U.S.-Pakistan
Centers for Advanced Studies in Water

Wastewater Treatment and Reuse to Approach Zero Water Discharge in Al-Rahim Textile Industries: Substantial Increase in Water-Use Efficiency in Textile Processing

Final Report 2019

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ACRONYMS AND ABBREVIATIONS

AD	Adsorption-Distillation
AFGI	Artistic Fabric & Garments Industries
AM	Artistic Milliners
ATI	Al-Rahim Textile Industries
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
CPI	Cleaner Production Institute, Pakistan
ETP	Effluent Treatment Plant
F/M	Food to Microbes Ratio
HRT	Hydraulic Retention Rime
MLSS	Mixed Liquor Suspended Solids
MLVSS	Mixed Liquor Volatile Suspended Solids
NO_3^-	Nitrate
PAC	Poly Aluminum Chloride
PO_3^-	Phosphate
PVA	Poly Vinyl Alcohol
PWMS	Processing Water Management System
RC	Recharge Condition
RO	Reverse Osmosis
SDI	Silt Density Index
SEPA	Sindh Environmental Protection Agency
TDS	Total Dissolved Salts
TOC	Total Organic Carbon
UF	Ultra Filtration
USPCAS-W	US-Pakistan Center for Advanced Studies in Water
VFA	Volatile Fatty Acids
YTM	Yunus Textile Mills
ZDHC	Zero Discharge of Hazardous Compounds

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EXECUTIVE SUMMARY

In Pakistan, the textile sector usually goes neglected when it comes to managing its water consumption and wastewater treatment. However, considering the acute water shortage for industries and immense pressure from regulatory authorities and international customers, the textile-related stakeholders have started to focus on maximizing water-use efficiency and development of wastewater treatment and reuse. Targeting the sustainable development goal 6.3 for improved water quality and 6.4 for improved water-use efficiency in textile processing, this project was initiated as an industry-academia collaboration between the U.S.- Pakistan Center for Advanced Studies in Water (USPCAS-W), Mehran University of Engineering and Technology (MUET), Jamshoro and Al-Rahim Textile Industries Ltd. (ATI), for water-related improvement in textile processing and development of wastewater treatment and reuse.

The primary objectives of the study were: i) to analyze and observe the textile processes carried at ATI and progress towards improvement and/or control of the excess water consumption, effective recycling, recovery and reuse, ii) to analyze the process related variation of produced wastewater for developing the operating conditions of wastewater/ effluent treatment plant (ETP) and reverse osmosis (RO) membranes operations, and iii) to explore a viable and indigenous option for the treatment of RO reject water and maximize water recovery. In executing the project, various observations and recommendations were made relating to progress in water-use efficiency in textile processing. For long-term improvement, a processing water management system (PWMS) was developed that provides a comprehensive framework to optimize and control water use as per process and textile goods quality requirements, to adopt and manage on-site water and wastewater recovery and reuse, and to make water-related process modification and maintenance.

By implementing the developed PWMS, process water consumption was reduced to 18% (around 200,000 gallons/day). Secondly, each textile process performed at ATI was analyzed in terms of composition and characteristics of generated wastewater to observe the waste load associated with each process and identification of any critical variation in wastewater quality that could adversely affect the operation of ETP and RO membranes. Thirdly, the operation of ETP and RO membranes were assessed and analyzed to observe their performance and process-related issues with adverse effects. For these, physio-chemical, biological, and membrane separation operations were analyzed to develop efficient and intensive wastewater treatment that could lead to zero water/liquid discharge from the industry. After the detailed investigation of ETP and RO membranes operations with all the faced challenges and issues, various scenarios were developed in which standard operating conditions were identified to

ensure smooth and effective operations. With the initial stabilization of ETP and RO membrane operations, 60-65% recovery of reclaimed water was achieved, and the recovered water was then analyzed and reused in textile processing operations at ATI. Finally, an indigenous and viable treatment method was explored and validated for treating RO reject, which was the adsorption assisted distillation. Through this, the rejected water with high TDS could be separated from a concentrated load of minerals, elements, and dissolved solids via evaporation and adsorption on an adsorbent bed, while the recovered distillate could be used as freshwater in textile processing. With such advancement, the separated concentrate could be easily handled via adsorbent bed backwashing and further concentrate solidification.

With practical viability of on-site water and wastewater management and reuse at ATI, the project addresses policy goals for the textile sector, on the adoption of sustainable water usage and textile productivity, and associated socio-economic development. Moreover, the end of pipe effluent treatment and reuse methods determined in this study could help in minimizing the water and environmental pollution.

1. INTRODUCTION

1.1 Background

In Pakistan, the textile sector is considered one of the main pillars that contribute to the country's economy by employing a high proportion of labor-force and sharing 57% of the total export. A significant proportion of these exports (25-30%) comprises of processed or finished products. The finishing of raw textile materials is performed in the textile wet processing industry involving various processes, i.e., bleaching, mercerizing, dyeing, printing, and finishing. During these processes, intensified use of resources is involved, i.e., water and energy, which is ultimately transformed into waste. Therefore, the textile sector is regarded as the highest contributor to environmental pollution (Daud *et al.*, 2012; Sala and Gutie´rrez-Bouza´n, 2014; Verma *et al.*, 2015). The manufacturing and processing of raw textiles require huge consumption of water, and most of the generated wastewater is disposed of in water bodies without any practical reuse, which is harmful to human and aquatic life (Sulak and Yatmaz, 2012; O¨ zbay *et al.*, 2013). The amount of wastewater produced by textile processing is estimated at 21–377 L kg^{-1} of textile product, depending on the type of the raw material being processed and the nature of machinery involved, i.e., continuous or exhaust processes (O¨ zbay *et al.*, 2013).

In Pakistan, only 15% of the generated municipal and industrial wastewater is treated before disposal (Murtaza *et al.*, 2012). Most of the wet textile industries do not or rarely treat the generated wastewater and ultimately dispose of to the Arabian Sea. Some big export-oriented groups like Gul-Ahmed, Al-Karam, Al-Abid, Lucky, Artistic, Denim, Soorty, Afroze, Naveena, etc., are using the conventional treatment of wastewater and its disposal as per the Sindh Environmental Protection Agency (SEPA) acceptable limits, without employing any practical reuse of partially treated water.

