverse-Osmosis, etc.

3.2.1.3 Evaluation of the treatment technologies

The selected treatment technologies are evaluated for the respective treatment efficiencies by performing the experiments based on preliminary investigations as well as on the basis of suggested experimental design.

3.2.1.3.1 Coagulation-flocculation-settling

Wastewater was collected from textile industry situated in Ludhiana and the initial characteristics of the wastewater was analysed. The set of 10 experiments were designed in CCD including 2 centre and 8 factorial type runs as per RSM (as presented in Table.3.3). The following four types of dosing treatments were tried-

- Dosing with NaOH/HCl and Alum
- Dosing with Lime/HCl and Alum
- Dosing with NaOH/HCl and $FeSO_4$
- Dosing with Lime/HCl and $FeSO_4$

Table 3.3 Set of Experimental design as per CCD

S. No.	Type	Factor 1	Factor 2	Factor 3
		A:pH	B:Coagulent dose	C:Polyelectrolyte
1	Factorial	6	500	1
2	Center	8.5	300	4
3	Center	8.5	300	4
4	Factorial	11	500	1
5	Factorial	6	100	7
6	Factorial	6	500	7
7	Factorial	11	500	7
8	Factorial	11	100	1
9	Factorial	6	100	1
10	Factorial	11	100	7

3.2.1.3.2 Electro-flocculation (EF)

EF is actually a combination of electro-oxidation, electro-coagulation, and electro-flocculation. Flotation also occurs during the electro-flocculation from the release of hydrogen. Anode and cathode electrodes are immersed in the effluent and DC electricity is applied for the electro-flocculation to occur. The electrodes used can be either sacrificial or non-sacrificial. On the application electricity, the following electrochemical reactions occurring at the anode and the cathode:

Anodic reaction – $M_{(s)} \rightarrow M_{(aq)}^{n+} + ne^{-}$ (1a)

$2H_2O_{(l)} \rightarrow 4H^{+}_{(aq)} + O_{2(g)} + 4e^{-}$ (1b)

Cathodic reaction – $M_{(aq)}^{n+} + ne^{-} \rightarrow M_{(s)}$ (2a)

$2H_2O_{(l)} + 2e^{-} \rightarrow 2OH^{-} + H_2\,(g)$ (2b)

Where, M is the electrode.

EF was studied on both the chloride rich and the sulphate rich textile dye bath effluents. The following four electrode pair combinations were studied.

- Aluminium–Aluminium
- Iron–Iron
- Stainless steel–Stainless steel
- Iron–Aluminium

The experimental setup used in the electro-flocculation studies is shown in Figures 3.1 and 3.2. The setup included an acrylic sheet reactor, a magnetic stirrer and a digital DC power system (ELNOVA Ltd, New Delhi- Model No. 664300300D of 0-30 Volts and 0-30 Amperes) including necessary wiring, controls and meters. The reactor had 415 mL working volume, and its dimensions were 6.1 cm length, 4.7 cm width and 33.3 cm height. The electrodes (anodes and cathodes) used were having 98cm^{2}effective electrode area and their dimensions were 4.9 cm width, 20 cm length and 3mm thickness. The two electrodes were maintained at 10mm distance in the reactor. For mixing the reactor contents, a magnetic bit was used and the reactor was placed over a magnetic stirrer.

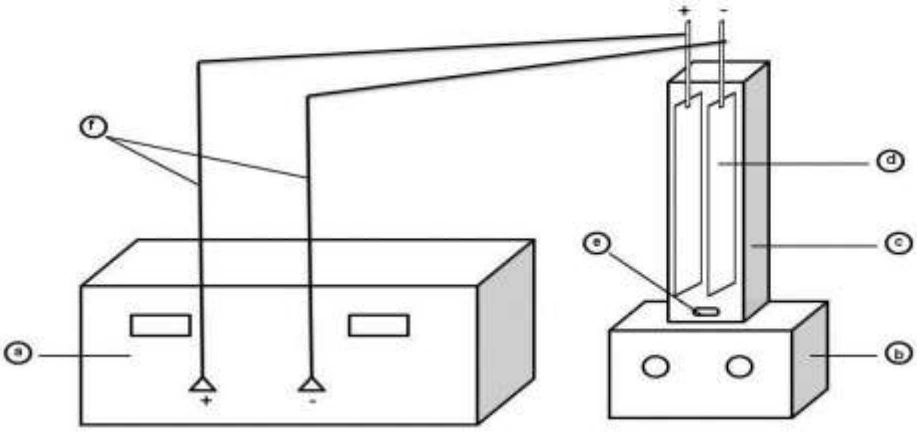


Fig.3.1 Schematic diagram of experimental setup (a) DC power supply (b) Magnetic stirrer (c) Reactor (d) Electrode (e) Magnetic bit (f) Interconnecting wires

Fig.3.2 Experimental setup for electroflocculation treatment of textile wastewater

Two process variables (voltage and treatment time) and two response variables (colour, COD/TOC) were used in the evaluation studies. After conducting a few preliminary experiments ranges of voltage and treatment time were decided and used in the experimental design as per IV-optimal design strategy of Response Surface Methodology (RSM). Using the experimental design the list of experiments to be conducted were obtained (see Table-3.4 for generic list of experiments).

Table 3.4- Generic list of set of experiments as per IV optimal design

Std	**Run**	**Type**	**Factor 1**	**Factor 2**
			A:Voltage	**B:Treatment time (min)**
19	4	Vertex	12.0	15.0
16	5	Vertex	4.0	15.0
18	7	Vertex	12.0	15.0
17	9	Vertex	4.0	15.0
1	10	Vertex	4.0	3.0
5	12	Vertex	12.0	3.0
4	16	Vertex	12.0	3.0
7	18	AxialCB	10.0	6.0
15	6	Interior	6.6	12.9
6	14	Interior	5.8	5.7
14	19	Interior	9.6	12.6
12	2	Center	8.0	9.0
11	3	Center	8.0	9.0
10	17	Center	8.0	9.0
13	1	Edge	12.0	9.6
3	8	Edge	7.6	3.0
8	11	Edge	4.0	8.4
9	13	Edge	4.0	8.4
2	15	Edge	7.6	3.0

The experiments designed were then conducted on the experimental setup with the filtered effluent in question and both the response variables and the process variables, along with the amperage and voltage were recorded. The electrode plates were rinsed with water after every experimental run in order to inhibit passivation of the electrodes.

During the run of the experiments, polarity of the electrodes was interchanged intermittently in order to improve the electro-flocculation performance. After treatment, the treated effluent was filtered and then analysed for the response variables. Sludge generated was also measured by gravimetrically. The results of the experiments were analysed (for developing, improving and optimizing processes) using the Response Surface Methodology (RSM).

Analysis of the results by RSM resulted in the statistical modelling of the electro-flocculation process. Using this model optimum process conditions for the effluent treatment were found. Then a few experiments at the optimal process variables were conducted and the results obtained were used for the validation of the statistical model of the electroflocculation treatment.

The treatment efficiencies, the energy consumption were then estimated and used to decide whether the treatment technology can be used for the pre-treatment of the wastewater. The study also involved selection of the electrodes (sacrificial/non-sacrificial) for use as anodes and cathodes in the treatment process.

3.2.1.3.3 Membrane Technology

The textile cotton dyebath wastewater rich in sulphate was segregated and treated using membranes (microfiltration, ultrafiltration and nanofiltration membranes) for decolourization.

3.2.1.3.3.1 Membrane unit

A table top membrane filtration system (shown in Fig-3.3 and 3.4) was used for the treatment of sulphate rich textile dye-bath effluent. The system had the following components:

1. 100 L capacity feed tank
2. Feed pump of 25 LPM capacity and 400 psi delivery pressure
3. 15 mm internal diameter piping and fittings (flow control valve, FCV; back pressure control valve, BPCV; bypass valve, BV)
4. UF/NF spirally wound membrane module with pressure gauges (of 0-40 kg/cm2 range) installed across the membrane
5. Permeate collection tank

The microfiltration membrane of 0.22 µm pore size and with characteristics as given in Table 3.5 have the filter medium of Polypropylene, Nylon 6, polytetrafluoroethylene, polyether sulfone, polyvinylidene fluoride, whereas the o-ring scaling was constructed from silicone, ethylene propylene diene rubber, nitrile rubber, fluoro elastomers and viton (synthetic rubber and fluoro polymer).

End caps and drainage/support was made up of polypropylene. The actual pilot units are shown in Fig. 3.5 and Fig. 3.6 for microfiltration and ultrafiltration/nanofiltration respectively.

3.2.1.3.3.2 Characteristics of Microfiltration, Ultrafiltration and Nanofiltration membranes used in pilot study

The characteristics of the MF, UF and NF membranes are mentioned in the Table 3.5.

Table 3.5 Characteristics of Microfiltration, Ultrafiltration and Nanofiltration membranes used in pilot study

S.No.	Membrane type	Microfiltration	Ultrafiltration	Nanofiltration
1	Configuration	Polypropylene, Nylon 6 -filter media	Spiral wound, Fiberglass Outer Wrap	Spiral wound, composite polyamide
2	Model/Make	Joy biotech enterprise	4040-UE50-QSF/ Trisep, USA	ESNA1-LF-4040/ Hydranautics
3	M.W.C.O (daltons)	1000000	100000	1000
4	Elemental Weight (Kg)	1	7	3.6
5	Length (inches)	20	40	40
6	Diameter (inches)	2.7	4.0	3.95
7	Permeate Tube (inches)	--	0.75	0.75
8	Active Membrane Area (ft^2)	1.26	80	85
9	Maximum Applied Pressure (bar)	4	41	41
10	Inlet Pressure (bar)	--	3-12	5-24
11	Outlet Pressure (bar)	--	1-10	4-23
12	Min. Reject Flow (LPM)	--	10	10

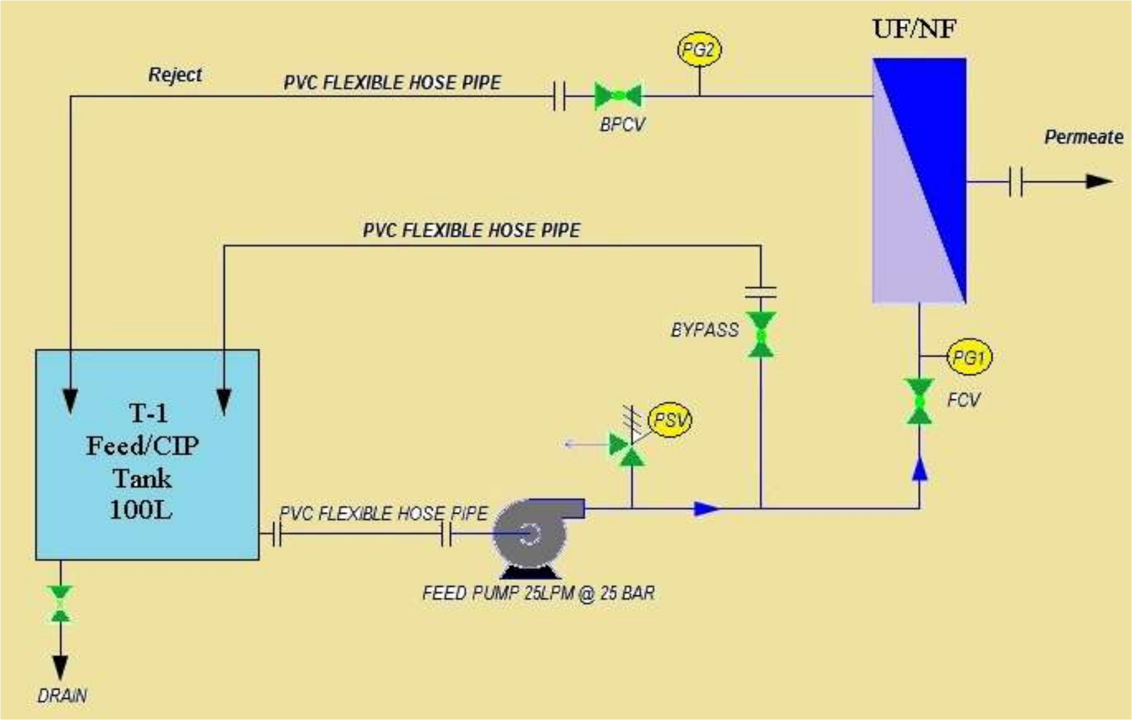


Fig. 3.3 Schematic representation of UF/NF membrane pilot system

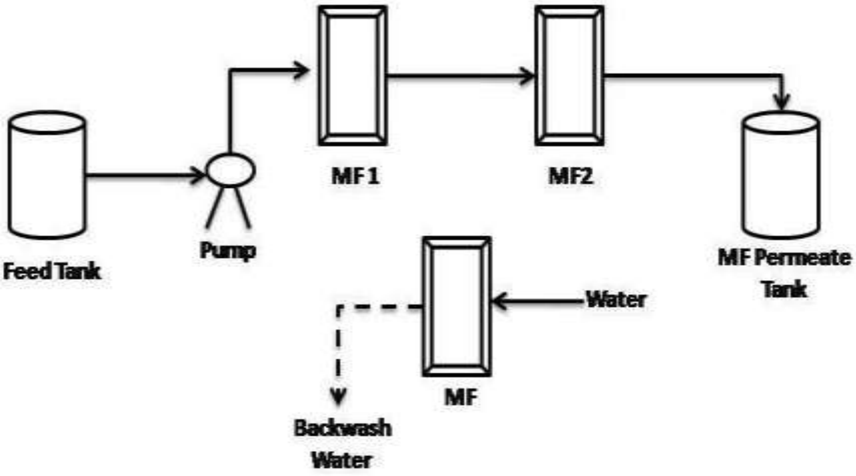


Fig. 3.4 Schematic representation of MF membrane pilot system

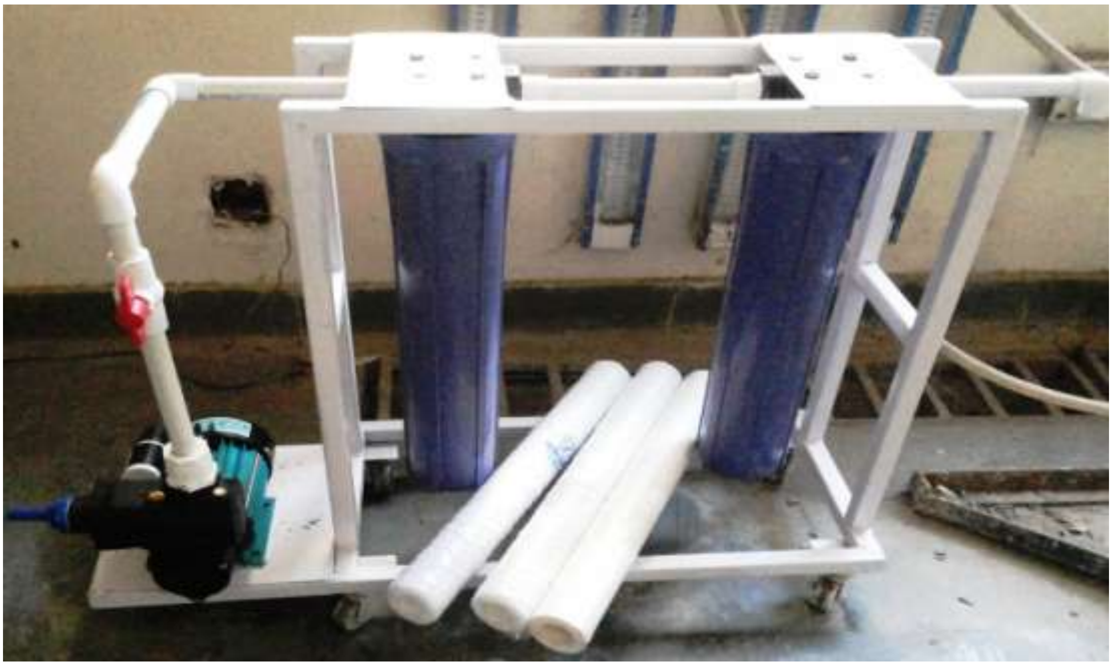


Fig. 3.5 Microfiltration membrane pilot system

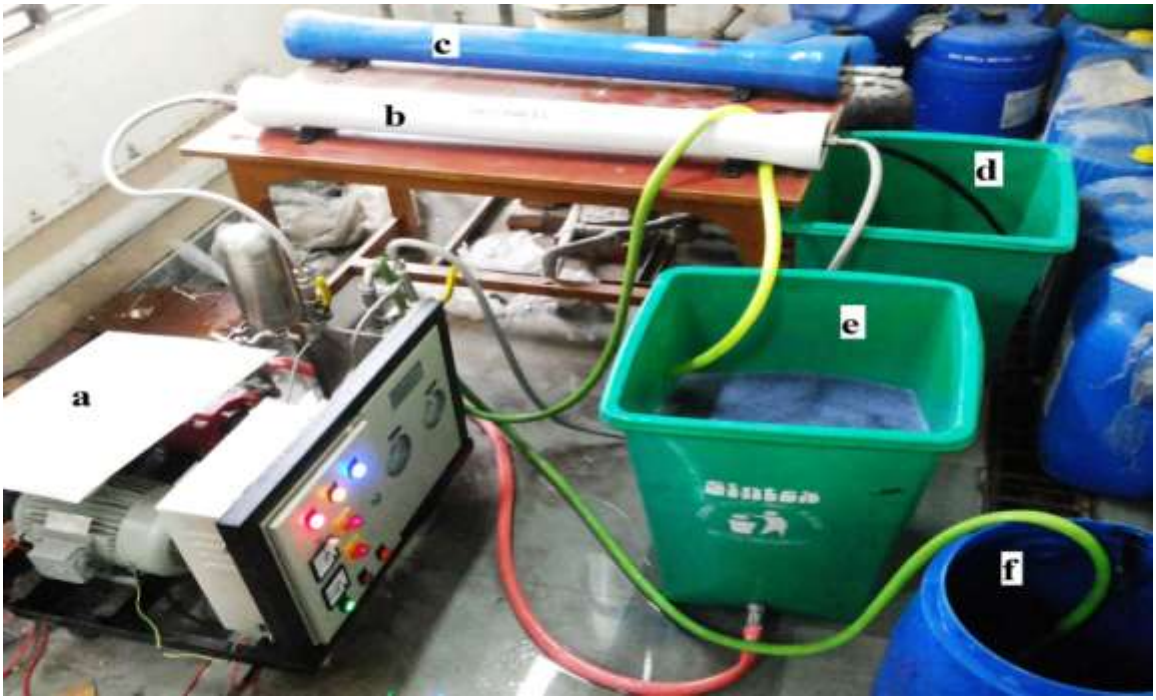


Fig. 3.6 Pilot plant of UF/NF membrane unit- a)- Membrane unit, b)- Ultrafiltration membrane, c)- Nanofiltration membrane, d)- Permeate tank, e)- Raw wastewater tank, f)- Retentate tank

3.2.1.3.3.3 Operation

Experiments with membranes were carried out using two different pilot plants of microfiltration and Ultrafiltration/Nanofiltration. All the interconnecting hose pipes and inlet/outlet connections of membrane (UF or NF) were connected. The feed tank was filled with 100 litres of wastewater. Then the main power supply is switched ON, following main switch on the panel. For process operation the bypass valve is initially turn ON followed by back pressure control valve. Then Flow control valve was turned ON slowly and gradually and bypass valve was turned OFF slowly. After some time the BPCV is turned OFF slowly and gradually till desired flow and pressure is achieved. The pressure was noted down at regular intervals. The FCV and BPCV were regulated to achieve desired flow and pressure. After completion of experiment BPCV was opened slowly to release the pressure of the system. After releasing the pressure of the system completely, push the “pump stop” button to stop the system. Inbetween the batch runs, the system was cleaned by circulating cleaning chemicals- sodium metabisulphite (SMBS) for 1 hr followed by cleaning with fresh water. Membrane cleaning procedure was followed with enhancing the feed flow rate to remove organic and inorganic constituents of wastewater that caused clogging of membrane. The Oil level of feed pump was checked regularly. The permeate and retentate feeds are collected separately. The permeate feed of ultrafiltration was collected and same was treated with nanofiltration membrane. The results obtained were compiled. The permeate flux was also evaluated by using the following equation:-

$$J = Q_p/A_{ms} \qquad \text{(Eq. 1)}$$

Where, J = Flux ($L/m^2.h$)

Q_p = Permeate flow (L/h)

A_{ms} = Surface area of membrane system (m^2)

The COD and color abatement rates were evaluated by using the following equation:-

$$R_{Pollt.} = (Pf\text{-}Pp/Pf) \times 100\% \qquad \text{(Eq. 2)}$$

Where, $R_{Pollt.}$ = Pollutant removal (%)

Pf = Feed pollutant concentration (mg/L), and

Pp = Permeate pollutant concentration (mg/L)

3.2.1.4 Development of a treatment scheme for the wastewater

On the basis of the results obtained through the treatment of chloride rich and sulphate rich cotton dyebath effluent by electroflocculation and membrane processes, the treatment scheme was developed.

3.2.2 Pre-treatment of the softener application wastewater

The softener application cotton wastewater and softener application polyester wastewater was segregated and treated using microfiltration and ultrafiltration membranes. The COD, TSS and turbidity removal efficiencies were estimated.

The textile cotton and polyester softener application wastewater were collected from a textile processing industry situated in Ludhiana, Punjab, India. The textile processing steps were performed in a soft flow machine of 300 kg capacity. The initial characteristics of wastewaters were compiled. The softener was applied at 45^{o}C for 30 minutes for both cotton and polyester processing in finishing step. In cotton textile processing the 1.5 % of silicon softener was added whereas in polyester textile processing the 0.4 % of silicon softener was added. The fabric to water ratio was 1:10. Silicone softeners generally consist of linear aminopolydimethylsiloxanes with a viscosity of 100–100,000 mPa·s. In the present study, the WETSOFT 235 hydrophilic macro-emulsion type silicone softener from Wacker metroark chemicals private limited was used having milky appearance with 25 % solid contents.

Inbetween the batch runs, for re-establishment of the membrane permeability, the system was cleaned by circulating cleaning chemical- sodium meta-bisulphite (SMBS) for 1 hr followed by cleaning with fresh water. Membrane cleaning procedure was followed for enhancing the feed flow rate to remove organic and inorganic constituents of wastewater that caused clogging of the membrane.

The permeate and retentate feeds are collected separately. The permeate feed of microfiltration was collected and same was treated with ultrafiltration membrane in batch process. The results obtained were compiled. The TSS and turbidity abatement rates were evaluated. The reduction/removal rates of different pollutants with the microfiltration/ultrafiltration process were calculated by using the following equation:

$$\mathrm{R}\ (\%) = (1 - \frac{Cp}{Ci})x\ 100 \qquad \text{(Eq. 3)}$$

Where Cp is the concentration in permeate and Ci is the initial concentration in the raw wastewater (Ouni and Dhahbi, 2010). The volumic reduction factor (VRF) was measured during experiment by using the following equation:

$$\mathrm{VRF} = \frac{Vi}{Vr} \qquad \text{(Eq. 4)}$$

Where Vi is the initial volume and Vr is the retentate volume of the wastewater used.

The transmembrane pressure (TMP) is the pressure difference across the membrane which drives movement of wastewater through membrane and is measured using the following equation:

$$\mathrm{TMP} = \mathrm{Pi} - \mathrm{Pp} \qquad \text{(Eq. 5)}$$

Where Pi is the pressure on the feed-water side of the membrane and Pp is the pressure on the permeate side of the membrane.

CHAPTER 4

RESULTS AND DISCUSSION

This chapter deals with the environmental analysis of the textile processing units. It also includes the activities, dyeing and other processing steps, environmental concerns associated and the strategies for the wastewater management. The schematic process and material flow diagrams were developed for the water treatment and supply systems, boilers and steam supply (and condensate recovery) systems, cooling towers and circulating cooling water systems and wastewaters collection, treatment and disposal systems. Water and steam consumption, wastewater generation and cooling water requirement are calculated and depicted before and after implementation of proposed modifications. The cotton textile dyebath effluents based on the moderating salts used were categorized and analyzed accordingly. The chloride rich cotton textile dye bath effluents were evaluated using coagulation-flocculation-settling and electroflocculation treatment technologies, and in case of sulphate rich effluents electroflocculation and membrane processes were used as pre-treatment technologies. The treatment strategy and experimental results obtained were presented and wastewater management model was conceptualized and developed.

4.1 ENVIRONMENTAL ANALYSIS OF TEXTILE PROCESSING INDUSTRIES

Environmental analysis of textile processing industries was carried out by visiting and thoroughly analysing the following textile processing industrial units:

1. Industrial unit –I: A cotton, polyester and acrylic (fabric, yarn and fiber) dyeing unit.
2. Industrial unit –II: A cotton and polyester fabric dyeing unit.

4.1.1 Textile Industrial Unit -I

The industrial unit-I was processing the following:

- Polyester, Cotton and Polyester-Cotton (P-C) fabric
- Cotton and Acrylic yarn
- Acrylic fiber

Core, support and peripheral activities of this textile processing unit are listed in Table 4.1.

Table 4.1- Activities of the textile processing unit -I

S. No.	**Process/Activities**	**Type/Medium**
1.	RFD	Scouring of cotton fabric
2.	Dyeing	Fiber dyeing Yarn dyeing Fabric dyeing
3.	Finishing	Wet finishing Drying Folding and finishing
4.	Packaging and shipping out	Packing of finished products and shipping out

The support and peripheral activities of this and almost all textile processing units also includes-

- Quality control labs
- Water treatment and supply
- Boiler and steam supply
- Electrical power supply
- Cooling towers and circulating cooling water system
- Compressed air system
- Stores

- Scrap yard
- Workshops (mechanical, electrical and civil)
- Air pollution control systems
- Wastewater collection, treatment and disposal system
- Amenities

4.1.1.1 Machinery/Equipment and other facilities

Machinery, equipment and other infrastructure facilities of the industrial unit are listed in Table- 4.2

Table 4.2-Machinery, equipment and other infrastructure facilities of the textile processing unit-I

S. No.	Machines	Capacity (kg/batch)	Number	Total capacity (kg/batch)
1	Soft flow machines	200	2	400
		300	3	900
		600	3	1800
		50	1	50
2	Winch machines	200	1	200
3	Cabinet dyeing machines	60	3	180
4	Top dyeing (HTHP) machines	500	1	500
		240	1	240
		200	1	200
		250	1	250
		10	1	10
5	Hydro-squeezers	300	1 (for fabric	300

			dewatering)	
		150	1 (for fiber and yarn dewatering)	150
6	Pole driers	---	3 units (1st of 6 poles, 2nd of 6 poles, and the 3rd of 2 poles)	---
7	Drier chambers	2 Tons/day capacity	1	Both yarn and fiber/cones was dried in the absence of sun drying

4.1.1.1.1 Soft flow machines

Soft flow machine has a dyeing drum filled with one or more continuous loops of fabric and liquid in a desired ratio (1:8). The fabric is continuously circulated through the liquid in the dyeing drum with the help of a liquid jet. Liquid of the dyeing drum is pumped, passed through a heat exchanger and used to create the jet, that powers the fabric circulation, and taken back into the drum. Contents of the dyeing drum as required are either heated or cooled through heating or cooling the circulating liquid in the heat exchanger with saturated steam or circulating cooled water respectively. The liquid circulation loop of the machine has a suction pipe connected to a small chemical/dye dosing tank for facilitating preparation and injection of dye and/or chemical solutions into the dyeing drum. The drum has an overflow drain, a bottom drain, and a direct process water inlet. Further, the dyeing drum has provision for injecting compressed air into to the head space for air cushioning.

4.1.1.1.2 Winch machines

Winch machine is a rectangular vessel with bottom smoothly sloping towards the inlet side. On the inlet side, there is a vertical perforated baffle wall to facilitate dosing of chemicals and dyes. Bottom of the chamber at the inlet end has a perforated steam tube for facilitating steam injection heating of the vessel contents. At the bottom of the vessel on one side there is a drain with necessary regulatory valves. The vessel has a water supply line with necessary regulatory valve. The winch machine has a temperature sensor. Fabric in the form of one or more continuous loops is maintained in the vessel for the processing. An electrically driven winch provided on the top of the winch facilitates circulation of the continuous loop of the fabric through the liquid of the vessel.

4.1.1.1.3 Warping machine

Warping machine is an insulated chamber. The yarn to be warped is hanged inside the chamber and then chamber is closed air tight. At the bottom of the chamber there is a steam coil mat. Through this mat, saturated steam is injected inside as and when required to raise the yarn temperature and to wet the yarn for facilitating warping. The chamber has sensors for knowing both temperature and pressure inside. Steam condensate generated inside the chamber is drained out as wastewater.

4.1.1.1.4 Cabinet dyeing machine

Cabinet dyeing machine is a front opening cabinet with doors that can be closed water tight. Within the cabinet there are provisions for hanging the warped yarn for processing (dyeing). The cabinet has a bottom coil mat for the cooling or heating of the cabinet contents (by circulating cooling water or supplying saturated dry steam respectively). The cabinet has provisions for the process water loading, for draining out the liquid content of the cabinet, and for the injection of chemicals and dyes. Further, the machine also has provisions for the circulation of the liquid content of the cabinet around the yarn.

4.1.1.1.5 Top dyeing and/or cone dyeing machines

Top dyeing machine (also called as HTHP-High temperature High Pressure machine) is a vertical cylindrical vessel with a central vertical perforated core pipe. A cylindrical carrier loaded with fiber/fiber cones (fibre/fiber cone top) is fitted around the core pipe and securely locked. Liquid of the vessel is forced to radially pass through the fiber from core pipe to peripheral annular space and from peripheral annular space to the core pipe alternately. For facilitating this, a main circulation pump and piping with external heat exchanger are provided. A chemical solution vessel, a pump and necessary piping and fittings are also provided for facilitating injection of the chemical/dye solutions. The machine vessel has a bottom drain for facilitating the draining out of the machine contents.

4.1.1.1.6 Hydrosqueezer

Fabric unloaded (after dyeing) from the soft-flow machine is loaded into the hydro-squeezing machine and the machine is run for the centrifugal dewatering of the fabric. The water coming out is drained out as wastewater. After hydro-squeezing the fabric is unloaded from the hydrosqueezer and sent to the pole drier for drying.

4.1.1.1.7 Pole driers

There are two sets of six pole driers each. Each drier includes a radiator heater, a blower and a perforated pole. The pole driers are operated in batches of two. For drying, the fabric is loaded on the pole and removed. Dyed fabric is loaded on the pole and pulled up over the perforated tube while hot dry air is passed out through the pole for drying. The blower associated with the pole drier sucks ambient air through the radiator heater and pushed out through the perforated pole. In the radiator heater, the incoming air is heated with saturated dry steam condensing in the radiator tubes. An overhead roller, driven by an electrical drive, is used both for slowly loading and pulling the fabric over the perforated tube. Enclosed space of the pole drier is sufficiently ventilated and the hot humid air emanating from the pole drier is simultaneously vented out.

4.1.1.1.8 Drier chamber

Yarn or fabric/fiber is loaded in trolley trays in the drier chamber. Hot dry air is passed through in the drier chamber for drying the yarn/fiber/fiber cones. Hot humid air carrying the removed moisture will be vented out from the drier chamber through a vent duct. Ambient air with the help of a blower is taken in, heated in a radiator heater by saturated dry steam and supplied to the drier chamber for the fiber/yarn drying.

4.1.1.2 Fabric, yarn and fiber processing/dyeing

Quantity and type of fabric, yarn and fiber that will be processed in this industrial unit are given in Table 4.3.

Table 4.3- Fabric, yarn and fiber to be processed by the industrial unit

S. No.	Type	Fabric	Fiber	Yarn
1	Cotton	Cotton (white): 2000 kg Light and medium shade: 1200 kg Dark shade: 800 kg	Cotton cones: 1000 kg	---
2	Polyester-Cotton	1000 kg	---	---
3	Polyester	Light and medium shades: 4800 Red, black & torquish shades: 3200 kg	---	---
4	Acrylic	---	500 kg	1000 kg
Total		**13000 kg**	**1500 kg**	**1000 kg**

Fabric dyeing was done in soft flow machines. Warping machine and cabinet dyeing machines was used in the dyeing of yarn. Fiber/cone dyeing was carried out in the top dyeing/cone dyeing machines. Winch machines were mostly used for fabric washing or at the maximum for cotton dyeing. Hydrosqueezers was used for the dewatering of dyed fabric, yarn and fiber. The dewatered fabric was dried on the pole driers. Dewatered yarn and fiber was either solar dried or dried in a drier chamber.

4.1.1.2.1 Fabric Dyeing

It includes dyeing of:

- Cotton (white, light and medium and dark shades)
- Polyester (light and medium, dark shades)
- Polyester-Cotton blend (light, medium and dark shades)

4.1.1.2.1.1 Processing steps for Cotton White Dyeing

1. Fill water, load fabric, raise temperature to 40°C, dose chemicals (wetting agent, anti-creasing agent, caustic, stabilizer, whitening agent), raise temperature to 60°C, dose peroxide, raise temperature to 98°C, hold for 30 minutes, check sample for quality – if the check fails, dose additional chemicals (wetting agent), maintain temperature at 95°C, hold for 25 minutes, and again go for the sample checking – if the quality is ok overflow cool/wash till temperature drops to 70°C, and then drain.
2. Fill water, raise temperature to 80°C, hold for 10 minutes, then drain.
3. Fill water, dose acetic acid, raise temperature to 60°C, hold for 30 minutes and then drain.
4. Fill water, dose softener chemical, and dose acetic acid, raise temperature to 40°C, hold for 30 minutes, unload the fabric and then drain.
5. Dewatering in Hydrosqueezer: Load the dyed fabric, spin for the desired duration and unload the dewatered Fabric.
6. Drying on pole driers and then Hang under the sun till properly dried

Chemical consumption in the processing steps for Cotton White Dyeing is listed in Table 4.4.

Table 4.4- Chemical consumption for cotton white dyeing

S. No.	**Chemical**	**Quantity (per 300 kg batch of cotton white)**
1	Wetting agent	2.1 kg
2	Anti-crease agent	2.1 kg
3	Caustic	6.0 kg
4	Stabilizer	2.1 kg
5	Peroxide	21 kg
6	Acetic acid	1.5 kg
7	Water softener	0.9 kg
8	Whitening agent	2.7 kg
9	Softener chemical	2 gpl
10	Others if any	Silicon softener: 0.6 kg

Process modifications to conserve water, energy and chemicals and minimize wastewater generation

1. Avoid overflow cooling. Instead cool in external heat exchanger with circulating cooling water.
2. Use the wastewater drained out in step-3 (acetic acid neutralization step) in step-2 for the fabric rinsing in the next batch of fabric processing.
3. Use circulating cooling water rather than process water in step-3 for acetic acid neutralization.
4. Collect the water drained out in step-4 and reuse in the step-4 in the next batch of fabric processing.

5. Improve the draining process through application of compressed air whenever the soft flow machine is drained.

4.1.1.2.1.2 Processing steps for Cotton Light and Medium Shade

1. Fill water, load fabric, raise temperature to 40°C, dose chemicals (anti-creasing agent, scouring agent and stabilizer), hold for 10 minutes, dose caustic, hold for 5 minutes, raise temperature to 60°C, dose peroxide, raise temperature to 95°C, hold for 45 minutes, check the sample for quality, (if the quality check fails, add scouring agent, hold for 10 minutes and again go for quality check), if the quality check passes overflow wash/cool to 60°C, and then drain.
2. Fill water, dose peroxide killer chemical, raise temperature to 80°C, hold for 10 minutes and drain.
3. Fill water, dose acetic acid, raise temperature to 60°C, hold for 30 minutes, check pH (should be 5.5) and drain out.
4. Fill water, check pH (if less than 6.5, apply overflow wash to raise pH to 6.5), dose chemicals (anticreasing agent, leveling agent and water softener), raise temperature to 40°C, dose dyes and chemicals (salt, soda and also caustic if needed), raise temperature to 60°C, hold for 30 minutes, check the sample for quality, (if the quality check fails, then cool to 40°C, dose dyes, raise temperature to 60°C, hold for 30 minutes time, and again go for quality check), if the quality check passes overflow cool/wash to 40°C, and then drain.
5. Fill water, hold for 15 minutes, and drain.
6. Fill water, raise temperature to 60°C, dose acetic acid, hold for 30 minutes and then drain.
7. Fill water, dose soap, raise temperature to 70°C, hold for 20 minutes, fill water to cool to 60°C, and then drain.

8. Fill water, raise temperature to 80°C, hold for 10 minutes, cool through filling water to 60°C and then drain.
9. Fill water, add softener, raise temperature to 40°C, hold for 30 minutes, unload the fabric and drain out the liquid.
10. Dewatering in Hydro-squeezer: Load the dyed fabric, spin for the desired duration and unload the dewatered Fabric.
11. Dry the dewatered fabric on pole driers.

Chemical consumption in the processing steps for cotton light and medium shade dyeing is listed in Table 4.5.

Table 4.5- Chemical consumption for cotton light and medium shade

S. No.	**Chemical**	**Quantity per 300 kg cotton (light and medium shades)**
1	Scouring agent (wetting agent)	2.1 kg
2	Anti-crease agent	2.1 kg
3	Stabilizer	1.5 kg
4	Peroxide	6 kg
5	Peroxide killer	1.5 kg
6	Acetic acid	1.5 + 1.5 + 0.6 kg
7	Leveling agent	1.5 kg
8	Water softener	2.1 kg
9	Dyes	1-3%
10	Salt	10-40 gpl
11	Soda	5 gpl
12	Caustic	0.5 kg
13	Softener	2 gpl

Process modifications to conserve water, energy and chemicals and minimize wastewater generation

1. Avoid overflow washing/cooling in step-1. Instead go for cool in external heat exchanger.
2. If functioning of peroxide killer chemical is not affected, use effluent of step-3 (acetic acid neutralization) in place of process water in step-2.
3. Use circulating cooling water in place of process water in step-3.
4. If, because of pH, water is drained out at step-4, then segregate it along with the effluent of Step-3 for reuse in step-2.
5. Avoid overflow washing/cooling in step-4. Instead, introduce an additional washing step.
6. Use circulating cooling water in place of process water in step-5 and in the washing step incorporated in place of overflow washing/cooling in step-4.
7. Combine step-6 (acetic acid neutralization) and step-7 (hot soap washing) into a single step (after neutralization without draining out, dose soap and carry out hot soap washing).
8. Use circulation cooling water in place of process water in step-6 cum step-7.
9. In step-7 and step-8 avoid filling process water for cooling. Instead if needed go for cooling in external heat exchanger.
10. Use circulating cooling water in place of process water in step-8 (for post hot soap washing).
11. Collect effluent from the step-9 and reuse this effluent in step-9 in place of process water.
12. Improve the draining process through application of compressed air whenever the soft flow machine is drained.

4.1.1.2.1.3 Processing steps for Cotton Dark shade

1. Fill water, load fabric, raise temperature to 40°C, dose chemicals (wetting agent, lubricant, oil wash and stabilizer), hold for 10 minutes, dose caustic, hold for 5 minutes, raise temperature to 60°C, dose peroxide, raise temperature to 95°C, hold for 45 minutes, check the sample for quality, (if the quality check fails, add scouring agent, hold for 10-15 minutes and again go for quality check), if the quality check passes, overflow cool to 60°C and then drain.
2. Fill water, dose acetic acid for neutralization, raise temperature to 60°C, hold for 30 minutes, check pH (should be 5.5) and then drain.
3. Fill water, dose peroxide killer chemical, raise temperature to 80°C, hold for 10 minutes and drain.
4. Fill water, check pH (if pH <6.0, drain out the bath and fill with fresh water), dose chemicals (Lubricant, Sequestering agent), raise temperature to 40°C, dose dyes and chemicals (salt, soda and also caustic if needed), raise temperature to 60°C, hold for 30 minutes, check the sample for quality, (if the quality check fails, then cool to 40°C, dose dyes, raise temperature to 60°C, hold for 30 minutes time, and again go for quality check), (if the quality check passes) overflow cool to 40°C, and then drain.
5. Fill water, raise temperature to 60°C, dose acetic acid, hold for 30 minutes and then drain.
6. Fill water, dose soap, raise temperature to 90°C, hold for 20 minutes, overflow cool to 60°C, and then drain.
7. Fill water, dose bioclean, raise temperature to 80°C, hold for 10 minutes, overflow wash and then drain.
8. Fill water, dose acetic acid and softener, raise temperature to 45°C, hold for 30 minutes, and unload the fabric and then drain.

9. Dewatering in Hydro-squeezer: Load the dyed fabric, spin for the desired duration and unload the dewatered Fabric.
10. Drying on pole driers and then Hang under the sun till properly dried.

Chemical consumption in the processing steps for cotton dark shade dyeing is listed in Table 4.6.

Table 4.6- Chemical consumption for a batch of 300 kg cotton (dark shade)

S. No.	Chemical	Quantity per 300 kg cotton (dark shade)
1	Scouring agent	0.7 gpl
2	Anti-crease agent	0.7 gpl
3	Stabilizer	0.5 gpl
4	Peroxide	1%
5	Peroxide killer	0.5 gpl
6	Acetic acid	0.5 gpl +0.5 gpl + 0.2 gpl
7	Leveling agent	0.5 gpl
8	Water softener	0.7 gpl
9	Dyes	4-8%
10	Salt	60-80 gpl
11	Soda	5 gpl
12	Caustic (optional)	1 gpl
13	Softener chemical	2 gpl

Environmental inputs/outputs in the processing steps for cotton dark shade dyeing is listed in Table 4.7 and the characteristics of cotton processing wastewater at different steps in textile industry is presented in Table 4.8.

Table 4.7 Environmental inputs/outputs for cotton dark shade dyeing

S.No.	**Inputs/Outputs**	**Processing steps**	**Description**	**Quantity per 200 kg cotton**
1	Chemical consumption	1.	Wetting agent LF	1 kg
			Lubricant LubMax	1 kg
			Stabilizer	600 g
			XNI oil wash	400 g
			Caustic (NaOH)	4 kg
			Peroxide	4 kg
		2.	Acetic Acid (CH_3COOH)	2.5 kg
		3.	Peroxide killer – Procil L	800 g
		4.	Lubricant DW	800 g
			LubMax	800 g
			Sequestering agent Manatil 4L	600 g
			Dye Yellow XL	412 g
			Dye Red X3BS	1.545 kg
			Dye Black HBL	6.180 kg
			Salt – NaCl	140 kg
			Soda Ash (Na_2CO_3)	2 kg
			Caustic	3 kg
		5.	Acetic Acid	2.5 kg
		6.	Soap DW	2 kg
		7.	Bioclean	2 kg
		8.	Acetic acid	500 g

			Softener Soft Tax P	5 kg
			Softener Silicon- 1540I	500 g
2	Water consumption	Overall	--	25145 liters
3	Steam Consumption	Overall	--	1428 Kg
4	Wastewater generation	Overall	--	25085 liters

Table 4.8- Characteristics of cotton processing wastewater at different steps in textile industry

Processing Steps		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Parameters	**Units**	**RFD**	**Neutralization-I**	**Peroxide killer**	**Dyeing**	**Neutralization-II**	**Soaping**	**Bioclean**	**Softener**
pH	--	11.41	5.5	6.2	11.37	5.18	6.97	7.01	6.8
BOD	mg/L	1612.5	1450	1150	--	--	--	--	--
COD	mg/L	4880	2760	2340	3280	1660	640	200	651.75
TSS	mg/L	242	15	14	54	164	187.5	130	130
TDS	mg/L	6764	2166	2246	84484	1414	706.25	616	766
O & G	mg/L	208.97	--	--	--	--	--	--	--
Color	Pt. Co. Unit	--	--	--	17200	1420	1240	330	16
Turbidity	NTU	110.3	2.6	3.3	4.3	31.9	56.2	32.8	32.8
Sulphide	mg/L	--	--	--	<1	<1	--	--	--
Sulphate	mg/L	--	--	--	743.17	103.69	--	--	--
Na	mg/L	--	--	--	26250	161	--	--	--
Cl	mg/L	--	--	--	40377.5	269.18	--	--	--
Total Alkalinity	mg/L	--	--	--	2626	--	161.6	303	121.2

Ph. Alkalinity	mg/L	--	--	--	1818	--	--	--	--
Total Hardness	mg/L	--	--	--	194.5	360	210	238	384
Ca	mg/L	--	--	--	76	110.76	60.37	77.86	96.1
Mg	mg/L	--	--	--	1.1	19.5	6.97	8.87	12.1
Carbonate	mg/L	--	--	--	1616	--	--	--	--
Bicarbonate	mg/L	--	--	--	--	--	161.6	303	121.2
As	ppm	--	--	--	<0.005	<0.005	--	--	--
Cr	ppm	--	--	--	<0.05	<0.05	--	--	--
Zn	ppm	--	--	--	0.206	0.088	--	--	--
Ni	ppm	--	--	--	0.553	0.063	--	--	--
Pb	ppm	--	--	--	1.124	0.261	--	--	--

Process modifications to conserve water, energy and chemicals and minimize wastewater generation

1. Avoid overflow washing/cooling in step-1. Instead go for cooling in external heat exchanger.
2. Use circulating cooling water in place of process water in step-2.
3. If functioning of peroxide killer is not affected, use effluent of step-2 (acetic acid neutralization) in place of process water in step-3.
4. If, because of pH, water is drained out at step-4, then segregate it along with the effluent of Step-2 for reuse in step-3.
5. Avoid overflow washing/cooling in step-4. Instead, introduce an additional washing step.
6. Use circulating cooling water in place of process water in step-5 and also in the washing step incorporated in place of overflow washing/cooling in step-4.