The wastewater produced from textile processes is a mixture of dyes, metals, soaps, solvents and chemical finishes and other pollutants; and its composition and intensity vary from industry to industry, depending on the process sequence, the types of equipment employed, type of textile products, types of chemicals in use, the weight of the textile products, fashion trends, and seasonal variations (Brik *et al.*, 2006; Kehinde and Aziz, 2014). Typical textile processes flow, and the associated pollutant load is shown in Fig. 1.1, adopted from the reported study (Holkar *et al.*, 2016), which accounts for a high pollutant loading in produced wastewater in terms of BOD (biochemical oxygen demand) and COD (chemical oxygen demand), dissolved solids, organic compounds, and metals. The conventional physio-chemical biological processes (scheme given in Fig. 1.2) is most common methods for textile wastewater treatment and involves the use of activated sludge process and extended aeration for the removal of BOD (biochemical oxygen demand) and COD (chemical Oxygen demand), while the obtained treated water still has dissolved solids, ionic and organic load, and not feasible to be reused in textile processes (Kehinde and Aziz, 2014; Holkar *et al*., 2016).

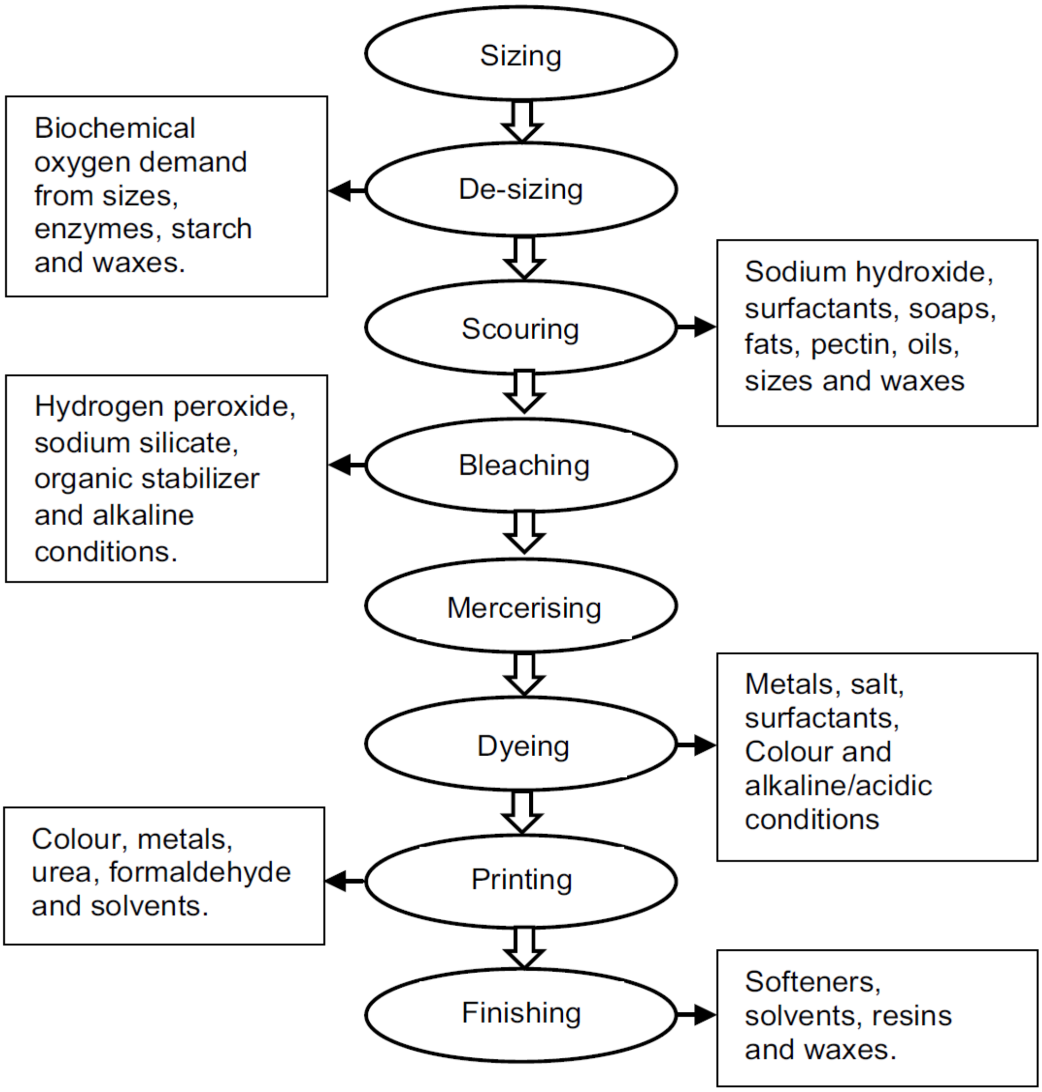


Fig. 1.1: The main pollutants discharged from each step of textile wet processes (Holkar *et al.*, 2016).

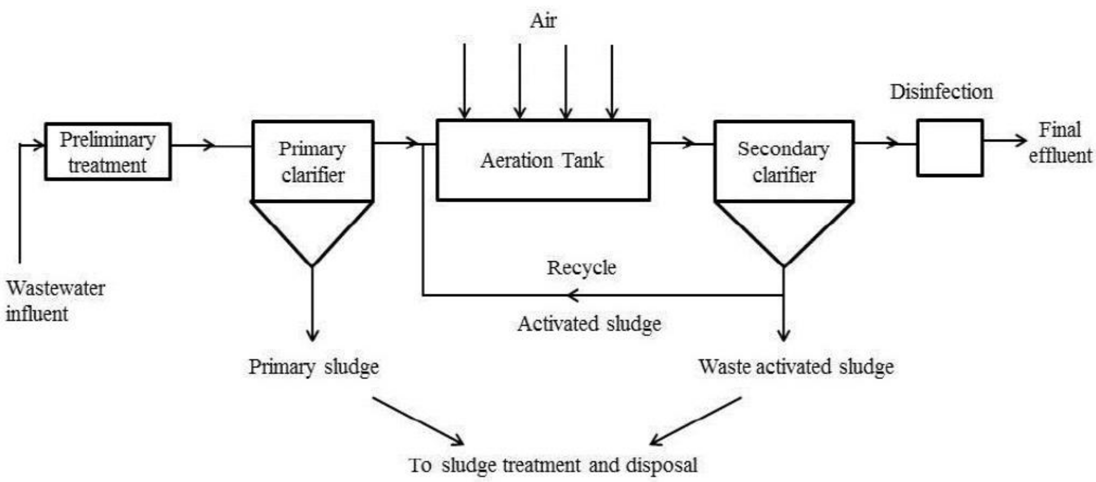


Fig. 1.2: Schematic layout for conventional physio-chemical biological processes.

Additionally, due to high variability in pollution load and intensive use of a variety of chemical compounds, salts, alkalis, soaps, and finishing agents, the intensive and cost-effective treatment of textile wastewater is still considered as challenging (Alma *et al*., 2018). Further, in Pakistan, environmental regulations are not the key drivers for industrial wastewater treatment initiatives; rather, the pressure from international customers like IKEA, Walmart, H&M, Levis, etc., is the main reason to invest in cleaner production practices and wastewater treatment. The international customers have put strong regulations on textile exporters in Pakistan and all over the world for zero discharge of hazardous compounds (ZDHC) in discharged effluent besides emphasizing the water conservation and reuse of treated water after intensive treatment. Besides, pondering the forecasted acute water shortage and high water cost in the near future are also motivating factors to signify the importance of recycling and reuse of industrial wastewater, including textile (UNEP, 2013; Yukseler *et al.*, 2017).

Focusing the challenge of intensive textile waste treatment and reuse, various studies have reported the use of membranes for the removal of colorants, dissolved solids and metals from the textile dyeing processes and further the reuse of the treated water along with the added advantages, i.e., less space for installation, low sludge production and maximum organic loading rate (Thanh *et al.*, 2012; Kim *et al.*, 2013; Bouhadjar *et al.*, 2015; Buscio *et al.*, 2015; Ali *et al.*, 2016). In principle, membrane technology, employs the use of permeable and semipermeable membranes for the reverse osmosis/ultra/nanofiltration of the industrial wastewater, which has proved to be a better alternative to conventional treatment processes with an advantage of low treatment cost (Ali *et al.*, 2016). In Pakistan, considering the water shortage and ZDHC requirements by the international exporters, some of the industries like Yunus Textile Mills (YTM), Artistic Fabric & Garments Industries (AFGI) and Artistic Milliners (AM) have integrated membrane filtration in the conventional treatment sequence and started reuse of reverse osmosis (RO) treated water in textile processes. Fig. 1.3 shows the example of employed membrane-based textile wastewater treatment, production of reclaimed water after several treatments, and reuse in textile processes in YTM, adopted from the study (Ali *et al.*, 2016). While employing membrane-based treatment of industrial wastewater, the membrane rejected water is considered another issue having a concentrated stream of salts, organics, minerals, elements, etc. and has adverse implications if disposed to open water stream. Distillation is a long-established technique for water purification from a wide range of pollutants, i.e., metals, salts, minerals, etc. However, due to high energy input, its usage is limited. Moreover, conventional distillation only deals with vaporization and condensation of distillate without focusing on the handling of solid residues.

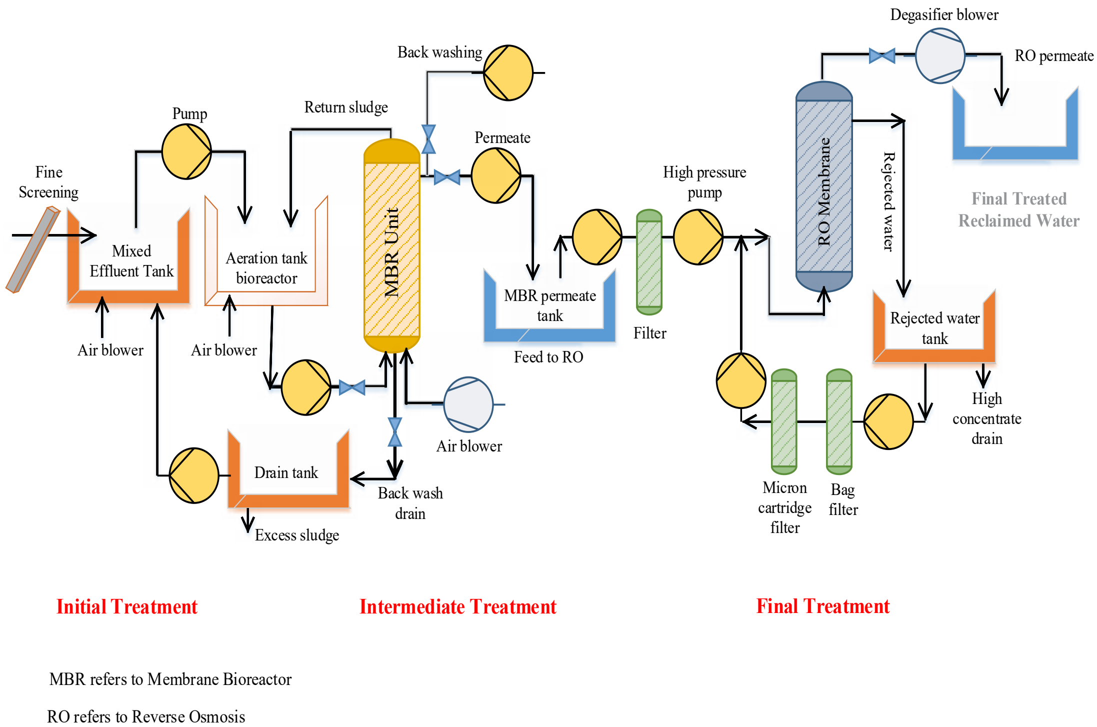


Fig. 1.3: Scheme showing the membrane-based wastewater treatment and generation of reclaimed water for practical usage, adopted from the reference (Ali *et al.*, 2016).