7. Combine step-5 (acetic acid neutralization) and step-6 (hot soap washing) into a single step (after neutralization without draining out dose soap and carry out hot soap washing).
8. Use circulation cooling water in place of process water in step-5 (cum step-6).
9. In step-6 and step-7 avoid filling process water for cooling. Instead if needed go for cooling in external heat exchanger.
10. Use circulating cooling water in place of process water in step-7 (for post hot soap washing).
11. Collect effluent from the step-8 and reuse this effluent in same step-8 in place of process water.
12. Improve the draining process through application of compressed air whenever the soft flow machine is drained.

4.1.1.2.1.4 Processing steps for Polyester Light and Medium shade

Fabric taken- 570 kg

Soft flow machine capacity- 600 kg/Batch

Water filled = 1:8, 4500 Litres

1. Fill water, load the fabric, dose chemicals (oil wash, leveling agent, acetic acid and Dispersing agent), check pH (should be 4.5 to 5), raise temperature to 60°C, dose dyes, raise temperature to 135°C, hold for 10- 30 minutes, cool to 70-75°C, and drain.
2. Fill water, raise temperature to 70-80°C, dose softener, hold for 30 minutes, and unload the fabric and drain.
3. Dewatering in Hydro-squeezer: Load the dyed fabric, spin for the desired duration and unload the dewatered fabric.
4. Drying on pole driers and then Hang under the sun till properly dried.

Chemical consumption in the processing steps for polyester light and medium shade dyeing is listed in Table 4.9 and the characteristics of polyester processing steps in textile industry-I is presented in Table 4.10.

Table 4.9- Chemical consumption for Polyester light and medium shade dyeing

Step	Chemical	Quantity per 570 kg Polyester	Percentage per 570 kg Polyester
1.	XNI oil wash	1.2 kg	0.21%
	Levelling agent DFT	2.400 Kg	0.42%
	Acetic Acid	3.000 Kg	0.52%
	Dispersing agent- Levocol WS	500 g	0.08%
	Dye G. Yellow 2GR	723 g	0.126%
	Dye Scarlet 3R	1.070 Kg	0.187%
	Dye Blue 2RX	2.764 Kg	0.483%
2.	Softener Soft A/C	14 Kg	2.45%

Table 4.10- Characteristics of polyester processing steps in textile industry

S.No.	Parameters	Units	Dyeing	Softener
1	pH	--	6.71	5.99
2	BOD	mg/L	430	283
3	COD	mg/L	1480.32	585.96
4	TSS	mg/L	38	108
5	TDS	mg/L	1138	982
6	Color	Pt. Co. Unit	1060	500
7	Turbidity	N.T.U.	236	239
8	As	ppm	<0.005	<0.005

9	Cr	ppm	<0.05	<0.05
10	Zn	ppm	0.05	0.05
11	Ni	ppm	<0.1	<0.1
12	Pb	ppm	<0.05	<0.05
13	Total Alkalinity	mg/L as $CaCO_3$	151.5	50.5
14	Ph. Alkalinity	mg/L as $CaCO_3$	Nil	Nil
15	Total Hardness	mg/L as $CaCO_3$	332	296
16	Hydroxide	mg/L as $CaCO_3$	Nil	Nil
17	Carbonate	mg/L as $CaCO_3$	Nil	Nil
18	Bicarbonate	mg/L as $CaCO_3$	151.5	50.5

Process modifications to conserve water, energy and chemicals and minimize wastewater generation

1. Use cooling water in place of process water in both step-1 and step-2.
2. Segregate and collect the effluent of step-2 and reuse it in step-2.

4.1.1.2.1.5 Processing steps for Polyester Dark shade (Red, Black, Torquish)

1. Fill water, load the fabric, dose chemicals (leveling agent, acetic acid and anticreasing agent), check pH (should be 4.5 to 5), raise temperature to 60°C, dose dyes, raise temperature to 135°C, hold for 10-30 minutes, cool to 70-75°C, and drain.
2. Fill water, dose hydrosulfite and caustic, raise temperature to 70°C, hold for 30 minutes and drain.
3. Fill water, dose acetic acid, raise temperature to 45°C, hold for 30 minutes and drain.
4. Fill water, raise temperature to 70-80°C, hold for 20 minutes, and drain.
5. Fill water, dose softener and acetic acid, hold for 30 minutes, unload the fabric and drain.

6. Dewatering in Hydro-squeezer: Load the dyed fabric, spin for the desired duration and unload the dewatered fabric.
7. Drying on pole driers and then hang under the sun till properly dried.

Chemical consumption in the processing steps for Polyester dark shade dyeing is listed in Table 4.11.

Table 4.11- Chemical consumption for Polyester dark shade dyeing

S. No.	Chemical	Quantity per 300 kg polyester
1	Leveling agent	0.3 gpl
2	Acetic acid	0.5 gpl
3	Anti-creasing agent	0.5 gpl
4	Caustic	1 gpl
5	Hydrosulfite	1 gpl
6	Softener chemical	2 gpl

Process modifications to conserve water, energy and chemicals and minimize wastewater generation

1. Use treated effluent in step-1 in place of process water.
2. Cool the machines in two steps, first flash cooling from 135°C to 105°C and then cooling in an external heat exchanger from 105°C to 75°C.
3. Use cooling water rather than process water in steps -2, and step -4.

4.1.1.2.1.6 Processing steps for Polyester-Cotton Blend (Light, medium and Dark shades)

1. Fill water, load fabric, dose chemicals (dispersing agent, anticreasing agent, wetting agent and acetic acid), check pH (should be 4.5 to 5), dose dyes, raise temperature to 130°C,

hold for 30 minutes, cool to 80°C, dose chemicals (caustic, peroxide, stabilizer - in case of dark shade caustic hydrosulfite are used in place of peroxide and stabilizer) hold for 30 minutes, cool to 70°C and drain.

2. Fill water, dose peroxide killer, raise temperature to 80°C, hold for 20 minutes, cool to 70°C and drain.
3. Fill water, dose acetic acid, raise temperature to 60°C, hold for 20 minutes, and drain.
4. Fill water, check pH (should be 6.5 to 7.0, if not ok then drain and again fill water), dose chemicals (leveling agent, sequestering agent, anti-creasing agent), raise temperature to 40°C, dose dyes, hold for 15 minutes, add salt, raise temperature to 60°C, hold for 30 minutes, add soda and caustic, hold for 45 minutes, check the shade (if not ok, dose additional dyes, run for 30 minutes and check the shade), if ok then drain.
5. Fill water, hold for 30 minutes and drain.
6. Fill water, add acetic acid, hold for 20 minutes, and drain.
7. Fill water, dose soap, raise temperature to 80-85°C, hold for 15 minutes, cool to 70°C, and drain.
8. Fill water, raise the temperature to 80°C, hold for 15 minutes, cool to 70°C and drain.
9. Fill water, add dye fixer if required, run for 20 minutes and drain.
10. Fill water, add softener, hold for 30 minutes, unload fabric and drain.
11. Dewatering in Hydro-squeezer: Load the dyed fabric, spin for the desired duration and unload the dewatered fabric.
12. Drying on pole driers and then Hang under the sun till properly dried.

Chemical consumption in the processing steps for Polyester-Cotton blend dyeing is listed in Table 4.12.

Table 4.12- Chemical consumption for Polyester-Cotton blend dyeing

S. No.	Chemical	Quantity per 300 kg polyester
1	Dispersing agent	0.3 -0.5 gpl
2	Anti-creasing agent	0.5 gpl + 0.5 gpl
3	Wetting agent	0.5 gpl
4	Acetic acid	0.5 gpl + 0.5 gpl + 0.5 gpl + 0.2 gpl
5	Polyester dyes	1 - 5%
6	Caustic	1.5 gpl in RFD, 1 gpl for dark shade, 0.3 gpl light shade and 0.5 gpl for medium shade
7	Peroxide (only for light and medium shades)	1.5 gpl
8	Stabilizer (only for light and medium shades)	0.5 gpl
9	Sodium hydrosulfite (dark shade)	1 gpl
10	Peroxide killer	0.5 gpl
11	Leveling agent	0.5 gpl
12	Sequestering agent	0.5 -0.7 gpl
13	Soda	5 gpl
14	Cotton dyes	0-7%
15	Salt	5 -80 gpl
16	Soap	0.5 -0.75 gpl
17	Dye fixer	0.5 – 1.0 gpl
18	Softener chemical	2 gpl

Process modifications to conserve water, energy and chemicals and minimize wastewater generation

1. Use treated effluent in place of process water in step-1.
2. Cool the machine contents in two steps first through flash cooling and then cooling in an external heat exchanger.
3. Use cooling water in place of process water in step-3.
4. Recycle and reuse the effluent from step-3 in step-2 in place of process water.
5. Combine steps 6 and 7 (first carry out neutralization with acetic acid and then without draining out the liquid go ahead with hot soap washing.
6. Use cooling water in place of process water in steps- 6, 7 and 8.
7. Segregate the effluents from steps -10 and reuse in same step-10 in place of process water.
8. Improve the draining process through application of compressed air whenever the soft flow machine is drained.

4.1.1.2.2 Yarn and Fiber Dyeing

It includes the processing steps for processing of Acrylic (yarn and fibre).

4.1.1.2.2.1 Processing steps for Acrylic yarn

1. Load acrylic yarn into the bulking machine, inject steam through the bottom perforated steam coils to raise temperature to 95-100°C, hold for 10-15 minutes, allow cooling, open the machine and unload the yarn.
2. Load the bulked yarn into cabinet dyeing machine, close the machine, filled water to the desired level (1:15), raise temperature to 40°C by passing steam through the bottom steam coils, dose chemicals (acetic acid, retardants, and sodium sulfate), hold for 10-15 minutes, dose dyes (acrylic dyes and cationic softener), raise temperature to 95-98°C, hold for the desired duration (20 minutes in case of light shades, 30 minutes in case of

medium shades and 40 minutes in case of dark shades), cool to 50°C by circulating cooling water through the bottom coils, drain out the liquid and unload the yarn.

3. Load the dyed yarn in hydro-squeezer, spin for the desired duration and unload the dewatered yarn.
4. Dry the yarn under the sun or in the drier chamber.

Chemical consumption in the processing steps for acrylic yarn dyeing is listed in Table 4.13.

Table 4.13-Chemical consumption for Acrylic yarn dyeing

S. No.	Chemical	Quantity
1	Acetic acid	0.5 – 2%
2	Retarder	0.25 – 0.5%
3	Sodium sulfate	2 – 4%
4	Cationic softener	1 – 2%
5	Acrylic dyes	0.017 - 2%

Process modifications to conserve water, energy and chemicals and minimize wastewater generation

1. Use cooling water at least partially in place of process water in the cabinet dyeing machine in step-2 and avoid heating to raise temperature to 40°C. This will conserve steam and saves the machine time.
2. Use circulating cooling water system for cooling the machine contents from 98°C to 50°C in step-2.
3. Segregate the steam condensate from all the places where steam is indirectly used (including at the radiator heater of the yarn/fiber drier chamber).

Processing steps for Acrylic yarn (Without using Bulking machine)

1. Raw acrylic yarns are taken into a machine; temperature is raised to 45-50°C and hold for 5 to10 min.

2. Fill water (1000-1200 L) in cabinet dyeing machine (60 kg capacity).
3. Load acrylic yarns in hangers in machine (60 kg), dose chemicals (leveling agent (0.3% or 180 gm), Acetic acid (0.3 to 1%), softener (0.5%), Dose dyes (Red GTL, Red 2B, Golden Yellow), raise temperature to 99°C, Then hold for 45 minutes.
4. Overflow cool to 30-35^{o}C and Drain.
5. Fill water (1000-1200 L) and Drain.
6. Dewatering (in Hydro-squeezer): Load the dyed yarn, spin for the desired duration and unload the dewatered yarns.

The characteristics of acrylic processing steps (Dyeing and Washing) in textile industry are presented in Table 4.14.

Table 4.14- Characteristics of dyeing and washing steps for acrylic in textile industry

S.No.	Parameters	Units	Dyeing	Washing
1	pH	--	4.6	6.8
2	Conductivity	µS/cm	834	662
3	Turbidity	N.T.U	4	3
4	COD	mg/L	1127	167
5	Colour	Pt. Co. Unit	106	69
6	TSS	mg/L	14	8
7	TDS	mg/L	866	502
8	Chloride	mg/L	49.98	26.99
9	Alkalinity	mg/L as $CaCO_3$	Nil	198.8
10	T. Hardness	mg/L as $CaCO_3$	266.56	258.23
11	BOD	mg/L	598.46	79.96

12	Zn	mg/L	1.082	0.205
13	Mg	mg/L	19.0	18.5
14	Ca	mg/L	75.8	64.8
15	Fe	mg/L	0.612	0.564
16	Pb	mg/L	<0.05	0.753
17	Ni	mg/L	<0.10	<0.10
18	Mn	mg/L	0.214	0.118
19	Na	mg/L	37.3	20.1
20	Sulphate	mg/L	240.32	179.41

4.1.1.2.2.2 Processing steps for Acrylic Fibres

1. Prepare acrylic top (load fiber into the fiber carrier), transfer the top into the top dyeing machine, safety lock the machine, fill water (1:11 ratio), raise temperature to 40°C by heating in external heat exchanger with steam, dose chemicals (acetic acid, retardants, sodium sulfate and cationic softener), hold for 10-15 minutes, dose dyes (injection dosing), raise temperature to 60°C, hold for 10 minutes, raise temperature to 98-100°C, hold for the desired duration (20 minutes in case of light shades, 30 minutes in case of medium shades and 40 minutes in case of dark shades), cool to 50°C by circulating cooling water in the external heat exchanger, drain out the water and unload the acrylic top (fiber carrier).
2. Load the dyed fiber in hydro-squeezer, spin for the desired duration and unload the dewatered fiber.
3. Sun dry it or dry in the drier chamber.

Chemical consumption in the processing steps for acrylic fibers dyeing is listed in Table 4.15.

Table 4.15- Chemical consumption for Acrylic fibres dyeing

S. No.	Chemical	Quantity
1	Acetic acid	0.5 – 2%
2	Retarder	0.25 – 0.5%
3	Sodium sulfate	2 – 4%
4	Cationic softener	1 – 2%
5	Acrylic dyes	<0.1 to 2%

Process modifications to conserve water, energy and chemicals and minimize wastewater generation

1. Use cooling water at least partially in place of process water in the top dyeing machine in step-1 and avoid heating to raise temperature to 40°C. This will conserve steam and saves the machine time.
2. Use circulating cooling water system for cooling the machine contents from 98°C to 50°C in step-1.
3. Segregate the steam condensate from all the places where steam is indirectly used (including at the radiator heater of the yarn/fiber drier chamber).

4.1.1.3 Utilities and other supporting facilities

The utilities and support activities related machinery/facilities of the industrial unit was presented in Table 4.16.

Table 4.16- Utilities and support activities related machinery/facilities of the industrial unit

S. No.	Machinery/facility	Number of units	Capacity
1	Water supply system	2	Two submersible pumps (one driven

			by 10 hp and the other by 15 hp electrical drives)
2	RO water plant	1	40 m^3/day capacity
3	Electrical power system	1	Comprising of LT panel, Stepdown transformers, capacitors bank and captive power systems (DG sets) Connected load of 350 kW
4	DG sets	2	1st of 180 kVA and 2nd of 350 kVA
5	Boiler -1 (rice husk, thudi, pudina and sarson fired)	1	3.6 ton steam per hour capacity.
6	Boiler -2 (wood fired)	1	0.8 ton steam per hour capacity A standby boiler
7	Air compressors	2	1st of 126 cfm and 2nd of 40 cfm

4.1.1.3.1 Water supply

Two submersible pumps (one driven by 10 hp and the other by 15 hp electrical drives) were used for extracting the ground water (raw water). The pumped out raw water was lifted and taken into a 30 m^3 capacity overhead tank and supplied under gravity to all the points of use. The points of water use include-

- RO water plant
- Dyeing machines
- Cooling tower and circulating cooling water system
- To amenities for domestic use

The plant was operated in two shifts (of 12 hours each) and a total 70 employees (40 in day shift and 30 in the night shift) was working in the industrial unit. These employees requires <7 m^3/day of water.

4.1.1.3.2 RO water plant

Reverse Osmosis (RO) water plant was used for generating <40 m^3/day of RO water required in the boilers for use as boiler feed water. Assuming 70% of the input water will be available as RO water, it was generating ~17 m^3/day of reject water. The total dissolved solids in input water, RO water and reject stream was 350 mg/l, 20 mg/l and 944 mg/l respectively.

4.1.1.3.3 Electrical power system

Connected load of the industrial unit was 350 kW and actual load was 240 kW. PSEB power grid was depended on for the power supply. During peak load hours and during power failures, DG sets was used as source of the power supply. From the grid, 11 kV power was drawn, metered and passed through a 400 kVA transformer, to step-down the voltage to 440 V, taken to the LT panel, and from there supplied to the points of use. The supplied power was mainly consumed for running the electrical drives.

For adjusting the power factor, capacitors will be provided parallel to the LT panel. Two DG sets, one of 180 kVA capacity and the other of 350 kVA capacity, was used. The DG sets consume 19 L per hour of diesel in case of 180 kVA DG set and 29 L per hour of diesel in case of 350 kVA DG set. After every 250 hours of running, engine oil of the DG sets was discarded and replaced by fresh oil. For avoiding noise pollution problems, the DG sets was acoustically enclosed and exhaust mufflers was provided.

4.1.1.3.4 Boilers and steam supply

It includes two no. of boilers- I and II, Steam supply system, compressors and compressed air supply system.

4.1.1.3.4.1 Boiler-I

This boiler is of 3.6 ton steam per capacity. Rice husk and biomass was burnt as fuels in this boiler. The boiler system has a FD fan, furnace, three pass fire tube boiler, heat recovery unit (HRU), cyclone (APCD), ID fan and stack (Approx 100ft). Daily 18-23 tons of rice husk or biomass was burnt as fuel in the boiler. Return steam condensate and RO water was used as boiler feed water. The boiler feed water was taken into a boiler feed water tank, maintained at elevated temperature through heating in the HRU of the boiler system, and pumped into the boiler with the help of boiler feed water pumps. The boiler was generating saturated steam at <120 lb/inch^2 (105-107 lb/inch^2) pressure. TDS and TSS levels in the boiler were regulated at the desired level through boiler blow down. 4-5% of the boiler feed water was blown down.

4.1.1.3.4.2 Boiler-II

This boiler is of 0.8 ton steam per hour capacity. Wood is burnt as fuel in this boiler. The boiler system includes a furnace, a boiler, a heat recovery unit (HRU), an ID fan and a stack (Approx 100ft). The system includes no FD fan and no APCD. Daily 3-5 tons of wood was burnt as fuel in the boiler. Return steam condensate and RO water was used as boiler feed water.

The boiler was generating saturated steam at <120 lb/inch^2 (105-107 lb/inch^2) pressure. TDS and TSS levels in the boiler were regulated at the desired level through boiler blow down. 4-5% of the boiler feed water was blown down.

4.1.1.3.5 Compressors and compressed air supply

Two compressors, one of 126 cfm capacity and the other of 40 cfm capacity were used for supplying the air required for pneumatic control and for the air cushioning in the dyeing machines. Lubricating oil was used in these machines and that needs replacement after every 300 hours running. Discarded lubricating oil is hazardous waste.

4.1.1.4 In-plant measures for waste minimization

The following strategies have been identified to have the potential to conserve water and minimize wastewater generation:

- Modifying the scheme of scouring and dyeing to eliminate overflow cooling and washing, to reduce the number of steps involved, and to recycle wherever feasible the wastewater generated at the down-stream steps in the upstream steps.
- Having a dedicated circulating cooling water system inclusive of a cooling tower and using the return cooling water in place of process water wherever feasible.
- Segregating the steam condensate and reusing as boiler feed water.
- Using the treated low/medium strength wastewater in the dyeing.

4.1.1.4.1 Cooling tower and circulating cooling water system

The cooling water requirements, detailed scheme and various types of facilities available with cooling water system are mentioned below.

4.1.1.4.1.1 Cooling water requirements

Cooling water is required in all the dyeing machines (soft-flow machines, cabinet dyeing machines, top dyeing machines and cone dyeing machines). A circulating cooling water system (comprising of a cooling water sump, cooling water pump and piping, overhead cooling water tank and distribution piping, return cooling water collection piping and pit, cooling tower, and pumps and piping for circulating the cooling water of the sump through the cooling tower) will be used for satisfying the cooling water requirements of the core industrial processes. Warm/hot return cooling water will be bled out from the circulating cooling water system, at the return cooling water pit, and pumped to the overhead tank for use as warm/hot water in the core processes in place of the process water wherever and whenever desired. Water level in the cooling water sump will be maintained at the desired level through adding process water as makeup water to compensate the evaporation and drift losses of the cooling water and the cooling water bled out for use in place of process water in the core processes. See Figure 4.1 for the detailed scheme of the circulating cooling water system.

Process wise cooling water requirements of the industrial unit-I are estimated and shown in the Table 4.17. In these estimations ΔT of the cooling water has been assumed as 12°C. Heat content of the dyeing machine (soft-flow, top dyeing and cone dyeing machines) plus fabric/fiber has been taken as equal to that of water of the same mass as the fabric or fiber. But in case of the cabinet dyeing machines, heat content of the machine plus yarn has been taken as equal to 1.5 times that of water of the same mass as the yarn. Further, heat losses from the machine are considered as compensated by the inefficiencies of the associated heat exchanger.

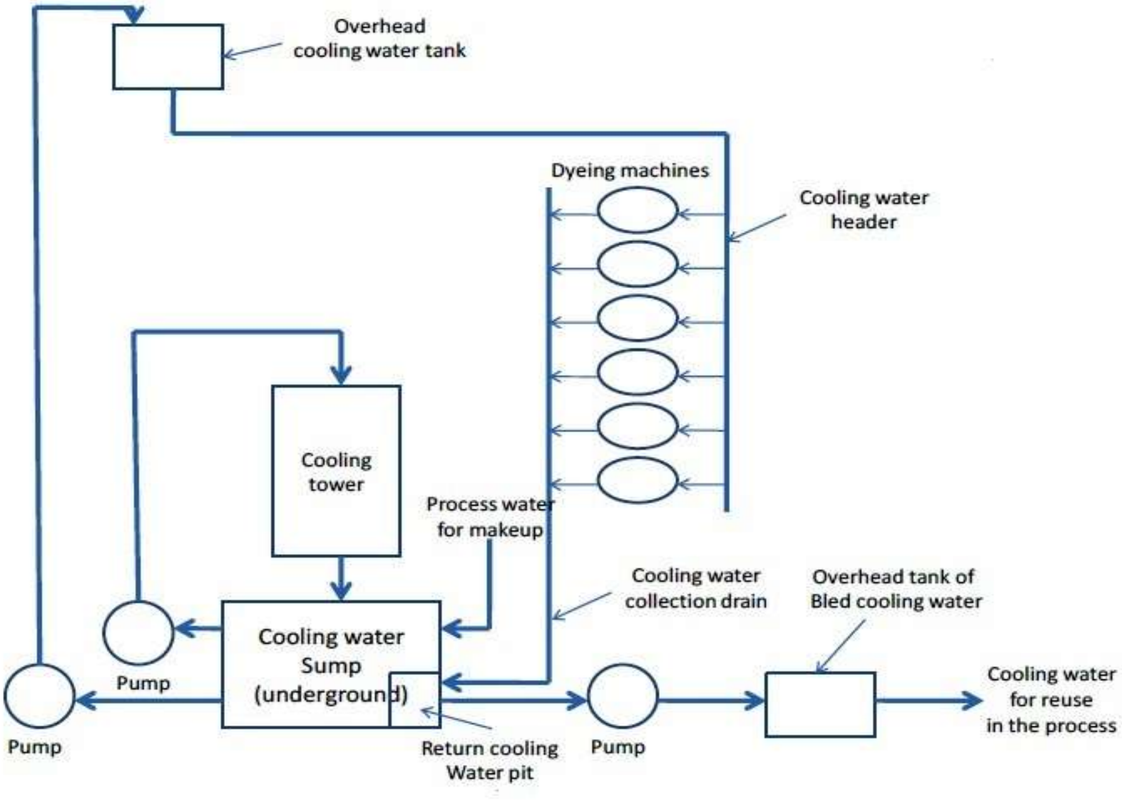


Fig 4.1- The detailed scheme of the circulating cooling water system.

Table 4.17- Cooling water requirements of the core processes of industrial unit-I

S.No.	**Core processes**	**Production capacity (kg/day)**	**Circulating cooling water requirement**	**Cooling bled out for use as process water**	**Cooling water requiring cooling**
			m^3/day (L/Kg in parenthesis)		
1	Cotton – white shade	2000	42 (21.0)	13 (6.5)	29 (14.5)
2	Cotton – light and medium slide	1200	87.3 (72.75)	39 (32.5)	48.3 (40.25)
3	Cotton – dark shade	800	58.2 (72.75)	26 (32.5)	32.2 (40.25)
4	Polyester –light and medium	4800	216 (45)	16.8 (3.5)	199.2 (41.5)
5	Polyester – dark shade	3200	156 (48.75)	44.8 (14)	111.2 (34.75)
6	Polyester – cotton	1000	71.75 (71.75)	18 (18)	53.75 (53.75)
7	Acrylic yarn	1000	70 (70)	10.6 (10.6)	65.4 (65.4)
8	Acrylic fiber	500	27.5 (55)	4.8 (9.6)	22.7 (45.4)
9	Woolen fiber	500	43.5 (87)	4 (8)	39.5 (79)
10	Cotton cone	1000	68.8 (68.8)	10 (10)	58.8 (58.8)
Total		**16000**	**840.55 (52.53)**	**187 (11.69)**	**659.55 (41.22)**

The maximum cooling water demand of the dyeing machines at any instance of time has been estimated at 5990 LPM (say 6000 LPM) on the basis of the assumption that at any given time a maximum of 50% of the dyeing machines (processing 2265 kg of fabric/yarn/fiber) will be in processing and demanding cooling water simultaneously. And, the demand of cooling water is assumed as spread over 20 minutes time.

4.1.1.4.1.2 Circulating cooling water system

Cooling water after use (return cooling water) will be collected into a drain pipe and conveyed into the cooling water sump through the return cooling water pit. The water will in fact overflow the return cooling water pit and get into the cooling water sump. The drain pipe will have open channel flow just as in a sewer and it will have sufficient number of vent pipes for venting out the gases released from the return cooling water specially when its temperature is >60^{o}C.

Water will be pumped from the cooling water sump and cooled in the cooling tower and collected back into the sump with the help of a pump and necessary piping. This circulation cooling will be carried out as long as the cooling water temperature remains above a set value. Cooled water from the sump will be pumped as and when required and supplied to the overhead cooling water tank as it gets emptied from use by the dyeing machines. Pumping of the cooling water to the overhead cooling water tank will be regulated by minimum and maximum cooling water level switches provided in the overhead cooling water tank.

The cooling water sump will have provisions for the addition of makeup water to compensate the evaporation, drift losses, leaks and the return cooling water used in the process from the return cooling water pit. Provisions will also be made to drain out all the water present in the circulating cooling water system (including that present in the sump and in the overhead tank) into the ETP if needed (contamination of the circulating cooling water by leaks in the heat exchanger of the dyeing machines may necessitate this).

4.1.1.4.1.3 Facilities of the circulating cooling water system

The circulating cooling water system will include the following facilities:-

1. Cooling water sump
2. Overhead cooling water supply tank
3. Return cooling water pit

4. Cooling tower
5. Pump and piping for circulating the cooling water through the cooling tower from the sump
6. Pump and piping for pumping the cooling water from sump to the overhead cooling water supply tank
7. Piping for supplying cooling water to the dyeing machines under gravity
8. Piping for draining the return cooling water back into the cooling water sump
9. Return cooling water pump and piping for pumping into a overhead tank and using as process water

4.1.1.4.2 Boilers and steam supply & steam condensate recovery systems

Steam requirements of the core processes are estimated at 68 tons/day when the industrial unit is run at its design capacity. Use of return cooling water, in place of process water, can bring down the steam requirement to 52 tons/day. The details on steam requirements were presented in Table 4.18. Here, the steam requirement calculations have considered the steam as 95% dry, the useful energy of the dry steam was taken as 540 kcal/kg, and the heat transfer efficiency at the dyeing machines as 90%. Heat requirements of the fabric and of the machine are considered as inclusive in these calculations.

Table 4.18- Steam requirements of the core processes of industrial unit-I

S.No.	**Core processes**	**Production capacity (kg/day)**	**Steam requirement, ton/day (kg/kg in parenthesis)**	
			when bled cooling water not used	**when bled cooling water used**
1	Cotton – white shade	2000	8.68 (4.34)	5.20 (2.60)
2	Cotton – light & medium	1200	7.7 (6.42)	5.58 (4.65)
3	Cotton – dark shade	800	5.19 (6.49)	3.83 (4.79)

4	Polyester –light & medium	4800	14.64 (3.05)	12.10 (2.52)
5	Polyester – dark shade	3200	13.18 (4.12)	10.78 (3.37)
6	Polyester – cotton	1000	5.99 (5.99)	4.43 (4.43)
7	Acrylic yarn	1000	3.71 (3.71)	3.13 (3.13)
8	Acrylic fiber	500	1.28 (2.55)	1.08 (2.16)
9	Woolen fiber	500	2.82 (5.63)	2.51 (5.02)
10	Cotton cone	1000	4.89 (4.89)	3.73 (3.73)
Total		**16000**	**68.08 (4.26)**	**52.37 (3.27)**

Assuming 30% energy losses in the steam distribution system (between the steam boiler and the actual steam use points), the steam generation requirements have been estimated at 75-98 tons/day. Assuming 70% thermal efficiency for the steam boiler, fuel (rice husk/biomass) requirement of the boiler has been estimated at 21 to 29 tons/day. In these calculations, energy content of steam has been taken as 650 kcal/kg, and calorific value of the rice husk have been taken as 3200 kcal/kg respectively.

Assuming boiler blow down losses at 5%, boiler feed water requirement for generating 75-98 tons/day of steam has been estimated at 79-103.2 m^3/day. With proper steam condensate recovery system in place, more than 70% of the boiler feed water requirements have been estimated can be met from the recovered steam condensate.

Provisions will be made for segregating the generated steam condensate (from the circulating cooling water) at the heat exchangers of all the dyeing machines. A common drain pipe with necessary air vents can be used to collect the condensate from all the points of generation and convey into a steam condensates tank. From here the condensate will be pumped (with the help of condensate level actuated pump) to the boilers for use as boiler feed water.

Alternately in place of steam condensates tank and pump a blow case pump can be used for pumping the collected condensate to the boiler. 5 kL capacity underground tank may be appropriate as a steam condensates tank. The condensate drain pipe may be maintained dipped in the condensate of the tank through maintaining certain minimum level of condensate in the tank. Use of RO water as boiler feed water will be limited just to use as makeup boiler feed water.

4.1.1.4.3 RO reject water stream

- The RO water plant, in the process of producing 27-35 m^3/day of RO water, will be generating 15 to 18 m^3/day of reject water. The TDS in the input water and RO water was 350 mg/L and 20 mg/L respectively, and the reject water has been estimated to have 944 mg/L of TDS.

- This reject water will be supplied to the amenities for domestic use. However this reject water will not be supplied to the drinking water closets. Left out reject water of the RO water plant will be taken into the cooling water sump of the circulating cooling water system.

4.1.1.4.4 Modifying the scheme of scouring and dyeing

4.1.1.4.4.1 Eliminating overflow cooling/washing and reducing the number of scouring and dyeing steps

Avoid overflow cooling/washing of the fabric. When only cooling is the requirement then practice cooling in the external heat exchanger with circulating cooling water. When both cooling and washing are required, then either go for first cooling in external heat exchanger, next draining out the bath contents and then fill water for washing or go for cycles of partial drain-fill-partial drain cycles of cooling and washing. The modifications for avoiding overflow cooling/washing are described earlier under the process modifications suggested for different dyeing processes.

Combine the post-scouring neutralization and hot soap wash steps into a single step to conserve water and minimize wastewater generation. The dyeing process where this combining is possible is indicated earlier under the process modifications suggested for different dyeing processes.

The above two when implemented can conserve over 100 m^3/day of water (Table 4.19). Implementation of these measures does not require any additional facilities and the associated machinery requires no physical modifications. The implementation requires only procedural changes and training of the operators.

4.1.1.4.4.2 Segregation and reuse of recyclable wastewaters

- Segregate and store the effluent generated from the post-scour neutralization step and reuse it in the post-scour washing in case of cotton and polyester-cotton fabric processing.
- Segregate and store the effluent generated from the softener application step and reuse the effluent in softener applicator step of the next batch of fabric processing. This will conserve water and softener chemical and minimize wastewater generation.
- Implementing these measures is estimated to conserve about 107 m^3/day water and reduce the wastewater generation by about the same amount (Table 4.19).
- Implementation of these measures may require provisions on the dyeing machines for separately draining out wash-water generated from the post-scour neutralization step of the cotton and polyester-cotton dyeing, and from the softener applicator steps of dyeing. Both these waters will be collected into two or more separate sumps of

appropriate liquid storage capacity (<$5m^3$). Separate drain pipes may be needed for conveying these waters from the dyeing machines to the collection sumps. The sumps will have overflow drains for allowing excess wastewaters into the ETP for treatment as low/medium strength wastewater. Further, necessary pumps, piping and fittings, and overhead effluent dose tanks of sufficient capacity (<5 m^3) will be provided for facilitating reuse of the effluent in the dyeing machines.

4.1.1.4.4.3 Use of warm return cooling water in place process water in the dyeing machines

- Use the warm return cooling water in place of the process water in all the steps where initial heating of the machine contents to 40°C or more temperature with steam is needed. This will minimize the process steam consumption and save the machine time. The steam requirements have been estimated to reduce to 52 tons/day from 68 tons/day (Table 4.19). This in turn will avoid generation of about 23 tons/day of steam.
- For facilitating this, the warm return cooling water will be pumped and stored in a overhead return cooling water tank (may be of 30 m^3 capacity) and from there through separate piping and fittings the water will be supplied to all the dyeing machines for use.

4.1.1.4.4.4 Reuse of treated low/medium strength dye effluent

- Use treated low/medium strength dye effluent in place of process water, specially, in polyester fabric dyeing for conserving water. Calculations indicate that about 72 m^3/day of the treated low/medium strength dye effluent can be reused in the polyester and polyester cotton dyeing (Table 4.19).

- For facilitating the use the treated secondary effluent will be filtered and chlorinated and stored in an overhead tank. From this tank through necessary piping and fittings the effluent will be supplied to the dyeing machines for reuse.

Table 4.19- Water, cooling water and steam consumption and wastewater generation

Fabric/Yarn/ Fiber/fibre cones	Quantity processed	Process Water	Cooling water	Recycle water	Treated effluent	Circ. Cooling Water	Steam	Condensate	Wastewater for recycling	WW
Cotton – white shade	L/kg	9.0	6.5	12.0	0.0	21.0	2.6	2.6	12.0	15.0
	For 2000 kg/day in m^3/day	18.0	13.0	24.0	0.0	42.0	5.2	5.2	24.0	30.0
	Without RW & TE recycling @	42.0	13.0	0.0	0.0	42.0	5.2	5.2	0.0	54.0
Cotton – light and medium slide	L/kg	16.2	32.5	12.0	0.0	72.8	4.7	4.7	12.7	48.2
	For 1200 kg/day in m^3/day	19.4	39.0	14.4	0.0	87.3	5.6	5.6	15.2	57.8
	Without RW & TE recycling @	33.8	39.0	0.0	0.0	87.3	5.6	5.6	0.0	72.2
Cotton – dark shade	L/kg	22.7	32.5	12.0	0.0	72.8	4.8	4.8	12.7	54.7
	For 800 kg/day in m^3/day	18.2	26.0	9.6	0.0	58.2	3.8	3.8	10.1	43.8
	Without RW & TE recycling @	27.8	26.0	0.0	0.0	58.2	3.8	3.8	0.0	53.4
Polyester – light and medium	L/kg	0.3	3.5	3.3	8.0	45.0	2.5	2.5	3.3	11.6
	For 4800 kg/day in m^3/day	1.2	16.8	15.6	38.4	216.0	12.1	12.1	15.6	55.7
	Without RW & TE recycling @	55.2	16.8	0.0	0.0	216.0	12.1	12.1	0.0	71.3
Polyester – dark shade	L/ kg	8.0	14.0	6.0	8.0	48.8	3.4	3.4	6.0	28.9
	For 3200 kg/day in m^3/day	25.6	44.8	19.2	25.6	156.0	10.8	10.8	19.2	92.5
	Without RW & TE recycling @	70.4	44.8	0.0	0.0	156.0	10.8	10.8	0.0	111.7
Polyester –	L/kg	19.7	18.0	11.5	8.0	71.3	4.4	4.4	12.7	45.4

cotton	For 1000 kg/day in m^3/day	19.7	18.0	11.5	8.0	71.3	4.4	4.4	12.7	45.4
	Without RW & TE recycling @	39.2	18.0	0.0	0.0	71.3	4.4	4.4	0.0	56.9
Acrylic yarn	L/kg	5.2	10.6	0.0	0.0	70.0	3.1	2.8	0.0	15.9
	For 1000 kg/day in m^3/day	5.2	10.6	0.0	0.0	70.0	3.1	2.8	0.0	15.9
	Without RW & TE recycling @	5.2	10.6	0.0	0.0	70.0	3.1	2.8	0.0	15.9
Acrylic fiber	L/kg	1.4	9.6	0.0	0.0	55.0	2.2	2.2	0.0	10.9
	For 500 kg/day in m^3/day	0.7	4.8	0.0	0.0	27.5	1.1	1.1	0.0	5.4
	Without RW & TE recycling @	0.7	4.8	0.0	0.0	27.5	1.1	1.1	0.0	5.4
Woolen fiber	L/kg	11.6	8.0	8.0	0.0	87.0	5.0	5.0	8.0	19.1
	For 500 kg/day in m^3/day	5.8	4.0	4.0	0.0	43.5	2.5	2.5	4.0	9.6
	Without RW & TE recycling @	9.8	4.0	0.0	0.0	43.5	2.5	2.5	0.0	13.6
Cotton cone	L/kg	17.0	10.0	8.5	0.0	68.8	3.7	3.7	8.5	26.7
	For 1000 kg/day in m^3/day	17.0	10.0	8.5	0.0	68.8	3.7	3.7	8.5	26.7
	Without RW & TE recycling @	25.5	10.0	0.0	0.0	68.8	3.7	3.7	0.0	35.2
Total	**For 16000 kg/day in m^3/day**	**130.8**	**187.0**	**106.8**	**72.0**	**840.5**	**52.4**	**52.0**	**109.3**	**382.8**
	Without RW & TE recycling @	**309.6**	**187.0**	**0.0**	**0.0**	**840.6**	**52.3**	**52.0**	**0.0**	**489.6**

@ RW and TE stand for Recycled Wastewater and Treated Effluent respectively.

4.1.1.5 Raw materials, energy, water, chemicals and important other materials and inventory of the wastes generated

Chemicals consumed by the industrial unit are shown in Table 4.20. This list excludes the chemicals required in the effluent treatment. Water requirements by the core processes of the industrial unit are shown in Table 4.21. Additional water as shown in Table 4.22 will be required at the RO water plant for use as boiler feed water, and by the circulating water system as makeup water.

Table 4.20- Chemical requirements of the core process

S. No.	Chemical	Amount (kg/day)
1	Common salt	1088
2	Cotton dyes	128
3	Polyester dyes	174
4	Acrylic dyes	16.1
5	Woollen dyes	12.6
6	Softening chemical	221
7	Peroxide	184
8	Soda ash	160
9	Acetic acid	126
10	Caustic	88.7
11	Anti-creasing agent	74.6
12	Water softener	66.4

13	Sodium sulfate	45.0
14	Wetting agent	34.6
15	Hydro-sulfite	33.6
16	Levelling agent	32.4
17	Stabilizer	29.7
18	Whitening agent	18.0
19	Dye fixer	18.3
20	Peroxide killer	13.2
21	Ammonium sulfate	10.0
22	Soap	9.8
23	Retarder	7.9
24	Sequestering agent	4.8
25	Silicone softener	4.0
26	Dispersing agent	3.2
Total		**2604**

Table 4.21- Process water requirements of the core processes

S. No.	Fabric Processed	Production capacity	Process water requirements			
			when CW, RW and TE are reused	when both CW and RW are reused	when only CW is reused	when no water is reused
			m^3/day (L/Kg in parenthesis)			
1	Cotton – white shade	2000	18.0 (9.0)	18.0 (9.0)	42.0 (21.0)	55.0 (27.5)
2	Cotton – light and medium slide	1200	19.5 (16.2)	19.5 (16.2)	33.8 (28.2)	72.8 (60.7)
3	Cotton – dark shade	800	18.2 (22.7)	18.2 (22.7)	27.8 (34.7)	53.8 (67.2)
4	Polyester –light and medium	4800	1.2 (0.25)	39.6 (8.25)	55.2 (11.5)	72.0 (15.0)
5	Polyester – dark shade	3200	25.6 (8.0)	51.2 (16.0)	70.4 (22.0)	115.2 (36.0)
6	Polyester – cotton	1000	19.7 (19.7)	27.7 (27.7)	39.2 (39.2)	57.2 (57.2)
7	Acrylic yarn	1000	5.2 (5.17)	5.2 (5.17)	5.2 (5.17)	15.8 (15.77)
8	Acrylic fiber	500	0.7 (1.4)	0.7 (1.4)	0.7 (1.4)	5.5 (11.0)
9	Woollen fiber	500	5.8 (11.6)	5.8 (11.6)	8.8 (19.6)	13.8 (27.6)
10	Cotton cone	1000	17.0 (17.0)	17.0 (17.0)	25.5 (25.5)	35.5 (35.5)
Total		**16000**	**130.9 (8.18)**	**202.9 (12.68)**	**308.6 (19.29)**	**496.6 (31.04)**

Table 4.22- Water requirements of circulating cooling water system and of the RO water plant

S. No.	Place of use	Condition of use	Quantity used	Remarks
1.	Circulating cooling water system	When circulating cooling water is not used as process water	26 m^3/day	Evaporation and drift losses are assumed at 2.5% and 0.5% respectively. Makeup water TDS and TDS tolerable in circulating cooling water are assumed at 350 and 2100 mg/L respectively.
		When circulating cooling water is used to full potential	207 m^3/day	
2.	RO water plant	When circulating cooling water is used as process water	<40 m^3/day	70% of the steam supplied is assumedly recovered as steam condensate and used as boiler feed water. 70% of the water fed to the RO water plant is assumedly recovered as RO water
		When circulating cooling water is not used as process water	<50 m^3/day	
3.	Amenities	When RO water plant rejects stream is used	<1 m^3/day	70 employees are assumed to be working in two shifts (40 in day shift and 30 in night shift) Per capita water requirement of the employees is assumed at 100 L.
		When RO reject water stream is not used	7 m^3/day	

Inventory of the wastewater generated from the core process is given in Table 4.23. Wastewaters generated from the utilities and services including amenities are shown in Table 4.24.

Table 4.23- Wastewater generation from the core processes

S.No.	**Fabric/yarn/fiber/ fiber cone processed**	**Production capacity (kg/day)**	**Wastewater generation in m^3/day (L/kg in parentheses)**		
			Without implementing modifications	**With all suggestion in place**	**With only cooling water and steam condensate segregation in place**
1	Cotton – white shade	2000	81.0 (40.5)	30 (15.0)	54.0 (27.0)
2	Cotton – light and medium slide	1200	126.24 (105.2)	57.84 (48.2)	73.02 (60.85)
3	Cotton – dark shade	800	88.64 (110.8)	43.76 (54.7)	53.36 (66.7)
4	Polyester –light and medium	4800	316.8 (66.0)	55.68 (11.6)	71.28 (14.85)
5	Polyester – dark shade	3200	260.16 (81.3)	92.48 (28.9)	111.68 (34.9)
6	Polyester - cotton	1000	139.4 (139.4)	45.4 (45.4)	56.9 (56.9)
7	Acrylic yarn	1000	134.6 (134.6)	15.9 (15.9)	15.9 (15.9)
8	Acrylic fiber	500	34.2 (68.4)	5.4 (10.8)	5.4 (10.8)
9	Woolen fiber	500	58.8 (117.6)	9.55 (19.1)	13.55 (27.1)
10	Cotton cone	1000	108.8 (108.8)	26.7 (26.7)	35.2 (35.2)
Total		**16000**	**1348.8 (84.3)**	**382.71 (23.92)**	**490.29 (30.64)**

Table 4.24- Wastewater generation from the utilities and services

S.No.	Source (utility/service)	Wastewater	Quantity (m^3/day)
1	Boilers	Boiler blow-down water	< 4-5
2	RO water plant	RO reject water (if not fully used and left out)	Negligible quantity
3	Amenities	Domestic wastewater	6

4.1.1.6 Effluent treatment plant

The effluent treatment plant was designed to treat all the wastewater generated (including effluent from utilities, cooling water, steam condensate, spills, washing/rinsing etc.)