Moreover, the textile sector has been neglected in terms of managing its water consumption and the implementation of cleaner production practices. These practices include on-site water reduction and improving the efficiency of water-related operations. According to the Cleaner Production Institute, Pakistan (CPI), a textile industry having water consumption of 75 L/kg of product or less is considered water efficient, water consumption between 76-200 L/kg are moderately efficient, and those having consumption of higher than 200 L/kg of product are water-inefficient. Moreover, CPI has assessed that in Pakistan, about 53% of textile industries fall under moderately water-efficient and water-inefficient categories. Considering the inefficient water use, the CPI, in collaboration with Netherland Embassy in Pakistan, conducted a study to evaluate and assess the ongoing practices and for further improvement in water and energy conservation in textile processes. It was concluded that 25-30% of textile wastewater pollution load could be minimized, and up to 20% of water consumption could be reduced on-site, i.e., within process operations (Naqvi *et al.,* 2020). It is, therefore, important to carefully investigate and manage the average consumption of each textile process to develop certain on-site methods by which the water consumption could be minimized at process/source.

Further, it is also important to characterize and analyze the textile processes in terms of intensity or quality of generated wastewater because of an associated process to process variation, as some pre-processes, i.e., de-sizing and bleaching resulted in high contamination, while others have a low amount of produced waste. However, this is a common practice to release the highly contaminated water in the mixed stream without employing any on-site treatment, i.e., sieving/physical filtration, to reduce the suspended load. Therefore, analysis and assessment of the primary on-site treatment are necessary for the prior wastewater treatment, to reduce the intensity of the waste before mixing all the wastewater generated from different processes and further discharge for the final treatment.

The possibility of the reuse of treated wastewater for the textile industry has rarely been investigated due to associated higher cost in treating the wastewater and lack of industry-academia collaboration that could support need-based academic research. But, in the near future, water supply is likely to reduce for industries due to forecasted acute shortage in the country's water resources. Therefore, it is necessary to consider certain research-based efforts in providing experimental knowledge for the reuse of the treated wastewater. This joint project with a textile processing industry has highlighted the considerations in making specific policies for managing and mitigating water consumption and its reuse in the textile sector, further to conserve water resources and to provide a steady supply for continuous productivity and developing economy of Pakistan.

1.2 The Project

Focusing on the water and wastewater challenges of the Pakistan textile industry and to improve industry-academia collaboration on industrial water issues, this joint project between USPCAS-W, MUET, Jamshoro, and Al-Rahim Textile Industries (ATI) was initiated through the financial support of USPCAS-W, USAID. The project focused on developing a water management system and adaptation of specific useful methods by which water consumption could be managed on-site, and the development of wastewater treatment system for practical reuse while minimizing the wastewater disposal. The project involved research and development related to the wastewater treatment and reuse to approach zero water discharge in textile processing. The project activities were jointly organized and managed by USPCASW-MUET and ATI. The primary targets of the project were:

i. to optimize the water consumption and to improve water-use efficiency

ii. to characterize textile processes as per the intensity and amount of generated wastewater, for the development of the on-site primary treatment(s) within the processes or generating other sources; to minimize the intensity of waste for the final treatment

iii. to develop the treatment processes/techniques and operating conditions, by which the quality of the reclaimed water could be improved for its effective reuse in textile processes and in minimizing the wastewater disposal, and

iv. to recommend the treatment and handling of RO membranes reject water.

1.3 Hypothesis

In textile processing, the development and implementation of the water management system, improvement in water-use efficiency, effective treatment, and reuse of reclaimed water could help to approach the concept of zero water discharge.

1.4 Objectives

1. To estimate and manage the average water consumption as per the process requirement, to improve water-use efficiency at ATI.
2. To identify and develop on-site water recycling within textile processes, to minimize water consumption at source and further to reduce wastewater generation.
3. To analyze the quality of the wastewater generated by different textile processes, in order to distinguish the intensity of waste related to each process and to identify the waste intensive process(es). Further, to develop and implement methods for waste intensity control at source, to reduce the organic loading in final wastewater treatment, to improve treatment efficiency.
4. To develop the wastewater treatment processes/techniques to be implemented by ATI for the treatment of generated mixed effluent, further, to obtain reclaimed water of desired quality to be reused in textile processes. Also, to jointly approach the concept of zero water discharge through continuous improvement in wastewater treatment processes, to ensure maximum availability and a steady supply of reclaimed water for process continuity.
5. To develop and provide a treatment plan to ATI for consideration of the treatment of generated rejected/brine water after project completion.

2. OVERVIEW OF TEXTILE PROCESSES

2.1 Brief Overview of ATI Processing Section

Established in 1991, ATI is a leading home textile manufacturer and exporter from Pakistan with a modern, state of the art plant and machinery to produce high quality finished towels, bedding, and kitchen linens. Constructed over an area of 38 acres of land at Nooriabad, Sindh, the mill has a vertically integrated setup that allows all production within the premises. ATI is one of the largest air-jet terry weaving, yarn-dyed, and jacquard towel manufacturing entity, equipped with modern continuous-range and exhaust machinery. With an annual capacity of 40 million pounds of finished terry towels, the ATI relies on the latest technology to ensure quality and on-time delivery. With independent power generation and negligible shortages in gas supply, ATI enjoys full capacity utilization. Due to vertical integration, all the processes are under one management. The vertical integration not only gives good control over all steps of production, but most importantly, it also contributes towards efficiency and lower cost of production. Their recent developments for environmental sustainability include recycling of wastes (hot water and hot air) and installation of the largest Textile Effluent Treatment Plant (ETP) in Asia to recycle more than 80% of wastewater from textile processes. Besides, they have collaborated with USPCAS-W for the development of a wastewater treatment plant to improve the process and recycle water efficiency (http://www.alrahimtextile.com/). The processing section of ATI is equipped with continuous and exhaust range machinery. The textile processing sequence is given in Fig. 2.1:

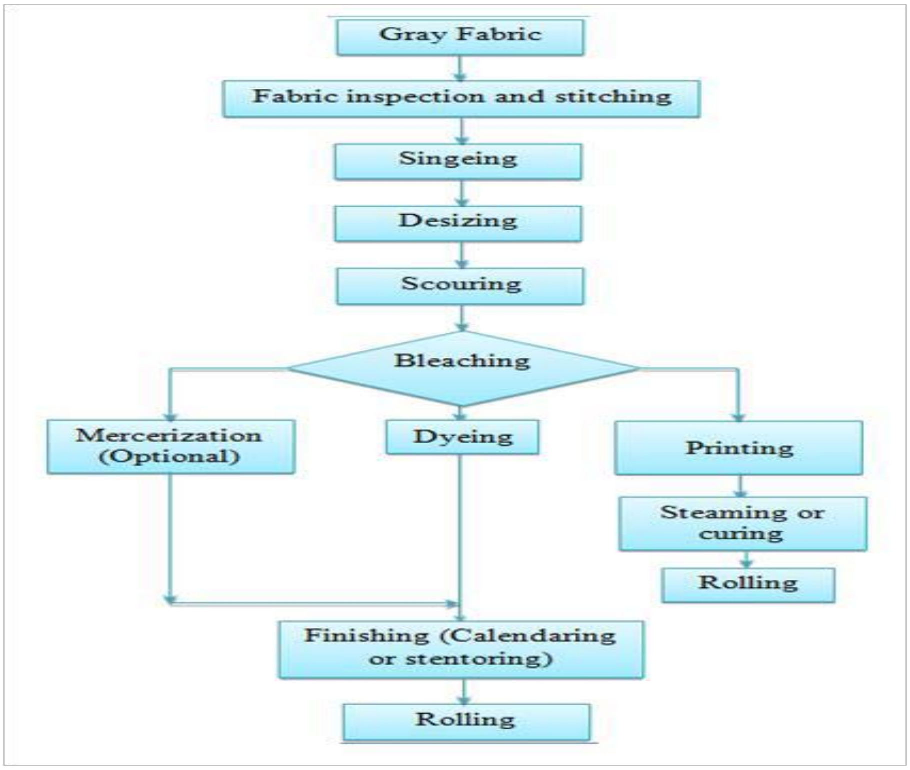


Fig. 2.1: Typical textile processing sequence

2.2 Sequence of Wet Processes

1. Singeing-Desizing
2. Exhaust Scour-Bleach
3. Mercerization
4. Exhaust Dyeing
5. Printing
6. Finishing

2.2.1 Singeing-desizing process

Singeing is the removal of protruding fibers from the surface of the textile fabric through flame burning to improve their surface appearance and to make the surface smooth for printing and dyeing. Moreover, desizing is the enzymatic removal of the starch/PVA sizes that were applied to the warp yarns during weaving operations to avoid yarn breaking during mechanical stress. The removal of size material is the initial step to improve the absorbency and chemical reactions for further processes, i.e., bleaching, dyeing, etc. The scheme of a continuous singeing-desizing machine is given in Fig. 2.2, which shows that textile product is introduced in the machine and passed through flame burners and further conveyed to desizing bath where it carries the enzymes for biological activity, i.e., decomposition of size through enzymatic activity, and finally the textile product is exited and rolled on batcher and left for 12-24 hr, to complete the enzymatic activity. The flame burner is fronted with steel roller to guide and convey the textile product for desizing; this roller gets heated due to exposure to flame. Therefore, it is cooled down by a cooling water stream inside the roller. Afterward, this water is collected and pumped back to the main supply tank. The drain of desizing bath after each cycle release high COD and BOD concentration that ultimately mix with the processing section effluent.

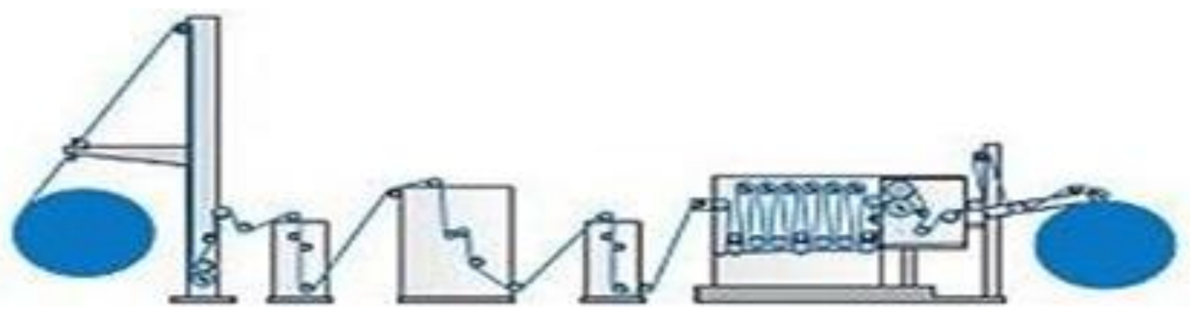


Fig. 2.2: Schematic of continuous singeing-desizing process (http://www.goller-hk.com)

2.2.2 Exhaust scouring-bleaching

The process of scouring is to make textile material highly and uniformly absorbent (removal of natural impurities like wax, fats, oils) by treating the material with NaOH (caustic soda). When oils and fats are heated with a solution of sodium hydroxide, they are hydrolyzed as glycerol and the alkali salts of fatty acid. These salts of fatty acid are soaps, which act as detergents for textile material. Scouring removes almost all the impurities except natural coloring matters, which are ultimately broken down with bleaching agents. Bleaching is necessary for producing white goods either as finished products or for dyeing pastel shades or for printing, by treating with H_2O_2 (hydrogen peroxide) in which atomic oxygen, superoxide anions, and hydroxyl ions perform bleaching action, i.e., oxidation of natural color. In ATI, the scouring-bleach process is performed either on a continuous range counter flow machine or a fully automated exhaust jet machine. On a continuous range machine, the textile product is conveyed to various water and chemical baths for washing and chemical recipe uptake, while the chemical reaction required for scouring and bleaching is obtained in a steamer (with a temperature of 100-102 °C), as shown in Fig. 2.3. The continuous range machine has an advantage of high production and low water consumption as compared to the exhaust process. While on exhaust machine, one lot of textile good (400-1000 kg) is continuously rolled inside a cylindrical vessel filled with water and