4.1.1.6.1 Units/Facilities of ETP

The ETP includes the following units:

1. Screen chamber
2. Equalization tank
3. Flash mixing tank
4. Primary clarifier
5. Secondary clarifier
6. Secondary effluent sump
7. Multi-grade sand filter
8. Activated carbon filter
9. Treated effluent sump
10. Final disposal
11. Sludge beds

12. Sludge pump and filter press system

13. Sludge storage room

14. Treatment chemicals storage room

4.1.1.6.2 Schematic representation of ETP

The Schematic representation of existing Effluent treatment plant was presented in Fig. 4.2.

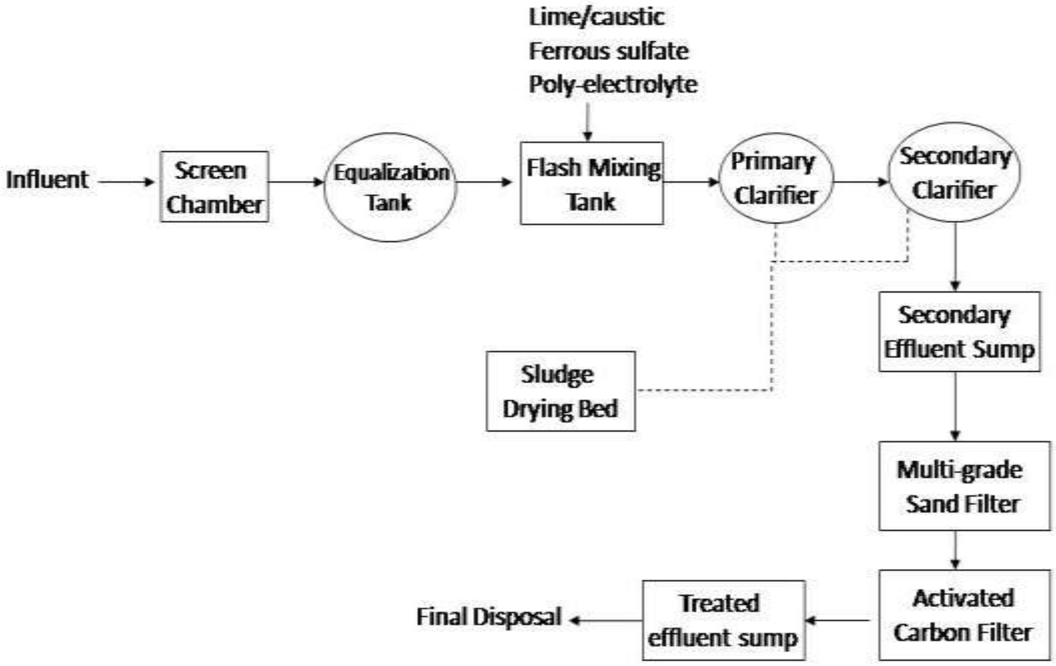


Fig- 4.2 Schematic representation of Effluent treatment plant of industry-I

4.1.1.6.3 Working and treatment through ETP

The ETP was composed of combination of unit operations and unit processes designed to reduce certain constituent of wastewater. The unit processes include the physical, chemical and biological treatment of wastewater. The influent was passed through screen chamber to prevent entry of heavy objects to avoid abrasion of mechanical equipments and clogging of hydraulic system prior to entry into the equalization tank. The effluent is collected in equalization tank to even out the variations in flow rate, pollutant characteristics and to eliminate shock loading. From equalization tank the effluent is pumped to Flash Mixing Tank (FMT) with the help of pump. Here high speed mixing of wastewater is done. The coagulants and neutralizing chemicals are added with wastewater during the turbulent that facilitates homogeneous combination of flocculates to produce micro-flocs.

The over flow of Flash Mixing Tank is taken into primary clarifier for separation of suspended solids. The settling sludge at the bottom of the clarifier is pumped out to sludge drying bed (SDB) by means of pumps. The effluent from primary sedimentation then becomes the influent for secondary treatment. The overflow from primary clarifier is taken into secondary clarifier for the removal of suspended solids. The settled sludge is collected at the center of secondary clarifier and part of it is re-circulated into equalization tank to maintain F/M ratio.

The tertiary processes are employed to remove residual soluble non-biodegradable organic compound, including surfactant, inorganic nutrients and salts, trace contaminants of various types and dissolved inorganic salts. The overflow water from secondary clarifier is collected in secondary effluent sump. From here, the effluent is pumped into the Multi-grade sand filter. This filtration process removes more of heavy particles like suspended and colloidal impurities. The filtrate from Multi-grade sand filter is transferred through pipes to the Activated Carbon Filter (ACF). Activated carbon is the sorption material having a relatively non-polar character and is thus well suited for removal of non-polar organics. The treated water from ACF was collected in a treated effluent sump from where it is routed for final disposal.

4.1.2 Textile Industry-II

This textile processing unit-II has the core facilities (Figure 4.3)-

- Knitting of grey yarn
- Dyeing of knitted fabric
- Raising and Tumbling
- Finishing of the fabric (out sourced)
- Packing and shipping out

Utilities and supporting activities

- Boiler (3.6TPH)
- Ground water pumping and supply system
- Soft water generation and supply system
- Power supply system (including DG sets)

4.1.2.1 Knitting of grey yarn

About 25 knitting machines are there, each of 250 Kg/day capacity. Total capacity of the knitting machines will be 3750 Kg/day. Fibres are generated at the rate of 1 Kg/day, were broomed and dispose of through selling to outside parties. Knitting oil is used in the knitting machines at the rate of 100L/Month for all the machines put together. While 80% of the oil used is lost, 20% is recovered as waste oil and disposed off through sale to outside parties. Each machine requires 3.5 cfm of compressed air of 7.5 kg/cm^2 pressure. The compressor system is provided having two compressors, each of 95 cfm capacity and air drying unit. This compressed air supplied by the system is used in the pneumatic control of the soft-flow machines in the dyeing section. Compressors require replacement of aged lubricating oil after running them for about 2000 hours with fresh lubricating oil. The aged lubricating oil (< 7 L) is disposed off as waste oil through sale to outside parties.

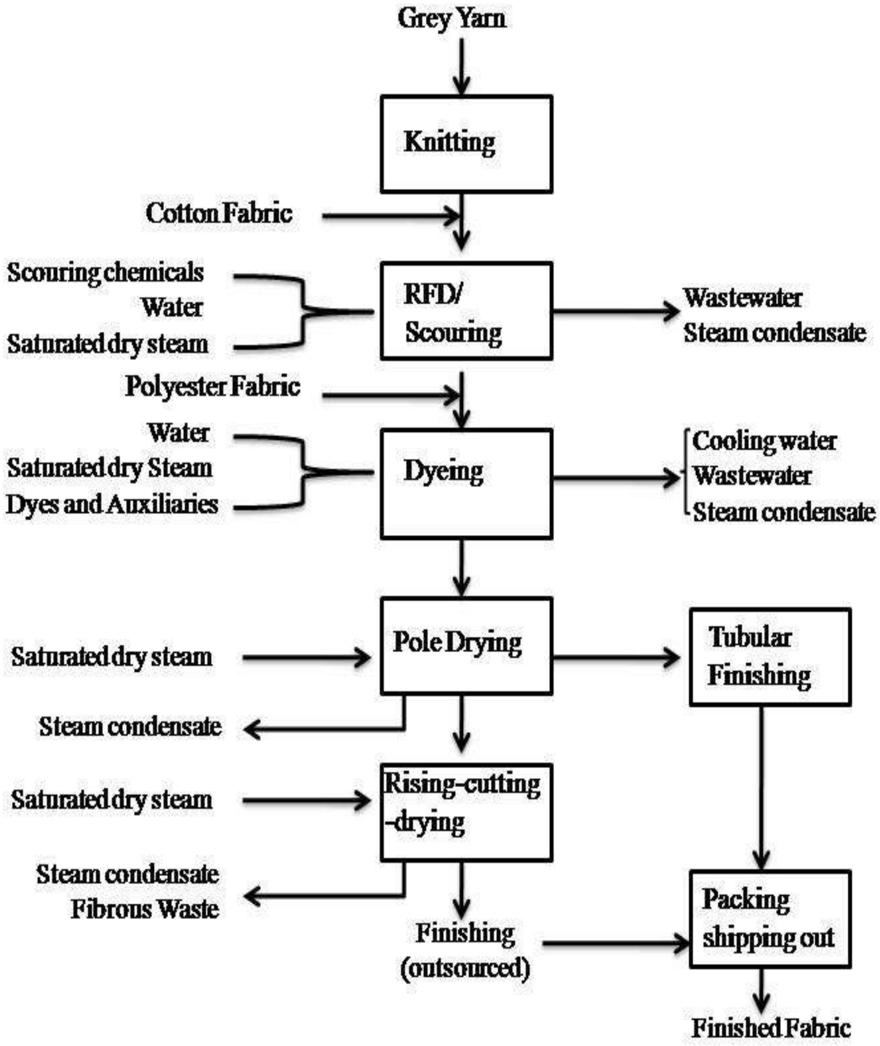


Fig. 4.3- Schematic representation of the core activities of industry-II

4.1.2.2 Dyeing of the Knitted fabric

For dyeing the knitted fabric, 7 soft flow machines (each of 250 kg fabric capacity), one hydrosqueezer and 12 pole driers was used. Daily 2500 kg cotton fabric and 4500 kg polyester fabric was dyed. In case of cotton fabric, the dyeing includes first scouring and then dyeing, whereas the polyester fabric was dyed directly without any scouring.

4.1.2.2.1 Scouring of Cotton fabric

1. Fill water in soft flow machine, load the fabric, dose with scouring chemicals (peroxide, caustic, soda ash, anti-creasing agent and wetting agents), and raise the temperature to 90^{o}C (in an external heat exchanger with saturated dry steam), hold for 40 min.
2. Open the overflow drain and the freshwater inlet for allowing overflow washing and cooling, till the temperature drops to 60^{o}C, stop both the overflow drain and freshwater inflow.
3. Dose acetic acid into soft-flow machine for neutralizing the fabric, run the machine for facilitating the neutralization and the drain out the liquid as wastewater.
4. Fill water in soft-flow machine, raise the temperature to 60-65^{o}C (in an external heat exchanger with saturated dry steam), run the machine for 30 min for washing and then drain out the liquid as wastewater.

4.1.2.2.2 Dyeing of Cotton fabric

1. Fill water in soft flow machine, dose with chemicals (salt, caustic, soda ash, anti-creasing agent and levelling agents) and dyes. Raise the temperature to 60-80^{o}C (in an external heat exchanger with saturated dry steam), hold for 40 min.
2. Open the overflow drain and the freshwater inlet for allowing overflow washing (for 10 min) and stop both the overflow drain and freshwater inflow, drain the liquid as wastewater.
3. Fill water, Dose acetic acid into soft-flow machine for neutralizing the fabric, raise the temperature to 60^{o}C (in an external heat exchanger with saturated dry steam), run the machine for facilitating the neutralization and the drain out the liquid as wastewater.

4. Fill water in soft-flow machine, dose the soaping agent, raise the temperature to 70°C (in an external heat exchanger with saturated dry steam), run the machine for 30 min for soaping and then drain out the liquid as wastewater.
5. Fill water in soft-flow machine, dose the softeners (cationic and silicone), and acetic acid (for pH adjustment), run the machine for 30 min to facilitate the softener application, unload the fabric and then drain out the liquid as wastewater.

4.1.2.2.3 Dyeing of Polyester

1. Fill water in soft flow machine; load the fabric, dose with acetic acid, levelling agent and dyes. Raise the temperature to 130-135°C (in an external heat exchanger with saturated dry steam), hold for 40 min.
2. Cool the soft-flow machine contents to 80°C in the external heat exchanger with fresh water. Freshwater used in the external heat exchanger is taken back into an overhead tank and reused as process water.
3. Unload the fabric and then drain out the liquid as wastewater, Load the fabric onto hydrosqueezer for drying.

4.1.2.3 Supporting activities

The supporting activities includes the boilers, ground water pumping and supply system, soft water production and its supply system and the electrical power systems comprising of DG sets.

4.1.2.3.1 Boiler (3.6 TPH) and steam supply system

An oil fired fire tube three pass boiler is apparently modified (to include a furnace) for burning rice husk as fuel. The boiler system includes a FD fan, furnace, boiler, heat recovery unit, APCD, ID fan and stack. The boiler system was also modified for facilitating burning of pet-coke as fuel. For taking care of high sulphur content of the pet-coke, pulverized lime stone was mixed with pet-coke and fed to the furnace. Furnace temperature are in the range of 500-550°C. Ash accumulating in the furnace chamber is removed once in every 2-3 hours and disposed off as fly ash. Front and rear end of the boiler is opened once a week for removing and disposing of the accumulated ash. Daily 18-20 tons of rice husk is burnt as fuel and since ash content of rice husk is 12-15% daily a maximum of 3 tons of fly ash is generated. Soft water is used as boiler feed water. This water is taken into a boiler feed water tank, maintained at elevated temperature through heating in the HRU, and pumped into the boiler with the help of boiler feed water pumps. Aqua treat boiler water conditioning chemical is dosed at the dose recommended by the supplier into the boiler feed water. Safety valve of the boiler is set at 150 lb pressure and steam is generated at <120 lb/inch^2 (105-107 lb/inch^2) pressure. The generated steam is supplied to the places of use as given below-

- Heat exchangers of the soft-flow machines
- Radiator heaters of the pole driers
- Radiator heaters of the tumbler driers
- Tumbler driers for direct injection

4.1.2.3.2 Ground water pumping and supply system

Ground water is pumped by one of the two submersible pumps provided by the industry. Each of the pumps is driven by a 7.5 hp electrical drive. The pumped out raw water is lifted and taken into an overhead tank and supplied under gravity to all points of use. The points of water use includes-

- Soft water plant for generating soft water and regeneration of the associated ion-exchanger resin bed.
- Soft-flow machines for use in cotton fabric scouring and for cotton and polyester fabric dyeing.

- Heat exchangers of the soft-flow machines for the cooling of the soft flow machine contents.
- To amenities for domestic use.

Water used in the heat exchangers of the soft-flow machines is collected into an underground sump and pumped back into the overhead tank. This ensures heating of the water being supplied to the plant.

This industry-II is operated in two shifts (of 12 hours each) and total 120-130 employees (70-75 in a day shift and 50-55 in the night shift) during January to June months and 160-170 employees (90-95 in day shift and 75-80 in the night shift) during July to December months work in the industrial unit. For domestic use these employees require 12-13 m^3/day of water during January-June months and 16-17 m^3/day of water during July- December months.

4.1.2.3.3 Soft water production and supply system

Soft water required for feeding the boiler is produced in the soft water plant from the raw water. Whenever needed the produced soft water is also used in the soft-flow machines for dyeing purpose. The soft water plant is comprised of an ion-exchange resin bed. This ion-exchange resin bed is regenerated after production of 80 m^3 of soft water. Regeneration involves four steps: backwash, chemical run, slow rinse and rapid rinse and all the steps generate wastewater.

4.1.2.3.4 Electrical power system (including DG sets)

Connected load of the industrial unit is 315 kW and actual load is around 235-240 kW. PSEB power grid is depended on for power supply. During peak load hours and during power failures, DG sets are used to supply the power. From the grid 11 kV power drawn, metered and passed through a 300 kVA transformer, to step-down the voltage to 440 V, taken to LT panel, and from there supplied to the following points of use-

- Soft-flow machines and dyeing section
- Pole driers and tubular machines
- Raising and tumbler unit
- Knitting section
- ETP and boiler
- Water supply
- Lighting and Fans

The supplied power is consumed mainly for two purposes:

a) To run the electrical drives

b) To heaters of the tubular machines (72-90 kW connected load).

There are three DG sets, two of 160 kVA capacity, and one of 320 kVA capacity. The DG sets consume 20 L/hr of diesel in case of 160 kVA DG set and 35 L/hr of diesel in case of 320 kVA DG set. After every 250 hours of running, engine oil of the DG sets is changed and this consumes about 30 L of fresh oil per DG set.

4.1.2.4 In-plant measures for waste minimization

The following strategies have been identified to have the potential to conserve water and minimize wastewater generation:

- Modifying the scheme of scouring and dyeing to eliminate overflow cooling and washing, to reduce the number of steps involved, and to recycle wherever feasible the wastewater generated at the down-stream steps in the upstream steps.
- Having a dedicated closed loop circulating cooling water system for heat recovery into the process water wherever feasible.
- Segregating the steam condensate and reusing as boiler feed water.
- Using the treated low/medium strength wastewater in the polyester dyeing.

4.1.2.4.1 Modified scheme of scouring and dyeing

The actual scheme of scouring and dyeing of cotton fabric and dyeing of polyester has been estimated to consume about 217 m^3/day of process water and 33.5 tons/day steam and generate 214 m^3/day of wastewater. Further, the process is estimated to require circulation of 137 m^3/day of cooling water through soft-flow heat exchangers. The details on water and steam consumption, wastewater generation and on cooling water requirements were presented in Table 4.25.

With slight modifications to the scheme of scouring and dyeing steps, and with adopting certain wastewater recycling and reuse steps, the water consumption and wastewater generation can be brought down to about 149.7 m^3/day and 146.35 m^3/day respectively.

Reuse of the treated effluent for the polyester dyeing can further reduce the raw water consumption by 61.2 m^3/day. This scheme also marginally reduces the steam consumption from 33.4 tons/day to 32.4 tons/day. However, these modifications to the scheme of dyeing and scouring increase the cooling water requirement from 137 m^3/day to 1019 m^3/day. Most of this increase is coming from the drop in ΔT from 40^oC to 12^oC. Otherwise the requirement of cooling water has been around 306 m^3/day.

The scheme of scouring and dyeing incorporating the proposed modifications is briefly described in the following sub-sections. Water and steam consumption, wastewater generation and cooling water requirement are presented in Table 4.26.

4.1.2.4.1.1 Cotton scouring (RFD)

- Fill water in soft flow machine, load the fabric to be dyed, and dosing with scouring chemicals (peroxide, soda ash, caustic and anti-creasing, wetting agents) while running the machine.
- Raise the temperature of the contents of the soft flow machine to 90^oC (in an external heat exchanger with saturated dry steam), holding at temperature for desired period,

cooling the contents (in the same external heat exchanger with circulating cooling water) to 60^{o}C and drain the liquid as scour bath dump.

- Filling the soft-flow machine with washwater-2, running the machine for some time to facilitate the washing of the fabric, and then draining out the liquid as washwater-1.
- Filling the soft-flow machine with process water, running the machine for some time to facilitate the washing of the fabric, and then draining out the liquid as washwater-2 (This washwater will be segregated stored and reused in the next batch of scouring for the first rinsing).
- Filling the soft-flow machine with hot wash water dosing acetic acid for neutralizing the fabric, running the machine for some time to facilitating neutralization and then draining out the liquid as neutralizing wastewater.
- Filling the soft-flow machine with process water, raising the temperature of contents of the machine to 60-65^{o}C (in external heat exchanger with saturated dry steam), running the machine for some time to facilitate washing the fabric and then draining out the liquid as hot wash water (This washwater will be segregated, stored and reused in the next batch of scouring for neutralization).

4.1.2.4.1.2 Cotton Dyeing

- Fill process water in the soft-flow machine, and dosing with chemicals (salt, caustic soda ash, and anti-creasing and levelling agents) and dyes while running the machine.
- Raising temperature of the contents of the soft-flow unit to 60-80^{o}C (in an external heat exchanger with saturated dry steam), holding at the temperature for the desired period, if needed cool the contents (in the same external heat exchanger with circulating cooling water) to 60^{o}C and then draining out the liquid as dye bath dump wastewater.

- Filling the soft-flow machine with process water, running the machine for some time to facilitate the washing of the fabric, and then draining out the liquid as dye washwater-1.
- Filling the soft-flow machine with process water, running the machine for some time to facilitate the washing of the fabric, and then draining out the liquid as dye washwater-2.
- Filling the soft-flow machine with process water, raising the machine contents to 60^{o}C (in an external heat exchanger with saturated dry steam),dosing acetic acid for neutralizing the fabric, running the machine for some time to facilitating neutralization, dosing soap, raising temperature of the machine content to 70^{o}C (in an external heat exchanger with saturated dry steam) and then draining out the liquid as soap wastewater. Here, neutralization and hot soap wash steps have been combined into a single step.
- Filling the soft-flow machine with softener water (with desired strength of cationic and silicone softener), running the machine for desired duration to facilitate application of the softener, unloading the fabric, and then draining out the liquid as softener water. The drained out softener water along with the softener water generated at hydrosqueezer was segregated, stored and reused in the next batch of dyeing as softener water.

4.1.2.4.1.3 Hydro-squeezing

- Load the fabric (unloaded form the soft-flow machine) into hydro-squeezing machine and run it for centrifugal dewatering.
- Consider the squeeze water coming out from the hydrosqueezer as softener water.
- Unload the fabric from the hydrosqueezer to the pole drier for drying.

4.1.2.4.1.4 Polyester Dyeing

- Extend the cooling of the soft-flow machine contents in the external heat exchanger till the temperature is reduced to 60°C.
- In place of overflow cooling and washing, practice the cool drain, fill process water, run, unload the fabric and reuse the liquid in the next batch of dyeing.
- Disperse dyes allow the use of water with relatively high TDS the treated low/medium strength wastewater after tertiary treatment will be used in place of process water in the polyester dyeing.

Table 4.25- Estimated water and steam consumption, wastewater generation and cooling water requirement for the actual scheme of scouring and dyeing

S.No.	Processing Step	Water consumption	Steam consumption	Wastewater generation	Cooling water
Cotton Dyeing (including scouring)					
1	Loading with water and fabric, dose scouring chemicals, raise temperature to 90°C and run for scouring	1800	512.5	---	---
2	Overflow washing for 10 min. (draining time)	3600	---	3600	---
3	Dose acetic acid, run for neutralization and drain	---	---	1175	---
4	Fill process water, rise temperature to 60-65°C, run for hot washing and drain.	1175	256.25	1175	---
5	Fill process water, dose chemicals and dyes, rise temperature to 60-80°C and run for dyeing.	1175	307.5	---	---

6	Overflow washing for 10 min. (draining time) and drain.	3600	---	4775	---
7	Fill process water, dose acetic acid, rise temperature to 60°C, run for neutralization and drain	1175	205	1175	---
8	Fill process water, dose soap, rise temperature to 70°C, run for soap washing and drain.	1175	307.5	1175	---
9	Fill process water, dose softeners (cationic and silicone softener) and acetic acid, run for softener application, unload fabric and drain	1175	---	1175	---
10	Load fabric on hydrosqueezer, spin for dewatering and unload fabric	---	---	425	---
Total for scouring and dyeing of 250 Kg/batch of cotton		14875	1589	14675	---
Polyester Dyeing					
1	Loading water and fabric, dose acetic acid, levelling agents and dyes, rise temperature 130-135°C, run for dyeing and cool to 80°C	1800	974	---	7611
2	Overflow washing and cooling for 10 min.	3600	---	3600	---
3	Unloading the fabric and	-1600	---	---	---

	load fabric for next batch of dyeing				
4	Load fabric on hydrosqueezer, spin for dewatering and unload the fabric	---	---	125	---
Total for 250 Kg/batch of polyester dyeing		**3800**	**974**	**3725**	**7611**
Total for 2500 Kg/day of cotton scoured and dyed, and for 4500 Kg/day of polyester dyed (L/day)		**217150**	**33415**	**213800**	**136991**

Table 4.26- Water and steam consumption, wastewater generation and cooling water requirement for the proposed new scheme of dyeing

S.No.	**Processing Step**	**Water consumption**	**Steam consumption**	**Wastewater generation**	**Cooling water**
Cotton Dyeing (including RFD)					
1	Loading with water and fabric, dose scouring chemicals, raise temperature to 90°C and run for scouring, cool to 60°C and drain as scour wastewater.	1800	512.5	1175	13837.5
2	Fill with washwater-2, run for washing and drain as washwater-1.	Recycle-1	---	1175	---
3	Fill with process water run	1175	---	Recycle-1	---

	for washing and drain as washwater-2				
4	Fill with hot washwater dose acetic acid run and drain as neutralizing wastewater	Recycle-2	---	1175	---
5	Fill process water, rise temperature to 60-65°C and drain as hot washwater	1175	256.25	Recycle-2	---
6	Fill process water, dose chemicals and dyes, rise temp. To 60-80°C run for dyeing, cool to 60°C and drain as dyebath dump	1175	410	1175	9225
7	Fill process water, run for washing and drain as dye washwater-1	1175	---	1175	---
8	Fill process water, run for washing and drain as dye washwater-2	1175	---	1175	---
9	Fill process water, dose acetic acid, rise temp. To 60°C, run for neutralization, dose soap, rise temp. To 70°C, run for	1175	307.5	1175	---

	soap washing and drain as soap wash water.				
10	Fill softener water, run, unload the fabric and drain as softener water.	Recycle-3	---	Recycle-3	---
11	Load fabric on hydrosqueezer, spin for dewatering and unload fabric	---	---	425	---
Total for scouring and dyeing of 250 kg/batch of cotton		8850	1486	8650	23063
Polyester Dyeing					
1	Load treated effluent (recycled) and fabric, dose acetic acid/green acid, levelling agents and dyes, rise temperature to 130-135^{o}C, run for dyeing and cool to 60^{o}C and drain as polyester dye wastewater.	1800	974	1600	43819
2	Fill with treated effluent (recycled), run washing, unload fabric and drain.	1600	---	1600	---
3	Load fabric on hydrosqueezer, spin for	---	---	125	---

	dewatering and unload the fabric				
Total for 250 kg/batch of polyester dyeing		**3400**	**974**	**3325**	**43819**
Total for 2500 Kg/day of cotton scoured and dyed, and for 4500 Kg/day of polyester dyed (L/day)		**149700 (of this 61.2 m^3/day is treated effluent)**	**32390**	**146350**	**1019363**

4.1.2.5 Raw materials, energy, water, chemicals and other important inputs and inventory of wastes generated

The raw materials, energy, water, chemicals and other important inputs are presented in Table no. 4.27

Table 4.27- The raw materials, energy, water, chemicals and other important inputs

1	**Raw Materials**		
1.1	Cotton and polyester yarn	3750 Kg/day	Fabric knitted from yarn was totally be dyed internally
1.2	Cotton and polyester fabric	7000 Kg/day	Cotton fabric dyed= 2500 Kg/day and Polyester fabric dyed= 4500 Kg/day
2	**Water**	145 to 150 m^3/day 235 m^3/day if treated effluent is not recycled	Water requirement is taken as 10% more than the estimated total consumption
2.1	Soft flow machines	88.5 m^3/day 150 m^3/day if treated effluent is not recycled	61 m^3/day of treated low/medium strength wastewater, after tertiary treatment, will be used in place of process water for the dyeing of polyester fiber.
2.2	Soft water plant	<40 m^3/day	>70% of the supplied steam will be recovered as

			condensate and used as boiler feed water and soft water will be used as make up boiler feed water. Boiler blow down is taken as 5%. Softener regeneration water consumption is 5-10% of the generated soft water.
2.3	Recycle water sumps associated with cotton scouring (for makeup)	<4 m^3/day	Make up water requirement is taking as 15% of the recycle water being handled.
2.4	Domestic water consumption	13-17 m^3/day	Water consumption is taken as 100 LPCD.
3	**Energy and Fuels**		
3.1	Electric Energy	410 KW	560 kW- connected load
3.2	Rice Husk	18-20 TPD	Either rice husk or pet-coke used as boiler fuel.
3.3	Pet-coke	7-8 TPD	
3.4	Diesel	35 L/Hour for 320 kVA DG set 20 L/Hour for 160 kVA DG set	Needed only during peak load hours and during PSEB grid power failures.
4	**Chemicals**		
4.1	Dyes	80 + 100 kg/day	About 80 kg in cotton dyeing and 100 kg in polyester dyeing
4.2	Salt (NaCl)	1080 + 50 kg/day	Used in cotton dyeing at 60 gpl and in soft water plant for the ion exchange resin bed regeneration
4.3	Soda Ash	172 kg/day	Used in both scouring and dyeing of cotton
4.4	Caustic	44 kg/day	Used in both scouring and dyeing of cotton

4.5	Peroxide	50 kg/day	Used in scouring of cotton
4.6	Neutralizer (Acetic acid)	82.5 + 45 kg/day	Used in both scouring and dyeing of cotton and dyeing of polyester
4.7	Neutralizer (Green Acid)	36 kg/day	Used in case of polyester dyeing as substitute to acetic acid
4.8	Levelling agent	5 + 18 kg/day	Used in cotton and polyester dyeing
4.9	Anti-creasing Agent	10 kg/day	Used in both scouring and dyeing of cotton
4.10	Wetting Agent	20 kg/day	Used in cotton scouring at 0.8 % rate
4.11	Soap	10 kg/day	Used in washing step
4.12	Water softener	5 kg/day	Used in both scouring and dyeing of some cotton shades
4.13	Fixer	4 kg/day	Used in certain shades of cotton

The inventory of the wastewater generated from cotton scouring, cotton dyeing, boiler, soft water system and other basic amenities are presented in Table 4.28.

Table 4.28- Inventory of the wastewater generated

S.No.	**Section**	**Waste Stream**	**Quantity and Characterization**	**Remarks**
1	Cotton Scouring	Scouring bath dump	It contains scouring chemicals (soda-ash, caustic anti-creasing agent and wetting agent) and impurities removed from the fabric. Temperature is around 60^{o}C. Generation rate is 1175 L/batch (11.75 m^3/day).	--
		Washwater-1 from washing of	It contains chemicals similar to that of scouring bath dump but at lower	--

		the fabric after scouring	strength (about 35 %). Temperature is about 47-50°C. Generation rate is 1175 L/batch (11.75 m^3/day).	
		Neutralizing wastewater	It contains scouring chemicals and other contaminants and also the acetic acid. Temperature is 60°C. Generation rate is 1175 L/batch (11.75 m^3/day).	--
		Overflows from the hot wash water and washwater-2 sumps	Relatively less polluted. If recycled then the overflow rates will be Nil.	Process water may be needed for maintaining the water level in these sumps.
2	Cotton Dyeing	Dyeing bath dump	It contains salt, soda-ash, caustic, levelling agent anti-creasing agent and residual dye. Temperature is around 60°C. Generation rate is 1175 L/batch (11.75 m^3/day).	Dyeing bath dump and washwater-1 stream should be segregated for separate treatment and disposal. Combined streams of these wastewaters (around 23.5 m^3/ day) are believed to have 85 % of the residual dyes and chemicals used in the dyeing process.
		Washwater-1 from the dyed fabric washing	It is similar to dyebath dump wastewater in composition but strength is around 35 % of it. Temperature is around 47°C. Generation rate is 1175 L/batch (11.75 m^3/day).	

		Washwater- 2 from the 2nd washing of the dyed fabric	It is similar to dyebath dump wastewater in composition but strength is around 13 % of it. Temperature is around 43°C. Generation rate is 1175 L/batch (11.75 m^3/day).	--
		Soap wash water from neutralization and soap washing of the dyed fabric	Temperature is about 70°C. It contains dyebath chemicals at 4% strength. It also contains acetic acid and soap being used in the neutralization and hot soap washing. Generation rate is 1175 L/batch (11.75 m^3/day).	---
		Overflow from the softener water sump	It contains cationic and silicone softeners. Overflow rate is > 4.25 m^3/day. Temperature is slightly above the ambient temperature.	--
3	Polyester dyeing	Dye bath dump	It contains residual dye, acetic acid and levelling agent. Temperature is 60°C. Generation rate is 1600 L/batch (28.8 m^3/day).	--
		Washwater and hydrosqueezer water	It also contains residual dye, acetic acid and levelling agent but strength is about 11 % of it. Temperature is around 43°C. Generation rate is 1725 L/batch (31.05 m^3/day).	--
4	Boiler	Boiler blow down water	< 4.55 m^3/day when run at full capacity and blow down rate is < 5 %	Steam condensate recovery and

				reuse as boiler feed water (upto 70%) will keep the blow down water much lower than this.
5	Soft Water Plant	Ion Exchange resin bed regeneration wastewater	About 2 m^3/day (0.7 m^3/day is of high TDS and 1.6 m^3/day is of low TDS but may have relatively higher TSS values).	Make up with soft water will be around 44% of the total boiler feed water consumed (when condensate recovery is 70%). Core processes assumed to use no soft water.
6	Amenities and services to the employees	Domestic wastewater	Around 11 m^3/day during January – June months and 14.5 m^3/day during July-December months.	Per capita water consumption by employees is taken as 100 L/day/shift. 85 % of the used water is believed to come out as wastewater.
High strength dye effluent from cotton dyeing				**23.5 m^3/day**
Low/medium strength effluents from scouring and dyeing process				**122.85 m^3/day**
Domestic wastewater				**11 to 14.5 m^3/day**
Other effluents (Least polluted and requires no treatment)				**6 m^3/day**

4.1.2.6 Effluent treatment plant

The effluent treatment plant was designed to treat all the wastewater generated (including effluent from utilities, cooling water, steam condensate, spills, washing/rinsing etc.)

4.1.2.6.1 Units/Facilities of ETP

The ETP includes the following units:

1. Equalization tank
2. Flocculator
3. Tube settler
4. Clarified effluent sump
5. Pressure sand filter
6. Activated carbon column
7. Treated effluent sump
8. Final disposal
9. Sludge beds
10. Sludge pump and filter press system
11. Sludge storage room
12. Treatment chemicals storage room

4.1.2.5.2 Schematic representation of ETP

The Schematic representation of existing effluent treatment plant was presented in Fig. 4.4.

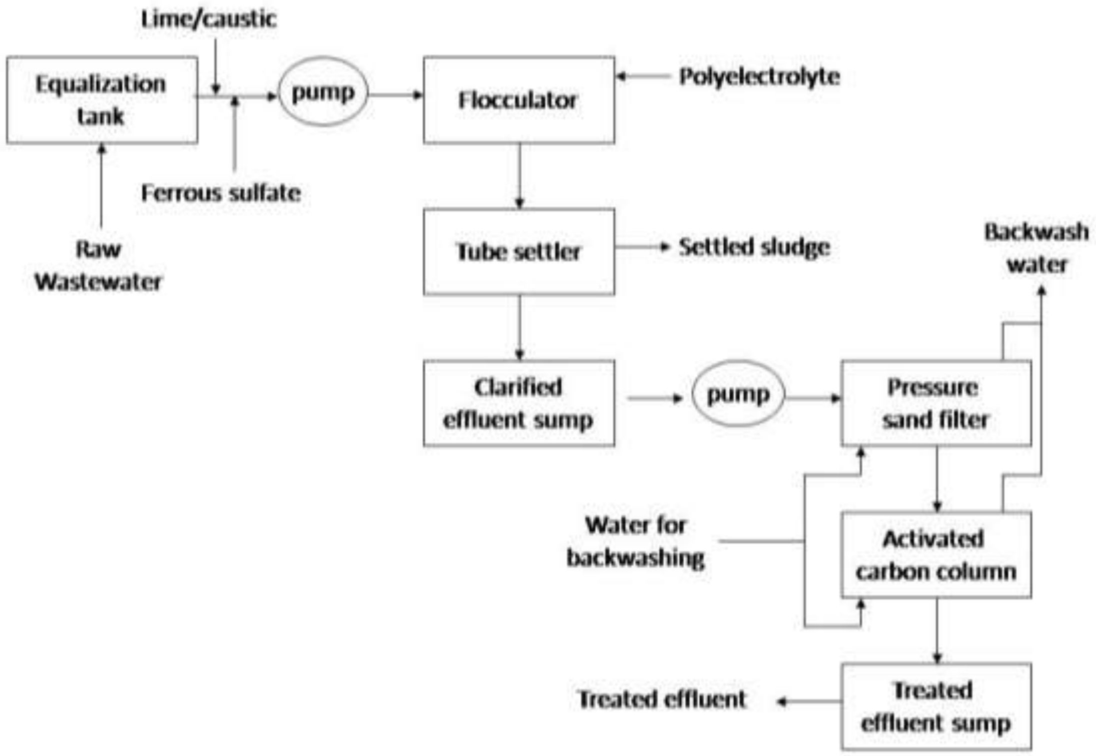


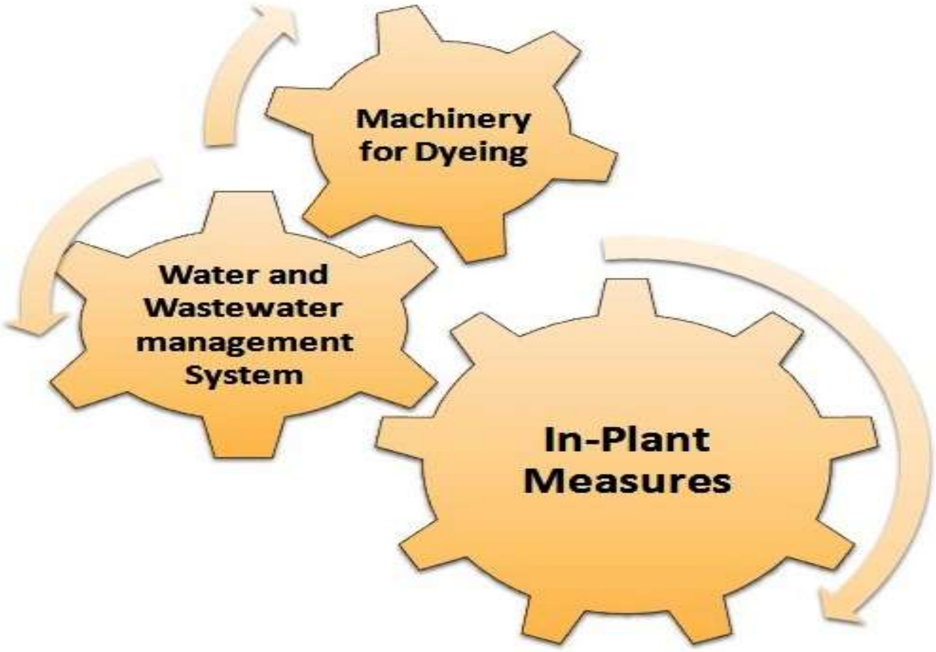
Fig. 4.4- Schematic representation of Effluent treatment plant of industry-II

4.1.1.5.3 Working and treatment through ETP

- All wastewaters generated are collected together in an equalization tank and treated.
- Treatment involved
  - Coagulation-flocculation-settling and filtration
  - Adsorption in activated carbon column
- Coagulating agents are dosed into wastewater while pumping from equalization tank to flocculation tank.
- Flocculating agent is dosed into flocculator and flocculation is brought about by hydraulic (and mechanical) mixing. Flocs formed are separated in the tube settler through gravity settling. Clarified effluent is polished in a pressure filter and further treated in activated carbon column prior to disposal.
- Sludge drained out from the tuber settler is dried in sludge drying beds and stored as hazardous waste.

4.2 WATER AND WASTEWATER MANAGEMENT MODEL FOR THE TEXTILE PROCESS INDUSTRY

The model encompasses the environmental concerns associated and opportunities and options for environmental performance improvements in various machineries used in textile processing as well as the in-plant measures for waste minimization and the water and energy conserving wastewater management system.



4.2.1 Machinery for dyeing- Environmental concerns associated and opportunities/options for environmental performance improvements

Dyeing involves use of the following machines:

- Soft-flow machines (Long tube, U-tube) – (fabric dyeing)
- Top dyeing machines (fiber and yarn dyeing)
- Cabinet dyeing (yarn dyeing)
- Jiggers (fabric dyeing)
- Winches (fabric dyeing)

Dyed textile is dewatered and dried on the following machines:

- Hydro-extractors
- Pole driers

4.2.1.1 Soft-flow machines

Soft-flow machines (shown in figure 4.5(a)) are used for the scouring and dyeing of textile fabric. Many modified versions of the soft-flow machines (such as, U-tube, long tube) are in use. Functionally all these machines are same. Please see figure 4.5(b) & 4.5 (c) for details on the functional components of a soft-flow machine.

Fig. 4.5(a) Soft-flow machine with components

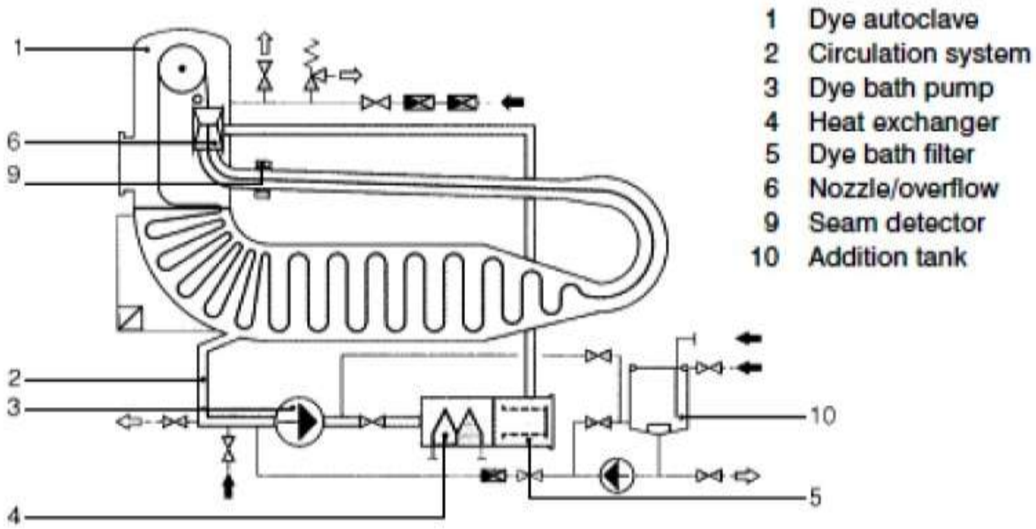


Fig. 4.1(b) Long Soft-flow machine with components

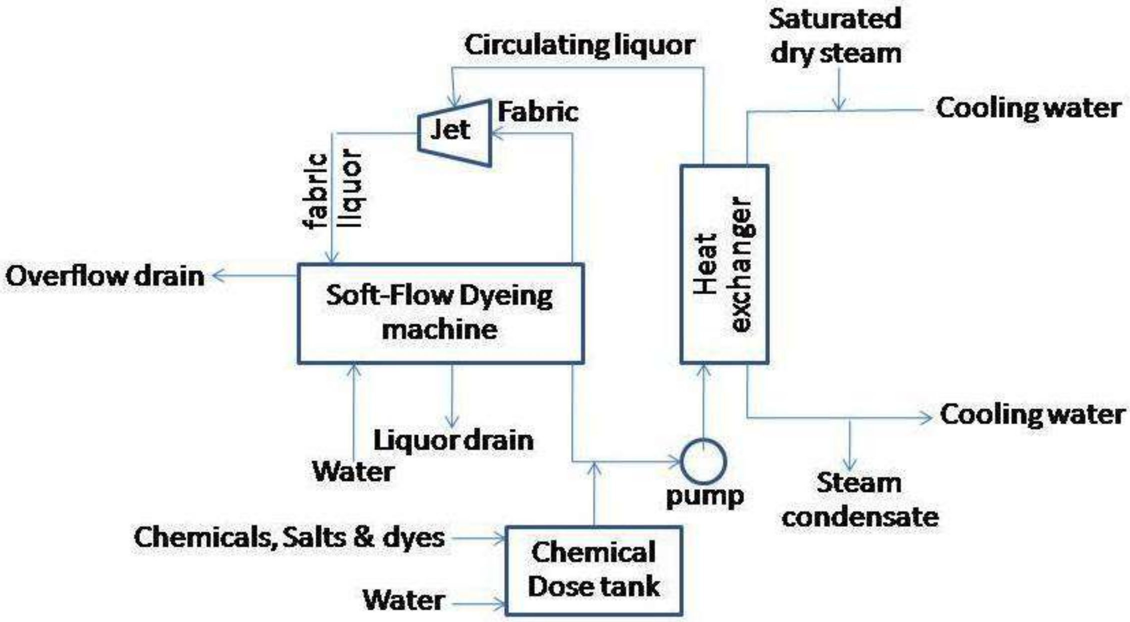


Fig. 4.5(c) Line diagram of Soft-flow machine

Processing of textile fabric in a soft flow machine includes the following:

- Filling the machine with water (process water/ soft water/ RO water/ hot water/ reclaimed water)

- Running the machine (involves circulation of the liquid contents of the machine through the soft-flow jet for running the fabric loop through the machine)
- Loading the fabric and loop making (liquid circulation through the jets facilitates the loading and circulation of the fabric loop)
- Raising the machine content’s temperature to desired levels, usually in steps (for this the machine contents are circulated through the external heat exchanger of the machine and heated by saturated dry steam)
- Dosing of chemicals and dyes (including the salts: NaCl and Na_2SO_4) – solutions of the chemicals are made usually in separate vessels and injected into the circulating machine liquid on the suction side of the circulation pump.
- Overflow cooling and/or washing of the fabric (water is continuously fed into the machine from the bottom and taken out as overflows from the machine top while the machine is running)
- Cooling the machine contents to the desired temperatures (for this the machine contents are circulated through the external heat exchanger of the machine and cooled by circulating cooling water).
- Quality checking of the fabric (failure of the quality checks may necessitate repetition of one or more of the process steps and may involve dosing of some of the chemicals and/or dyes)
- Draining out the liquid contents of the machine
- Neutralization/ washing/ rinsing (and even cooling) of the fabric through filling the machine with water, soap water, hot/warm water, or acidic water (acetic acid, green acid, etc.), running the machine for desired duration and then draining out the machine liquid contents
- Unloading of the fabric

Environmental concerns associated with the use of soft-flow machine for the dyeing of the textile fabric include

- Use of chemicals and dyes including common salt and glauber salt
- Use of saturated dry steam
- Use of compressed air for pressurizing the machine contents
- Electrical energy for powering the drives and pumps used
- Heat losses to the surroundings of the machine
- Wastewater generation
- Steam condensate generation
- Return cooling water with higher delta T
- Risk of burn injuries from the physical contact with the machine surfaces

Opportunities and options for environmental performance improvements

- Running the machine on full loads for conserving water, chemicals and energy
- Use of reclaimed water to conserve virgin fresh water
- Use of hot water for conserving steam needed in the heating of the machine contents
- Lowering the liquor to fabric ratio for conserving water, chemicals and energy and for minimizing wastewater generation
- Not practicing the overflow washing and/or cooling (for water conservation)
- Venting out the soft flow machine to atmospheric pressure prior to cooling the machine contents, at temperatures >100^{o}C, in external heat exchangers
- Segregation and collection of the steam condensate for reuse as boiler feed water
- Segregation of high strength wastewaters from the low strength wastewaters for enhancing the treatability, and the recycle and reuse potential
- Segregation and collection of the return cooling water for use as hot water in the process

4.2.1.2 Top dyeing and/or cone dyeing (HTHP) machines

Top dyeing machine (also called as HTHP - High Temperature High Pressure machine) is a vertical cylindrical vessel with a central vertical perforated core pipe. A cylindrical carrier loaded with fiber or yarn slivers is fitted around the core pipe and securely locked. Liquid of the vessel is forced to radially pass through the fiber/yarn alternatively from core pipe to peripheral annular space, and from peripheral annular space to the core pipe. For facilitating this, a main circulation pump and piping, with external heat exchanger and chemicals and/or dyes dosing system, is provided. The chemical and/or dye dosing system includes a solution vessel, a pump and necessary piping and fittings. The machine vessel has a bottom water inlet, a bottom drain and a top overflow drain for facilitating overflow washing and/or cooling, and for draining out of the machine contents.