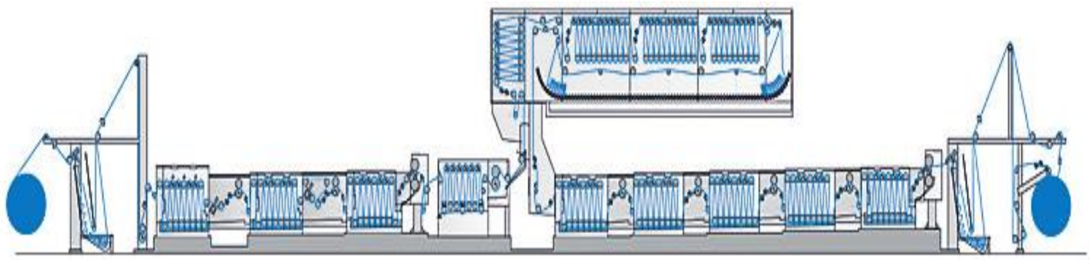


Fig. 2.3: Schematic of the continuous scouring-bleaching process (http://www.goller-hk.com)

chemicals at a certain liquor ratio recipe, i.e., 1:5 or 1:6 (*weight of textile good in kg: the amount of water in liter*). The rolling of textile goods continues inside the vessel until the required bleaching is achieved. The scheme of the exhaust process is shown in Fig. 2.4. The typical chemical compounds to perform scouring and bleaching are caustic soda, H_2O_2, wetting agent, soaps, acids stabilizer, and sequestering agent. The water baths (11 in total) are used for washing/rinsing before and after scouring and bleaching processes and have the temperature of 70-90°C; these water baths are filled with water and continuously recharged with freshwater to maintain the water level and to take out the produced impurities from the process in the form of produced wastewater. The wastewater produced from the scouring-bleaching process has high temperature and pH, a high concentration of dissolved and suspended solids, a COD load of around 2000-4000 mg/L, and a BOD load of around 800-1600 mg/L (Yaseen and Scholz, 2019).

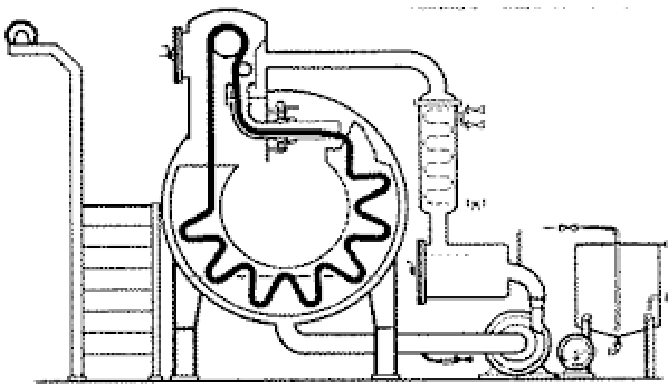


Fig. 2.4: Schematic of exhaust bleaching process (https://www.hse.gov.uk/textiles/high-temperature.htm)

2.2.3 Mercerization

The objective of mercerization is to increase the affinity for dyes/pigments, to give lustrous aesthetic, and to increase the tensile strength and dimensional stability of the textile product. This process is optional and is mostly done for the products where dark and intense shades/colors are required. In this process cotton textile product or its blends dipped in a solution of NaOH (at concentration generally 28 °Be initially, then 8 °Be after in the stabilizing chamber) and under stretched tension (using chains or bow rollers), as shown in Fig. 2.5. On continuous range machine after mercerization, the textile product is washed and finally dried on cylinder dryers. The wastewater produced during the mercerization process has a high temperature, pH, and ionic loading of dissolved NaOH (Yaseen and Scholz, 2019), which could be minimized by recovering the NaOH from mixed wastewater employing evaporation and condensation technology used to separate water from NaOH.

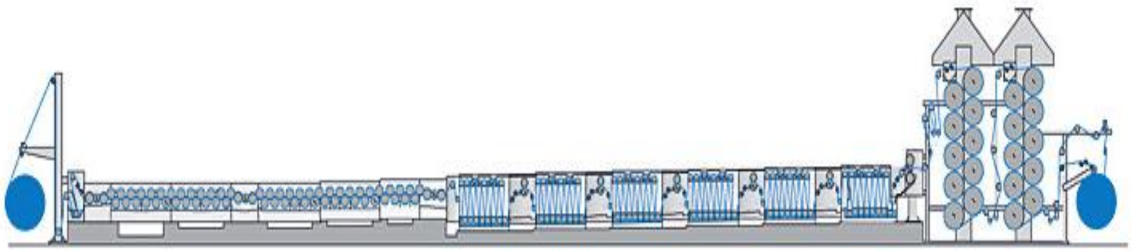


Fig. 2.5: Schematic of continuous mercerization process (http://www.goller-hk.com)

2.2.4 Exhaust dyeing process

Dyeing is the process of uniform, and even coloring of textile products, which is achieved by immersing the textile product in dyeing recipe (comprised of dissolved dye/pigment, alkali, salt, and leveling agent); and then at increased kinetics the color/dye is fixed employing temperature or another form of energy like ultrasonic, pressure, etc. At ATI, the textile products are dyed by two processes, continuous and exhaust ones. In continuous process, performed at pad steam dyeing machine, the textile product is immersed in dye recipe bath and conveyed to steamer, where fixation of dye onto textile product is rapidly achieved due to induced energy kinetics in promoting the reaction and penetration of dye molecule inside/over the textile product. After steamer, the textile product is conveyed to the water bath for washing/rinsing and removal of unfixed dye and finally dried at cylindrical dryers; the process scheme is shown in Fig. 2.6. While in the exhaust process, the textile product is continuously being immersed and rolled inside the cylindrical vessel (shown in Fig. 2.4) containing the dye recipe until the required shade and intensity are achieved. Before dying, bleaching and washing are performed in the same vessel to keep the continuity of bleaching and dyeing process of the same lot. The wastewater produced after the dyeing process has high temperature and pH and is highly concentrated with unfixed metal-containing dyes, alkalis, and dissolved salts (Yaseen and Scholz, 2019).