Please see Figure-4.6(a,b,c) for details.

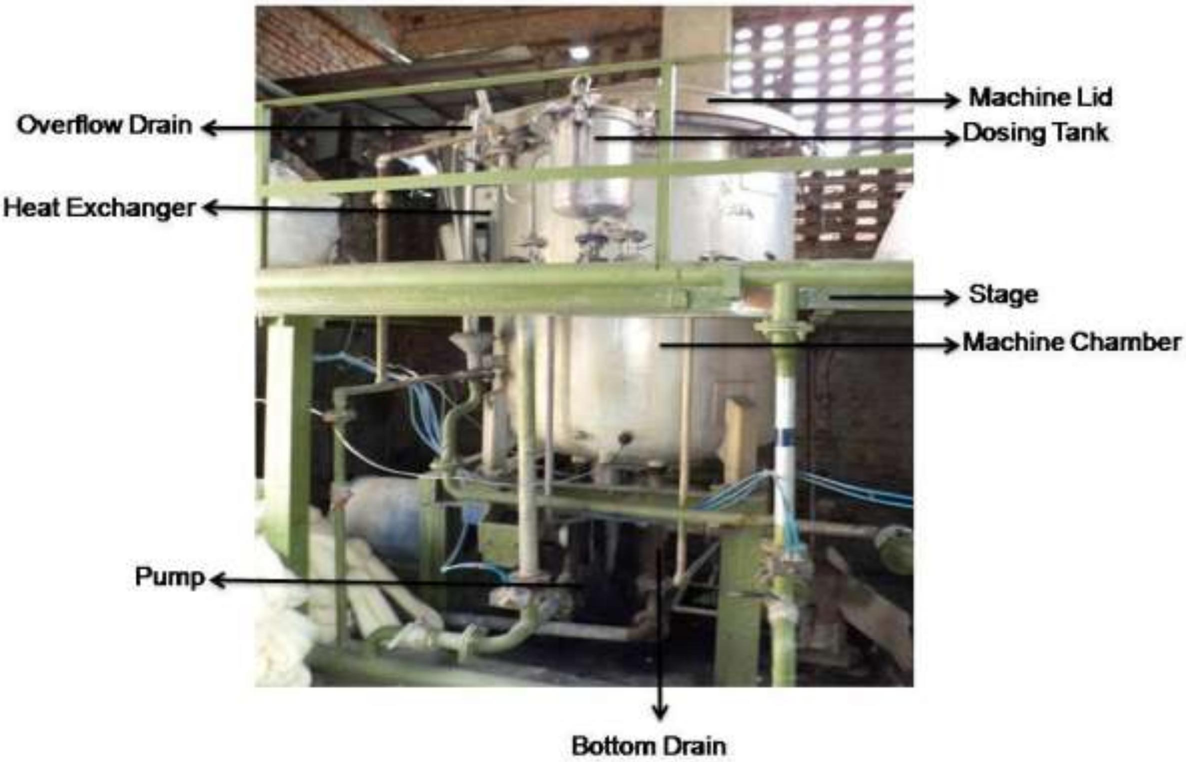


Fig. 4.6(a) HTHP machine with components

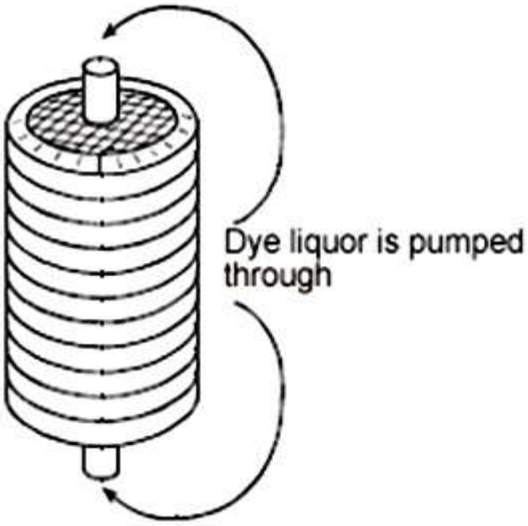


Fig. 4.6(b) Dye liquor pumped through the carrier with help of perforations

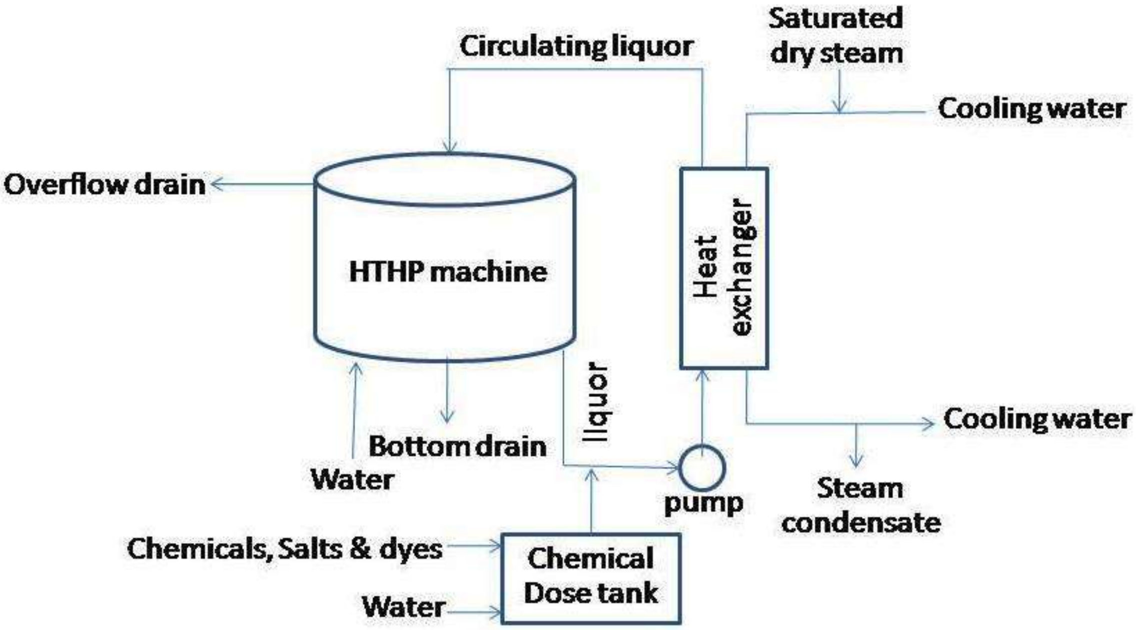


Fig. 4.6(c) Line diagram of HTHP machine

Processing of textile fabric in a Top dyeing/HTHP machine includes the following:

1. Loading the fiber/yarn into the fiber carrier (the top), transferring the top into the top dyeing machine vessel, and safety locking the machine.

2. Filling the machine vessel with water (process water/ soft water/ RO water/ hot water/ reclaimed water) and running the machine by switching on the liquid circulation system.
3. Raising the machine content’s temperature to desired levels, usually in steps (for this the machine contents are heated by saturated dry steam)
4. Dosing of chemicals (acetic acid, retardants, sodium sulfate and cationic softener) and/or dyes (injection dosing) using the chemicals and/or dyes dosing system.
5. Cooling the machine contents to the desired temperatures (for this machine contents are cooled by the circulating cooling water).
6. Quality checking of the fibre/yarn (failure of the quality checks may necessitate repetition of one or more of the process steps and may involve dosing of some of the chemicals and/or dyes)
7. Draining out the water and unload the fiber carrier.

Environmental concerns associated with the use of Top dyeing/HTHP machine include

- Use of chemicals and dyes including common salt and glauber salt.
- Use of saturated dry steam
- Use of compressed air for pressurizing the machine contents
- Electrical energy for powering the pump drives used
- Heat losses to the surroundings of the machine
- Wastewater generation
- Steam condensate generation
- Return cooling water with higher delta T
- Risk of burn injuries from the physical contact with the machine surfaces

Opportunities and options for environmental performance improvements

- Running the machine on full loads for the conservation of water, chemicals and energy

- Use of reclaimed water to conserve virgin fresh water
- Use of hot water for conserving steam needed to heat the machine contents
- Lowering the liquor to fabric ratio to the minimum possible for conserving water, chemicals and energy, and for minimizing wastewater generation.
- Venting out the machine vessel to atmospheric pressure prior to the cooling of the machine contents in external heat exchangers
- Segregating and collecting the steam condensate for reuse as boiler feed water
- Segregating the high strength wastewaters from the low strength wastewaters for enhancing the treatability, and the recycle and reuse potential
- Segregating and collecting the return cooling water for use as hot water in the process

4.2.1.3 Cabinet dyeing machine

Cabinet dyeing machine is a front opening cabinet with doors that can be closed water tight. Within the cabinet there are provisions for hanging the warped yarn for processing (dyeing). The cabinet has a bottom coil mat for the cooling or heating of the cabinet contents (by circulating cooling water or supplying saturated dry steam respectively). The cabinet has provisions for the process water loading, for draining out the liquid content of the cabinet, and for the injection of chemicals and dyes. Further, the machine also has provisions for the circulation of the liquid content of the cabinet around the yarn. Please see Figure-4.7(a, b c) for details.

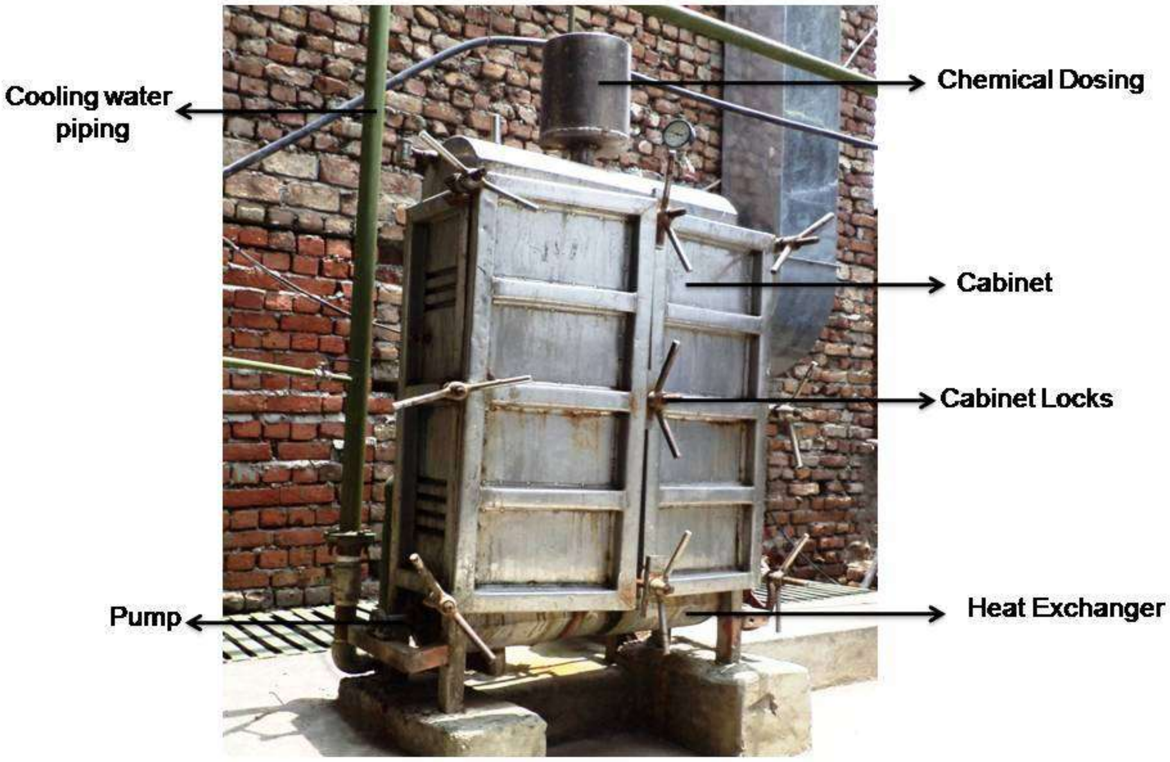


Fig. 4.7(a) Cabinet Dyeing machine with components

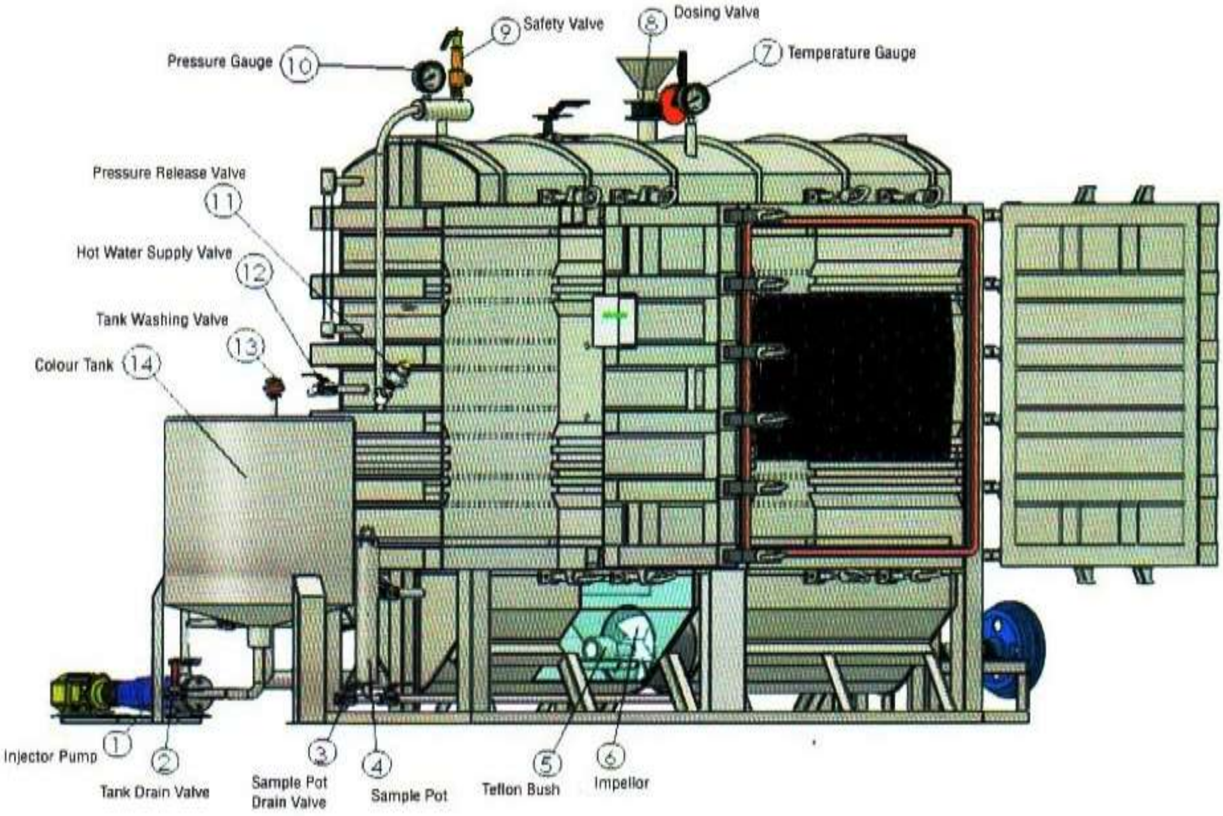


Fig. 4.7(b) Silent Features of Advanced Cabinet Dyeing machine

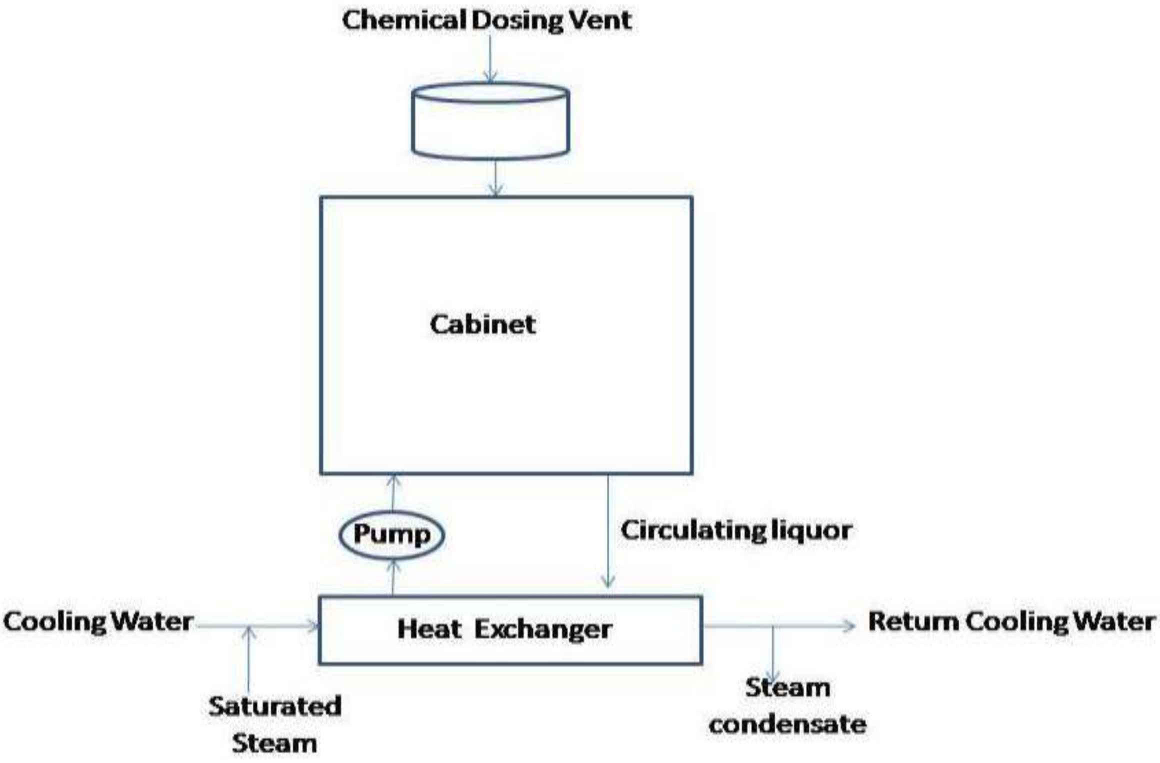


Fig. 4.7(c) Line diagram of Cabinet dyeing machine

Processing of textile yarn in a cabinet dyeing machine includes the following:

1. Bulking of the yarn
2. Loading the bulked yarn into cabinet dyeing machine on hangers and closing the machine.
3. Filling cabinet with water to the desired level, and running the machine (the water circulation system is switched on for this purpose)
4. Raising the temperature of the cabinet contents to desired levels (usually in steps) by passing saturated dry steam through the bottom steam coils.
5. Dosing chemicals, salts and dyes using the chemicals and/or dyes dosing system
6. Cooling to desired level by circulating cooling water, draining out the liquid and unload the yarn.

Environmental concerns with the use of cabinet dyeing machine include

- Use of chemicals and dyes including common salt and glauber salt.

- Use of saturated dry steam
- Electrical energy for powering the pump drives
- Heat losses to the surroundings of the machine
- Wastewater generation
- Steam condensate generation
- Return cooling water with higher delta T
- Risk of burn injuries from the physical contact with the machine surfaces

Opportunities and options for environmental performance improvements

- Running the machine on full loads for conserving water, chemicals and energy
- Use of reclaimed water to conserve virgin fresh water
- Use of hot water for conserving steam needed to heat the machine contents
- Segregating and collecting the steam condensate for reuse as boiler feed water
- Segregation of high strength wastewaters from the low strength wastewaters for enhancing the treatability and the recycle and reuse potential
- Segregating and collecting the return cooling water and use as hot water in the process

4.2.1.4 Jigger dyeing Machine

Jiggers are used for the fabric dyeing in cases where the processing temperature is <100^{o}C. Fabrics other than polyester, and polyester-viscose, and polyester-cotton blends are usually dyed in the jiggers. Jiggers are also often used dyeing the cotton or viscose component of the polyester blends after dyeing the polyester component in jet dyeing machines. Jigs exert considerable lengthwise tension on the fabric and are more suitable for the dyeing of woven fabrics. The jigger machines have two main rollers which revolve on smooth bearings and are attached to with a suitable driving mechanism, which can be reversed when required. The fabric is wound on one of the main rollers and fed from the other. The fabric move from one roller to the other through the dye liquor trough located at the lower part of the machine. There are various arrangements of guide rollers at the bottom of liquor trough and during each passage the cloth passes around these guide rollers. The concentrated dye liquor is usually introduced directly into the dyebath in two equal portions, which are added just before commencing the first and second ends. The liquor is agitated by the movement of the fabric through the dyebath. Several horizontal spray pipes are fitted across the full width of the trough in order to expedite fabric rinsing. Live steam injected into the bottom of the trough through a perforated pipe across the width of the jig heats the liquor. Please see Figure-4.8(a, b) for details.

Fig. 4.8(a) Jigger dyeing machine

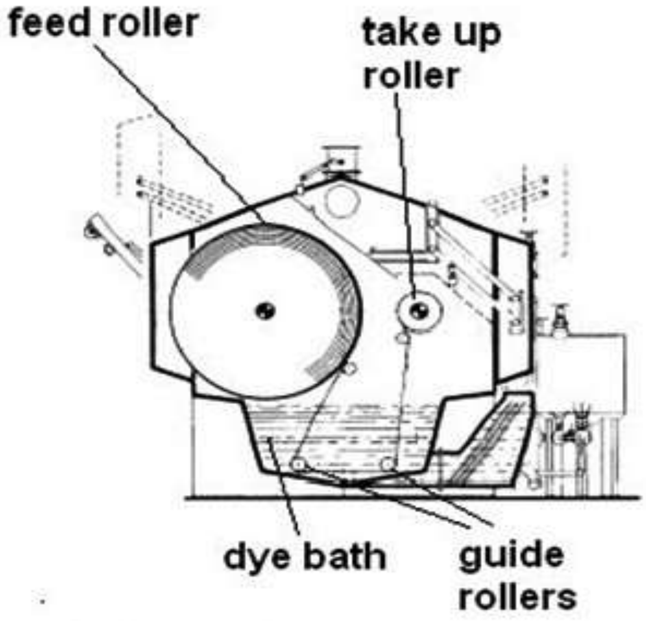


Fig. 4.8(b) Silent Features of Jigger dyeing machine

Processing of textile fabric in a jigger dyeing machine includes the following:

- Loading of fabric.
- Repeated filling/refilling of the jigger with water, end to end running of the fabric, for specified number of times (while maintaining constant levels of water, chemicals, dyes and temperature) and draining out the jigger contents.
- Dosing of chemicals and dyes.
- Heating to and maintaining of the jigger contents at specified temperature through steam injection.
- Overflow washing by end to end running of the fabric for specified number of times, while adding water and allowing continuous liquor overflow.
- Unloading of fabric

Environmental concerns with the use of jigger dyeing machine include

- Wastewater generation is mainly from the overflow washing.

- The injected steam on condensation increases the volume of the jigger contents and dilutes the chemicals and dyes, and may necessitate dosing of more than required quantities of chemicals and dyes.
- Covering the top of the jig minimizes the heat loss to the atmosphere, keeps the temperature uniform on all parts of the fabric and minimizes exposure of the liquor and the cloth to air.
- Minimizing exposure to air is important when using sulphur or vat dyes since these dyes can be oxidized by atmospheric oxygen.
- Risk of burn injuries from the physical contact with the machine surfaces.
- Electrical energy for powering the pump drives.

Opportunities and options for environmental performance improvements

- Running the machine on full loads for conserving water, chemicals and energy
- Replace the overflow washing by a) start filling of water and running of the fabric, and b) stop water inflow after filling to desired level, stop running after 2 ends of running and drain, and continue this two step washing process till satisfactory level of washing (stopping of bleeding of dye) is achieved. Use of squeeze rolls, if feasible, can further conserve water and minimize wastewater generation through minimizing the number of wash drains.
- Use of reclaimed water to conserve virgin fresh water
- Use of hot water for conserving steam needed to heat the machine contents
- Segregation of high strength wastewaters from the low strength wastewaters for enhancing the treatability and the recycle and reuse potential
- In case of cotton dyeing, segregate the dye bath and the initial one or two post dyeing wash dumps from other baths dumps. In other cases also, the bath dumps that contain high salt content may also be segregated. This will minimize TDS levels of other wastewaters and enhance their reuse potential as reclaimed water after necessary

treatment. The segregated dye bath effluent can also be reused in the dyeing of cotton after necessary decolourization, which can result in minimization of salt or glauber salt consumption.

- Segregating and collecting the return cooling water and use as hot water in the process
- Run the jigger with the lowest liquor level and minimize the total number of drains or machine dumps. The level of filling can influence the chemical and steam consumption marginally.
- For better application, deliver the input water at the bottom of the jigger vessel.

4.2.1.5 Winch dyeing Machine

Winches are used for the fabric dyeing in cases where the processing temperature is <100^{o}C. It is preferably used for the pre-dyeing steps – scouring, bleaching, washing etc. Fabrics other than polyester, and polyester-viscose, and polyester-cotton blends are usually dyed in the winches. Winches are also often used for dyeing the cotton or viscose component of the polyester blends after dyeing the polyester component in jet dyeing machines. If, covered and pressurized (high pressure and high temperature), winches can also be used for polyester dyeing.

Winch machine is a rectangular vessel with bottom smoothly sloping towards the inlet side. On the inlet side, there is a vertical perforated baffle wall to facilitate dosing of chemicals and dyes. Bottom of the chamber at the inlet end has a perforated steam tube for facilitating steam injection heating of the vessel contents. At the bottom of the vessel on one side there is a drain with necessary regulatory valves. The vessel has a water supply line with necessary regulatory valve. The winch machine has a temperature sensor. Fabric in the form of one or more continuous loops is maintained in the vessel for the processing. It is obligatory to stitch the head of the rope with the tail. An electrically driven winch provided on the top of the winch (covered with a notable blanket to stop fabric slip) facilitates circulation of the continuous loop of the fabric through the liquid of the vessel. The fabric is loaded from side A and then operated through the machine with scrolling (by using rack) and then unloaded from the side B. Please see Figure-4.9 (a, b) for details.

Fig. 4.9(a) Winch dyeing machine

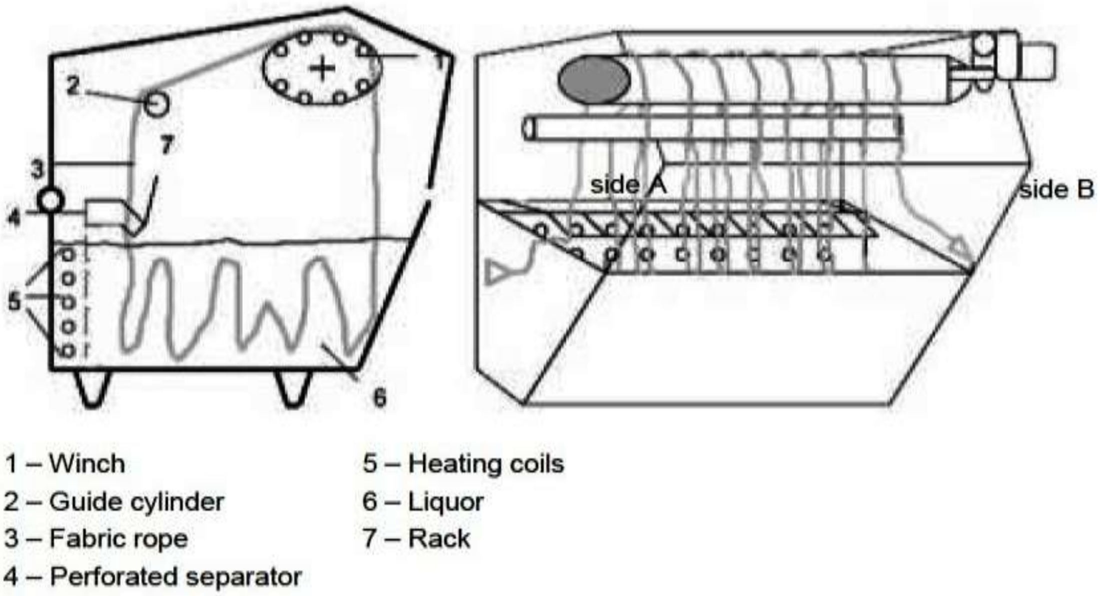


Fig. 4.9(b) Silent Features of Winch dyeing machine

Environmental concerns with the use of winch dyeing machine include

- The injected steam on condensation increases the volume of the winch contents and dilutes the chemicals and dyes, and may necessitate dosing of more than required quantities of chemicals and dyes.
- Minimizing exposure to air is important when using sulphur or vat dyes since these dyes can be oxidized by atmospheric oxygen.
- Risk of burn injuries from the physical contact with the machine surfaces.
- Electrical energy for powering the pump drives.

Opportunities and options for environmental performance improvements

- Running the machine on full loads for conserving water, chemicals and energy
- Minimize the use of winches for dyeing and even for washing.
- Cover the winches (if need may pressurize then) for minimizing the heat loss.
- Practice indirect heating of the winch machine contents through using steam coils at the bottom for recovering the steam condensate and avoiding dilution and volume increase of the winch baths.
- Segregate the dye bath from other bath dumps if cotton and its blends are dyed. In other cases also, if high salt levels are suspected, segregate the bath dumps. This will minimize TDS levels of other wastewaters and enhance their reuse potential as reclaimed water after necessary treatment. The segregated dye bath effluent can also be reused in the dyeing of cotton or viscose or their blends after necessary decolourization, which can result in minimization of salt or glauber salt consumption.

4.2.1.6 Hydro-squeezer

Hydro-squeezer is used for dewatering of fabrics/yarns. It is basically a spinner. Water or liquid from the fabric or yarn is separated through spinning in a screen tub.

Hydro-extraction reduces the water content in the fabric to 15% (polyester) to 40% (cotton) moisture level.

The Hydro-squeezer is showed in Figure 4.10.

Fig. 4.10 Hydro-squeezer machine

Processing of textile fabric/yarn in a Hydro-squeezer includes the following:

- Fabric unloaded (after dyeing) from the soft-flow/cabinet dyeing machine is loaded into the hydro-squeezing machine well and closed from top.
- With the help of motor the loaded well is spinned for separating liquid from fabric.
- The hydro-squeezer can reduce the moisture content of the fabric/yarn to 20% to 30% moisture level.
- The water coming out is drained out as wastewater.
- After hydro-squeezing the fabric is unloaded.

Environmental concerns with the use of hydro-squeezer include

- Electrical energy for powering the drives/motors

- Centrifugally separated water comes out as wastewater

Opportunities and options for environmental performance improvements

- Collection of low strength wastewaters for recycle and reuse potential

4.2.1.7 Pole-Driers

Pole-drier is used for the drying up of the dyed fabric. Each drier includes a radiator heater, a blower and a perforated pole. The pole-driers are presented in Figure 4.11.

Processing of textile fabric in a Pole-Drier includes the following:

- The dyed fabric is loaded on the pole and pulled up over the perforated tube.
- The hot dry air is passed out through the pole for drying.
- The blower associated with the pole drier sucks ambient air through the radiator heater and pushed out through the perforated pole.

Fig. 4.11 Pole-drier

- In the radiator heater, the incoming air is heated with saturated dry steam condensing in the radiator tubes.
- An overhead roller, driven by an electrical drive, is used both for slowly loading and pulling the fabric over the perforated tube.

- Enclosed space of the pole drier is sufficiently ventilated and the hot humid air emanating from the pole drier is simultaneously vented out.

Environmental concerns with the use of pole-driers include

- Electrical energy for powering the radiator heater/blowers/drives.
- Ventilation for work-zone environment.

4.2.2 Water management model

Quantity of water used depends on

- the machine capacity
- the amount of fabric loaded
- Number of liquor drains involved in the processing
- Liquid to fabric ratio after draining out the liquid from the machine

The chemicals used include

- Dyes
- Caustic lye and/or caustic soda
- Common salt/glauber salt (for cotton and viscose)
- Sulfuric acid (for woolen fabric dyeing)
- Acetic acid/green acid/hydrochloric acid (for neutralization)
- Applicator softener chemicals
- Peroxide, stabilizing agents and peroxide killer
- Leveling agents, wetting agents, etc.

Saturated dry steam is used for the heating of the dyeing machine contents. Amount of steam consumed depends on

- Heating rate, initial temperature, final temperature to be attained and holding time at the temperature

- Ambient temperature and heat loss from machine surface
- Specific heat of the machine material and the fabric
- Mass of the machine material, the fabric and the quantity of the liquor present in the machine
- Heat exchanger efficiency

Use of steam for the heating generates steam condensate which is having both water value and heating value. The quantity generated will be almost equal to the steam consumed (dryness of the steam can make the difference on both steam consumption and condensate generation).

Similarly the cooling water to be passed through the heat exchanger depends on

- Cooling rate, and initial temperature and final temperature to which the machine should be cooled
- Ambient temperature and heat loss from machine surface
- Specific heat of the machine material and the fabric
- Mass of the machine material, the fabric and the quantity of the liquor present in the machine
- Heat exchanger efficiency
- Incoming cooling water temperature

The dyeing process typically involves-

1. Cold wash
2. Pre-treatment
3. Hot wash
4. Neutralization
5. Cold wash
6. Dye for polyester and/or dye for cotton

7. Cold wash
8. Neutralization
9. Dye fix and unload fabric

The dyeing process can be as simple as the following

1. Load fabric and cold wash.
2. Rope dye the fabric
3. Cold wash and unload fabric

Polyester-cotton blends are dyed either in the same bath or in two separate baths (first the polyester and then the cotton component). Sometimes the cotton is dyed separately on a different dyeing machine (winch or jigger).

4.2.2.1 Water consumed and wastewater generated from the processing of fabric

- Liquid to fabric ratio (which may vary from 1.5 to 6.0) during the fabric processing, and after the draining, number of drains involved in the processing (vary with the fabric being processed and with the dyeing process adopted by the industrial unit), and extent of overflow cooling/washing practiced determine the water consumed and wastewater generated.
- Number of drains of liquor from the dyeing machine depends on the number of steps involved in the dyeing process. The number of steps involved may vary with the textile being processed. Polyester-Cotton dyeing may involve the maximum number of steps, while polyester and acrylic dyeing may involve the least number of steps.
- Draining will not result in draining of all the liquor and some water will remain with the fabric and this water content may vary with the textile being processed. For cotton this value is the maximum and for polyester it may be the minimum.
- Each jet dyeing machine has a specified fabric batch capacity and water capacity. Most often the quantity of fabric loaded is different from this specified value. It may

vary with the textile being processed and with the batch size available for the processing.

Overflow cooling/washing is practiced either for cooling the contents of the jet dyeing machine or for washing the fabric free of the chemicals and dyes or for both. Quantity of water consumed and wastewater generated depends on

- Plug flow conditions existing in the dyeing machine
- Relative location of inlet and outlet of the dyeing machine
- Level of cooling or washing or both required
- Specific heat of the machine material and the fabric
- Mass of the machine material, the fabric and the quantity of the liquor present in the machine
- Human error associated with the duration of overflow washing and with the rate of water use

Monitoring the time taken for the initial filling of the dyeing machine and the duration for which the overflow cooling/washing is practiced can help in assessing the water consumed and the wastewater generated from the overflow cooling/washing.

4.2.2.2 Steam condensate generation

Steam condensate is generated at the external heat exchanger of the dyeing machine from the heating and holding of the machine contents at desired temperature. This condensate is the high quality water (comparable to DM water in quality) with recoverable heat. This condensate is most often drained out as wastewater.

4.2.2.3 Cooling water

Cooling water is generated at the external heat exchangers of the dyeing machines from the cooling of the machine contents from a higher temperature to a lower temperature. This cooling water is usually hot (temperature is around 60°C) and its quality is comparable with that of the fresh process water. This water is most often drained out as wastewater.

4.2.2.4 Measures for conserving water and energy, and for minimizing wastewater generation

1. Minimize the number of drains involved in the overall dyeing process.
2. Replace the overflow cooling with partial drain, fill, run and partial drain cycles of cooling to achieve the desired level of cooling.
3. Replace the overflow washing with fill, run and drain cycles of washing to achieve the desired level of washing.
4. If cotton is dyed, segregate the dye bath (and also the baths containing high chemicals or salts) from other baths dumps. This will regulate the TDS levels of other wastewaters and enhance their reuse potential as reclaimed water after necessary treatment. The segregated dye bath effluent, after necessary decolourization, can be reused in the dyeing of cotton and salt or glauber salt consumption can be significantly reduced.
5. Minimize the liquid to fabric ratio and the number of drains or machine dumps. There are machines with liquid to fabric ratio as low as 1.5.
6. Maximize the fabric load and run the machine as far as possible at full load. This can marginally reduce the chemical consumption (many of the chemicals, such as salt, glauber salt, are used as concentrations in the liquid rather than as fraction of the fabric loaded).
7. Minimize the use of winch machines and long tube jet dyeing machines. These have higher liquid to fabric ratios.
8. For minimizing the cooling water requirements, in case of polyester dyeing, subject the hot liquor of the machine to flash venting to drop the temperature upto around 100°C

prior to cooling in the external heat exchanger. This can be planned to recover the flashed vapours as high quality foul condensate.

9. For minimizing the internal cooling requirements maximize the cooling in the external heat exchanger with the circulating cooling water.
10. Collect the steam condensate generated at the heat exchanger and convey to the boiler for reuse as boiler feed water. This can minimize the use of water treatment plants (in soft water plants, de-alkalized water plants, DM water plants RO water plants) and reduce fuel consumption in the boilers.
11. Collect the hot cooling water, recycle as much of it as possible as hot process water, and recycle and reuse the rest (if needed after necessary cooling) as process water. This can result in waste heat recovery, and significant steam and boiler fuel conservation.

4.2.2.5 Overflow cooling/washing- in jet dyeing machines

Overflow cooling/washing is practiced either for cooling the contents of a jet dyeing machine or for washing the fabric free of the residual chemicals and dyes, or for both. It involves wasteful consumption of water and generation of wastewater. For water conservation and for minimizing wastewater generation, the overflow cooling/washing should be completely stopped and alternative ways of cooling and/or washing should be practiced.

4.2.2.5.1 Alternative to overflow cooling

In place of overflow cooling, in the jet dyeing machines the following can be practiced:

1. Stop running of the fabric and partially drain out the machine contents (liquor) while maintaining enough liquor in the machine for the proper running of the fabric.
2. Close the drain valve and add as much water as possible to the machine without affecting the running of the fabric due higher liquor levels.
3. Close the water inlet, run the fabric for at least one cycle, then open the drain for partially draining out the liquor as done in the first step.

4. Repeat these steps till the temperature of the machine contents drops to the desired level.

A jet machine (weighing 2000 kg) of 150 kg fabric capacity with liquid to fabric ratio of 6:1 will normally hold 900 L of liquor. If the maximum and minimum liquor that can be held in the machine is taken as 750 L and 1050 L respectively, if the specific heat content of the machine material and of the fabric is taken as 0.12 kcal/kg, and if temperature of the water used is taken as 30^{o}C, then water required for cooling the machine contents from 85^{o}C to 53^{o}C is estimated as presented in Table 4.29.

Table 4.29- Water required for cooling the machine contents from 85^{o}C to 53^{o}C

Step	**Quantity of liquor drained**	**Initial temperature**	**Quantity of water added**	**Final temperature**
1	150	85	300	72
2	300	72	300	61
3	300	61	300	53
Total	750	---	900	---

Initial and final liquor content of the dyeing machine is 900 L and 1050 L respectively. Assuming use of 1.5 inch process water supply pipe and 4 m/sec. water flow velocity, 3.394 minutes time is required for filling the machine with 900 L water. If the overflow washing is done for 10 minutes, the process water consumed will be 2652 L which is almost 3 times to the water required by the above method. Replacing the overflow cooling by the partial drain, fill and fabric run cycles of cooling is estimated to result in about 65% reduction in the water consumption and wastewater generation.

4.2.2.5.2 Alternative to overflow washing

After the needed partial drain, fill and run fabric cycles of cooling to the desired temperature, in place of overflow washing, *'drain, fill and fabric run'* cycles can be employed for achieving the desired level of washing. Usually 2 cycles or at the maximum 3 cycles of *'drain, fill and fabric run'* may be required for achieving the desired level of washing.

For a jet dyeing machine of 150 kg fabric capacity with liquid to fabric ratio of 6:1, assuming 3.4 minutes time for filling the machine with water and 20 minutes for the overflow washing, water consumption for the overflow washing can be estimated at about 5300 L. On the other hand, the alternate method of washing (of *'drain, fill and fabric run'* cycles) is estimated to consume 1575 to 2400L. Water consumed here depends on the liquid to fabric ratio in the machine after draining out the liquor. The above levels of consumptions are estimated on the basis of the assumption of liquid to fabric ratio of 1 to 2.5. Replacing the overflow washing is estimated to result in almost 60% reduction in the water consumption and wastewater generation.

4.2.2.6 Overflow washing- in jiggers

In jiggers overflow washing is practiced after every step of processing. The washing involves running the fabric for specified number of ends with both inlet and outlet left open. During washing the jigger is run at full liquor capacity (150L) and during chemical treatment and dyeing the liquor taken may be just half the capacity (75 to 80 L). Replacement of this overflow washing with the following cycles of two steps can both reduce the water consumption and the wastewater generation:

- Start filling of water and running of the fabric together, and stop the water filling after filling to the desired level.
- Stop running of the fabric after running for two ends, and drain out the liquor.

A jigger of 150 kg (or 450 m length) fabric capacity may hold about 150 L of water. For estimating the water required to achieve the same level of washing by both the methods the following assumption are made:

- 150 kg of the fabric holds 300 L of water (2:1 liquor to fabric ratio) when run on the jigger.
- Filling 150 L water takes 1 minute time and running of the fabric for one end takes 3 minutes time.
- During the alternate batch washing, each time the tub will be filled to the capacity and the fabric will be run for two ends each time.
- Efficiency of washing is 75% (i.e. contaminant level in the water of the fabric will be 1.25 times to present in the liquor of the tub).

Quantity of water consumed/wastewater generated and time taken for the washing for both overflow washing and the batch washing are estimated and is presented in Table 4.30. The batch wash process when compared with the overflow washing process will be consuming about 40% less, but the time required for washing will increase to 89 min from 33 min.

Table 4.30- Quantity of water consumed and time taken for the washing for overflow washing and the batch washing

S.No.	Steps	Number of Washes	Water consumed (L)	Time taken (min.)
1	Overflow washing at 150 LPM water and 150 m/min fabric run	8	3703	33
2	Batch washing in tub with 100% level of water	15	2220	89

4.2.2.7 Flash cooling of the dyeing machine contents

Dye machine contents are at present to from about 130^{o}C to below 80^{o}C temperature by circulating the dye machine contents through an external heat exchanger, where the heat is transferred to the circulating cooling water.

It is possible to flash the circulating machine contents (liquor) in a flash tank and send the liquor back to the dyeing machine. This will result in flash steam generation and instantaneous cooling of the liquor without using any cooling water. By this approach it is possible to cool the machine contents to about 100°C. Assuming 650 Kcal enthalpy for the flash steam, flash cooling, of 150 kg capacity dyeing machine (of 2000 kg mass) contents (900L) from 130°C to 105°C, is estimated to produce over 40 kg flash steam. For the further cooling of the machine contents (to 60-80°C), one can use the external heat exchanger and circulating cooling water. The flash steam generated can be used, and the foul steam condensate generated from such use may be of better quality water for reuse as hot water. Flash cooling of the machine contents can marginally reduce the volume of the dye bath dump wastewater generation.

4.2.2.8 Cooling water system for dyeing machines

A closed loop circulation of the cooling water between the heat exchangers and the cooling towers can minimize the water consumption in cooling and limit just to a) evaporation losses b) drift losses c) cooling tower blow-down losses and d) water losses through leaks. But the recoverable heat content of the cooling water is lost and, for cooling the water through dissipating this waste heat, additional energy (in the form of electrical energy) is consumed.

Jet dyeing machines, top dyeing machines and cabinet dyeing machines use external heat exchanger for both heating and cooling of the machine contents (liquor) with saturated dry steam and cooling water respectively. The machine contents are usually heated or cooled at a specified rate (at about 1.5°C/minute or <4°C/minute respectively). Cooling of the machine contents is usually carried out from above 100°C to <80°C. This generates relatively higher temperature return cooling water, which has both water and energy value.

Collect the return cooling water from all the external heat exchangers into the first chamber of a two chambered return cooling water pit. Make provision for the overflow of excess cooling water from the first chamber into the second one. Pump the first chamber return cooling water into the overhead tank, and supply as hot process water to all the dyeing machines for use. Cool the cooling water of the second chamber to the desired temperature by circulating through a cooling tower. Pump the water to the overhead process water tank for reuse both as process water and as cooling water.

Collect the return cooling water from each of the heat exchangers into a header that carries to return cooling water to the return cooling water collection pit under gravity. The header is sized to carry the return cooling water for a condition when 2/5th of the dyeing machines are under cooling. The header may be provided a slope equal to the diameter of the header in mm (a 150 mm diameter header can have a slope of 1 in 150 towards the collection pit). The header may be provided a few vents for the release of entrapped gases.

Header of the return cooling water may be made to release the cooling water at the bottom of the first chamber of the return cooling water collection pit. Cooling water overflowing into the second chamber of the pit may not always require cooling in the cooling tower, and, if most of the return cooling water can be reused as hot/warm process water, cooling of the water in the second chamber in a cooling tower may not be required. Hot water demands of the Jiggers and Winches are quite significant and use of the return cooling water in these machines may also be considered. Pumping of the cooling water without any cooling from the second chamber of the pit into the overhead process water tank may not significantly alter the temperature of the process water. The pipelines used for the pumping of hot water and the cool water may be sized to carry the water velocities <7 m/sec.

There can be leaks in the heat exchanger and the cooling water can get contaminated with the dyeing machine liquor in circulation. Necessary provisions should be made to detect such leaks and to drain out the contaminated cooling water into the sewer leading to the ETP. At the outlet of each of the heat exchangers a short section of see through piping and a drain with control valve for diverting the cooling water into the sewer may be provided. A photocell detecting dye in the cooling water can be used for automatic detection of contamination and draining out of the contaminated cooling water. Similarly, drain out arrangements may also be made on the return cooling water collection pit for emptying the contents into the sewer leading to the ETP.

The return cooling water can be available at >55°C temperature for reuse. Assuming the process water temperature as 30°C, reuse of the return cooling water as hot/warm process water can avoid use of steam for heating the dyeing machine contents at least upto attaining 50°C temperature. This can amount to 25 to 30% and even more steam energy conservation on dyeing machines. If the steam consumption is 6 kg/kg of fabric processed, through reusing the return cooling water as hot process water, the steam consumption can be brought down to <4.5 kg/kg of fabric. Reuse of the return cooling water as hot/warm process water as suggested above almost eliminates the wastewater generation from the cooling water system and conserves water.

4.2.3 In-plant measures for waste minimization

The following strategies have been identified to have the potential to conserve water and minimize wastewater generation:

- Modifying the scheme of scouring and dyeing to eliminate overflow cooling and washing, to reduce the number of steps involved, and to recycle wherever feasible the wastewater generated at the down-stream steps in the upstream steps.
- Having a dedicated circulating cooling water system inclusive of a cooling tower and using the return cooling water in place of process water wherever feasible.
- Segregating the steam condensate and reusing as boiler feed water.
- Using the treated low/medium strength wastewater in the dyeing.

- Best in-plant management practices

4.2.3.1 Eliminating overflow cooling/washing and reducing the number of scouring and dyeing steps

Avoid overflow cooling/washing of the fabric. When only cooling is the requirement then practice cooling in the external heat exchanger with circulating cooling water. When both cooling and washing are required, then either go for first cooling in external heat exchanger, next draining out the bath contents and then fill water for washing or go for cycles of partial drain-fill-partial drain cycles of cooling and washing. The modifications for avoiding overflow cooling/washing are already described earlier under the process modifications suggested for different dyeing processes.

Combine the post-scouring neutralization and hot soap wash steps into a single step to conserve water and minimize wastewater generation.

The above two when implemented can conserve water. Implementation of these measures does not require any additional facilities and the associated machinery requires no physical modifications. The implementation requires only procedural changes and training of the operators.

4.2.3.2 Segregation and reuse of recyclable wastewaters

Segregate and store the effluent generated from the post-scour neutralization step and reuse it in the post-scour washing in case of cotton and polyester-cotton fabric processing.

Segregate and store the effluent generated from the softener application step and reuse the effluent in softener applicator step of the next batch of fabric processing. This will conserve water and softener chemical and minimize wastewater generation. Implementing these measures is estimated to conserve water and reduce the wastewater generation by about the same amount.

Implementation of these measures may require provisions on the dyeing machines for separately draining out washwater generated from the post-scour neutralization step of the cotton and polyester-cotton dyeing, and from the softener applicator steps of dyeing. Both these waters will be collected into two or more separate sumps of appropriate liquid storage capacity ($<5m^3$). Separate drain pipes may be needed for conveying these waters from the dyeing machines to the collection sumps. The sumps will have overflow drains for allowing excess wastewaters into the ETP for treatment as low/medium strength wastewater. Further, necessary pumps, piping and fittings, and overhead effluent dose tanks of sufficient capacity ($<5\ m^3$) will be provided for facilitating reuse of the effluent in the dyeing machines.

Segregation and handling of drained out dye bath effluents

Most of the chemicals (including the salts, sodium chloride or sodium sulfate) and all the dyes are used in the dye bath, and most of the used chemicals and dyes are drained out in the form of dye bath dumps into the sewer leading to the effluent treatment plant as wastewater. Salts and chemicals addition is the maximum in the dyeing of cotton textiles or cotton textile blends. Assuming liquor to fabric ratio of 6:1 during processing and 2.5:1 after draining out the bath, about 60% of the salt and chemicals are drained out in the dye bath dumps. The dye bath effluent, especially from the cotton dyeing, usually has >3% TDS. Mixing of this effluent with other effluents of the textile processing industry makes the total effluent TDS rich. This in turn makes both the effluent treatment and the use of treated effluent as reclaimed water very difficult. Segregation of the dye bath effluents from other effluents thus can enhance the recycle and reuse potential of the other effluent after treatment.

4.2.3.3 Use of warm return cooling water in place process water in the dyeing machines

Use the warm return cooling water in place of the process water in all the steps where initial heating of the machine contents to $40^{o}C$ or more temperature with steam is needed. This will minimize the process steam consumption and save the machine time.

For facilitating this, the warm return cooling water will be pumped and stored in the overhead return cooling water tank (may be of 30 m^3 capacity) and from there through separate piping and fittings the water will be supplied to all the dyeing machines for use.

4.2.3.4 Reuse of treated low/medium strength dye effluent

Use treated low/medium strength dye effluent in place of process water, specially, in polyester fabric dyeing for conserving water. Calculations indicate that more than 50 m^3/day of the treated low/medium strength dye effluent can be reused in the polyester and polyester cotton dyeing.

For facilitating the use the treated secondary effluent will be filtered and chlorinated and stored in an overhead tank. From this tank through necessary piping and fittings the effluent will be supplied to the dyeing machines for reuse.

4.2.3.5 Other management practices of pollution prevention

- Substitution of hard to treat chemicals with easier to treat chemicals in various dye auxiliaries.
- Spillage of dyes and other hard to treat chemicals can be overcome by upgrading employee work practices.
- Dyer must comprehend the application of dyes onto textiles.

- Assortment of dyes which reacts/exhaust with minimum amount of salts and auxiliaries and right-first-time (RFT) approach to attain best dyeing.

- Analyzing the effluent for the metals and pre-screening of all the available chemicals before use (incoming raw materials/chemicals/auxiliaries/salts quality control), to reduce the metal pollution and other toxicity.

- Water conservation audit system should be established to minimize the water wastage like- running hoses, defective amenities, leakage of pumps, valves, pipes etc.,

- Management should encourage the workers awareness towards water conservation, routine machinery maintenance, and good house-keeping, dye usage, chemical handling and pollution prevention practices.

4.2.4 Wastewater management system

The wastewaters generated will be segregated into the following four streams:

1. High strength dye effluent

2. Low/medium strength effluent from scouring and dyeing

3. Effluent from the utilities and services

4. Domestic wastewater

Scheme of treatment for the wastewaters-

4.2.4.1 Treatment scheme for the low/medium strength dye effluent

The low/medium strength dye effluent will be collected into one of the three equalization/reaction tanks. Once a tank is full, the incoming effluent will be diverted into the next equalization tank. Effluent of the filled tank will be sampled and experimented in the laboratory for finding out the chemicals and their doses required for neutralization-precipitation/coagulation-flocculation treatment (for color removal). While mixing the tank contents with the help of a diffused aeration system, the tank contents will be subjected to the chemical treatment. The treated effluent, with the precipitates and flocs (formed from the chemical treatment), will then be pumped and passed through a clari-flocculator. Clarified effluent, overflowing the clari-flocculator, will be collected into a primary effluent sump. Settled bottom sludge of the clari-flocculator will be drained into a sludge sump.

Wastewater from the primary effluent sump will be pumped, passed through a sand filter, for the removal of any residual flocs, and taken into an Activated Sludge Plant (ASP) for the biological treatment and removal of BOD/COD. In the ASP the wastewater will be aerated with the help of a diffused aeration system for the biological treatment. Treated and clarified secondary effluent of the ASP will be collected into a treated effluent sump. At regular intervals fixed volume of biological sludge will be wasted from the ASP into the sludge sump.

Treated secondary effluent of the sump, as and when required, will be pumped, passed through a pressure sand filter, if needed, chlorinated, and taken to an overhead tank for reuse in the soft-flow machines for polyester dyeing. Excess of the treated secondary effluent will be allowed to overflow the sump as treated effluent for disposal on land in a Karnal System.

The pressure sand filters, once get sufficiently clogged, will be backwashed with the treated and filtered secondary effluent, and the backwash water generated will be taken back into any one of the three equalization/reaction tanks for treatment along with the raw effluent.

Sludge drained into the sludge sump will be pumped and passed through a filter press for dewatering. The dewatered sludge will be sun dried, packed in plastic bags and stored in an earmarked hazardous waste storage space. Once in every 3 months the sludge stored will be transported to the Treatment Storage Disposal Facility for disposal. Filtrate generated at the filter press will be taken back into any one of the three equalization/reaction tanks for treatment along with the raw effluent.

4.2.4.2 Treatment scheme for the high strength dye effluent

The high strength dye effluent will be collected into a raw wastewater sump. From here the wastewater will be pumped and taken into a hopper bottom vessel (which will be used as a reaction tank, as a flocculator and also as a clarifier) for the primary treatment. Through experimentation on the sample collected from the vessel, dose of chemicals required for the treatment will be found. After switching on the diffused aeration system, the chemicals will be dosed and aerated for the coagulation and flocculation to occur. Then the aeration system will be switched off and the wastewater will be allowed to settle. After settling, the clarified effluent layer of the tank will be decanted into a Sequencing Batch Reactor (SBR) for secondary treatment and removal of BOD/COD. The settled bottom sludge will be drained out into the Sludge Sump.

While filling the SBR, diffused aeration system will be turned on and aeration will be continued for about 8 hours (even after filling). Then aeration will be stopped and contents of the SBR-2 will be allowed to settle for over two hour’s period. Once clarified, the supernatant will be decanted, as treated secondary effluent, into a treated effluent sump and the SBR will be kept ready for the next batch of biological treatment. Whenever the accumulated settled sludge is observed crossing the set level in the SBR, the aeration will be switched on, and desired volume of the mixed liquor of the SBR will be drained out into the sludge sump.

4.2.4.3 Management of the wastewaters from utilities and services

This wastewater has relatively high TDS and moderate levels of suspended solids and is not organically polluted.

This wastewater will be mixed with the treated low/medium strength wastewater prior to disposal.

4.2.4.4 Management of the domestic wastewater

The domestic wastewater generated at different points will be collected into a baffled anaerobic reactor for treatment and the treated effluent will be pumped into the ASP of the low strength dye effluent treatment plant for further treatment.

4.3 EFFLUENT TREATMENT PLANT

The effluent treatment plant was suggested for treating 500 m^3/day of low/medium strength dye effluents and 50 m^3/day of high strength dye effluents.

4.3.1 Facilities/Units of ETP

The ETP includes the following units:

1. Tray screen
2. Equalization/reaction tanks (for low/medium strength effluents)– (3 numbers)
3. Coagulated/flocculated effluent pumps (2 numbers)
4. Clari-flocculation tank
5. Pressure sand filter for primary effluent
6. ASP (activated sludge treatment plant)
7. Treated (low/medium strength) effluent sump
8. Secondary effluent pumps (2 numbers)
9. Pressure sand filter for secondary effluent
10. Online electro-chlorinator
11. Filtered secondary effluent tank

12. Karnal system of irrigation
13. Equalization tank (for high strength effluents)
14. High-strength dye effluent pumps (2 numbers)
15. Coagulation-flocculation-settling tank
16. Sequencing batch reactor with supernatant decanting facility
17. Treated (high strength) effluent sump
18. Diffused aeration systems (3 numbers)
19. Sludge sump
20. Sludge pump and filter press system (2 numbers)
21. Sludge storage room
22. Treatment chemicals storage room

4.3.2 ETP- Schematic representation

The schematic process and material flow diagram of the Effluent Treatment Plant (ETP) used for the treatment of both the low/medium strength and the high strength effluent is shown in Figure-4.12.

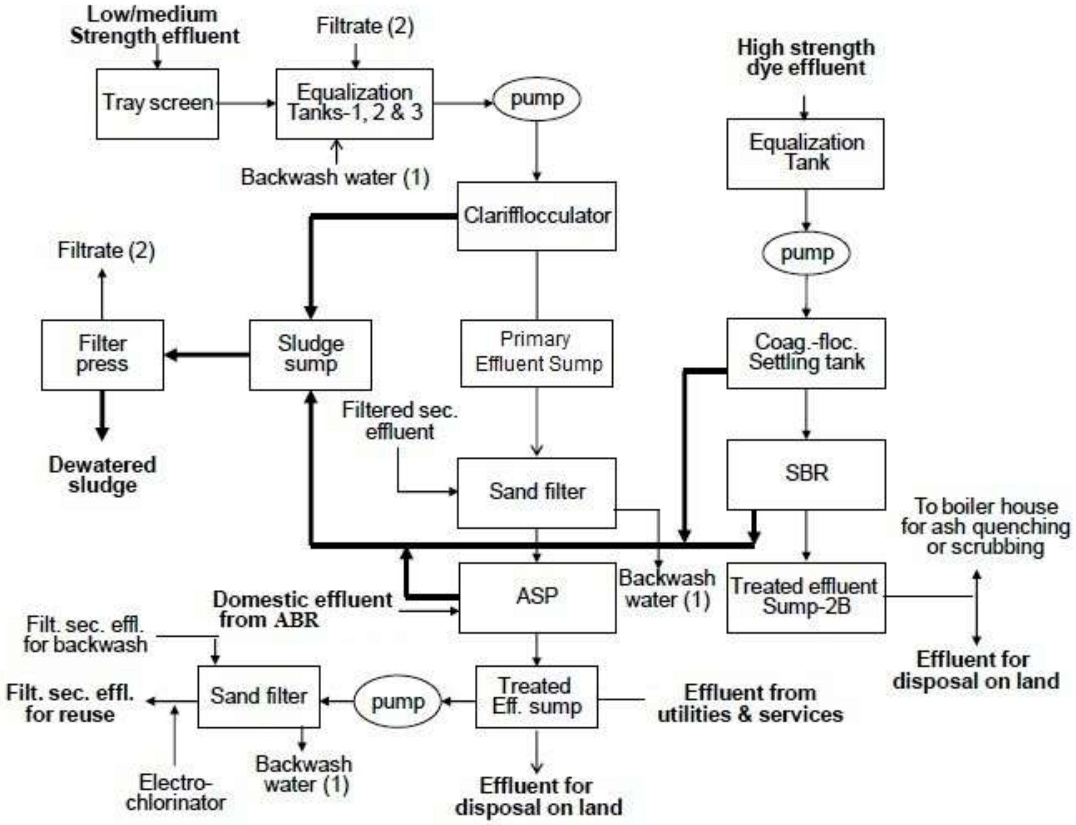


Fig. 4.12- Schematic representation of effluent treatment plant

4.3.3 Working and treatment through ETP

The incoming wastewater was screened in the tray screen prior to collecting into one of the three equalization/reaction tanks. Wastewater from the industrial unit was made to fall into the tray and pass through the screen prior to entry into any one of the three equalization/reaction tanks.

Two tray screens were provided. One will screen the low/medium strength effluent prior to its entry into one of the three equalization/reaction tanks, and the other one will screen the high strength effluent prior to its entry into the high strength effluent equalization tank. Three outlets are provided at the bottom of the screen chamber for carrying the screened wastewater independently into the three equalization/reaction tanks. Three tanks, each of 7m x 4m x (4.5 + ≥0.3) m dimensions and 126 m^3 liquid holding capacity, was used as the equalization/reaction tanks for the primary treatment of the low/medium strength wastewater stream. These tanks were provided with diffused aeration system for facilitating mixing and aeration of the contents. Further, provisions were made for dosing the primary treatment chemicals (ferrous sulfate/alum and lime/caustic/acid).

Raw low/medium strength wastewaters was received by one of the three tanks and once the tank is full (accumulated about 126 m^3 of wastewater), inflow of the raw wastewater was stopped and diverted to the next tank, and the wastewater of the tank then undergoes coagulation and flocculation through dosing the treatment chemicals while aerating and mixing the tank contents. After the coagulation and flocculation, the wastewater with suspended flocs was pumped and loaded on a clari-flocculator for primary settling. Only one pump will be in use while the other one is a standby pump. The clari-flocculator has 25 m^3/hour clarification capacity. Flocculated wastewater from the three equalization/reaction tanks will be loaded from the top into the flocculation zone over the conical plate. Clarified effluent overflowing into the peripheral trough will be collected into the primary effluent sump. The settled sludge will be drained into the sludge sump once a day when the clari-flocculator is not in use. The clari-flocculator can hold >16 m^3 of sludge.

4.4 WASTEWATER TREATMENT TECHNOLOGIES

The wastewater treatment technologies selected for evaluation in case of the chloride rich cotton textile dye bath effluents were coagulation-flocculation-settling and electroflocculation, and in case of sulphate rich effluents electroflocculation and membrane processes were selected, whereas, membrane processes was also selected for the treatment of softener application wastewater.

4.4.1 Dosing of dye effluents

The coagulation and flocculation process was tried for the wastewater collected from a textile dyeing industry having initial characteristics as mentioned in Table 4.31. Numerous types of chemicals- coagulants and flocculants were used as already mentioned in literature review. The jar test was performed to know the accurate/actual dose amount and particular coagulant amount to be used for the textile wastewater.

Table 4.31- Initial Characteristics of textile wastewater-treatment with chemical coagulation/flocculation

S.No.	Parameter	Unit	Value
1	pH	--	7.21
2	Color	Pt. Co. Unit	1580
3	Turbidity	N.T.U	30
4	COD	mg/L	676.42
5	Alkalinity	mg/L as $CaCO_3$	689.5
6	OH^-	mg/L as $CaCO_3$	Nil
7	CO_3^{2-}	mg/L as $CaCO_3$	Nil
8	HCO_3^-	mg/L as $CaCO_3$	689.5
9	Total Hardness	mg/L as $CaCO_3$	65.38

10	Ca	mg/L	10.47
11	Mg	mg/L	6.9
12	Sulphate	mg/L	208.60
13	Chloride	mg/L	1494.58
14	TDS	mg/L	3638
15	TSS	mg/L	40
16	Conductivity	mS/cm	5.89

In this study, the coagulation and flocculation process was tried using Aluminium sulphate (Alum) $Al_2(SO_4)_3.18H_2O$, Ferrous sulphate (Copperas) $FeSO_4.7H_2O$ and polyelectrolyte. HCl/NaOH and Lime was used for adjusting the pH. The design was prepared having full factorial with 2 centre points of 10 experimental runs with 4 sets. The 10 experiments are shown in Table 4.32.

Table 4.32- Set of Experimental design as per CCD

		Factor 1	Factor 2	Factor 3
Run	Type	A:pH	B:Coagulent dose	C:Polyelectrolyte
1	Factorial	6	500	1
2	Center	8.5	300	4
3	Center	8.5	300	4
4	Factorial	11	500	1
5	Factorial	6	100	7
6	Factorial	6	500	7
7	Factorial	11	500	7
8	Factorial	11	100	1

9	Factorial	6	100	1
10	Factorial	11	100	7

Sample volume of 200 ml was used for each experimental run. pH, Coagulating dose and polyelectrolyte was taken as Factors, with two responses – Color removal efficiency and Turbidity removal efficiency. The 4 sets for coagulation experiments were-

i. Set 1- Coagulating agent, **Alum-** pH adjusters, **NaOH/HCl**
ii. Set 2- Coagulating agent, **Alum**- pH adjusters, **Lime/HCl**
iii. Set 3- Coagulating agent, **$FeSO_4$**- pH adjusters, **Lime/HCl**
iv. Set 4- Coagulating agent, **$FeSO_4$**- pH adjusters, **NaOH/HCl**

4.4.1.1 Set 1- Dosing with Alum as coagulating agent and NaOH/HCl as pH adjusters

The Turbidity and color analysis was presented in Table 4.33 where, Alum is used as coagulating agent and NaOH/HCl as pH adjusters.

Table 4.33- Results of Set 1, when Alum and NaOH/HCl was used

Run	**Factor 1** **pH**	**Factor 2** **Coagulant dose**	**Factor 3** **Polyelectrolyte**	**Turbidity** **(N.T.U)**	**Colour** **(Pt. Co. unit)**
1	6	500	1	13.1	219
2	8.5	300	4	89.3	1520
3	8.5	300	4	88	1470
4	11	500	1	29.7	1310
5	6	100	7	74.5	1340
6	6	500	7	8.47	156
7	11	500	7	33.3	1320
8	11	100	1	23.8	1350

9	6	100	1	51.2	1280
10	11	100	7	74.5	1340

In Set 1, the maximum turbidity and color removal efficiency of 71.8% and 90.1 % was achieved with alum dose of 500 ppm, polyelectrolyte- 7 ppm and at pH 6.0. At the more basic pH i.e. 8.5 to 11 units, only upto 20% of color removal efficiency was obtained. The lowest removal efficiency of 3.8% only was achieved when pH was adjusted at 8.5 units with NaOH and mixing 300 ppm of Alum dose and 4 ppm of polyelectrolyte. In this case final turbidity was also increased to 89.3 N.T.U with negative removal efficiency.

4.4.1.2 Set 2- Dosing with Alum as coagulating agent and Lime/HCl as pH adjusters

The Turbidity and color analysis was presented in Table 4.34 where, Alum is used as coagulating agent and Lime/HCl as pH adjusters.

Table 4.34- Results of Set 2, when Alum and Lime/HCl was used

Run	Factor 1 pH	Factor 2 Coagulant dose	Factor 3 Polyelectrolyte	Turbidity (N.T.U)	Colour (Pt. Co. unit)
1	6	500	1	12.69	253
2	8.5	300	4	31.4	940
3	8.5	300	4	28.4	910
4	11	500	1	9.99	850
5	6	100	7	66.9	1430
6	6	500	7	6.23	216
7	11	500	7	11.26	750
8	11	100	1	46.3	1350
9	6	100	1	70.9	1550
10	11	100	7	45.6	1290

In Set 2, the Lime and HCl was used as pH adjusting reagents and again Alum was used as coagulant. 86.3% of color removal efficiency and 79.2 % of turbidity removal efficiency was achieved when pH was maintained at 6.0, with addition of 500 ppm of coagulant dose and 7 ppm of polyelectrolyte. The lowest removal efficiency of only 1.9% for color and -136.3% for turbidity was achieved with 100 ppm of alum dose, 1ppm of polyelectrolyte and at pH 6.0.

4.4.1.3 Set 3- Dosing with $FeSO_4$ as coagulating agent and Lime/HCl as pH adjusters

The Turbidity and color analysis was presented in Table 4.35 where, $FeSO_4$ is used as coagulating agent and Lime/HCl as pH adjusters.

Table 4.35- Results of Set 3, when $FeSO_4$ and Lime/HCl was used

Run	Factor 1 pH	Factor 2 Coagulant dose	Factor 3 Polyelectrolyte	Turbidity (N.T.U)	Colour (Pt. Co. unit)
1	6	500	1	96.9	2960
2	8.5	300	4	42.9	1520
3	8.5	300	4	52.1	1640
4	11	500	1	15.7	840
5	6	100	7	57.6	1370
6	6	500	7	100	2860
7	11	500	7	21.3	860
8	11	100	1	103	2030
9	6	100	1	55.5	1530
10	11	100	7	95.4	2020

Lime and HCl was used as pH adjusting reagents in Set 3 and $FeSO_4$ was used as coagulating agent. In this case, the maximum removal efficiency of 47.7 % and 46.8% for turbidity and color respectively was achieved at pH 11.0, with 500 ppm $FeSO_4$ and 1 ppm of polyelectrolyte. At same pH of 11.0 and 1 ppm of polyelectrolyte but 100 ppm of $FeSO_4$ dose the -28.5% and -243.3 % of color and turbidity removal efficiency was obtained which was showing the effect of concentration of coagulant dose.

4.4.1.4 Set 4- Dosing with $FeSO_4$ as coagulating agent and NaOH/HCl as pH adjusters

The Turbidity and color analysis was presented in Table 4.36 where, $FeSO_4$ is used as coagulating agent and NaOH/HCl as pH adjusters.

Table 4.36- Results of Set 4, when $FeSO_4$ and NaOH/HCl was used

Run	Factor 1 pH	Factor 2 Coagulant dose	Factor 3 Polyelectrolyte	Turbidity (N.T.U)	Colour (Pt. Co. unit)
1	6	500	1	93.7	2290
2	8.5	300	4	64.9	2310
3	8.5	300	4	72.4	2530
4	11	500	1	80.1	2430
5	6	100	7	72	1550
6	6	500	7	89.4	1870
7	11	500	7	89.3	2590
8	11	100	1	89.8	2070
9	6	100	1	83.5	1600
10	11	100	7	83.3	1900

In Set 4, the NaOH and HCl was used as pH adjusting reagents and $FeSO_4$ as coagulating agent. In all the 10 experimental runs the negative (lowest) color as well as turbidity removal efficiencies was obtained. The Pareto chart for Set 1, 2 and 3 was presented in Figure 4.13, 4.14 and 4.15 respectively.

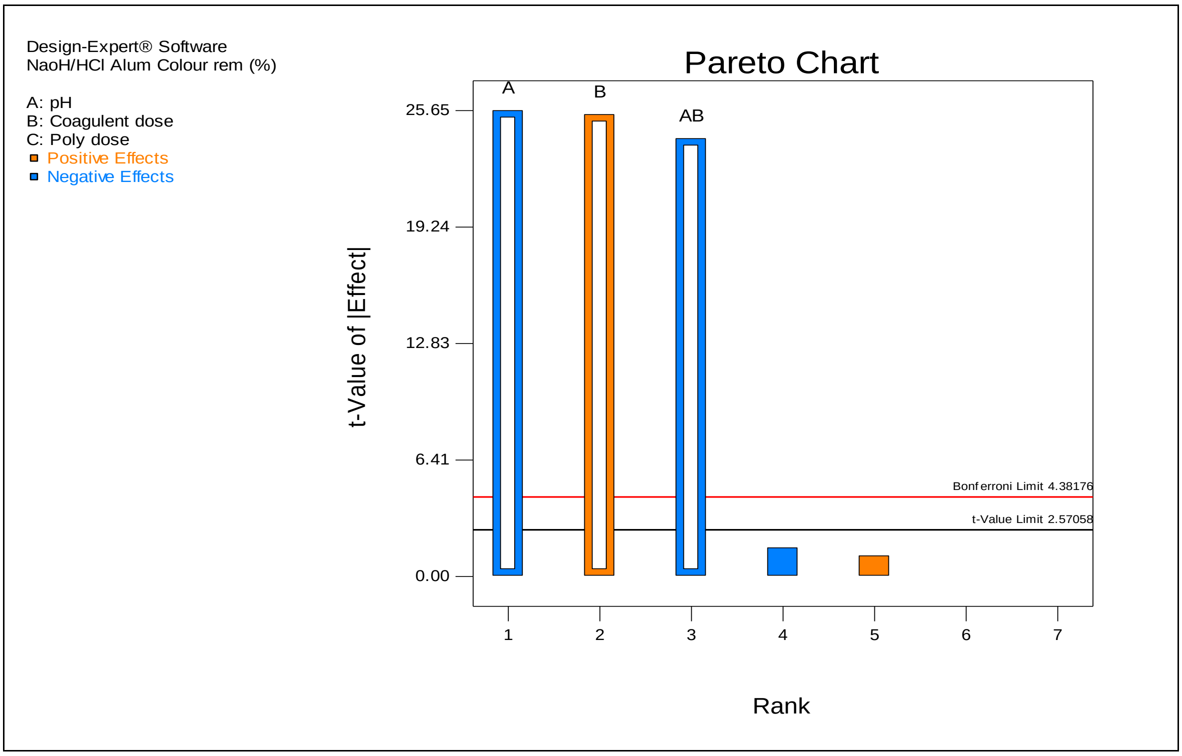


Fig. 4.13- Pareto chart for color removal for Set 1

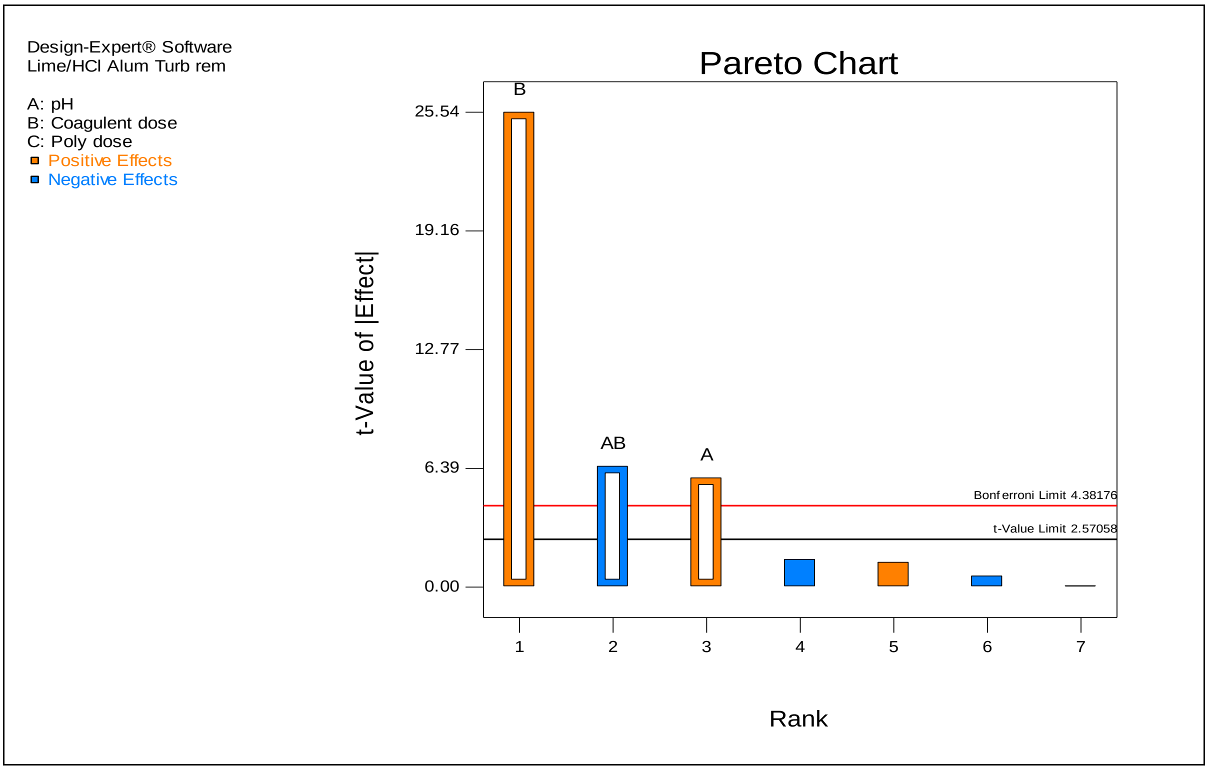


Fig. 4.14- Pareto chart for Turbidity removal for Set 2

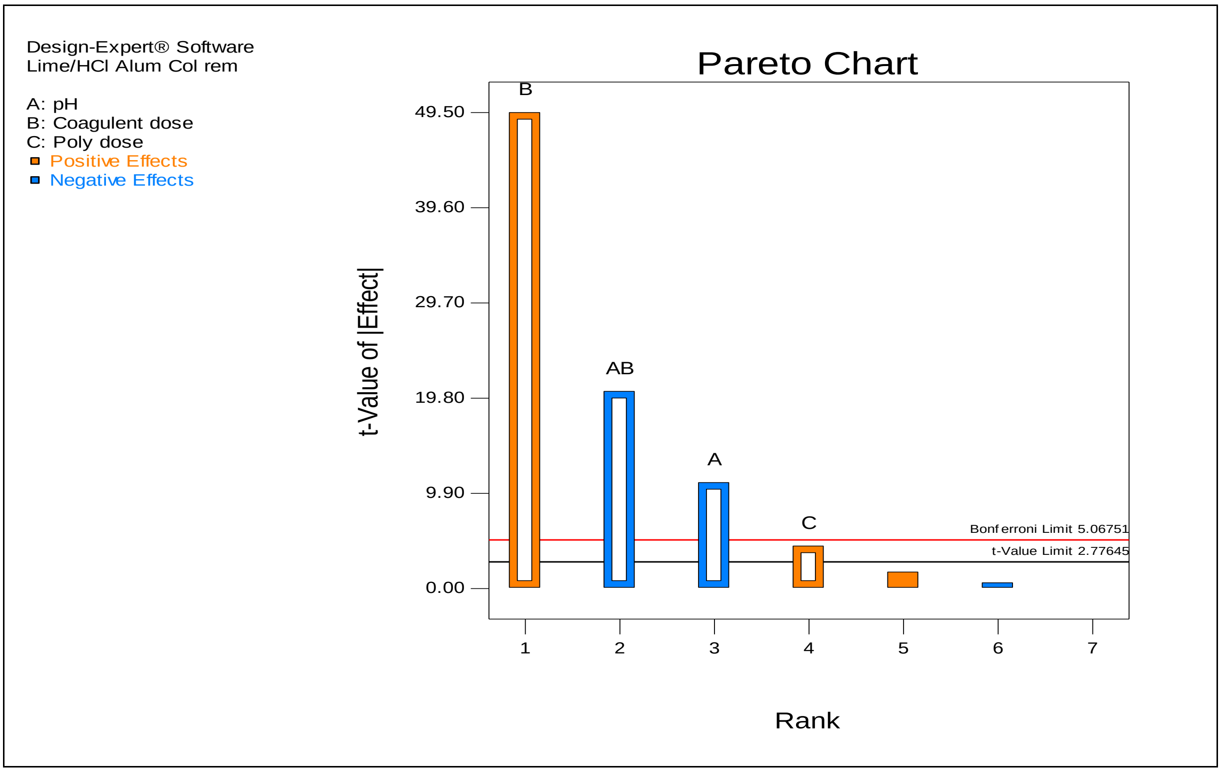


Fig. 4.15- Pareto chart for color removal for Set 3

In set 1, the polyelectrolyte has no effect on colour removal and not a term in the model both as linear form and as well as in interaction form. In set 2 also, the polyelectrolyte has also no effect on turbidity removal and not a term in the model both as linear form and as well as in interaction form. In set 3 the polyelectrolyte has also no effect on colour removal and not a term in the model both as linear form and as well as in interaction form. All the experimental runs with different coagulating agents (Alum as well as $FeSO_4$) and by using different pH adjusting reagents i.e. NaOH/HCl and Lime/HCl, it was concluded that Alum was the better option for getting maximum color as well as turbidity removal efficacies. To achieve higher color and turbidity removal efficiencies, pH should be decreased as concluded from the design of experiments. Another set of 18 experiments was performed with coagulant dose of 500 ppm and polyelectrolyte usage of 0, 0.5, 1.0 and 1.5 ppm. The HCl consumed for each experiment was also studied for acid usage purpose. The results of these 18 experiments are presented in Table 4.37. The initial turbidity was 30 N.T.U and initial colour was 1580 Pt. Co. Unit.

Table 4.37- Results of various experiments with variable pH, coagulant and polyelectrolyte doses

S.No.	HCl consumed (mL)	Factor 1 pH	Factor Coagulant dose (ppm)	Factor 3 Polyelectrolyte (ppm)	Turbidity (N.T.U)	Colour (Pt. Co. Unit)
1	0	7	500	1.5	10.2	640
2	1.5	6.4	500	0	18.9	538
3	1.54	6.2	500	0	13.2	416
4	1.7	6	500	0	6.1	225
5	1.9	5.8	500	0	6.9	197
6	2	5.7	500	0	7.1	186
7	2.04	4	500	0	7.4	227
8	2.3	5.5	500	1.5	12.3	187
9	2.3	5.5	500	0	10.5	212
10	2.3	5.5	500	0	9.2	222
11	2.3	5.5	500	0.5	12.9	252
12	2.3	5.5	500	1	10.9	292
13	2.3	5.5	500	1.5	9.6	236
14	2.1	5.6	500	0	7.9	209
15	2.3	5.2	500	0	10.8	232
16	2.5	4.8	500	0	9	291
17	2.5	4	500	1.5	20.9	542
18	2.8	3.8	500	0	9.7	303

The pH was varied in-between 3.8 to 7.0 units. The coagulant dose of 500 ppm was used through-out the experiments. The addition of alum was causing decrease of approximate 0.88 pH units. The need of polyelectrolyte was observed by using it in some of the experiments. The maximum color removal efficiency of 88.2 % was obtained at two separate experimental runs. First, when pH was adjusted at 5.7 units without addition of polyelectrolyte, and secondly when pH was adjusted to 5.5 units with addition of 1.5 ppm of polyelectrolyte.

The turbidity and color removal efficiency was also estimated after filtration with whatman No. 1 filter paper and it comes out to be 95.7 % and 89.6 % respectively, which emphasize on the filtration or settling process after coagulation as presented in Table 4.38.

Table 4.38- Turbidity and color removal efficiency after filtration

S.No.	**Factor 1 pH**	**Factor Coagulant dose (ppm)**	**Factor 3 Polyelectrolyte (ppm)**	**Turbidity (N.T.U)**	**Colour (Pt. Co. Unit)**
1	5.5	500	0.5	2.3	164
2	5.5	500	1	1.3	175

The dis-advantages of the coagulation process was practically observed as detailed below-

- Formation of sludge that has to be treated subsequently
- Relatively time consuming process
- Continuous input of chemicals required.

However, the sludge amount can be reduced when only the high strength dyebath wastewater was treated (Golob, *et. al.* 2005).

4.4.2 Electroflocculation of dye effluents

The electroflocculation treatment on sulphate rich wastewater (SRWW) and chloride rich wastewater (CRWW) and for all the four combinations of electrodes was performed. IV-optimal design strategy of RSM with Design Expert Software was used for the design of experiments. Total 19 experiments included; six model points, five replicates at center point and additional three center runs and five runs for estimating the *Lack of fit*. The study was also focused on finding out the best sacrificial electrode material for the wastewater. Two process variables (voltage and treatment time) were varied as per IV-optimal design strategy of RSM. COD removal efficiency (Response I) and Color removal efficiency (Response II) were taken as responses. ANOVA model was constructed which best fits the response data. Energy consumptions and sludge formations was also evaluated.

The wastewater was collected from a cotton textile processing industry located in Ludhiana, Punjab, India. The cotton textile dyeing process which includes use of Glauber's salt ($Na_2SO_4.10H_2O$) as wetting agent to facilitate dyeing action which also leads to maximum exhaustion of the dyes was rich in sulphate and have the initial characteristics presented in Table 4.39.

Table 4.39- Characteristics of sulphate rich cotton textile dyebath dump wastewater

S.No.	Parameter with units	Value
1	Color (Pt Co units)	1000
2	COD (mg/L)	1243
3	Turbidity (NTU)	217
4	Conductivity (mS/cm)	51.2
5	pH	10.8
6	TDS (mg/L)	61203

7	TSS (mg/L)	27
8	Sulphate (mg/L)	29134
9	Total Alkalinity (mg/L as $CaCO_3$)	13053
10	Sodium (mg/L)	19400
11	Chloride (mg/L)	645
12	Surfactants (ppm)	<0.1
13	Phenols (ppm)	<0.1
14	Sulfide (mg/L)	10.4
15	Sulfite (mg/L)	5
16	Calcium (mg/L)	41.3
17	Magnesium (mg/L)	20.4

4.4.2.1 Electroflocculation treatment of SRWW with Al-Al electrode

The results obtained from the laboratory experimentation with Al-Al electrodes in electroflocculation treatment of SRWW are presented in Table 4.40 and Table 4.41.