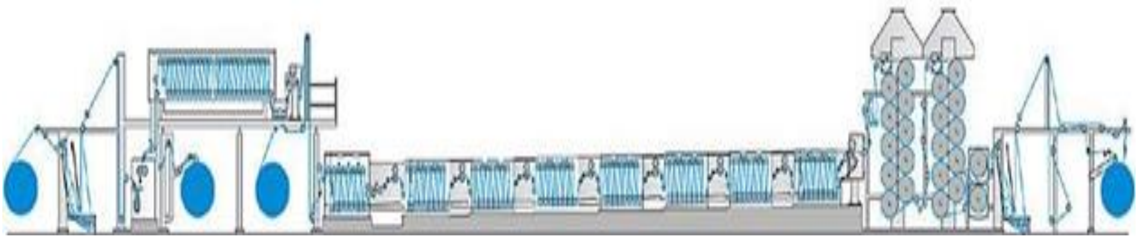


Fig. 2.6: Schematic of continuous pad steam dyeing process (http://www.goller-hk.com)

2.2.5 Printing

Printing is the localized/patterned coloring process, in which the textile products are colored on desired/designed patterns. At ATI there are two rotary printing machines, having different number of rotary screens. The rotary screens are coated with a film, which is then engraved to make any pattern, from which the coloring solution is squeezed out magnetically, to print the textile product. On both machines 12 colors can be printed at a time. Printing is either done using pigments or reactive dyes. Printing patterns are designed in the designing department, which is equipped with the latest CAD-CAM equipment, and the exact design patterning or engraving is performed on the rotary screens. During printing, the textile product is stuck and laid straight over a blanket having the sticky polyvinyl alcohol (PVA) or any other glue, to avoid textile product slippage during printing. The printing recipe includes dye/pigment, thickening agent, binder, urea, alkali, etc. After printing, the fabric is conveyed to the steamer/curing chamber with a temperature of 120-180°C for the fixation of color. The schematic flow of the printing process is shown in Fig. 2.7. The printed fabric is washed and rinsed to remove the unfixed dye and residues of thickener and binder. The produced wastewater after printing washing is loaded with unfixed metal-containing dyes/pigments, alkalis, and organic binder and thickener, also have high temperature and pH.

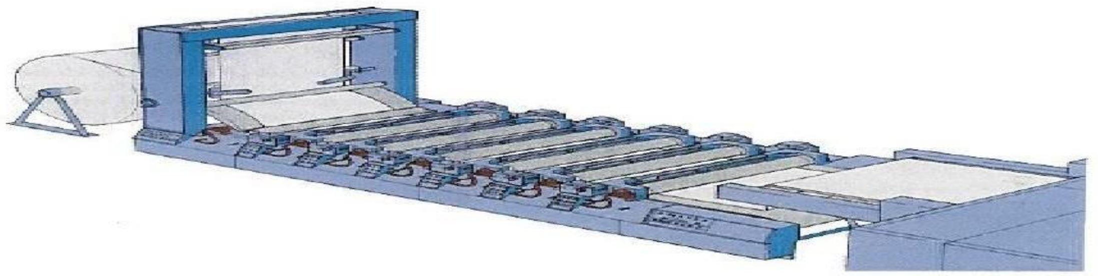


Fig. 2.7: Schematic of rotary screen printing machine (https://www.efi.com)

2.2.6 Finishing

The finishing of textile goods involves the chemical and physical treatments to achieve the desired effect i.e., softness, glow, aesthetic, etc., and also to set the dimensions (length and width) and skew and bow of the textile goods as per requirements. In ATI, the stented machine is used for finishing purposes. Initially, the textile good is immersed in a liquid bath of a certain finishing chemical recipe and then conveyed to the stented chamber, where a combination of heating and chain stretching is applied to the textile good as per the dimensions adjustment requirement. The heating causes softness for stretching and setting the dimension and also helps to achieve chemical reactions of the applied finishes. The schematic of the finishing process at the stenter machine is shown in Fig. 2.8. The produced wastewater from finishing operation is low in quantity; however, the pollution load of finishing agents, i.e., silica-based softeners, could be found in it.

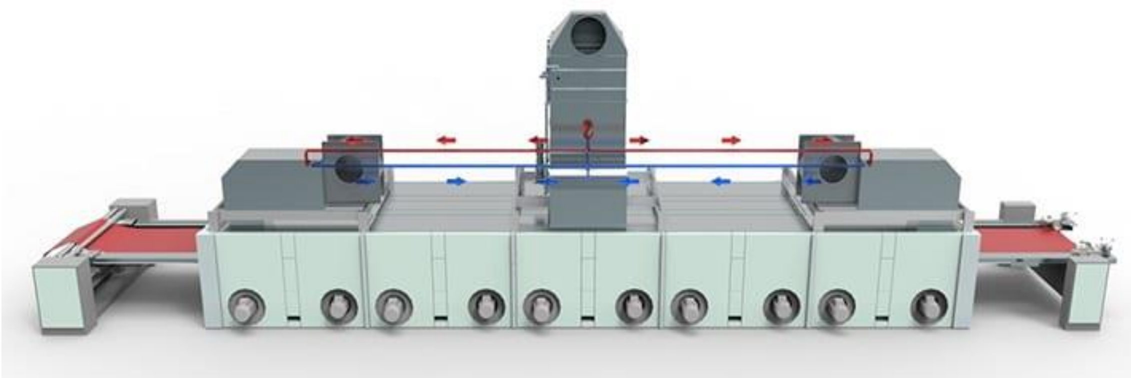


Fig. 2.8 Schematic of the finishing process at the stenter machine (https://www.monforts.de/en/)

2.2.7 Cone dyeing

In the processing section of ATI, cone dyeing is carried out to dye the packaged cone yarns before weaving operation. The round cone on which the yarns are packaged has central opening and perforations to allow the dye solution penetration and diffusion inside the packaged yarn. Like exhaust dyeing of textile fabric, this process is taken in a hot closed vessel where the colored solution recipe (including dye, salt, alkali, leveling agent) is hydraulically pumped inside/outside the round cones for dyeing of yarns, as shown in the scheme given in Fig. 2.9.

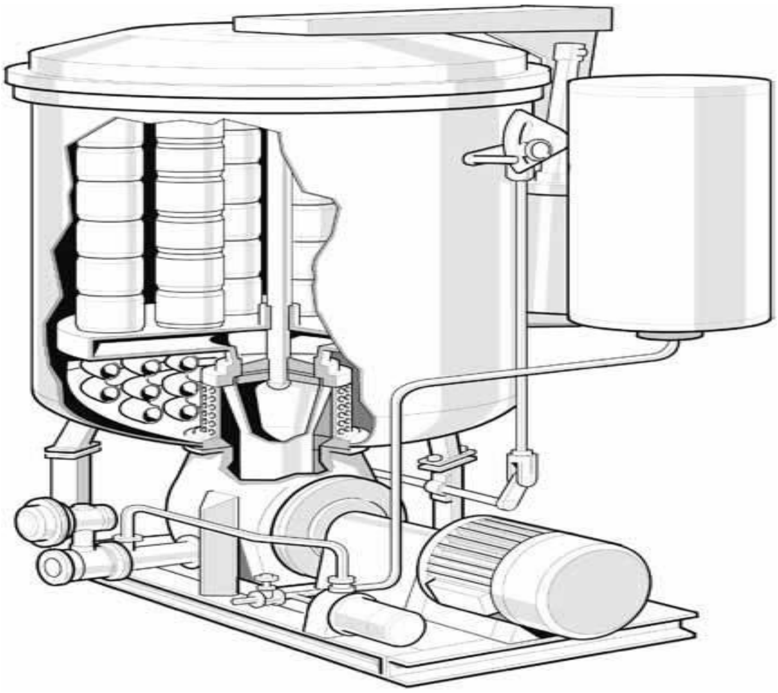


Fig. 2.9 Schematic of cone dyeing process (https://www.hse.gov.uk/textiles/high-temperature.htm)