Table 4.40- Results of experimentation on sulphate rich wastewater with Al-Al electrodes at different voltages and treatment times

1= 12 V; 15 min.			**2= 4 V; 15 min.**			**3= 12 V; 15 min.**		
Time (Min.)	Volt (V)	Current (A)	Time (Min.)	Volt (V)	Current (A)	Time (Min.)	Volt (V)	Current (A)
0	12	1.3	0	4	1.1	0	12	0.9
1	12	1.9	1	4	2.5	1	12	1.1
2	12	2.3	2	4	3.2	2	12	2.3
3	12	3.8	3	4	5.2	3	12	4.3
4	12	4.3	4	4	5.6	4	12	5.4
5	12	4.7	5	4	6.0	5	12	6.5
6	12	5.2	6	4	6.0	6	12	7.8
7	12	5.8	7	4	6.0	7	12	8.2
8	12	6.1	8	4	5.9	8	12	8.8
9	12	6.9	9	4	5.8	9	12	9.5
10	12	7.5	10	4	4.7	10	12	9.9
11	12	8.7	11	4	4.6	11	12	10.3

12	12	9.9	12	4	4.5	12	12	10.7
13	12	10.2	13	4	5.4	13	12	11.4
14	12	11.4	14	4	5.4	14	12	12.4
15	12	12.5	15	4	5.4	15	12	13.7
Total Current		**102.5**	**Total Current**		**77.3**	**Total Current**		**123.2**
4= 4 V; 15 min.			**5= 4 V; 3 min.**			**6= 12 V; 3 min.**		
Time (Min.)	Volt (V)	Current (A)	Time (Min.)	Volt (V)	Current (A)	Time (Min.)	Volt (V)	Current (A)
0	4	1.2	0	4	0.5	0	12	1.4
1	4	2.5	0.5	4	0.7	0.5	12	2.3
2	4	3.7	1.0	4	1.2	1	12	2.9
3	4	4.5	1.5	4	1.4	1.5	12	3.1
4	4	4.9	2.0	4	1.6	2.0	12	3.2
5	4	5.4	2.5	4	2.2	2.5	12	3.3
6	4	5.2	3.0	4	2.3	3.0	12	3.3
7	4	5.7						
8	4	4.2						
9	4	3.8						
10	4	4.0						
11	4	4.2						
12	4	4.3						
13	4	4.5						
14	4	4.6						
15	4	4.6						
Total Current		**67.3**	**Total Current**		**9.9**	**Total Current**		**19.5**
7= 12 V; 3 min.			**8= 10 V; 6 min.**			**9= 6.6 V; 12.9 min.**		
Time (Min.)	Volt (V)	Current (A)	Time (Min.)	Volt (V)	Current (A)	Time (Min.)	Volt (V)	Current (A)
0	12	0.8	0	10	0.8	0	6.6	0.8
0.5	12	0.9	1	10	1.2	1	6.6	1.6
1.0	12	1.1	2	10	1.3	2	6.6	1.8
1.5	12	2.3	3	10	1.5	3	6.6	1.8
2.0	12	3.8	4	10	2.3	4	6.6	2.8
2.5	12	5.6	5	10	2.7	5	6.6	2.9
3.0	12	6.2	6	10	3.1	6	6.6	2.8
						7	6.6	3.8
						8	6.6	3.7
						9	6.6	3.7
						10	6.6	4.7
						11	6.6	5.6
						12	6.6	5.7
						12.54	6.6	5.6
Total Current		**20.7**	**Total Current**		**12.9**	**Total Current**		**47.3**

10= 5.8 V; 5.7 min.				**11= 9.6 V; 12.6 min.**				**12= 8 V; 9 min.**		
Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)
0	5.8	0.4		0	9.6	0.5		0	8	1.2
1	5.8	1.7		1	9.6	0.7		1	8	1.9
2	5.8	2.1		2	9.6	2.3		2	8	3.8
3	5.8	2.2		3	9.6	4.0		3	8	4.3
4	5.8	2.2		4	9.6	4.4		4	8	5.1
5	5.8	2.5		5	9.6	4.6		5	8	5.5
5.42	5.8	3.1		6	9.6	4.8		6	8	5.7
				7	9.6	5.0		7	8	6.3
				8	9.6	5.2		8	8	6.8
				9	9.6	5.3		9	8	7.1
				10	9.6	5.5				
				11	9.6	5.7				
				12	9.6	5.7				
				12.36	9.6	5.8				
Total Current		**14.2**		**Total Current**		**59.5**		**Total Current**		**47.7**

13= 8 V; 9 min.				**14= 8 V; 9 min.**				**15= 12 V; 9.6 min.**		
Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)
0	8	0.5		0	8	1.0		0	12	1.0
1	8	1.9		1	8	1.2		1	12	2.5
2	8	3.3		2	8	3.4		2	12	3.9
3	8	3.7		3	8	3.5		3	12	4.8
4	8	4.0		4	8	4.6		4	12	5.5
5	8	4.6		5	8	4.8		5	12	6.7
6	8	5.3		6	8	4.9		6	12	7.4
7	8	5.8		7	8	5.2		7	12	8.1
8	8	6.2		8	8	5.4		8	12	8.2
9	8	6.6		9	8	5.8		9	12	8.5
								9.36	12	8.8
Total Current		**41.9**		**Total Current**		**39.8**		**Total Current**		**65.4**

16= 7.6 V; 3 min.				**17= 4V; 8.4 min.**				**18= 4 V; 8.4 min.**		
Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)
0	7.6	1.1		0	4	1.7		0	4	1.6
0.5	7.6	2.3		1	4	2.6		1	4	2.9

1.0	7.6	2.4		2	4	3.4		2	4	4.4
1.5	7.6	3.5		3	4	4.6		3	4	4.4
2.0	7.6	3.9		4	4	4.8		4	4	5.1
2.5	7.6	4.6		5	4	5.2		5	4	5.6
3.0	7.6	4.7		6	4	5.4		6	4	5.6
				7	4	5.8		7	4	5.7
				8	4	5.9		8	4	5.9
				8.24	4	5.9		8.24	4	6.1
Total Current		**22.8**		**Total Current**		**44.7**		**Total Current**		**47.3**
19= 7.6 V; 3 min.										
Time (Min.)	Volt (V)	Current (A)								
0	7.6	1.2								
0.5	7.6	2.5								
1.0	7.6	2.9								
1.5	7.6	3.7								
2.0	7.6	4.4								
2.5	7.6	4.7								
3.0	7.6	5.1								
Total Current		**24.5**								

Table 4.41- Results of experimentation on sulphate rich wastewater with Al-Al electrodes

Electrodes	**Voltage (V)**	**Time (min)**	**Current density (A/m^2)**	**Color (Pt Co Units)**	**COD (mg/L)**	**Conductivity (mS/cm)**	**pH**	**Power consumption (kWh/m^3)**	**Sludge generation rate (g/L)**
Al-Al	12	15	653	227	549	51.5	11.1	51.9	14.4
Al-Al	4	15	492	364	575	50.5	11.2	13.0	13.3

Al-Al	12	15	785	184	484	50.8	11.4	62.4	13.6
Al-Al	4	15	429	870	609	51.8	10.6	11.3	12.9
Al-Al	4	3	144	1200	924	52.6	10.1	0.7	9.4
Al-Al	12	3	284	1120	851	50.8	10.3	4.5	10.4
Al-Al	12	3	301	720	786	50.7	10.4	4.8	10.4
Al-Al	10	6	188	930	931	50.7	10.2	4.9	7.9
Al-Al	6.6	12.9	344	880	857	51.9	10.1	12.9	7.6
Al-Al	5.8	5.7	207	970	948	50.6	10.6	3.0	7.5
Al-Al	9.6	12.6	433	550	783	51.6	10.2	23.1	8.5
Al-Al	8	9	486	566	743	50.2	10.3	15.4	8.3
Al-Al	8	9	427	730	873	51.9	10.2	13.5	9.4
Al-Al	8	9	406	750	865	51.8	10.1	12.9	9.7
Al-Al	12	9.6	606	640	750	51.6	10.2	30.8	10.6
Al-Al	7.6	3	332	970	989	51.2	10.6	3.3	7.6
Al-Al	4	8.4	456	760	923	50.5	10.0	6.7	7.4
Al-Al	4	8.4	482	880	956	51.5	10.3	7.1	6.0
Al-Al	7.6	3	357	740	914	50.2	9.7	3.5	7.9

With Al-Al electrodes the maximum removal efficiencies for COD and Color came out to be 61% and 81.6% respectively at 12V and 15 min. treatment time. The sludge generation rate of 13.6 g/L was obtained. The current density of 785.7 A/m^2 and power consumption of 62.4 kWh/m^3 was also observed. Above pH 10, soluble species $Al(OH)_4^-$, is the predominant hydrolysis product which tends to drop the COD removal efficiency and this is in accordance with the amphoteric character of aluminium hydroxide $Al(OH)_3$ that precipitates at pH 6-7. The initial pH of wastewater was a key parameter with Al-Al electrodes. The removal efficiency of COD was 61.1% at 785.7 A/m^2, 39.7 % at 606.6 A/m^2 and 31.5% at 284.2 A/m^2 after 12 V treatments with Al-Al electrodes. At high current density, the extent of anodic dissolution of aluminium increases resulting in greater amount of precipitate and COD removal (Un, *et al.* 2009).

4.4.2.2 Electroflocculation treatment of SRWW with Fe-Fe electrode

The results obtained from the laboratory experimentation with Fe-Fe electrodes in electroflocculation treatment of SRWW are presented in Table 4.42 and Table 4.43.

Table 4.42- Results of experimentation on sulphate rich wastewater with Fe-Fe electrodes at different voltages and treatment times

1= 12 V; 15 min.				**2= 4 V; 15 min.**				**3= 12 V; 15 min.**		
Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)
0	12	28.3		0	4	5.8		0	12	26.0
1	11.6	31.5		1	4	5.4		1	11.6	31.5
2	9.9	31.5		2	4	5.4		2	9.2	31.5
3	8.3	31.5		3	4	5.3		3	8.6	31.5
4	7.6	31.5		4	4	5.3		4	7.9	31.5
5	7.2	31.5		5	4	5.4		5	7.7	31.5
6	7.0	31.5		6	4	5.1		6	7.5	31.5
7	6.8	31.5		7	4	4.7		7	7.2	31.5
8	6.7	31.5		8	4	4.8		8	7.0	31.5
9	6.5	31.5		9	4	4.4		9	6.9	31.5
10	6.4	31.5		10	4	3.8		10	6.9	31.5
11	6.3	31.5		11	4	3.4		11	7.2	31.5
12	6.3	31.5		12	4	3.3		12	7.2	31.5
13	6.5	31.5		13	4	3.2		13	8.1	31.5
14	6.9	31.5		14	4	3.2		14	10.9	28.4
15	8.1	31.5		15	4	3.1		15	12	25.3
Total Current		**500.8**		**Total Current**		**71.6**		**Total Current**		**489.2**
4= 4 V; 15 min.				**5= 4 V; 3 min.**				**6= 12 V; 3 min.**		
Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)
0	4	3.3		0	4	3.2		0	12	26.4
1	4	4.8		0.5	4	3.2		0.5	12	27.4
2	4	5.4		1.0	4	5.0		1.0	12	30.0
3	4	6.1		1.5	4	5.1		1.5	11.6	31.5
4	4	6.4		2.0	4	5.5		2.0	10.6	31.5

5	4	6.5		2.5	4	5.6		2.5	9.7	31.5
6	4	6.5		3.0	4	5.6		3.0	9.0	31.5
7	4	6.0								
8	4	5.6								
9	4	5.4								
10	4	4.9								
11	4	4.4								
12	4	4.3								
13	4	4.3								
14	4	4.3								
15	4	4.2								
Total Current		**82.4**		**Total Current**		**33.2**		**Total Current**		**209.8**
7= 12 V; 3 min.				**8= 10 V; 6 min.**				**9= 6.6 V; 12.9 min.**		
Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)
0	12	24.3		0	10.0	19.8		0	6.6	9.9
0.5	11.4	31.5		1	10	22.3		1	6.6	11.5
1.0	11.2	31.5		2	10	25.1		2	6.6	13.2
1.5	10.2	31.5		3	10	27.4		3	6.6	13.0
2.0	9.8	31.5		4	9.4	31.5		4	6.6	13.0
2.5	8.9	31.5		5	8.5	31.5		5	6.6	11.5
3.0	8.3	31.5		6	8.0	31.5		6	6.6	11.1
								7	6.6	12.5
								8	6.6	12.9
								9	6.6	13.5
								10	6.6	14.8
								11	6.6	16.3
								12	6.6	17.6
								12.54	6.6	17.4
Total Current		**213.3**		**Total Current**		**189.1**		**Total Current**		**188.2**
10= 5.8 V; 5.7 min.				**11= 9.6 V; 12.6 min.**				**12= 8 V; 9 min.**		
Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)
0	5.8	9.0		0	9.6	19.9		0	8	15.0
1	5.8	9.2		1	9.6	24.1		1	8	17.0
2	5.8	10.6		2	9.6	24.5		2	8	19.4
3	5.8	11.6		3	9.6	26.1		3	8	14.9
4	5.8	10.8		4	9.4	31.5		4	8	16.0
5	5.8	9.9		5	8.5	31.5		5	8	18.6
5.42	5.8	9.9		6	8.1	31.5		6	8	24.1
				7	7.7	31.5		7	8	26.5
				8	7.5	31.5		8	8	29.2
				9	7.3	31.5		9	8	31.0
				10	7.2	31.5				

				11	7.3	31.5				
				12	7.4	31.5				
				12.36	7.5	31.5				
Total Current		**71.0**		**Total Current**		**409.6**		**Total Current**		**211.7**
13= 8 V; 9 min.				**14= 8 V; 9 min.**				**15= 12 V; 9.6 min.**		
Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)
0	8	12.9		0	8	13.5		0	12	27.9
1	8	14.2		1	8	15.6		1	11.0	31.5
2	8	16.1		2	8	17.2		2	10.1	31.5
3	8	16.0		3	8	14.4		3	8.8	31.5
4	8	13.4		4	8	16.2		4	8.3	31.5
5	8	14.9		5	8	20.9		5	7.9	31.5
6	8	18.7		6	8	23.5		6	7.6	31.5
7	8	22.7		7	8	25.5		7	7.5	31.5
8	8	25.6		8	8	27.2		8	7.5	31.5
9	8	27.3		9	8	28.8		9	7.8	31.5
								9.36	8.0	31.5
Total Current		**181.8**		**Total Current**		**202.8**		**Total Current**		**342.9**
16= 7.6 V; 3 min.				**17= 4V; 8.4 min.**				**18= 4 V; 8.4 min.**		
Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)
0	7.6	9.9		0	4	3.6		0	4	3.5
0.5	7.6	10.0		1	4	4.7		1	4	4.5
1.0	7.6	11.4		2	4	5.3		2	4	6.3
1.5	7.6	12.4		3	4	5.3		3	4	6.8
2.0	7.6	13.2		4	4	5.7		4	4	5.7
2.5	7.6	13.6		5	4	5.1		5	4	4.5
3.0	7.6	13.1		6	4	4.6		6	4	3.9
				7	4	4.1		7	4	3.5
				8	4	3.8		8	4	3.0
				8.24	4	3.7		8.24	4	2.9

Total Current		**83.6**		**Total Current**		**45.9**		**Total Current**		**44.6**
19= 7.6 V; 3 min.										
Time (Min.)	Volt (V)	Current (A)								
0	7.6	11.9								
0.5	7.6	12.3								
1.0	7.6	12.9								
1.5	7.6	14.6								
2.0	7.6	15.6								
2.5	7.6	16.2								
3.0	7.6	16.7								
Total Current		**100.2**								

Table 4.43- Results of experimentation on sulphate rich wastewater with Fe-Fe electrodes

Electrodes	**Voltage (V)**	**Time (min)**	**Current density (A/m^2)**	**Color (Pt Co Units)**	**COD (mg/L)**	**Conductivity (mS/cm)**	**pH**	**Power consumption (kWh/m^3)**	**Sludge generation rate (g/L)**
Fe-Fe	12	15	3193	43	324	54.7	10.9	240.7	24.6
Fe-Fe	4	15	456	23	562	53.2	11.9	11.4	8.2
Fe-Fe	12	15	3119	50	335	54.9	10.5	235.1	28.2
Fe-Fe	4	15	525	27	554	51.9	10.0	13.2	8.1
Fe-Fe	4	3	483	497	752	51.8	9.2	2.4	3.7
Fe-Fe	12	3	3058	90	407	51.8	9.2	46.1	11.2
Fe-Fe	12	3	3109	80	403	50.8	10.7	46.8	10.5
Fe-Fe	10	6	2756	23	353	52.0	10.8	69.2	12.7

Fe-Fe	6.6	12.9	1371	25	404	52.6	11.2	48.9	11.7
Fe-Fe	5.8	5.7	1034	43	746	51.9	11.4	14.3	6.5
Fe-Fe	9.6	12.6	2985	23	506	52.7	11.8	151.2	20.8
Fe-Fe	8	9	1833	36	590	51.7	11.7	55.2	15.0
Fe-Fe	8	9	1578	25	618	51.7	11.3	47.6	14.6
Fe-Fe	8	9	772	43	612	51.7	11.2	53.4	15.1
Fe-Fe	12	9.6	3180	23	561	52.2	11.5	153.4	24.0
Fe-Fe	7.6	3	1218	149	652	50.9	11.8	11.6	8.1
Fe-Fe	4	8.4	383	66	659	52.2	11.3	5.3	8.9
Fe-Fe	4	8.4	373	100	713	52.3	11.7	5.2	9.0
Fe-Fe	7.6	3	1460	146	576	50.7	11.6	13.9	8.0

The maximum removal efficiencies of 73.9% and 95.7% for COD and Color respectively were observed when treated with Fe-Fe electrodes at 12V for 15 min. treatment time. 24.6 g/L of sludge was generated at current density of 3193.8 A/m^2 and power consumption of 240.7 kWh/m^3. An increase in current density also increases the amount of sludge and also increases power consumption. Sludge generation with Fe-Fe electrodes is more than Al-Al electrodes as Fe is heavier than Al and it induces formation of higher floc sizes (Kara, *et al.* 2013). The COD and Color removal efficiency is higher with Fe-Fe electrode than Al-Al electrodes. This agrees with literature on Orange II, mono-azo acid dye performed by chafi, *et al.* 2011.

4.4.2.3 Electroflocculation treatment of SRWW with Fe-Al electrode

The results obtained from the laboratory experimentation with Fe-Al electrodes in electroflocculation treatment of SRWW are presented in Table 4.44 and Table 4.45.

Table 4.44- Results of experimentation on sulphate rich wastewater with Fe-Al electrodes at different voltages and treatment times

1= 12 V; 15 min.				**2= 4 V; 15 min.**				**3= 12 V; 15 min.**		
Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)
0	12	20.2		0	4	1.4		0	12	23.9
1	12	26.9		1	4	4.4		1	12	30.9
2	12	27.9		2	4	4.4		2	11.3	31.6
3	11.4	31.6		3	4	4.0		3	10	31.6
4	11.2	31.6		4	4	3.9		4	9.6	31.6
5	11.3	31.6		5	4	3.6		5	9.7	31.6
6	12	28.8		6	4	3.5		6	10.5	31.6
7	12	18.6		7	4	3.4		7	12	26.6
8	12	15.7		8	4	3.2		8	12	18.0
9	12	14.4		9	4	3.1		9	12	18.8
10	12	15.1		10	4	3.0		10	12	15.6
11	12	17.2		11	4	2.8		11	12	15.2
12	12	12.9		12	4	2.7		12	12	18.6
13	12	15.7		13	4	2.6		13	12	14.8
14	12	14.5		14	4	2.6		14	12	14.7
15	12	14.7		15	4	2.6		15	12	14.7
Total Current		**337.4**		**Total Current**		**51.2**		**Total Current**		**369.8**
4= 4 V; 15 min.				**5= 4 V; 3 min.**				**6= 12 V; 3 min.**		
Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)
0	4	1.4		0	4	0.2		0	12	16.8
1	4	2.7		0.5	4	0.2		0.5	12	19.7
2	4	2.7		1.0	4	0.5		1.0	12	23.4
3	4	2.6		1.5	4	0.6		1.5	12	25.2
4	4	2.6		2.0	4	0.8		2.0	12	25.8
5	4	3.7		2.5	4	0.6		2.5	12	28.4
6	4	3.7		3.0	4	0.6		3.0	12	30.8
7	4	3.8								
8	4	3.9								
9	4	3.8								
10	4	3.0								
11	4	2.0								
12	4	2.2								
13	4	2.2								
14	4	2.2								
15	4	2.2								
Total Current		**44.7**		**Total Current**		**3.5**		**Total Current**		**170.1**
7= 12 V; 3 min.				**8= 10 V; 6 min.**				**9= 6.6 V; 12.9 min.**		

Time (Min.)	Volt (V)	Current (A)
0	12	22.1
0.5	12	26.0
1.0	12	28.6
1.5	12	30.5
2.0	12	31.1
2.5	10.9	31.6
3.0	10.5	31.6
Total Current		**201.5**

Time (Min.)	Volt (V)	Current (A)
0	10	14.0
1	10	19.1
2	10	22.2
3	10	25.0
4	10	26.5
5	10	27.8
6	10	28.8
Total Current		**163.4**

Time (Min.)	Volt (V)	Current (A)
0	6.6	4.7
1	6.6	8.6
2	6.6	9.2
3	6.6	10.0
4	6.6	9.9
5	6.6	9.7
6	6.6	10.7
7	6.6	10.7
8	6.6	11.2
9	6.6	11.4
10	6.6	11.9
11	6.6	12.3
12	6.6	12.6
12.54	6.6	12.9
Total Current		**145.8**

10= 5.8 V; 5.7 min.

Time (Min.)	Volt (V)	Current (A)
0	5.8	2.9
1	5.8	3.2
2	5.8	3.3
3	5.8	3.5
4	5.8	3.8
5	5.8	4.0
5.42	5.8	4.2
Total Current		**24.9**

11= 9.6 V; 12.6 min.

Time (Min.)	Volt (V)	Current (A)
0	9.6	10.8
1	9.6	14.1
2	9.6	15.0
3	9.6	14.6
4	9.6	14.3
5	9.6	15.6
6	9.6	19.4
7	9.6	20.6
8	9.6	21.4
9	9.6	21.7
10	9.6	21.6
11	9.6	21.8
12	9.6	19.6
12.36	9.6	17.7
Total Current		**248.2**

12= 8 V; 9 min.

Time (Min.)	Volt (V)	Current (A)
0	8	8.0
1	8	9.9
2	8	12.1
3	8	13.1
4	8	12.0
5	8	14.1
6	8	14.0
7	8	15.4
8	8	15.9
9	8	16.4
Total Current		**130.9**

13= 8 V; 9 min.

Time (Min.)	Volt (V)	Current (A)
0	8	8.7
1	8	10.8
2	8	11.5
3	8	11.1

14= 8 V; 9 min.

Time (Min.)	Volt (V)	Current (A)
0	8	9.8
1	8	11.5
2	8	12.4
3	8	13.2

15= 12 V; 9.6 min.

Time (Min.)	Volt (V)	Current (A)
0	12	17.8
1	12	24.3
2	12	26.5
3	12	30.0

4	8	12.4		4	8	14.3		4	12	31.2
5	8	14.3		5	8	14.4		5	11.7	31.6
6	8	15.2		6	8	15.5		6	12	29.6
7	8	16.5		7	8	16.3		7	12	23.2
8	8	17.5		8	8	17.0		8	12	17.0
9	8	18.2		9	8	17.7		9	12	14.0
								9.36	12	13.0
Total Current		**136.2**		**Total Current**		**142.1**		**Total Current**		**240.4**
16= 7.6 V; 3 min.				**17= 4V; 8.4 min.**				**18= 4 V; 8.4 min.**		
Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)
0	7.6	6.0		0	4	1.9		0	4	2.8
0.5	7.6	6.5		1	4	1.96		1	4	2.7
1.0	7.6	7.0		2	4	1.7		2	4	2.2
1.5	7.6	7.3		3	4	1.5		3	4	2.2
2.0	7.6	7.6		4	4	1.4		4	4	2.23
2.5	7.6	7.8		5	4	1.4		5	4	2.2
3.0	7.6	8.1		6	4	1.5		6	4	2.3
				7	4	1.5		7	4	2.3
				8	4	1.5		8	4	2.3
				8.24	4	1.5		8.24	4	2.4
Total Current		**50.3**		**Total Current**		**15.86**		**Total Current**		**23.63**
19= 7.6 V; 3 min.										
Time (Min.)	Volt (V)	Current (A)								
0	7.6	5.0								
0.5	7.6	5.2								
1.0	7.6	5.7								
1.5	7.6	6.0								
2.0	7.6	6.6								
2.5	7.6	6.9								
3.0	7.6	7.6								

Total Current		**43.0**								

Table 4.45- Results of experimentation on sulphate rich wastewater with Fe-Al electrodes

Electrodes	Voltage (V)	Time (min)	Current density (A/m^2)	Color (Pt Co Units)	COD (mg/L)	Conductivity (mS/cm)	pH	Power consumption (kWh/m^3)	Sludge generation rate (g/L)
Fe-Al	12	15	2152	90	449	54.6	11.6	166.4	50.5
Fe-Al	4	15	326	507	606	52.4	10.8	8.4	10.3
Fe-Al	12	15	2358	100	412	54.3	11.2	182.4	50.0
Fe-Al	4	15	285	680	864	53.3	11.0	7.3	9.8
Fe-Al	4	3	51	970	1220	53.4	10.7	0.3	3.2
Fe-Al	12	3	2479	73	379	51.2	10.9	38.4	17.4
Fe-Al	12	3	2937	65	362	51.8	11.1	45.4	18.1
Fe-Al	10	6	2381	50	326	53.2	11.8	61.4	25.8
Fe-Al	6.6	12.9	1062	33	339	52.9	11.8	38.9	22.1
Fe-Al	5.8	5.7	363	500	714	52.5	10.2	5.15	8.9
Fe-Al	9.6	12.6	1809	60	367	54.8	10.9	94.0	32.9
Fe-Al	8	9	1336	36	343	53.7	10.9	41.3	23.6
Fe-Al	8	9	1390	33	360	53.4	10.8	43.0	21.7
Fe-Al	8	9	1450	30	387	53.9	11.4	44.9	21.1
Fe-Al	12	9.6	2395	104	444	52.3	10.8	118.6	42.0
Fe-Al	7.6	3	733	522	680	53.2	10.3	7.1	7.1

Fe-Al	4	8.4	162	900	1200	53.4	10.9	2.3	9.1
Fe-Al	4	8.4	241	553	920	52.7	10.6	3.4	8.4
Fe-Al	7.6	3	627	465	680	53.7	10.7	6.1	6.3

In Fe-Al electrode treatment, for the increase in current density from 51 A/m^2 to 2937 A/m^2, the decolorization rate increases from 3% to 93.5%. Applying current density of 2381 A/m^2 leads to decolorization rate of 95%. This agrees with the literature in which by doubling the current density from 5.46 A/m^2 to 10.91 A/m^2, the decolorization rate increases from 49.2% to 98.9% for removal of indigo carmine dye (Secula, *et al.* 2011). In present study, no significant changes observed with respect to pH and conductivity (σ) after treatment with all four electrode combinations with respect to original σ of 51.2 and pH of 10.8 units.

4.4.2.4 Electroflocculation treatment of SRWW with SS-SS electrode

The results obtained from the laboratory experimentation with SS-SS electrodes in electroflocculation treatment of SRWW are presented in Table 4.46 and Table 4.47.

Table 4.46- Results of experimentation on sulphate rich wastewater with SS-SS electrodes at different voltages and treatment times

1= 12 V; 15 min.				**2= 4 V; 15 min.**				**3= 12 V; 15 min.**		
Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)
0	12	25.9		0	4	4.2		0	12	27.3
1	12	27.5		1	4	3.7		1	12	27.5
2	12	29.1		2	4	3.5		2	12	29.2
3	11.4	31.6		3	4	3.5		3	11.2	31.7
4	10.6	31.6		4	4	3.5		4	10.4	31.7
5	10.1	31.6		5	4	3.5		5	9.9	31.7
6	9.6	31.6		6	4	3.5		6	9.6	31.7
7	9.4	31.6		7	4	3.5		7	9.4	31.7
8	9.8	31.6		8	4	3.5		8	10	31.7
9	10.7	31.6		9	4	3.6		9	12	31.6
10	12	27.6		10	4	3.6		10	12	28.2
11	12	25.7		11	4	3.6		11	12	26.9

12	12	23.8
13	12	22.2
14	12	21.1
15	12	20.4
Total Current		**444.5**

12	4	3.7
13	4	3.7
14	4	3.7
15	4	3.7
Total Current		**58**

12	12	25.4
13	12	24.2
14	12	23.2
15	12	23.2
Total Current		**456.9**

4= 4 V; 15 min.

Time (Min.)	Volt (V)	Current (A)
0	4	3.9
1	4	3.8
2	4	3.8
3	4	3.8
4	4	3.8
5	4	3.8
6	4	3.8
7	4	3.9
8	4	3.9
9	4	3.9
10	4	4.0
11	4	4.0
12	4	4.0
13	4	4.0
14	4	4.0
15	4	4.0
Total Current		**62.4**

5= 4 V; 3 min.

Time (Min.)	Volt (V)	Current (A)
0	4	2.7
0.5	4	2.8
1.0	4	2.8
1.5	4	2.7
2.0	4	2.7
2.5	4	2.7
3.0	4	2.7
Total Current		**19.1**

6= 12 V; 3 min.

Time (Min.)	Volt (V)	Current (A)
0	12	27.5
0.5	12	28.3
1.0	12	27.4
1.5	12	27.3
2.0	12	28.6
2.5	12	30.4
3.0	11.8	31.6
Total Current		**201.1**

7= 12 V; 3 min.

Time (Min.)	Volt (V)	Current (A)
0	12	30.3
0.5	12	31.3
1.0	12	30.0
1.5	12	31.3
2.0	11.6	31.6
2.5	11.8	31.6
3.0	10.4	31.6
Total Current		**217.7**

8= 10 V; 6 min.

Time (Min.)	Volt (V)	Current (A)
0	10	22.5
1	10	22.8
2	10	22.2
3	10	24.2
4	10	26.6
5	10	28.9
6	10	30.9
Total Current		**178.1**

9= 6.6 V; 12.9 min.

Time (Min.)	Volt (V)	Current (A)
0	6.6	10.3
1	6.6	10.4
2	6.6	11.3
3	6.6	11.2
4	6.6	11.7
5	6.6	11.9
6	6.6	12.1
7	6.6	12.4
8	6.6	12.8
9	6.6	12.9
10	6.6	13.2
11	6.6	13.5
12	6.6	13.6
12.54	6.6	13.6
Total Current		**170.9**

10= 5.8 V; 5.7 min.				**11= 9.6 V; 12.6 min.**				**12= 8 V; 9 min.**		
Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)
0	5.8	8.6		0	9.6	19.7		0	8	13.3
1	5.8	8.8		1	9.6	20.9		1	8	14.0
2	5.8	9.1		2	9.6	20.4		2	8	14.0
3	5.8	9.0		3	9.6	22.0		3	8	13.8
4	5.8	9.0		4	9.6	24.0		4	8	14.3
5	5.8	9.2		5	9.6	27.0		5	8	15.5
5.42	5.8	9.4		6	9.6	28.2		6	8	16.0
				7	9.6	29.6		7	8	15.9
				8	9.6	31.0		8	8	16.3
				9	9.6	31.7		9	8	16.7
				10	9.6	31.7				
				11	9.6	30.0				
				12	9.6	27.2				
				12.36	9.6	26.6				
Total Current		**63.1**		**Total Current**		**370**		**Total Current**		**149.8**
13= 8 V; 9 min.				**14= 8 V; 9 min.**				**15= 12 V; 9.6 min.**		
Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)
0	8	13.9		0	8	13.0		0	12	29.0
1	8	14.4		1	8	13.8		1	12	29.0
2	8	14.3		2	8	14.2		2	11.6	31.5
3	8	14.7		3	8	14.1		3	11.4	31.7
4	8	15.1		4	8	14.4		4	10.9	31.7
5	8	15.7		5	8	14.8		5	10.8	31.7
6	8	16.2		6	8	15.1		6	10.7	31.7
7	8	16.6		7	8	15.7		7	10.4	31.7
8	8	17.1		8	8	16.2		8	12	28.3
9	8	17.5		9	8	16.7		9	12	26.3
								9.36	12	25.5
Total Current		**155.5**		**Total Current**		**148.0**		**Total Current**		**328.1**
16= 7.6 V; 3 min.				**17= 4V; 8.4 min.**				**18= 4 V; 8.4 min.**		
Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)
0	7.6	9.0		0	4	2.2		0	4	1.9
0.5	7.6	9.4		1	4	2.2		1	4	1.9

1.0	7.6	9.5		2	4	2.2		2	4	1.9
1.5	7.6	10.3		3	4	2.3		3	4	1.9
2.0	7.6	10.3		4	4	1.8		4	4	1.7
2.5	7.6	10.4		5	4	2.1		5	4	1.8
3.0	7.6	10.4		6	4	2.1		6	4	1.9
				7	4	2.1		7	4	2.0
				8	4	2.1		8	4	2.0
				8.24	4	2.1		8.24	4	2.0
Total Current		**69.3**		**Total Current**		**21.2**		**Total Current**		**19**
19= 7.6 V; 3 min.										
Time (Min.)	Volt (V)	Current (A)								
0	7.6	11.6								
0.5	7.6	11.8								
1.0	7.6	12.1								
1.5	7.6	12.5								
2.0	7.6	12.6								
2.5	7.6	12.5								
3.0	7.6	12.5								
Total Current		**85.6**								

Table 4.47- Results of experimentation on sulphate rich wastewater with SS-SS electrodes

Electrodes	**Voltage (V)**	**Time (min)**	**Current density (A/m^2)**	**Color (Pt Co Units)**	**COD (mg/L)**	**Conductivity (mS/cm)**	**pH**	**Power consumption (kWh/m^3)**	**Sludge generation rate (g/L)**
SS-SS	12	15	2834	2120	796	53.8	10.5	231.5	6.2

SS-SS	4	15	369	1170	894	50.7	10.6	10.0	3.6
SS-SS	12	15	2914	2210	718	54.5	10.5	238.0	6.0
SS-SS	4	15	397	1030	906	51.0	10.7	10.8	3.1
SS-SS	4	3	278	1070	918	51.5	10.6	1.5	3.1
SS-SS	12	3	2931	1560	808	52.7	10.6	47.8	5.0
SS-SS	12	3	3173	1560	828	51.8	10.6	51.8	5.4
SS-SS	10	6	2595	1600	800	52.1	10.6	70.6	4.6
SS-SS	6.6	12.9	1245	1410	783	51.5	10.6	48.1	4.4
SS-SS	5.8	5.7	919	1300	972	51.1	10.6	13.7	4.4
SS-SS	9.6	12.6	2696	1580	799	51.8	10.1	148.0	7.1
SS-SS	8	9	1528	1400	873	51.0	10.7	49.9	7.0
SS-SS	8	9	1586	1390	849	52.3	10.6	51.8	6.3
SS-SS	8	9	1510	1500	865	51.5	10.5	49.3	8.0
SS-SS	12	9.6	3043	1560	824	50.6	10.4	159.0	6.9
SS-SS	7.6	3	1010	1050	1030	50.1	10.5	10.4	6.0
SS-SS	4	8.4	216	990	1071	50.6	10.7	3.3	3.3
SS-SS	4	8.4	193	910	939	50.2	10.6	2.9	3.8
SS-SS	7.6	3	1247	1210	1013.5	51.0	10.4	12.9	7.2

The SS-SS electrodes were not efficient as it gives only 42% and 9% maximum removal efficiency for COD and Color at 12V 15 min. and 4V 8.4 min. respectively. Sludge generation rate is observed least for SS electrodes irrespective of the higher current density. Electrolytic process using SS electrodes appeared to be less efficient than other electrode combinations in present study. Therefore, it is observed that COD and Color removal efficiency with SS were much lower than those obtained from experiments with other electrode combinations. The Fe-Al electrodes gave 73.8% and 95% maximum removal efficiency for COD and Color respectively at 10V and 6 min. treatment time. The sludge generation rate of 25.8 g/L was observed for this experimental run at current density of 2381 A/m^2 and power consumption of 61.4 kWh/m^3.

From the obtained results, only Fe-Al electrodes showed promising results, thus it is used for statistical modeling for given textile sulphate rich wastewater. Response surface methodology was used for the process optimization. While treating with SS-SS electrode, the maximum removal efficiency for COD is 42% only and 17 out of 19 values came out to be negative for color removal, thus it was impossible to fit the model. The model with Al-Al electrode had low prediction capability. The model with Fe-Fe treatment had serious problem with *Lack of fit*, which indicate model signal is low as compared to noise. The maximum removal efficiency for responses was achieved with Fe-Al electrodes and here also the model navigates in design space. With the help of Design Expert Software (trial version 8.0) ANOVA model was constructed which best fits the response data. For checking experimental reproducibility which is the major issue in RSM the sequential experimental designs were performed, whose values were obtained from the best solutions from the Design expert software. The experimental design as per IV-optimal criteria with actual and predicted removal efficiencies for Fe-Al electrode combinations are presented in Table 4.48 and the ranges of different responses for different combination of electrodes are presented in Table 4.49.

Table 4.48- Experimental design as per IV-optimal criteria with actual and predicted removal efficiencies for Fe-Al electrode combinations

S. No.	Factor 1	Factor 2	Response 1		Response 2	
	A:Voltage (V)	B:Treatment time (min)	COD removal eff. (%)		Color removal eff. (%)	
			Actual	Predicted	Actual	Predicted

1	5.84	5.75	42.56	38.27	50.00	51.27
2	12.00	9.60	64.28	66.70	89.60	101.49
3	10.00	6.00	73.77	70.98	95.00	96.05
4	7.61	3.00	45.29	53.07	47.80	60.43
5	8.00	9.00	72.41	67.61	96.40	91.80
6	8.00	9.00	68.87	67.61	97.00	91.80
7	4.00	8.40	25.99	17.21	44.70	29.82
8	9.60	12.60	70.47	76.72	94.00	101.65
9	8.00	9.00	71.12	67.61	96.70	91.80
10	4.00	8.40	3.46	17.21	10.00	29.82
11	12.00	15.00	66.85	65.43	90.00	88.73
12	4.00	15.00	51.25	42.56	49.30	44.38
13	12.00	15.00	63.88	65.43	91.00	88.73
14	7.61	3.00	45.29	53.07	53.50	60.43
15	12.00	3.00	69.51	68.26	92.70	87.33
16	4.00	3.00	1.85	-3.52	3.00	-6.42
17	6.58	12.87	72.73	65.91	96.70	82.07
18	12.00	3.00	70.88	68.26	93.50	87.33
19	4.00	15.00	30.49	42.56	32.00	44.38

Table 4.49- Ranges of different responses for different electrode combinations

Electrode combinations	Fe-Fe	Fe-Al (optimum)	Al-Al	SS-SS
COD removal (%)	39.5 – 73.9	1.8 – 73.8 (75.5)	20.4 – 61.1	13.8 – 42.2
Color removal (%)	50.3 – 97.7	3.0 – 97.0 (91.5)	Maximum 81.6	Maximum 9.0

Current density (A/m^2)	373.5 – 3193.9	51.0 – 2937.0 (1242)	144.3 – 785.7	193.9 – 3043.9
Power consumption (kWh/m^3)	2.4 – 240.8	0.3 – 182.4 (55.3)	0.8 – 62.4	1.5 – 238.0
Sludge generation rate (g/L)	3.7 – 28.2	3.2 – 50.5 (24.1)	6.0 – 14.4	3.1 – 8.0

Values given in parenthesis is at optimized conditions

4.4.2.5 Statistical modeling for COD removal efficiency with Fe-Al electrodes

The ANOVA sequential model sum of squares proposed quadratic model as best fit models. Backward elimination method was applied to remove any non significant model terms. This eliminates the square term for treatment time. Reduced ANOVA model was again generated and the fitted quadratic model has 99.99% significance level (F=38.5, degree of freedom=4) with *Lack of fit* not significant (p-value=0.693). The results of ANOVA statistics for COD removal are given in Table 4.50.

Table 4.50- Results of ANOVA statistics for COD removal for Fe-Al electrode combinations

Source	**Sum of Squares**	**df**	**Mean Squares**	**F-Value**	**p-value Prob >F**
Model	8845	4	2211	38.5	< 0.0001*
A-Voltage (V)	6004	1	6004	105	< 0.0001*
B-Treatment time (min)	1140	1	1140	20	0.0005*
AxB	1064	1	1064	19	0.0007*
A^2	2267	1	2267	39	< 0.000*
Lack of fit	323	7	46	1	0.6934$^{\#}$

* significant at $p<0.05$

# not significant at $p<0.05$					
Std. Dev.	7.579		R^2	0.917	
Mean	53.207		Adjusted R^2	0.893	
C.V. %	14.244		Predicted R^2	0.834	

The CV of 14.24% and predicted $R^2=0.834$ was close to adjusted R^2 of 0.893. Also, S/N ratio of 20.6 indicated that model noise is not significant as compared to signal. Thus, model could be navigated in the design space. The unit-less regression equation in terms of coded factors is given in Eq. (6) and in terms of actual factors in Eq. (7).

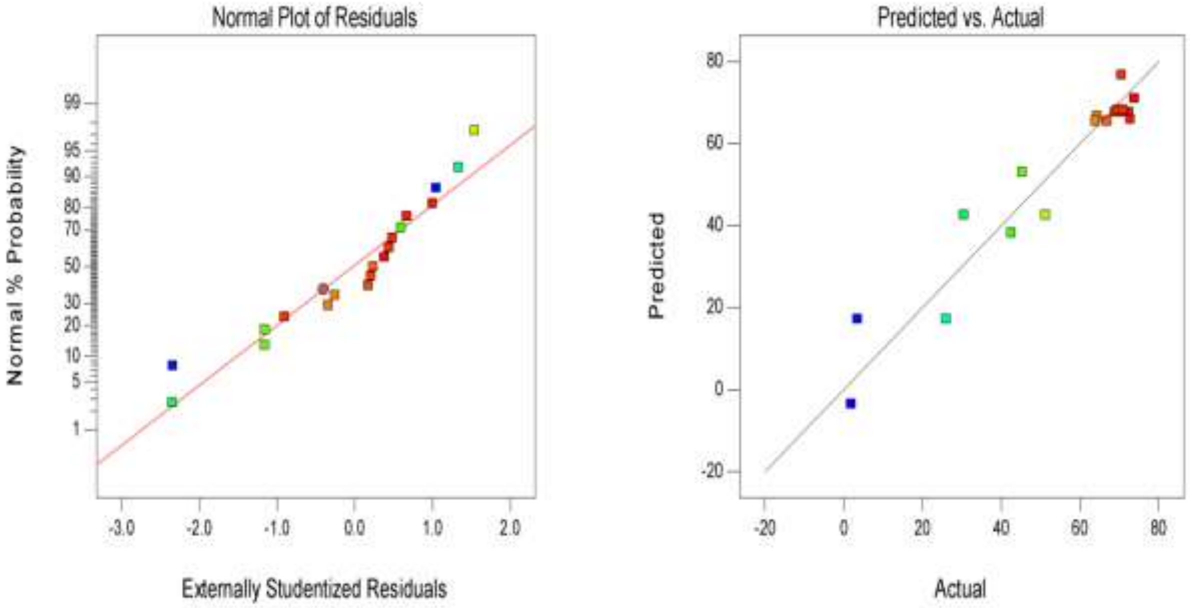
COD removal eff. (%) = $+ 67.61 + 23.66 \times A + 10.81 \times B - 12.23 A \times B - 24.43 \times A^2$ (Eq. 6)

where, A: Voltage and B: Treatment time is in coded units.

COD removal eff. (%) = $- 130.328 + 34.930 V + 5.877 \times min - 0.50943 V \times min - 1.52686 V^2$ (Eq. 7)

where, A: Voltage (V) and B: Treatment time (min) are in actual units.

Before moving to the response surface plots, diagnostic statistics were studied using normal plot of residuals to satisfy the normal distribution of error as given in Fig. 4.16 a. The actual *vs.* predicted response plot for percentage swelling is given in Fig. 4.16 b. The response plots were generated using regression equations.



a

b

Fig. 4.16 (a) Normal probability plot and **(b)** Actual *vs.* Predicted plot for COD removal efficiency for Fe-Al electrode combinations

COD removal efficiency was taken as response and voltage and treatment time varied in the designed space. The maximum COD removal efficiency of 75% was obtained at 7.6 V and 14 min treatment time. Whereas, just 2% COD removal efficiency was obtained at 4 V and 3 min. The 3D contour plot between COD removal efficiency *vs.* voltage and treatment time is given in Fig. 4.17. There is antagonistic interaction between voltage and treatment time and this indirectly indicated that one of them should be minimized and another should be maximized. Looking at unitless regression coefficients in Eq. (6), it is advisable to maximize treatment time and minimize the voltage to get best results.

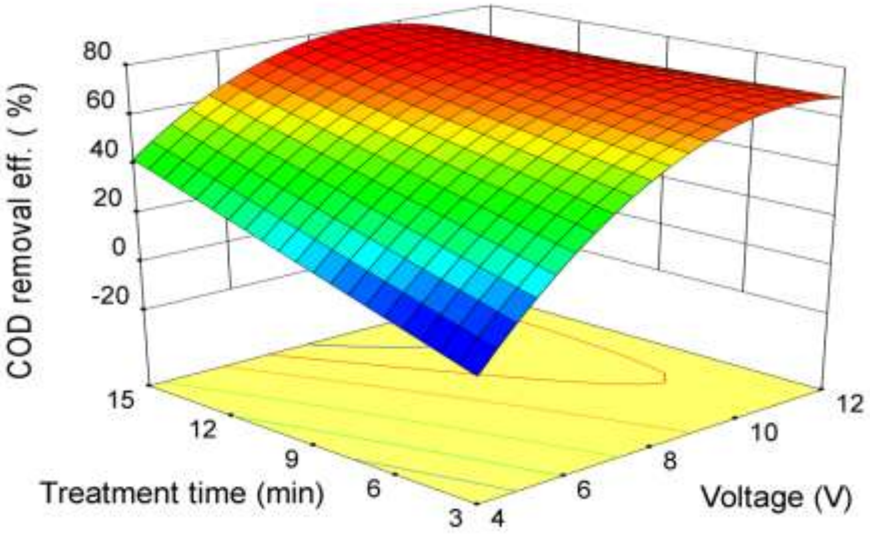


Fig. 4.17- Three dimensional contour plot showing COD removal efficiency *vs.* Voltage and treatment time for Fe-Al electrode combinations

4.4.2.6 Statistical modeling for Color removal efficiency with Fe-Al electrodes

The Color removal efficiency was also modelled and best fitted equations for unit less and actual are given in Eq. (8) and Eq. (9) respectively.

Color rem. eff. (%) = + 91.80 + 34.53 A + 13.05 B - 12.35 A x B - 24.78 A^2 - 13.52 B^2 (Eq. 8)

where, A: Voltage and B: Treatment time is in coded units.

Color rem. eff. (%) = -163.412 + 38.041 V + 13.052 min - 0.514 V x min - 1.548 V^2 - 0.375 min^2 (Eq. 9)

where, A: Voltage (V) and B: Treatment time (min) are in actual units.

The results of ANOVA statistics for color removal are presented in Table 4.51.

Table 4.51- Results of ANOVA statistics for Color removal for Fe-Al electrode combinations

Source	**Sum of Squares**	**df**	**Mean Squares**	**F-value**	**p-value Prob > F**
Model	16459	5	3292	26	< 0.0001*
A-Voltage (V)	12531	1	12531	99	< 0.0001*
B-Treatment time (min)	1639	1	1639	13	0.0033*
AxB	1078	1	1078	8	0.0121*
A^2	2013	1	2013	16	0.0016*
B^2	582	1	582	5	0.0517*
Lack of fit	881	6	147	1	0.3532#
*significant at p<0.05					
#not significant at p<0.05					
Std. Dev.	11.267		R^2	0.909	
Mean	69.626		Adjusted R^2	0.874	
C.V. %	16.182		Predicted R^2	0.782	

Numerical optimization was achieved through desirability plot by simultaneously solving fitted models. The 3D contour plot between color removal efficiency *vs.* voltage and treatment time is given in Fig. 4.18.

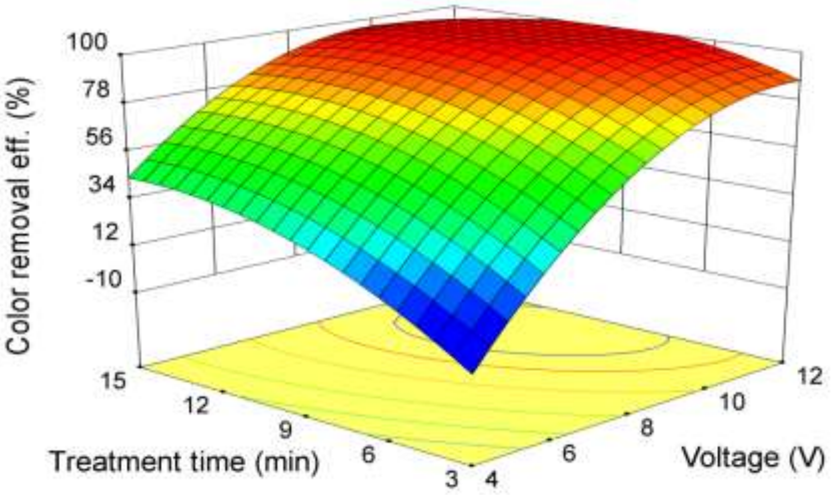


Fig. 4.18 Three dimensional contour plot showing Color removal efficiency vs. Voltage and treatment time for Fe-Al electrode combinations

The independent variables were set within the range and COD removal efficiency was set as maximize and color removal efficiency was set as within the range. Through random sampling point, best process conditions were achieved at 7.6 V and 14 min to achieve 75% COD removal efficiency and 91% color removal efficiency. The results were verified by validation testing at new proposed conditions. The COD and color comes out to be 304.5 mg/L and 85 Pt. Co. unit respectively which ensures the reliability of response functions predictions as presented as values at optimum conditions in Table 4.49. The current density and power consumption are 1242 A/m^2 and 55.3 kWh/m^3 respectively with sludge generation rate of 24.15 g/L. The 2.54 mg/L calcium is detected i.e. 94% is removed, whereas there is no variations obtained for total dissolved solids, sulphate, chloride, Na and Mg in treated wastewater at optimum conditions. The wastewater after treatment can be concentrated for salt recovery.

The cotton textile dyeing process which includes use of common salt (NaCl) as wetting agent to facilitate dyeing action which also leads to maximum exhaustion of the dyes was rich in chloride. The initial characteristics of this CRWW wastewater are presented in Table 4.52.

Table 4.52- Characterization of the chloride rich cotton textile dyebath dump wastewater

S.No.	Parameter with units	Value
1	Color (Pt Co units)	2135
2	COD (mg/L)	756
3	TOC (mg/L)	45.72
4	Turbidity (NTU)	385
5	Conductivity (mS/cm)	32
6	pH	9.53
7	TDS (mg/L)	12820
8	TSS (mg/L)	138
9	Sulphate (mg/L)	255.13
10	Total Alkalinity (mg/L)	130.06
11	Sodium (mg/L)	4360
12	Chloride (mg/L)	8249.86
13	Surfactants (ppm)	Nil
14	Phenols (ppm)	<0.1
15	Sulfide (mg/L)	<1
16	Sulfite (mg/L)	<2
17	Calcium (mg/L)	79.5
18	Magnesium (mg/L)	23.3

4.4.2.7 Electroflocculation treatment of CRWW with Al-Al electrode

The results obtained from the laboratory experimentation with Al-Al electrodes in electroflocculation treatment of CRWW are presented in Table 4.53 and Table 4.54.

Table 4.53- Results of experimentation on chloride rich wastewater with Al-Al electrodes at different voltages and treatment times

1= 12 V; 15 min.				**2= 4 V; 15 min.**				**3= 12 V; 15 min.**		
Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)
0	12	17.6		0	4	1.4		0	12	19.5
1	12	21.1		1	4	2.2		1	12	23.7
2	12	24.4		2	4	2.8		2	12	26.0
3	12	28.0		3	4	3.2		3	12	28.2
4	12	30.4		4	4	3.8		4	12	29.4
5	11.9	31.6		5	4	4.1		5	11.4	29.7
6	12	27.6		6	4	4.2		6	11.2	26.4
7	12	18.3		7	4	4.1		7	11	21.9
8	12	17.0		8	4	4.2		8	10.4	19.2
9	12	16.0		9	4	4.2		9	11.1	19.0
10	12	15.8		10	4	4.3		10	12	18.1
11	12	15.0		11	4	4.4		11	12	18.7
12	12	14.9		12	4	4.4		12	12	18.5
13	12	14.4		13	4	4.4		13	12	18.5
14	12	14.3		14	4	4.4		14	12	18.1
15	12	13.8		15	4	4.5		15	12	17.8
Total Current		**320.2**		**Total Current**		**60.6**		**Total Current**		**352.7**
4= 4 V; 15 min.				**5= 4 V; 3 min.**				**6= 12 V; 3 min.**		
Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)
0	4	1.5		0	4	4.3		0	12	19.3
1	4	4.0		0.5	4	4.8		0.5	12	21.4
2	4	4.1		1.0	4	4.8		1.0	12	22.5
3	4	4.1		1.5	4	4.9		1.5	12	23.4
4	4	4.3		2.0	4	5.0		2.0	12	26.6
5	4	4.4		2.5	4	5.0		2.5	12	27.3
6	4	4.4		3.0	4	5.1		3.0	12	28.9
7	4	4.4								
8	4	4.5								
9	4	4.6								
10	4	4.7								
11	4	4.8								

12	4	4.9								
13	4	5.0								
14	4	5.1								
15	4	5.2								
Total Current		**70.0**		**Total Current**		**33.9**		**Total Current**		**169.4**
7= 12 V; 3 min.				**8= 10 V; 6 min.**				**9= 6.6 V; 12.9 min.**		
Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)
0	12	20.9		0	10	16.4		0	6.6	8.2
0.5	12	22.6		1	10	19.3		1	6.6	9.2
1.0	12	24.4		2	10	21.6		2	6.6	9.7
1.5	12	24.9		3	10	23.3		3	6.6	10.5
2.0	12	27.1		4	10	25.1		4	6.6	10.7
2.5	12	28.1		5	10	26.5		5	6.6	11.3
3.0	12	29.6		6	10	27.4		6	6.6	11.7
								7	6.6	11.7
								8	6.6	12.1
								9	6.6	12.5
								10	6.6	12.8
								11	6.6	13.1
								12	6.6	13.4
								12.54	6.6	13.9
Total Current		**177.6**		**Total Current**		**159.6**		**Total Current**		**160.8**
10= 5.8 V; 5.7 min.				**11= 9.6 V; 12.6 min.**				**12= 8 V; 9 min.**		
Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)
0	5.8	6.5		0	9.6	14.1		0	8	2.2
1	5.8	7.3		1	9.6	16.6		1	8	5.0
2	5.8	7.6		2	9.6	17.4		2	8	6.5
3	5.8	7.9		3	9.6	18.6		3	8	7.8
4	5.8	7.5		4	9.6	19.9		4	8	8.8
5	5.8	8.5		5	9.6	21.1		5	8	9.7
5.42	5.8	8.5		6	9.6	22.1		6	8	10.3
				7	9.6	22.9		7	8	10.9
				8	9.6	23.3		8	8	11.6
				9	9.6	23.0		9	8	12.1
				10	9.6	20.2				
				11	9.6	17.7				
				12	9.6	15.7				
				12.36	9.6	15.2				
Total Current		**53.8**		**Total Current**		**267.8**		**Total Current**		**84.9**

13= 8 V; 9 min.				**14= 8 V; 9 min.**				**15= 12 V; 9.6 min.**		
Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)
0	8	8.3		0	8	9.9		0	12	17.6
1	8	10.0		1	8	12.6		1	12	20.4
2	8	10.2		2	8	13.3		2	12	23.1
3	8	10.3		3	8	14.3		3	12	25.5
4	8	10.7		4	8	14.8		4	12	28.1
5	8	12.9		5	8	16.0		5	12	30.0
6	8	13.6		6	8	16.4		6	11.7	30.4
7	8	14.4		7	8	17.5		7	11.1	25.2
8	8	15.1		8	8	17.8		8	10.2	18.8
9	8	15.2		9	8	17.4		9	11.5	17.3
								9.36	12	17.3
Total Current		**120.7**		**Total Current**		**150.0**		**Total Current**		**253.7**

16= 7.6 V; 3 min.				**17= 4V; 8.4 min.**				**18= 4 V; 8.4 min.**		
Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)
0	7.6	12.4		0	4	3.4		0	4	3.5
0.5	7.6	13.0		1	4	3.7		1	4	3.9
1.0	7.6	13.5		2	4	3.9		2	4	4.1
1.5	7.6	14.2		3	4	3.8		3	4	4.4
2.0	7.6	14.4		4	4	3.8		4	4	4.5
2.5	7.6	14.9		5	4	3.8		5	4	4.5
3.0	7.6	15.4		6	4	3.9		6	4	4.6
				7	4	3.8		7	4	4.6
				8	4	4.0		8	4	4.7
				8.24	4	3.9		8.24	4	4.7
Total Current		**97.8**		**Total Current**		**38.0**		**Total Current**		**43.5**

19= 7.6 V; 3 min.		
Time (Min.)	Volt (V)	Current (A)
0	7.6	10.8
0.5	7.6	11.7
1.0	7.6	12.1

1.5	7.6	12.4								
2.0	7.6	12.8								
2.5	7.6	13.2								
3.0	7.6	13.3								
Total Current		**86.3**								

Table 4.54- Results of experimentation on chloride rich wastewater with Al-Al electrodes

Electrodes	Voltage (V)	Time (min)	Current density (A/m^2)	Color (Pt Co Units)	COD (mg/L)	Conductivity (mS/cm)	pH	Power consumption (KWh/m^3)	Sludge generation rate (g/L)
Al-Al	12	15	2041.84	451	303	33.8	9.4	162.24	34.2
Al-Al	4	15	386.73	2110	735	32.4	9.4	10.24	7.2
Al-Al	12	15	2248.98	461	307	33.7	9.6	178.70	37.2
Al-Al	4	15	445.92	2260	726	32.5	9.3	11.81	14.3
Al-Al	4	3	493.88	2750	466	31.6	9.5	2.62	3.6
Al-Al	12	3	2469.39	1130	449	31.7	9.7	39.24	7.9
Al-Al	12	3	2588.78	1150	458	32.7	9.9	41.14	9.7
Al-Al	10	6	2326.53	800	693	32.3	9.7	61.62	12.8
Al-Al	6.6	12.9	1171.43	910	346	32.2	9.5	44.03	15.8
Al-Al	5.8	5.7	783.67	1300	111	32.8	9.7	11.44	8.6
Al-Al	9.6	12.6	1952.04	830	228	33.5	9.4	104.23	26.2
Al-Al	8	9	866.33	1260	553	30.8	9.6	27.53	10.2
Al-Al	8	9	1231.63	1000	537	31.3	9.7	39.14	8.1

Al-Al	8	9	1530.61	910	569	31.2	9.6	48.65	15.8
Al-Al	12	9.6	2353.06	390	268	33.3	9.5	119.66	18.0
Al-Al	7.6	3	1425.51	2130	651	31.2	9.3	14.35	8.2
Al-Al	4	8.4	387.76	2560	594	31.4	9.3	5.75	7.8
Al-Al	4	8.4	443.88	2060	570	30.8	9.3	6.58	7.3
Al-Al	7.6	3	1258.16	2320	668	30.8	9.6	12.66	9.4

4.4.2.8 Electroflocculation treatment of CRWW with Fe-Fe electrode

The results obtained from the laboratory experimentation with Fe-Fe electrodes in electroflocculation treatment of CRWW are presented in Table 4.55 and Table 4.56.

Table 4.55 Results of experimentation on chloride rich wastewater with Fe-Fe electrodes at different voltages and treatment times

1= 12 V; 15 min.				**2= 4 V; 15 min.**				**3= 12 V; 15 min.**		
Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)
0	12	17.6		0	4	4.5		0	12	19.1
1	12	20.4		1	4	4.9		1	12	21.7
2	12	22.4		2	4	5.1		2	12	25.3
3	12	26.0		3	4	5.2		3	12	28.3
4	12	25.2		4	4	5.3		4	12	31.5
5	12	25.6		5	4	5.3		5	11.4	31.5
6	12	27.9		6	4	5.4		6	11.2	31.5
7	12	31.4		7	4	5.5		7	11	31.5
8	10.7	31.5		8	4	5.5		8	10.4	31.5
9	10.6	31.5		9	4	5.4		9	11.1	31.5
10	11.1	31.5		10	4	4.8		10	12	24.0
11	12.0	20.1		11	4	4.2		11	12	19.0
12	12	21.1		12	4	3.9		12	12	22.4
13	12	21.1		13	4	3.8		13	12	20
14	12	23.7		14	4	3.7		14	12	19
15	12	19.9		15	4	3.6		15	12	19.8
Total Current		**396.9**		**Total Current**		**76.1**		**Total Current**		**407.6**
4= 4 V; 15 min.				**5= 4 V; 3 min.**				**6= 12 V; 3 min.**		

Time (Min.)	Volt (V)	Current (A)
0	4	5.3
1	4	5.4
2	4	5.5
3	4	5.6
4	4	5.7
5	4	5.8
6	4	6.0
7	4	6.0
8	4	6.1
9	4	6.2
10	4	6.3
11	4	6.3
12	4	6.3
13	4	6.2
14	4	6.1
15	4	6.0
Total Current		**94.8**

Time (Min.)	Volt (V)	Current (A)
0	4	4.5
0.5	4	4.7
1.0	4	4.8
1.5	4	4.8
2.0	4	4.8
2.5	4	5.0
3.0	4	5.2
Total Current		**33.8**

Time (Min.)	Volt (V)	Current (A)
0	12	20.6
0.5	12	21.7
1.0	12	22.8
1.5	12	24.8
2.0	12	26.0
2.5	12	28.2
3.0	12	29.4
Total Current		**173.5**

7= 12 V; 3 min.

Time (Min.)	Volt (V)	Current (A)
0	12	17.9
0.5	12	18.6
1.0	12	20.0
1.5	12	21.5
2.0	12	22.0
2.5	12	24.3
3.0	12	26.1
Total Current		**150.4**

8= 10 V; 6 min.

Time (Min.)	Volt (V)	Current (A)
0	10	16.2
1	10	17.9
2	10	20.0
3	10	20.0
4	10	17.2
5	10	17.7
6	10	18.8
Total Current		**127.8**

9= 6.6 V; 12.9 min.

Time (Min.)	Volt (V)	Current (A)
0	6.6	7.9
1	6.6	8.2
2	6.6	8.7
3	6.6	8.7
4	6.6	9.0
5	6.6	9.3
6	6.6	9.7
7	6.6	10
8	6.6	10
9	6.6	9.8
10	6.6	9.4
11	6.6	9.3
12	6.6	9.2
12.54	6.6	9.2
Total Current		**128.4**

10= 5.8 V; 5.7 min.

Time (Min.)	Volt (V)	Current (A)
0	5.8	6.2
1	5.8	7.3
2	5.8	7.8
3	5.8	8.0

11= 9.6 V; 12.6 min.

Time (Min.)	Volt (V)	Current (A)
0	9.6	15.5
1	9.6	16.4
2	9.6	18.5
3	9.6	19.2

12= 8 V; 9 min.

Time (Min.)	Volt (V)	Current (A)
0	8	10.4
1	8	11.4
2	8	12
3	8	12.7

4	5.8	8.2		4	9.6	20.5		4	8	13.4
5	5.8	8.4		5	9.6	20.9		5	8	13.5
5.42	5.8	8.5		6	9.6	18.5		6	8	14.1
				7	9.6	17.6		7	8	14.2
				8	9.6	18.5		8	8	13.4
				9	9.6	19.4		9	8	13.0
				10	9.6	20.6				
				11	9.6	21.4				
				12	9.6	22.8				
				12.36	9.6	24.4				
Total Current		**54.4**		**Total Current**		**274.2**		**Total Current**		**128.1**
13= 8 V; 9 min.				**14= 8 V; 9 min.**				**15= 12 V; 9.6 min.**		
Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)
0	8	10.0		0	8	13.3		0	12	19.4
1	8	10.4		1	8	14.3		1	12	21.7
2	8	12.1		2	8	15.1		2	12	24.7
3	8	12.8		3	8	16.1		3	12	27.5
4	8	13.2		4	8	17.2		4	12	30.3
5	8	13.7		5	8	17.9		5	12	31.5
6	8	14.3		6	8	18.0		6	11.7	31.5
7	8	14.5		7	8	16.8		7	11.1	31.5
8	8	14.5		8	8	15.6		8	10.2	31.5
9	8	14.1		9	8	14.8		9	11.5	31.5
								9.36	12	23.6
Total Current		**129.6**		**Total Current**		**159.1**		**Total Current**		**304.7**
16= 7.6 V; 3 min.				**17= 4V; 8.4 min.**				**18= 4 V; 8.4 min.**		
Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)
0	7.6	9.1		0	4	5.1		0	4	5.3
0.5	7.6	9.5		1	4	5.3		1	4	5.4
1.0	7.6	10.2		2	4	5.5		2	4	5.5
1.5	7.6	10.4		3	4	5.5		3	4	5.6
2.0	7.6	11.1		4	4	5.6		4	4	5.7
2.5	7.6	11.4		5	4	5.8		5	4	5.7
3.0	7.6	12.2		6	4	5.8		6	4	5.8
				7	4	5.9		7	4	5.9
				8	4	5.9		8	4	6.0
				8.24	4	5.9		8.24	4	6.0

Total Current		**73.9**		**Total Current**		**56.3**		**Total Current**		**56.9**
19= 7.6 V; 3 min.										
Time (Min.)	Volt (V)	Current (A)								
0	7.6	10.6								
0.5	7.6	11.1								
1.0	7.6	11.3								
1.5	7.6	11.6								
2.0	7.6	11.9								
2.5	7.6	12.3								
3.0	7.6	12.5								
Total Current		**81.3**								

Table 4.56- Results of experimentation on chloride rich wastewater with Fe-Fe electrodes

Electrodes	**Voltage (V)**	**Time (min)**	**Current density (A/m^2)**	**Color (Pt Co Units)**	**COD (mg/L)**	**Conductivity (mS/cm)**	**pH**	**Power consumption (KWh/m^3)**	**Sludge generation rate (g/L)**
Fe-Fe	12	15	2530.61	32	428	35.3	11.5	190.77	17.3
Fe-Fe	4	15	484.69	63	242	33.3	12.1	12.18	9.3
Fe-Fe	12	15	2598.98	26	405	34.9	11.4	195.92	22.7
Fe-Fe	4	15	604.08	43	230	31.9	11.5	15.18	9.8
Fe-Fe	4	3	492.86	375	441	31.9	10.1	2.48	3.2

Fe-Fe	12	3	2528.57	87	381	31.9	10.4	38.12	8.7
Fe-Fe	12	3	2191.84	89	405	31.7	10.4	33.05	7.9
Fe-Fe	10	6	1863.27	84	204	32.2	10.3	46.82	10.1
Fe-Fe	6.6	12.9	935.71	92	242	31.9	10.6	33.36	9.1
Fe-Fe	5.8	5.7	792.86	133	149	31.7	10.3	10.98	5.7
Fe-Fe	9.6	12.6	1997.96	42	767	32.2	11.1	101.21	19.0
Fe-Fe	8	9	1307.14	46	532	31.2	11.2	39.41	12.4
Fe-Fe	8	9	1322.45	53	502	31.7	11.0	39.88	12.1
Fe-Fe	8	9	1623.47	45	516	31.5	11.0	48.95	13.5
Fe-Fe	12	9.6	2826.53	43	527	33.3	11.5	136.37	22.2
Fe-Fe	7.6	3	1077.55	130	510	31.8	10.6	10.29	5.8
Fe-Fe	4	8.4	574.49	98	553	32.1	10.5	8.08	6.4
Fe-Fe	4	8.4	580.61	99	467	31.5	10.8	8.17	6.3
Fe-Fe	7.6	3	1184.69	138	406	31.3	10.6	11.31	6.1

4.4.2.9 Electroflocculation treatment of CRWW with Fe-Al electrode

The results obtained from the laboratory experimentation with Fe-Al electrodes in electroflocculation treatment of CRWW are presented in Table 4.57 and Table 4.58.

Table 4.57- Results of experimentation on chloride rich wastewater with Fe-Al electrodes at different voltages and treatment times

1= 12 V; 15 min.			**2= 4 V; 15 min.**			**3= 12 V; 15 min.**		
Time (Min.)	Volt (V)	Current (A)	Time (Min.)	Volt (V)	Current (A)	Time (Min.)	Volt (V)	Current (A)
0	12	15.2	0	4	4.2	0	12	18.8
1	12	19.0	1	4	4.7	1	12	22.8
2	12	22.9	2	4	4.9	2	12	25.9
3	12	24.4	3	4	4.9	3	12	23.1

4	12	23.4		4	4	5.0		4	12	22.2
5	12	21.7		5	4	5.2		5	12	21.8
6	12	21.8		6	4	5.0		6	12	22.2
7	12	22.1		7	4	5.3		7	12	20.3
8	12	21.2		8	4	5.6		8	12	16.7
9	12	19.1		9	4	5.8		9	12	16.8
10	12	18.3		10	4	4.3		10	12	15.4
11	12	18.6		11	4	3.9		11	12	14.1
12	12	17.3		12	4	3.5		12	12	14.0
13	12	17.9		13	4	3.3		13	12	13.0
14	12	16.7		14	4	3.2		14	12	13.7
15	12	16.2		15	4	3.2		15	12	12.7
Total Current		**315.1**		**Total Current**		**72.0**		**Total Current**		**293.5**
4= 4 V; 15 min.				**5= 4 V; 3 min.**				**6= 12 V; 3 min.**		
Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)
0	4	2.9		0	4	4.4		0	12	17.8
1	4	4.0		0.5	4	4.6		0.5	12	19.1
2	4	4.2		1.0	4	4.5		1.0	12	20.0
3	4	4.4		1.5	4	4.6		1.5	12	21.1
4	4	4.6		2.0	4	4.6		2.0	12	21.7
5	4	4.7		2.5	4	4.7		2.5	12	22.3
6	4	4.9		3.0	4	4.7		3.0	12	16.8
7	4	4.9								
8	4	4.5								
9	4	3.9								
10	4	3.5								
11	4	3.2								
12	4	2.9								
13	4	2.6								
14	4	2.3								
15	4	2.3								
Total Current		**59.8**		**Total Current**		**32.1**		**Total Current**		**138.8**
7= 12 V; 3 min.				**8= 10 V; 6 min.**				**9= 6.6 V; 12.9 min.**		
Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)
0	12	22.9		0	10	14.6		0	6.6	7.6
0.5	12	23.3		1	10	14.7		1	6.6	9.2
1.0	12	24.8		2	10	16.5		2	6.6	9.7
1.5	12	26.6		3	10	18.2		3	6.6	10.6
2.0	12	28.5		4	10	18.3		4	6.6	10.8
2.5	12	22.1		5	10	15.3		5	6.6	9.8
3.0	12	18.2		6	10	14.6		6	6.6	7.7
								7	6.6	6.6
								8	6.6	6.2
								9	6.6	5.9

						10	6.6	5.7
						11	6.6	5.6
						12	6.6	5.5
						12.54	6.6	5.4
Total Current		**166.4**	**Total Current**		**112.2**	**Total Current**		**106.3**
10= 5.8 V; 5.7 min.			**11= 9.6 V; 12.6 min.**			**12= 8 V; 9 min.**		
Time (Min.)	Volt (V)	Current (A)	Time (Min.)	Volt (V)	Current (A)	Time (Min.)	Volt (V)	Current (A)
0	5.8	4.6	0	9.6	13.5	0	8	10.8
1	5.8	6.0	1	9.6	14.8	1	8	11.5
2	5.8	6.0	2	9.6	15.5	2	8	11.8
3	5.8	6.0	3	9.6	16.6	3	8	12.5
4	5.8	6.2	4	9.6	16.9	4	8	12.9
5	5.8	6.3	5	9.6	14.4	5	8	12.3
5.42	5.8	6.3	6	9.6	13.0	6	8	11.2
			7	9.6	12.4	7	8	9.5
			8	9.6	12.0	8	8	10.1
			9	9.6	11.7	9	8	10.9
			10	9.6	11.8			
			11	9.6	11.6			
			12	9.6	11.2			
			12.36	9.6	11.7			
Total Current		**41.4**	**Total Current**		**187.1**	**Total Current**		**113.5**
13= 8 V; 9 min.			**14= 8 V; 9 min.**			**15= 12 V; 9.6 min.**		
Time (Min.)	Volt (V)	Current (A)	Time (Min.)	Volt (V)	Current (A)	Time (Min.)	Volt (V)	Current (A)
0	8	12.7	0	8	8.3	0	12	21.0
1	8	14.4	1	8	11.6	1	12	23.0
2	8	15.0	2	8	12.5	2	12	24.4
3	8	15.8	3	8	14.1	3	12	24.8
4	8	16.7	4	8	13.7	4	12	25.7
5	8	13.0	5	8	10.2	5	12	22.1
6	8	14.4	6	8	9.4	6	12	23.1
7	8	13.1	7	8	8.3	7	12	20.0
8	8	12.3	8	8	9.4	8	12	22.6
9	8	11.7	9	8	6.7	9	12	21.0
						9.36	12	19.0

Total Current		**139.1**		**Total Current**		**104.2**		**Total Current**		**246.7**
16= 7.6 V; 3 min.				**17= 4V; 8.4 min.**				**18= 4 V; 8.4 min.**		
Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)
0	7.6	11.6		0	4	3.0		0	4	4.0
0.5	7.6	11.8		1	4	3.6		1	4	3.5
1.0	7.6	12.0		2	4	3.7		2	4	3.5
1.5	7.6	12.5		3	4	3.7		3	4	3.5
2.0	7.6	13.1		4	4	3.7		4	4	3.4
2.5	7.6	13.8		5	4	3.8		5	4	3.2
3.0	7.6	14.0		6	4	3.8		6	4	3.4
				7	4	4.2		7	4	3.5
				8	4	4.1		8	4	3.4
				8.24	4	4.2		8.24	4	3.5
Total Current		**88.8**		**Total Current**		**37.8**		**Total Current**		**34.9**
19= 7.6 V; 3 min.										
Time (Min.)	Volt (V)	Current (A)								
0	7.6	13.0								
0.5	7.6	12.8								
1.0	7.6	13.1								
1.5	7.6	13.6								
2.0	7.6	14.0								
2.5	7.6	14.7								
3.0	7.6	15.2								
Total Current		**96.4**								

Table 4.58- Results of experimentation on chloride rich wastewater with Fe-Al electrodes

Electrodes	Voltage (V)	Time (min)	Current density (A/m^2)	Color (Pt Co Units)	COD (mg/L)	Conductivity (mS/cm)	pH	Power consumption (KWh/m^3)	Sludge generation rate (g/L)
Fe-Al	12	15	2009.18	94	866	33.4	11.1	155.45	29.1
Fe-Al	4	15	459.18	72	874	33.1	11.5	11.84	8.0
Fe-Al	12	15	1871.43	98	850	33.2	11.4	144.79	24.1
Fe-Al	4	15	381.63	198	819	32.0	10.9	9.84	8.6
Fe-Al	4	3	467.35	278	820	32.1	9.9	2.41	3.3
Fe-Al	12	3	2023.47	32	529	32.0	11.1	31.31	9.6
Fe-Al	12	3	2425.51	32	498	31.3	10.1	37.53	11.7
Fe-Al	10	6	1635.71	76	717	33.4	10.3	42.18	12.5
Fe-Al	6.6	12.9	774.49	141	702	31.3	11.9	28.34	10.3
Fe-Al	5.8	5.7	603.06	280	717	33.2	10.3	8.57	6.3
Fe-Al	9.6	12.6	1363.27	86	717	33.4	11.3	70.88	15.7
Fe-Al	8	9	1158.16	73	411	33.1	10.8	35.84	13.8
Fe-Al	8	9	1419.39	49	378	32.9	11.2	43.93	14.2
Fe-Al	8	9	1063.27	142	396	31.7	10.4	32.90	10.9
Fe-Al	12	9.6	2288.78	58	835	31.8	10.5	113.33	15.7
Fe-Al	7.6	3	1293.88	55	655	31.3	10.4	12.68	7.2
Fe-Al	4	8.4	385.71	57	906	31.8	10.5	5.57	5.4
Fe-Al	4	8.4	356.12	69	976	31.4	10.2	5.14	4.6
Fe-Al	7.6	3	1405.10	38	678	32.3	10.6	13.77	6.4

4.4.2.10 Electroflocculation treatment of CRWW with SS-SS electrode

The results obtained from the laboratory experimentation with SS-SS electrodes in electroflocculation treatment of CRWW are presented in Table 4.59 and Table 4.60.

Table 4.59- Results of experimentation on chloride rich wastewater with SS-SS electrodes at different voltages and treatment times

1= 12 V; 15 min.				**2= 4 V; 15 min.**				**3= 12 V; 15 min.**		
Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)
0	12	18.8		0	4	3.8		0	12	17.3
1	12	21.3		1	4	4.9		1	12	21.3
2	12	27.6		2	4	4.9		2	12	26.5
3	11.8	31.6		3	4	5.0		3	12	30.3
4	10.9	31.6		4	4	5.2		4	11.3	31.7
5	10.3	31.6		5	4	5.3		5	10.9	31.7
6	10.3	31.6		6	4	5.3		6	10.7	31.7
7	9.9	31.6		7	4	5.5		7	10.6	31.7
8	10.1	31.6		8	4	5.6		8	10.8	31.7
9	12	25.0		9	4	5.7		9	12	21.2
10	12	19.3		10	4	5.8		10	12	20.9
11	12	19.5		11	4	5.8		11	12	19.8
12	12	20.3		12	4	5.8		12	12	19.7
13	12	19.1		13	4	5.8		13	12	20.3
14	12	18.4		14	4	5.8		14	12	18.6
15	12	17.6		15	4	5.8		15	12	17.8
Total Current		**396.5**		**Total Current**		**86.0**		**Total Current**		**392.2**
4= 4 V; 15 min.				**5= 4 V; 3 min.**				**6= 12 V; 3 min.**		
Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)
0	4	3.0		0	4	1.9		0	12	18.9
1	4	4.0		0.5	4	2.2		0.5	12	20.4
2	4	3.8		1.0	4	2.3		1.0	12	22.7
3	4	3.7		1.5	4	2.3		1.5	12	26.8
4	4	3.8		2.0	4	2.3		2.0	12	28.3
5	4	3.8		2.5	4	2.1		2.5	12	30.8
6	4	3.9		3.0	4	2.4		3.0	11.6	31.7
7	4	3.9								
8	4	3.9								
9	4	3.9								
10	4	3.9								
11	4	4.0								
12	4	4.0								

13	4	4.0								
14	4	4.1								
15	4	4.1								
Total Current		**61.8**		**Total Current**		**15.5**		**Total Current**		**179.6**
7= 12 V; 3 min.				**8= 10 V; 6 min.**				**9= 6.6 V; 12.9 min.**		
Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)
0	12	18.1		0	10	13.5		0	6.6	4.4
0.5	12	20.2		1	10	14.5		1	6.6	5.4
1.0	12	24.6		2	10	18.5		2	6.6	5.7
1.5	12	25.2		3	10	20.6		3	6.6	6.9
2.0	12	27.8		4	10	22.2		4	6.6	7.5
2.5	12	30.2		5	10	23.8		5	6.6	8.5
3.0	11.8	31.7		6	10	24.9		6	6.6	9.0
								7	6.6	9.4
								8	6.6	9.8
								9	6.6	10.1
								10	6.6	10.1
								11	6.6	10.9
								12	6.6	11.2
								12.54	6.6	11.4
Total Current		**177.8**		**Total Current**		**138.0**		**Total Current**		**120.3**
10= 5.8 V; 5.7 min.				**11= 9.6 V; 12.6 min.**				**12= 8 V; 9 min.**		
Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)
0	5.8	1.9		0	9.6	11.2		0	8	8.1
1	5.8	3.9		1	9.6	12.1		1	8	10.8
2	5.8	4.7		2	9.6	13.5		2	8	11.3
3	5.8	5.5		3	9.6	15.0		3	8	12.9
4	5.8	6.0		4	9.6	17.2		4	8	13.7
5	5.8	6.8		5	9.6	19.0		5	8	14.4
5.42	5.8	7.2		6	9.6	21.1		6	8	15.1
				7	9.6	23.2		7	8	16.7
				8	9.6	24.8		8	8	16.2
				9	9.6	26.2		9	8	17.0
				10	9.6	26.4				
				11	9.6	26.3				
				12	9.6	27.4				
				12.36	9.6	27.6				
Total Current		**36.0**		**Total Current**		**291.0**		**Total Current**		**136.2**
13= 8 V; 9 min.				**14= 8 V; 9 min.**				**15= 12 V; 9.6 min.**		

Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)
0	8	9.3		0	8	10.2		0	12	18.6
1	8	9.5		1	8	11.1		1	12	21.2
2	8	9.6		2	8	13.0		2	12	23.1
3	8	10.0		3	8	15.2		3	12	27.2
4	8	12.1		4	8	16.2		4	11.4	31.7
5	8	13.4		5	8	16.7		5	10.5	31.7
6	8	14.5		6	8	17.1		6	9.9	31.7
7	8	15.2		7	8	17.6		7	9.7	31.7
8	8	16.0		8	8	18.4		8	9.7	31.7
9	8	16.5		9	8	19.0		9	10.4	31.7
								9.36	12.0	25.8
Total Current		**126.1**		**Total Current**		**154.5**		**Total Current**		**306.1**
16= 7.6 V; 3 min.				**17= 4V; 8.4 min.**				**18= 4 V; 8.4 min.**		
Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)		Time (Min.)	Volt (V)	Current (A)
0	7.6	6.5		0	4	1.6		0	4	1.5
0.5	7.6	7.0		1	4	1.6		1	4	1.6
1.0	7.6	7.5		2	4	1.7		2	4	1.6
1.5	7.6	7.7		3	4	1.7		3	4	1.7
2.0	7.6	8.4		4	4	1.7		4	4	1.7
2.5	7.6	8.6		5	4	1.7		5	4	1.7
3.0	7.6	9.2		6	4	1.7		6	4	1.7
				7	4	1.8		7	4	1.7
				8	4	1.8		8	4	1.7
				8.24	4	1.9		8.24	4	1.7
Total Current		**54.9**		**Total Current**		**17.2**		**Total Current**		**16.6**
19= 7.6 V; 3 min.										
Time (Min.)	Volt (V)	Current (A)								
0	7.6	7.6								
0.5	7.6	8.3								
1.0	7.6	8.8								
1.5	7.6	9.6								

2.0	7.6	9.6								
2.5	7.6	9.6								
3.0	7.6	9.6								
Total Current		**63.1**								

Table 4.60- Results of experimentation on chloride rich wastewater with SS-SS electrodes

Electrodes	Voltage (V)	Time (min)	Current density (A/m^2)	Color (Pt Co Units)	COD (mg/L)	Conductivity (mS/cm)	pH	Power consumption (KWh/m^3)	Sludge generation rate (g/L)
SS-SS	12	15	2528.57	12	63	35.9	11.9	206.5	24.4
SS-SS	4	15	547.96	30	674	32.1	10.9	14.92	9.7
SS-SS	12	15	2501.02	10	72	36.4	11.6	204.25	25.0
SS-SS	4	15	393.88	47	690	33.2	10.5	10.72	8.4
SS-SS	4	3	225.51	1950	771	31.8	10.2	1.23	3.6
SS-SS	12	3	2618.37	80	594	32.1	10.2	42.77	9.2
SS-SS	12	3	2591.84	83	567	31.8	10.2	42.33	10.3
SS-SS	10	6	2011.22	38	616	32.5	10.9	54.75	12.8
SS-SS	6.6	12.9	876.53	44	412	32.1	10.9	33.86	12.7
SS-SS	5.8	5.7	524.49	274	728	31.9	10.0	7.87	5.1
SS-SS	9.6	12.6	2120.41	41	132	32.6	11.6	116.37	21.4
SS-SS	8	9	1389.80	44	242	33.3	11.2	45.40	15.0
SS-SS	8	9	1286.73	57	228	31.7	10.3	42.03	13.9

SS-SS	8	9	1576.53	53	268	32.1	11.1	51.5	14.1
SS-SS	12	9.6	2839.80	11	268	33.2	11.4	148.43	23.3
SS-SS	7.6	3	800.00	650	190	31.1	9.7	8.27	4.0
SS-SS	4	8.4	175.51	970	632	31.4	9.6	2.67	4.2
SS-SS	4	8.4	169.39	1160	672	31.6	9.7	2.58	5.0
SS-SS	7.6	3	919.39	478	133	31.7	9.5	9.51	4.6

The response functions, COD and color removal observed in the experiments with all the electrode combinations are shown in Fig. 4.19(a) and 4.19(b) respectively.

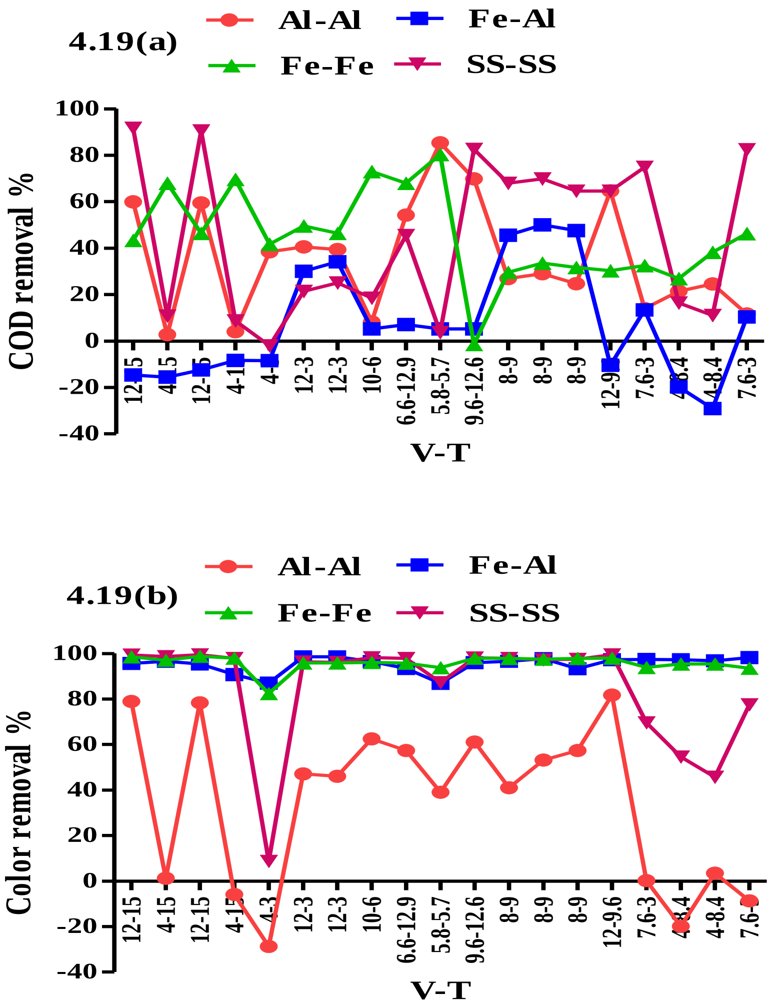


Fig. 4.19 (a) COD removal % and (b) Color removal % with all electrode combinations at respective experimental runs

The first set of experimental runs with Al-Al electrodes were analyzed and maximum COD removal efficiency of 85.3 % at 5.8 V and 5.7 min. treatment time was observed. Sludge generation was 8.6 g/L at 783.67 A/m^2 current density. Power consumption was 11.44 KWh/m^3. The maximum color removal efficiency (81.7 %) was observed at 12V and 9.6 min. treatment time.

Current density was 2353.06 A/m^2. Power consumption and sludge generation were 119.66 KWh/m^3 and 18.0 g/L respectively. In the experiments, power consumption and sludge generation were found positively related (3.6 g/L at 2.62 KWh/m^3 and 37.2 g/L at 178.7 KWh/m^3). At higher power consumption levels, more of the sacrificial electrode (Al) must be getting dissolved and generating more sludge. The Al ions dissolved from the Al anode undergo hydrolysis in the wastewater and form various monomeric and polymeric aluminium hydroxides ($Al(OH)_2^+$, $Al(OH)_2^{2+}$, $Al_6(OH)_{15}^{3+}$, $Al_7(OH)_{17}^{4+}$, $Al_{13}(OH)_{34}^{5+}$ etc). At pH ≥ 7 (between 9.3-9.9 pH) these hydroxides undergo polymerization and $Al(OH)_3$ converts into amorphous $Al(OH)_4^-$ through consuming OH^- ions. The amorphous $Al(OH)_4$ in turn helps in the coagulation process.

Maximum COD removal efficiency of 50 % at 8 V and 9 min. treatment time was observed with Fe-Al electrode combination. Sludge generation was 14.2 g/L at the current density of 1419.39 A/m^2 and power consumption was 43.93 KWh/m^3. More than 90 % of color removal efficiency was observed in most of experimental runs. The maximum removal (98 %) was observed at 12 V and 3 min. treatment time and at 2425.51 A/m^2 current density. Power consumption was 37.53 KWh/m^3 and sludge generation rate was 11.7 g/L. Here also power consumption and sludge generation rates in these experimental runs were positively related (3.3 g/L was sludge generation at 2.41 KWh/m^3 power consumption and 29.1 g/L sludge generation at 155.45 KWh/m^3 power consumption). In some of the experimental runs (4 V- 3 min, 8.4 min, 15 min and 12 V- 9.6 min, 15 min) COD was found increasing with the treatment, from the original COD (756 mg/L) to 820 mg/L, 976 mg/L, 819 mg/L, 835 mg/L, 866 mg/L respectively. The increase in COD was also reported in a study by Zaroual, *et al.* (2006). The increase in COD occurs due to leaching of organic matter from the sludge generated during experimental run. Even some compounds form stable products with Fe^{2+} and remain in solution which directly contributes in enhancing the COD (Moreno-Casillas, *et al.* 2007).

The SS-SS electrode combination gave maximum of 91.7 % COD removal and 99.5 % Color removal at 12 V and 15 min. at 2528.57 A/m^2 current density. Power consumption was 206.5 KWh/m^3 and sludge generation was 24.4 g/L for this experimental run. With increase in current density, dissolution rate of anode also increases. This enhances the metal hydroxides flocs formation and this in turn increased the color and COD removal rates.

The Fe-Fe electrode combination gave 80.3% maximum COD removal efficiency at 5.8V and 5.7 min. treatment time. Sludge generation rate for this experimental run was 5.7 g/L at 792.86 A/m^2 current density. Power consumption was 10.98 KWh/m^3. At 12 V and 15 min. treatment time the maximum color removal efficiency (98.8 %) was observed with 22.7 g/L sludge generation rate and 2598.98 A/m^2 current density. Power consumption was 195.92 KWh/m^3. In all the experimental runs with Fe-Fe electrode combination, formation of brown color flocs was observed. Oxidation of ferrous iron into ferric iron could be responsible for this.

SEM of electrodes before performing various EC experiments (Figure 4.20a) was taken which depicts the plain and uniform surface of Fe electrode. Figure 4.20b shows the rough surface and presence of troughs and dents of various sizes on its surface resulting due to release of Fe ions (Eq. 10) during dissolution of electrodes (Jagati, *et al.* 2015)

$$\text{Anodic reaction} \quad Fe\,(s) \longrightarrow Fe^{2+} + 2e^{-} \qquad \text{(Eq. 10)}$$

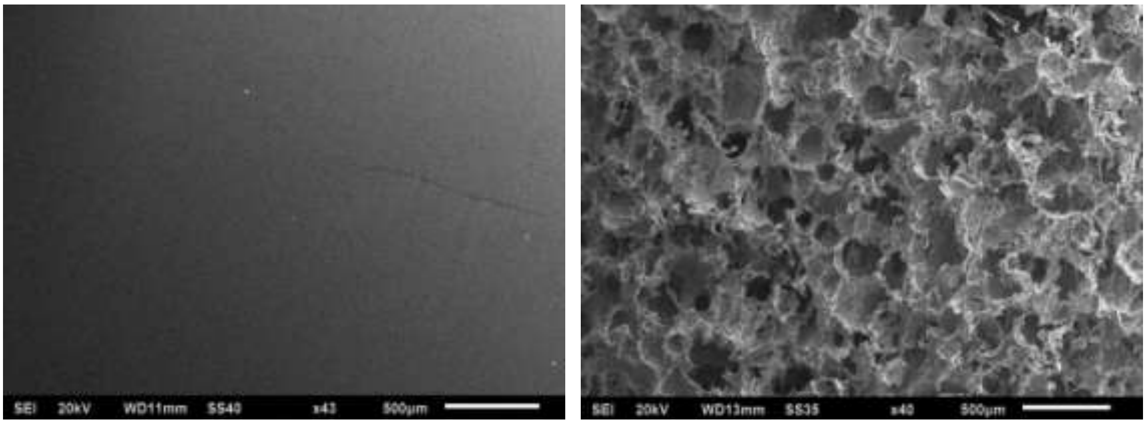


Fig. 4.20(a) SEM image of Fe Electrode before EC (b) SEM image of Fe Electrode after EC

No significant change was observed in pH and conductivity (σ) with the electro-flocculation of CRWW with all the four electrode combinations because ions after treatment is insignificant and hence conductivity is not rising and also in alkaline medium electrolytic processes contains little pH buffering capacity as founded in previous work (Zaroual, *et al*. 2006) and it also shows that some of the chlorine derivatives were not produced during electrolytic process as supported by another research (Vaghela, *et al.* 2005)

pH was not adjusted by adding any acid or basic solutions to maintain stability of active intermediates participating in electrolytic process in real time treatment. Due to higher concentration of NaCl in CRWW the chlorine gas evolves at anode which destroys the passive oxide film and forms hypochlorite and OCl^- species during EC. At higher pH (as in our case its 9.53), OCl^- species of chlorine which is strong oxidant, dominates which enhances the COD removal efficiency (Deborde and Von Gunten, 2008). As concluded from the experiments the color removal efficiencies with Al-Al electrodes were lower, hence the Al-Al electrodes appeared to be less efficient than SS-SS and Fe-Fe electrodes. For Fe and SS electrodes the phase transfer as well as redox reactions helps in color removal as compared to

Al electrodes in which only phase transfer exists as reported previously by Kabdaşlı, *et al.* 2009.

4.4.2.11 Statistical modeling for Color removal efficiency with Fe-Fe electrodes for CRWW

From the experimental runs, Fe-Fe electrodes are giving promising results, thus it is used for statistical modeling and RSM. The model is significant but *Lack of fit* is not significant. This indicated that model cannot be navigated in the design space (higher noise than signal S/N ratio). The ratio of max to min color removal is only 1.05, for good model which should be more than 1.5. Under these circumstances, it was concluded that the color will be removed also efficiently at low voltage at less treatment time. In an investigation by Kashefialasl, *et al.* (2006) the 8 g/L of NaCl (19.13 mS/cm of conductivity) increase the color removal efficiency by 83% at 2.9 V and 127.8 A/m^2 whereas in our research also with CRWW having high conductivity (32 mS/cm), with Fe electrode 98.8 % color removal efficiency was achieved at 12 V and at current density of 2598.98 A/m^2, thus it needs low voltage for efficient electroflocculation. Therefore, IV-optimal design strategy of RSM with Design Expert Software was used again for the design of experiments. The 7 experiments were designed and conducted for CRWW with Fe-Fe electrode combination for color removal model. The color removal efficiency, current density, power consumption and sludge generation rate were estimated as shown in Table 4.61.

Table 4.61- Set of experimental design as per IV optimal design and results of experimentation on CRWW with Fe-Fe electrodes

S.No.	**Voltage (V)**	**Time (min.)**	**Current density (A/m^2)**	**Color (Pt. Co. Unit)**	**Color removal (%)**	**Power consumption (KWh/m^3)**	**Sludge generation rate (g/L)**

1	1	1	57.14	1440	32.6	0.02	0.0182
2	1	1	52.04	1569	26.5	0.02	0.0163
3	1	3.25	42.86	940	56.0	0.06	0.1062
4	1	7.75	36.73	126	94.1	0.12	0.3462
5	1	10	38.78	79	96.3	0.16	0.6456
6	1	10	42.86	106	95.0	0.18	0.6310
7	1	5.5	43.88	209	90.2	0.10	0.2626

The original dyebath wastewater was dark red colored, which became pigment red at 1V and 3.25 min. treatment time. The sample looks alike coral pink at 1V 5.5 min. treatment time. After 1V and 10 min. treatment time, the color was almost clear and the sample was representing aesthetically suitable.

The aesthetic representation of these experiments is shown in Figure 4.21.

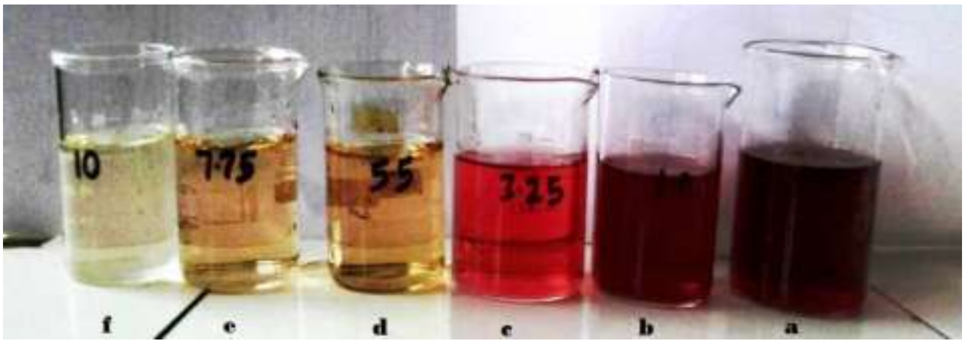


Fig.4.21 Aesthetic representation of original sample (a); Samples at 1 V 1min. (b); 1V 3.25 min. (c); 1 V 5.5 min.(d); 1V 7.75 min. (e) and 1V 10 min. (f)

The results of ANOVA statistics for color removal are given in Table 4.62.

Table 4.62- Results for ANOVA statistics for Color removal for CRWW

Source	**Sum of Squares**	**dF**	**Mean Square**	**F Value**	**Prob>F**	
Model	5699	2	2849	121	0.0003	significant
A-Time	5084	1	5084	217	0.0001	
A^2	615	1	615	26	0.0069	
Residual	94	4	23			
Lack of fit	74	2	37	4	0.2071	not significant
Std. Dev.		4.845	R^2	0.984		
Mean		70.100	Adjusted R^2	0.976		
C.V. %		6.912	Predicted R^2	0.951		
PRESS		283.609	Adeq Precision	21.192		

The CV of 6.91 % and predicted R^2=0.951 was closed to adjusted R^2 of 0.976. Also, S/N ratio of 21.2 indicated that model noise is not significant as compared to signal. Thus, model could be navigated in the design space. The unit-less regression equation in terms of coded factors is given in Eq. (11) and in terms of actual factors in Eq. (12).

Color removal efficiency (%) = $+84.46 + 33.61 \times A - 22.34 \times A^2$ (Eq. 11)

Where, A: Voltage are in coded units.

Color removal efficiency (%) = $+10 + 19.604 \times \text{min} - 1.103 \times \text{min}^2$ (Eq. 12)

Where, min: are in actual units.

ANOVA model was significant and the optimized process conditions are 1V and 8.2 min. to achieve 96.6 % color removal efficiency (Figure 4.22).

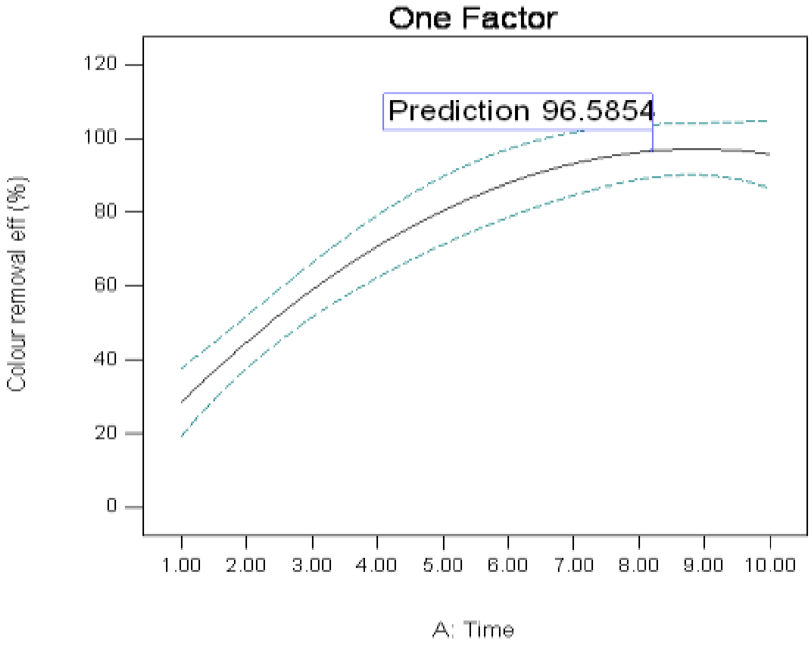


Fig. 4.22 Predicted plot for color removal efficiency at 1V and 8.2 min

The results were verified by validation testing at new proposed conditions. The predicted color removal efficiency value was 96.6 % which was consistent with the practical color removal value of 94.4%. The Total Organic Carbon (TOC) was analysed (TOC-VCPH, Shimadzu, Japan) in lieu of COD for the optimum condition and it comes out to be 13.96 mg/L and indicates 69.5 % TOC removal with sludge generation of 0.46 g/L. The Na, Cl, Ca and Mg was 4010 mg/L, 8132.8 mg/L, 78.2 mg/L and 22.1 mg/L respectively for the treatment at optimum conditions.

4.4.3 Membrane processes for dye effluents

The textile cotton dyebath wastewater rich in sulphate and softener application wastewater was segregated and treated using membranes (microfiltration, ultrafiltration and nanofiltration membranes) for decolourization. A table top membrane filtration system as described in Chapter 3 was used for the treatment of respective textile wastewater.

4.4.3.1 Microfiltration, Ultrafiltration and Nano-filtration treatment of Sulphate rich wastewater (SRWW)

The principle physio-chemical characteristics of sulphate rich cotton dyebath wastewater was presented in Table 4.63.

Table 4.63- Characteristic of sulphate rich cotton dyebath wastewater for membrane treatment

S.No.	Parameters	Units	Value
1	TSS	mg/L	154
2	TDS	mg/L	20780
3	Sulphate	mg/L	12521
4	Turbidity	N.T.U	67.8
5	Cu	mg/L	0.30
6	Zn	mg/L	0.24
7	Fe	mg/L	2.5
8	Mg	mg/L	12.7
9	Ca	mg/L	67.7
10	Na	mg/L	6880
11	K	mg/L	30.3
12	pH	--	10.14
13	Conductivity	mS/cm	34.4
14	COD	mg/L	1573.5
15	Color	Pt. Co. Unit	2180
16	Chloride	mg/L	409.4

The characteristics of wastewater after treatment with microfiltration, ultrafiltration and nanofiltration are presented in Table 4.64. The inlet and outlet pressure for UF membrane was adjusted to 5 and 3 kg/cm^2 and the inlet and outlet pressure for NF membrane was adjusted to 18 and 15 kg/cm^2 respectively.

Table 4.64- Characteristics of Textile Dyebath Wastewater after MF, UF and NF treatment

S.No.	Parameters (Units)	Microfiltration	Ultrafiltration	Nanofiltration
1	TSS (ppm)	42	18	4
2	TDS (ppm)	19094	17852	362
3	Sulphate (ppm)	12003.4	10312.2	214.8
4	Turbidity (N.T.U)	13.8	3.4	Nil
5	Cu (ppm)	0.20	0.13	0.04
6	Zn (ppm)	<0.05	<0.05	<0.05
7	Fe (ppm)	1.37	1.29	<0.05
8	Mg (ppm)	8.9	5.7	1.01
9	Ca (ppm)	64.9	37.7	3.94
10	Na (ppm)	6520	6130	115.5
11	K (ppm)	24.9	18.3	0.85
12	pH	10.14	10.14	8.41
13	Conductivity (mS/cm)	27.6	17	0.57
14	COD (ppm)	905.36	388.6	37.02
15	Color (Pt. Co. Unit)	960	690	22

16	Chloride (ppm)	374.9	353.3	28.45

The Microfiltration unit removes 42.5 % and 82.8% of the COD and color respectively. The microfiltration process is appropriate for the removal of the colloidal dyes from the exhausted dyebath after dyeing processing steps but the auxiliary chemicals are left over in the permeate, emphasizing the reuse of the auxiliary chemicals (Marcucci *et al.* 2001).

Whereas the COD and color removal efficiencies were 97.6 % and 98.9 % respectively using NF membrane. The quality of permeate through NF was very good and can be easily used in respective processing steps. The UF removed 57 % of the COD and this retained COD fraction was responsible for the membrane fouling as also mentioned in other study (Gozalvez-Zafrilla *et al.* 2008).

Chloride and sulphate ions retention rate with NF were 92 % and 98 % respectively. The COD removal obtained with UF membrane was not enough for reusing of permeate in process because of molecular size of the dyestuffs. The color and COD removal efficiencies was represented in Fig. 4.23. Values of Na, SO_4^{2-}, Cl^- and TDS after treatment with MF, UF and NF were also represented in Fig. 4.24. These figures depict the decrease in abatement rates of respective pollutants by using MF, UF and NF subsequently.

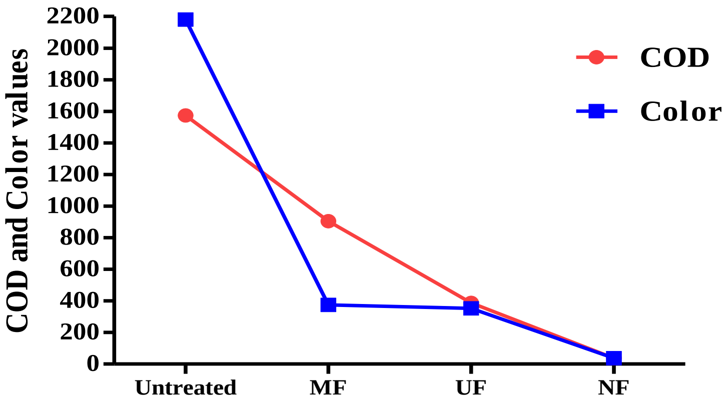


Fig. 4.23 COD and color values after treatment with MF, UF and NF

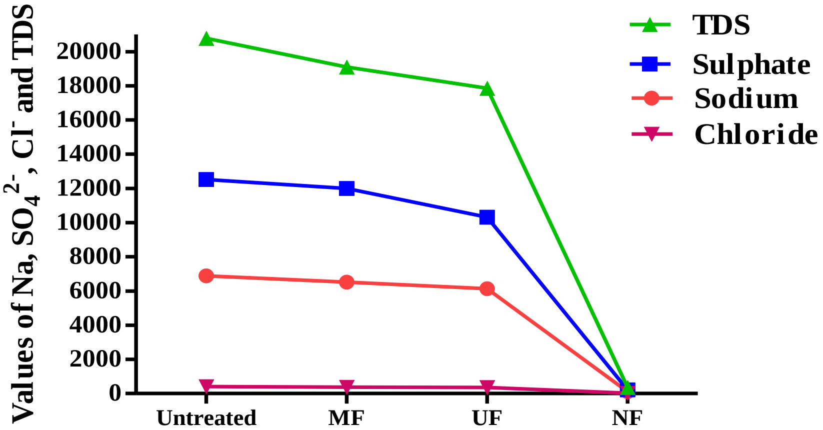


Fig. 4.24 Values of Na, SO_4^{2-}, Cl^- and TDS after treatment with MF, UF and NF

The combined UF/NF was much efficient as NF fouling was reduced as well as the water recovery was higher as supported by another research (Arnal *et al.* 2008). UF has not been widely accepted in textile industries as the direct reuse is impossible with these membranes and it requires further filtration by NF (Tang and Chen, 2002).

The permeate flux was evaluated with both UF and NF membranes. The permeate flux was reduces with time due to deposition of organic and inorganic components present in the wastewater on the membrane surface. The highest flux value obtained with UE50 and ESNA 1 were determined as 48.439 L/m^2.h and 25.076 L/m^2.h at 30^{o}C respectively the lowest permeate flux were determined as 29.063 L/m^2.h and 13.678 L/m^2.h at 30^{o}C respectively. The permeate flux at 15 min, 20 min and 25 min was 38.751 L/m^2.h, 33.907 L/m^2.h and 31.485 L/m^2.h respectively with UF membrane. The permeate flux at 15 min, 20 min and 25 min was 22.796 L/m^2.h, 18.237 L/m^2.h and 15.957 L/m^2.h respectively with NF membrane. The graph of permeate flux with time with respect to UF and NF membranes was represented in Fig. 4.25. The gradual decrease of permeate flux with time due to membrane fouling was also concluded by other researchers (Ellouze, *et al.* 2012; Kaykioglu, *et al.* 2017).

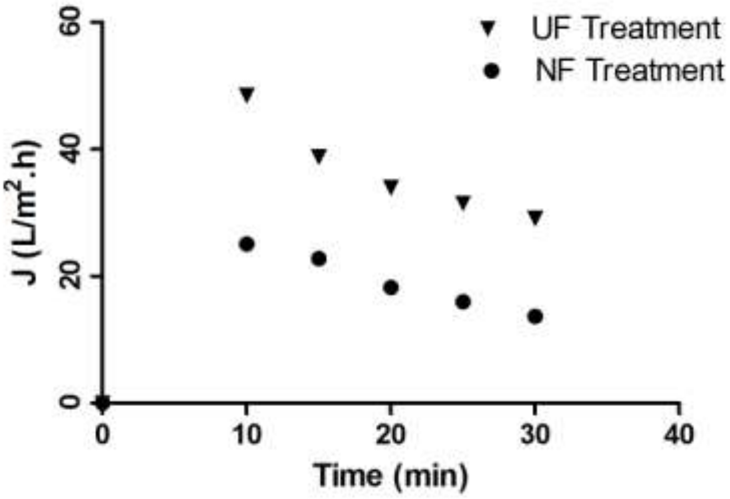


Fig. 4.25 Variation of permeate flux with time with UF and NF treatment

Thus permeate after treatment with nanofiltration membrane can be easily reused in dyebath reconstitution and the retentate can be concentrated for the recovery of salts. UF is very useful as pre-treatment option before NF as this is economically viable as well as decreases the operating cost and maintenance problems. The UF membranes as a pre-treatment alternative have been considered and recommended by various researchers in previous studies also (Barredo-Damas *et al.* 2005; Koyuncu *et al.* 2004; Sostar-Turk *et al.* 2005). The characteristics of wastewater after treatment with NF was also achieving process water quality mentioned in the literature and the obtained NF permeate can be reused in the textile processing industry as the process water. The monovalent ions (NaCl) are easier to filter than the bivalent ions (Na_2SO_4). The membrane selectivity hence depends upon the salt retention as well as on the dye retention, if the pore size of the selected membrane was small, the ions retained onto membrane will be large (which results in decrease of the permeate flux) and if the pore size was large, then the dye molecules will eventually passes through it, which decreases the colour abatement rate (Van der Bruggen, *et al.* 2001).

4.4.3.2 Microfiltration and Ultrafiltration treatment of Cotton Softener Application Wastewater (CSAWW)

The initial characteristics of cotton softener application wastewater were presented in Table-4.65.

Table 4.65- Initial characteristics of cotton softener application wastewater

S.No.	**Parameter**	**Units**	**Results**
1	Total Suspended Solids	mg/L	16
2	Total Dissolved Solids	mg/L	664
3	Turbidity	N.T.U	9
4	pH	--	7.65
5	Conductivity	µS/cm	743
6	Chemical Oxygen Demand	mg/L	570.2
7	Chloride	mg/L	42.1
8	Total Hardness	mg/L as $CaCO_3$	309.5
9	Total Alkalinity	mg/L as $CaCO_3$	204.6
10	Silicon	mg/L	13.53
11	Iron	mg/L	1.26
12	Calcium	mg/L	64.8
13	Zinc	mg/L	0.27
14	Magnesium	mg/L	33.6
15	Copper	mg/L	0.38
16	Nickel	mg/L	0.08
17	Aluminium	mg/L	0.33
18	Manganese	mg/L	0.11
19	Lead	mg/L	0.16
20	Chromium	mg/L	0.14
21	Sodium	mg/L	46.28

22	Potassium	mg/L	9.65

4.4.3.3 Microfiltration and Ultrafiltration treatment of Polyester Softener Application Wastewater (PSAWW)

The initial characteristics of polyester softener application wastewater were presented in Table 4.66.

Table 4.66- Initial characteristics of Polyester softener application wastewater

S.No.	Parameter	Units	Results
1	Total Suspended Solids	mg/L	20
2	Total Dissolved Solids	mg/L	504
3	Turbidity	N.T.U	11
4	pH	--	7.73
5	Conductivity	µS/cm	778
6	Chemical Oxygen Demand	mg/L	114.3
7	Chloride	mg/L	41.1
8	Total Hardness	mg/L as $CaCO_3$	358.7
9	Total Alkalinity	mg/L as $CaCO_3$	377.2
10	Silicon	mg/L	12.98
11	Iron	mg/L	0.98
12	Calcium	mg/L	70.8
13	Zinc	mg/L	0.10
14	Magnesium	mg/L	34.7
15	Copper	mg/L	0.01
16	Nickel	mg/L	0.06

17	Aluminium	mg/L	0.23
18	Manganese	mg/L	0.06
19	Lead	mg/L	0.15
20	Chromium	mg/L	0.10
21	Sodium	mg/L	39.84
22	Potassium	mg/L	9.38

The cotton and polyester softener wastewater characteristics after treatment with MF and UF are presented in Table 4.67 and 4.68 respectively. The tables represent the retentate and permeate characteristics of MF and UF in both wastewaters.

Table 4.67- Cotton Softener Wastewater characteristics after MF and UF

S.No.	Parameter (Units)	MF Retentate	MF Permeate	UF Retentate	UF Permeate
1	Total Suspended Solids (mg/L)	12	4	10	2
2	Total Dissolved Solids (mg/L)	690	640	654	640
3	Turbidity (N.T.U)	9	7	9	2
4	pH	7.39	7.74	7.63	7.73
5	Conductivity (µS/cm)	749	744	737	718
6	Chemical Oxygen Demand (mg/L)	574.37	578.51	487.59	458.77
7	Chloride (mg/L)	41.1	41.1	43.07	37.32
8	Total Hardness (mg/L as $CaCO_3$)	333.31	330.13	314.26	304.79
9	Total Alkalinity (mg/L as $CaCO_3$)	200.31	213.1	238.67	240.80

In the treatment of cotton softener wastewater, the 87.5% removal was observed in total suspended solids whereas 77.8 % removal was observed in turbidity. The maximum TSS removal efficiency with microfiltration system was 75 % whereas, 50 % removal efficiency was observed with ultrafiltration membrane system, taking MF permeate as feed water for UF system. The maximum turbidity removal efficiency with microfiltration system was 22.2 % only whereas, 71.4 % removal efficiency was observed with ultrafiltration membrane system. With ultrafiltration separation, the removal efficiencies for TDS, conductivity, COD and chloride was observed as 3.6%, 3.4%, 19.5% and 11.3% respectively.

Table 4.68- Polyester Softener Wastewater characteristics after MF and UF

S.No.	Parameter (Units)	MF Retentate	MF Permeate	UF Retentate	UF Permeate
1	Total Suspended Solids (mg/L)	18	12	18	4
2	Total Dissolved Solids (mg/L)	508	504	510	480
3	Turbidity (N.T.U)	13	8	16	1
4	pH	7.34	7.49	7.43	7.62
5	Conductivity (µS/cm)	784	780	772	741
6	Chemical Oxygen Demand (mg/L)	104.08	85.71	118.36	53.06
7	Chloride (mg/L)	43.07	42.1	40.2	38.3
8	Total Hardness (mg/L as $CaCO_3$)	395.2	365	372.99	360.29
9	Total Alkalinity (mg/L as $CaCO_3$)	319.65	343.09	345.22	332.43

In the treatment of polyester softener wastewater, the 80 % removal was observed in Total suspended solids whereas 90.9 % removal was observed in turbidity. The maximum TSS removal efficiency with microfiltration system was 40 % whereas, 66.7 % removal efficiency was observed with ultrafiltration membrane system. The maximum turbidity removal efficiency with microfiltration system was 27.3 % only whereas, 87.5 % removal efficiency was observed with ultrafiltration membrane system. The removal efficiencies for TDS, conductivity, COD and chloride was observed as 7.0%, 4.7%, 53.6% and 6.8% respectively with ultrafiltration membrane system.

The retention rate does not exceed 25 % because of the large pore diameters of the MF membrane. The retention rate for MF membrane comes out to be 25 % for the TSS for the cotton softener application wastewater. The retention rate for MF membrane comes out to be 10 % for the TSS for the polyester softener application wastewater. The microfiltration process was unable to reduce the TDS, because only 3.6 % was reduced, whereas negligible reduction in COD, chloride and conductivity was observed in treatment of cotton softener wastewater.

The silicon concentration before and after membrane treatment remains almost same. The reduction of silicone in the treated permeate did not vary significantly. 1.8 % silicon reduction was observed for cotton softener application wastewater and 4.1 % silicon reduction for polyester softener application wastewater. The silicone softener present are usually stayed onto the fabric with electrostatic attraction, and it was found that only washing and rinsing liquor was polluting the softener application wastewater in both polyester and cotton cases. In another study also, the polydimethylsilioxane is degraded and oxidized into CO_2, SiO_2 and H_2O when adsorbed onto particulate matter from effluent and became part of sludge (Griessbach and Lehmann, 1999). Silicon softener was tried to recover from wastewater by ultrafiltration membrane process but it is not effective to do so. In a study the polyvinyl alcohol was concentrated and recovered as retentate by ultrafiltration in the hollow–fibre polysulfone cartridge (Yeh, 2000). The TMP for ultrafiltration membrane for cotton and polyester softener application wastewaters was approx. 5 bar for each of them. The permeate flux with UF comes out to be 87.19 L/m^2.h and 96.87 L/m^2.h with PSAWW and CSAWW respectively at 28^{o}C. It was also concluded that as the alkalinity of PSAWW feed-water (MF permeate) was high (343.09 mg/L as $CaCO_3$) with respect to CSAWW which is 213.1 mg/L as $CaCO_3$, the permeate flux was tends to decrease when the alkalinity of the respective feed increases. It was also in concurring to the research done by Zhang *et al.* (2014). The flow remains the same hence there is no change in the permeate flux through spiral wound ultrafiltration membrane. The decrease in permeate flux was not observed during the UF operation. Permeate flux is increased when the pressure is enhanced but in result decreases the average rejection coefficient (Watters, 1991). The pH value remains unchanged (~7) for the permeate and retentate feed in both MF and UF treatment. It has been observed that the cotton and polyester softener application wastewaters contain negligible amounts of heavy metals; the heavy metal concentration totally depends upon the textile auxiliaries and softeners (in finishing wastewaters). Metal Concentrations in cotton and polyester softener application wastewater in retentate and permeate feeds of the ultrafiltration treatment is presented in Table 4.69.

Table 4.69- Metal Concentrations in cotton and polyester softener wastewater in UF Retentate and Permeate

S.No.	Parameter (Units)	Cotton Softener		Polyester Softener	
		UF Retentate	UF Permeate	UF Retentate	UF Permeate
1	Silicon (ppm)	13.53	13.38	12.98	12.71
2	Iron (ppm)	0.34	0.30	0.36	0.36
3	Calcium (ppm)	60.7	41.06	66.2	63.6

4	Zinc (ppm)	0.35	0.34	0.01	0.03
5	Magnesium (ppm)	32.69	28.93	32.64	34.35
6	Copper (ppm)	0.02	0.02	0.01	0.01
7	Nickel (ppm)	0.04	0.04	0.03	0.03
8	Aluminium (ppm)	0.03	0.02	0.01	<0.01
9	Manganese (ppm)	0.01	0.01	0.03	0.04
10	Lead (ppm)	0.26	0.23	0.24	0.26
11	Chromium (ppm)	<0.05	<0.05	<0.05	<0.05
12	Sodium (ppm)	43.59	39.54	38.26	38.44
13	Potassium (ppm)	8.80	7.78	9.08	8.97

Volumic reduction factor (VRF) for cotton through MF and UF was 18.5 and 24.1 respectively whereas for polyester through MF and UF it comes out to be 21.6 and 17.2 respectively. Volume measurement of the permeate and retentate during cotton and polyester softener finishing wastewater treatment for finding out the VRF was presented in Table 4.70.

Table 4.70- Volume measurement during cotton and polyester wastewater treatment

S. No.	**Treatments**	**Volume (Litres)**	
		Cotton wastewater	**Polyester wastewater**
1	Untreated wastewater	102	108
2	Microfiltration- Retentate	5.5	5
3	Microfiltration- Permeate	96.5	103
4	Ultrafiltration- Retentate	4	6
5	Ultrafiltration- Permeate	85	87

4.4.4 Treatment scheme for chloride and sulphate rich dyebath wastewaters

Dye bath effluents, especially from the dyeing of cotton, polyester and polyester-cotton blend textiles, should be segregated from all other wastewaters. The segregated wastewater should be decolourized and concentrated to desired TDS level. Decolourization of the wastewater can be done by either of the following methods:

- Electro-flocculation: Chloride rich cotton dye bath wastewater can be easily decolourized by this process but not the sulfate containing wastewater.
- Coagulation/precipitation-flocculation-settling treatment: Cotton dye bath effluent can be easily decolorized with alum at slightly acidic pH (5.5 to 6.0).
- Microfiltration, Ultrafiltration and Nano-filtration: There are reports of using this approach for the decolourization. Sulphate rich cotton dye bath wastewater can be easily decolourized by this process

Concentrating the decolourized effluent becomes important otherwise all the decolourized effluent cannot be reused because of relatively larger volume of the effluent. The concentrated decolourized effluent may be used in the preparation of the salt solution and dosing into the dyeing machine. Vacuum evaporation in a multiple effect evaporator may prove very appropriate for the concentrating. The vapors can be recovered as foul condensates, which also can be reused in the textile processing. Treatment scheme for chloride rich dyebath wastewater and sulphate rich dyebath wastewater was presented in Figure- 4.26. After the removal of color and other pollutants with the respective pre-treatment processes i.e. electroflocculation and membrane processes for sulphate rich dyebath wastewater and chloride rich dyebath wastewater respectively.

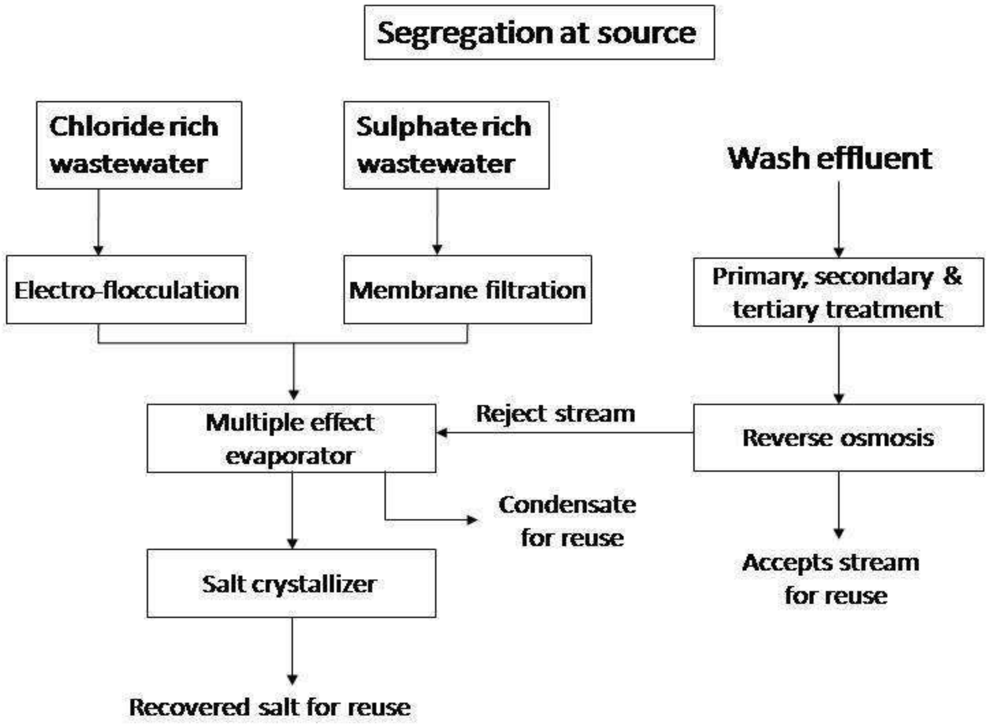


Fig. 4.26 Treatment scheme for chloride rich dyebath wastewater and sulphate rich dyebath wastewater

The treated dyebath wastewater was collected in a collection tank of variable capacity i.e. 20 m^3 to 50 m^3 which further depends upon the quantity of dyebath. The wastewater is further treated through multiple stage evaporation system (multiple effect evaporator) consisting of 4 stages or as required. The number of effects enhances the economy of an evaporator system. The condensate formed through MEE can also be reused. The evaporation inside the MEE continues till the density of water reaches 1.24 mg/cc. When the concentrate achieves the required density, then it is suitable for the water crystallization process in crystallizer for recovery of common salt as well as glauber’s salt. The mixed salt crystallizers can be used to attain zero liquid discharge (ZLD) criteria. The water having the crystals was further transferred to another crystal collection tank. After purity check it was again reused in the subsequent steps of dyeing process.

CHAPTER 5

CONCLUSIONS

It deals with the investigations and summarizes the findings of the study which includes the environmental concerns associated with all the major and minor activities in textile processing units. The implementation of the respective process modifications steps suggested was elaborated which results in savings in water, energy and chemicals. The selected treatment technologies were analyzed. On the basis of the results from the present study, the following conclusions are drawn.

5.1 Environmental analysis of industries and strategies for wastewater management

- The environmental analysis of textile processing units was conducted which includes the core, supporting and peripheral activities of respective processing units. The machinery/equipments and other infrastructure facilities was surveyed and listed accordingly. The quantity and type of fabric, yarn and fiber which undergoes processing was also elaborated. The processing steps includes dyeing of fabric i.e. cotton (white, light & medium and dark shades), polyester (light & medium and dark shades) polyester-cotton blend (light & medium and dark shades); yarn and fiber i.e. acrylic yarn and acrylic fibres was thoroughly studied. The chemical consumption for each textile processed was quantified separately. The remarks regarding process modifications to conserve water, energy and chemicals and to minimize wastewater generation was described.
- The points of water use i.e. steam and cooling water was also identified. The characteristics of specific streams were also analyzed to know the exact strength and reuse potential. The in-plant measures and strategies for waste minimization was

identified and suggested accordingly to conserve water and to minimize wastewater generation i.e. by modifying the scheme of scouring and dyeing to eliminate overflow cooling and washing strep and also to reduce the number of processing steps and to recycle the wastewater generated at downstream steps in upstream steps. The dedicated cooling water system was described which can be put up in operation and the return cooling water should be used in place of process water. The steam condensate should be segregated and reuse as boiler feed water. The treated low and medium strength wastewater should be used in subsequent textile processing steps wherever feasible.

Industrial unit-I

- The production capacity of industrial unit-I was 16000 kg/day of fabric, yarn and fiber (2 ton cotton white and 2 ton cotton coloured fabric; 8 ton polyester and 1 ton polyester-cotton fabric; 1 ton acrylic yarn and 1 ton cotton cones; and 0.5 ton acrylic and 0.5 ton woollen fiber). It have 9 soft-flow dyeing machines amounting to 3150 kg/batch dyeing capacity, 3 cabinet dyeing machines amounting to 180 kg/batch capacity, 2 cone dyeing machines amounting to 750 kg/batch capacity, 2 top dyeing machines amounting to 450 kg/batch capacity, and also a winch machine of 200 kg/batch capacity for the processing of 16 ton/day of fabric, yarn and fiber.
- The industrial unit-I was consuming around 1090 kg/day of salt, 330 kg/day of dyes, 221 kg/day of soften chemical, 184 kg/day of peroxide, 160 kg/day of soda ash, 127 kg/day of acetic acid, 89 kg/day of caustic and about 400 kg/day of other chemicals, such as, levelling agents, anti-creasing agents, wetting agents, soaps, water softeners, dye fixers, peroxide stabilizers, etc. Among other inputs lubricating oils and engine oils, boiler chemicals and ETP chemicals are important.

- The circulating cooling water requirement for the processing of 16 ton/day textile in textile processing industry-I was 52.9 L/Kg (846.55 m^3/day) which includes cooling bled out for use as process water of 11.69 L/Kg (187 m^3/day) and the cooling water requiring cooling was 41.22 L/Kg (659.55 m^3/day).
- When only cooling water is reused, the process water requirement was reduced from 496.6 m^3/day (31.04 L/Kg) to 308.6 m^3/day (19.29 L/Kg). When both recycled wastewater and cooling water was reused it reduces to 202.9 m^3/day (12.68 L/Kg) and when cooling water, recycled wastewater and treated effluent was reused, it was further reduces to 130.9 m^3/day (8.18 L/Kg).
- The steam requirement of the core process was 68.08 T/day when industrial unit-I is running at its design capacity. But, by using the return cooling water instead of process water the steam requirement comes down at 52.37 T/day (3.27 kg/kg). The overall steam generation requirement was estimated at 75-98 T/day and the fuel requirement of boiler was estimated at 21-29 T/day. Boiler feed water requirement for generating this steam was estimated at 79-103.2 m^3/day.
- Collection of all the steam condensate wherever generated (including at the steam traps of steam lines) and its use as boiler feed water, and limiting the use of RO water just as a makeup boiler feed water are expected to reduce the RO water requirement by 48-68 m^3/day (from 75-103 m^3/day to 27-35 m^3/day). Further, use of RO water plant in place of soft water plant will almost eliminate the need for regeneration chemicals and the generation of regeneration wastewater (the reject stream RO plant will be reused in amenities and in the circulating cooling water system). As a fringe benefit use of RO water and return steam condensate will be reducing the boiler blow down wastewater generation.

- When in-plant measures was implemented i.e. by eliminating overflow cooling/washing and reducing the number of scouring and dyeing steps, around 100 m^3/day of water was conserved. 107 m^3/day of water was conserved and around 107 m^3/day of wastewater generated was reduced when segregation and reuse of recyclable wastewater was implemented. The 72 m^3/day of treated low/medium strength dye wastewater was used in place of process water in polyester and polyester- cotton blend dyeing process. Further, this is expected to have the fringe benefits like reduced chemical consumption.
- The wastewater generation was estimated at 1348.8 m^3/day (84.32 L/Kg) without implementing any modifications. By implementing only cooling water and steam condensate segregation, the wastewater generation was reduced to 63.6 % i.e. 490.29 m^3/day (30.64 L/Kg) and when all the suggested measures was implemented, the wastewater generation was further reduced to 382.71 m^3/day (23.92 L/Kg) i.e. overall reduction of 71.6 %. 48-50 m^3/day of this wastewater was high strength wastewater needing segregation and handling separately. In addition to these the industrial unit was generating <5 m^3/day of boiler blow-down water and <6 m^3/day domestic wastewater. The industrial unit should reuse all the reject water of the RO water plant both in amenities and in the circulating cooling water system.

Industrial unit-II

- The in-plant measures of waste minimization by suggesting strategies which shows potential to conserve water and minimizing wastewater generation was also implemented in industry-II. This industry consumes 1130 kg/day of salt, 180 kg/day of dyes, 172 kg/day of soda ash, 445 kg/day of caustic, 50 kg/day of peroxide, 128 kg/day of acetic acid and about 75 kg/day of other chemicals, such as levelling agents, anti-creasing agents, wetting agents, soaps, water softeners and fixers. Among other inputs, the lubricating oils and engine oils, and packaging materials (non-woven plastic sheets and polyethylene) are important.

- The actual scheme of scouring and dyeing of cotton fabric and polyester has estimated to consume 217.15 m^3/day of process water, 33.41 T/day of steam and generates 213.8 m^3/day of wastewater and it also requires 136.99 m^3/day of circulating cooling water.
- With slight modifications to the scheme of scouring and dyeing processing steps and also by adopting some wastewater recycling and reuse steps, the water consumption and wastewater generation was brought down to 149.7 m^3/day and 146.35 m^3/day respectively which shows 31 % overall reduction opportunity.
- The reuse of treated effluent of polyester dyeing can reduce the raw water consumption by 61.2 m^3/day which further increase about 58.6 % of reduction in wastewater generation. The modifications and the recycle (suggested) scheme also reduces the steam consumption from 33.41 T/day to 32.39 T/day. However, these modifications also increase the cooling water requirement from 136.99 m^3/day to 1019.36 m^3/day.
- Industry-II was generating average about 170 m^3/day of wastewater. This wastewater includes about 24 m^3/day of high strength dye effluent from cotton dyeing, about 125 m^3/day of low/medium strength effluent from scouring and dyeing, <15 m^3/day of domestic effluent and about 6 m^3/day of other effluents from the soft water plant and the boiler.

Segregation of effluents

- Wastewaters generated by the above-said industrial units should be segregated into four streams (namely, a) high strength dye effluents; b) low/medium strength effluents; c) effluent from the utilities and services and d) domestic wastewater in order to facilitate easy treatment and reuse of the treated effluent, to avoid treatment of the otherwise not polluted wastewater from the utilities and services, and to facilitate disposal on land for irrigation.
- Dye baths drained during dyeing of cotton, polyester-cotton and acrylic fabric/yarn/fiber should be segregated as high strength wastewater and treated separately.
- The Low/medium strength effluent should be first subjected to batch physicochemical treatment (coagulation/precipitation-flocculation-settling and filtration) and then to continuous biological treatment in activated sludge process plant. The biologically treated effluent should be filtered, disinfected and reused in the industrial plant, specially, in the polyester dyeing.
- Wastewater from the utilities and services should be mixed with the treated secondary effluent with any treatment for disposal. The domestic wastewater may be subjected to primary treatment in a 2-stage baffled anaerobic reactor and then pumped into the activated sludge process plant for further treatment along with the low/medium strength effluent.

Wastewater management model

- The water and wastewater management model was suggested which encompasses the processing, relative environmental concerns and the opportunities and options for environmental performance improvements for the various dyeing machineries as well as the in-plant measures and waster and energy conservation for the waste minimization. The alternative to overflow cooling/washing was presented which helps in water conservation and minimizing wastewater generation. The treatment scheme for low/medium strength wastewater and high strength wastewater was developed.

5.2 Development of treatment technologies

- The coagulation and flocculation process was tried for textile wastewater by using Alum ($Al_2(SO_4)_3.18H_2O$), Ferrous sulphate ($FeSO_4.7H_2O$) and polyelectrolyte. The factorial experimental design was prepared as per CCD and 4 sets of coagulation experiments were processed. It was concluded that the alum was the better option for achieving the maximum color and turbidity removal efficiency. The color and turbidity removal efficiency of 88.2 % and 79.6 % respectively was obtained when pH was adjusted inbetween 5.5 to 6.0 and treated with 500 ppm of alum. After filtration, the color and turbidity removal efficiencies was observed as 89.6 % and 95.7 % respectively, which emphasizes on the settling process after coagulation.
- In the electrolytic treatment of sulfate-rich textile dyebath dump wastewater, four electrode combinations viz. Fe–Fe, Fe (Anode)–Al (Cathode), Al–Al, and SS–SS was tried. Response surface methodology fitted well the experimental data for Fe–Al electrode combination and gave 75 % and 91% COD and color removal efficiencies, respectively, with 55.3 kWh/m^3 of power consumption. Antagonistic Interaction between voltage and treatment time was observed, which indicated low voltage and higher treatment time for best results. Although, experimental data for other electrode combinations could not be fitted well using regression modeling, under best operating conditions, Fe-Fe electrode combination gave 74% and 97% removal efficiency for COD and color, respectively. Al–Al electrode combination gave maximum COD removal of 61% and the power consumption is lowest among all the four combinations, which suggests Al–Al combination as pre-treatment method. SS–SS

electrode combination was found ineffective in decolorizing the textile wastewater with 42% COD removal (max.) under best operating conditions. The dyebath dump wastewater can easily be reused after the de-colorization treatment and treated water can be used as process water to reduce the consumption of glauber's salt and hence sodium sulfate in the dyebath preparation.

- The chloride rich textile dyebath wastewater was treated efficiently with iron electrodes. At 12 V and 15 min. treatment time the maximum removal efficiency of 98.8 % for color was observed with sludge generation rate of 22.7 g/L at current density of 2598.98 A/m^2 with power consumption of 195.92 KWh/m^3. ANOVA model was significant with Fe-Fe electrodes and optimized process conditions are 1 V and 8.2 min. to achieve 96.6 % color removal efficiency with only 0.46 g/L of sludge generated. TOC removal efficiency was 69.5 %. The NaCl present in wastewater increases the performance of EC process with no additional electrolyte usage. This treated colourless textile dyebath CRWW may be reused for the reconstitution of dyebath without adding NaCl to dyeing recipe. Overall, the electrolytic processes have the potential to treat textile dyebath chloride rich wastewater which thus enhances the reuse potential of treated effluent.
- The textile cotton dyebath wastewater rich in sulphate was treated using microfiltration, ultrafiltration and nanofiltration with spiral-wound module on a pilot scale. The dyebath wastewater with high values of chemical oxygen demand (1573.5 mg/L) and total dissolved solids (~21 gpl) was first segregated from the dyeing processing as dyebath and treated separately using pressure driven membranes in batch process. The highest flux value obtained with UF and NF was determined as 48.439 L/m^2.h and 25.076 L/m^2.h at 30^{o}C respectively. The chemical oxygen demand and color removal efficiencies were 97.6% and 98.9% respectively after Nano-

filtration (NF) treatment. The 80% of the dissolved solutes were recovered in retentate feed of NF, which can be used in reconstitution of dyebath.

- The effectiveness of the microfiltration and ultrafiltration membrane separation techniques in treating softener wastewater was also tried. Ultrafiltration comes out as commercially viable technique to lower the biodegradable and non-biodegradable pollutant from the wastewater. On-site study was suggested because process can run continuously and it may operate under the real conditions. The permeate flux with UF comes out to be 87.19 L/m^2.h and 96.87 L/m^2.h with PSAWW and CSAWW respectively. The Turbidity and Total suspended solids removal efficiencies were 77.8 % and 87.5 % in cotton softener application wastewater and 90.9 % and 80 % in polyester softener application wastewater respectively with MF and UF membrane processes.

5.3 FUTURE RESEARCH

- The air emissions, solid waste, hazardous waste, noise pollution and storm-water management can be a scope of research in textile processing industries.
- The natural coagulants can also be considered and evaluated as coagulants or its aids for textile high strength wastewater treatment which can be effectively use at wider ranges of pH.
- Innovative filtering techniques and treatment steps can be developed which emphasises on the cost effective smaller crystallizer systems. The permeate water can be combined with process water in different ratios to be used in the various textile processing steps.

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