The produced wastewater from the cone dyeing process has high temperature and pH, high loading of color, COD, BOD, dissolved ions, and suspended solids (loose fibers, lint, etc.).

2.2.8 Wastewater/Effluent Treatment Plant (ETP)

At ATI, the installation of the wastewater treatment plant was completed in April 2018 as a joint project between USPCAS-W, MUET, and ATI, and the operation of ETP was started in May 2018. The ETP plant (layout given in Fig. 2.10) is based on physio-chemical and biological treatment of mixed wastewater/influent. In brief, primary treatment includes the sieve screening for physical sepration of large particles,and a primary clarifier for addition of synthetic coagulant (poly aluminum chloride (PAC)) and pH stabilization. While extended aeration basin for secondary treatment involves activated sludge biological process for COD and BOD removal and at the final stage, secondary clarifier is used for clearing suspended load. After the secondary treatment, the BOD, COD, and suspended load could be reduced to 90-95%, and color removal could be achieved up to 60-80%; however, the dissolved content in the form of TDS has negligible removal. The partially treated water can be disposed of as per SEPA acceptable limits. Moreover, the partially treated water can be utilized at reverse osmosis (RO) membranes for tertiary/intensive treatment to reduce the dissolved and remaining content, i.e., salts, minerals, organics, microbes, etc. At ATI, 3-stage RO membranes are installed for the intensive treatment of partially treated water, and further reuse of the reclaimed/ RO permeate in the processing section.

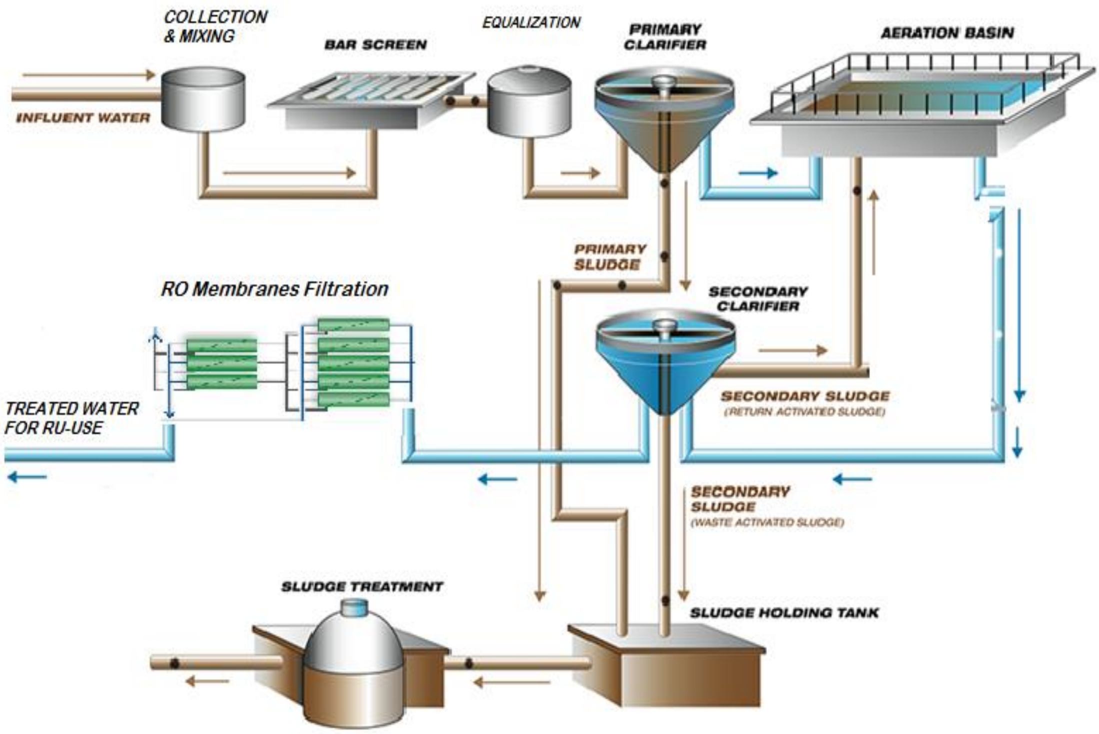


Fig. 2.10 Layout of the effluent treatment plant (ETP) at the ATI, Nooriabad

2.3 Textile Processing Wastewater Classification

As per the various process chemical inputs and amount of produced wastewater, the textile industry wastewater in classified into four categories:

1. **Hard to treat**: This includes the proportion from bleaching, dyeing, and finishing processes that induce metal-containing dye colorants, soaps, and organic finishing agents in the mixed wastewater influent.
2. **Hazardous**: Most of the hard to treat pollutants induced from bleaching, dyeing, and finishing process are also hazardous for aquatic and human life, depending on their reactive nature and stimulated toxicity in a natural environment.
3. **Dispersible**: This includes the proportion in undissolved or semi-dissolved form, i.e., foams, greases, oils, fats, lint, printing pigment, and other types of emulsions resulted from organic compounds and could be found floated in the mixed wastewater. These impurities have adverse impacts on biological and RO treatment and could be removed by employing physical (fine sieving) or chemical separation (coagulation).
4. **High volume**: This includes the produced water generated in high amounts from bleaching, mercerizing, and dyeing processes, and contaminated with dissolved and suspended solids, ions, alkalis, organic, and inorganic compounds.

These four classes are also summarized in Fig. 2. 11.

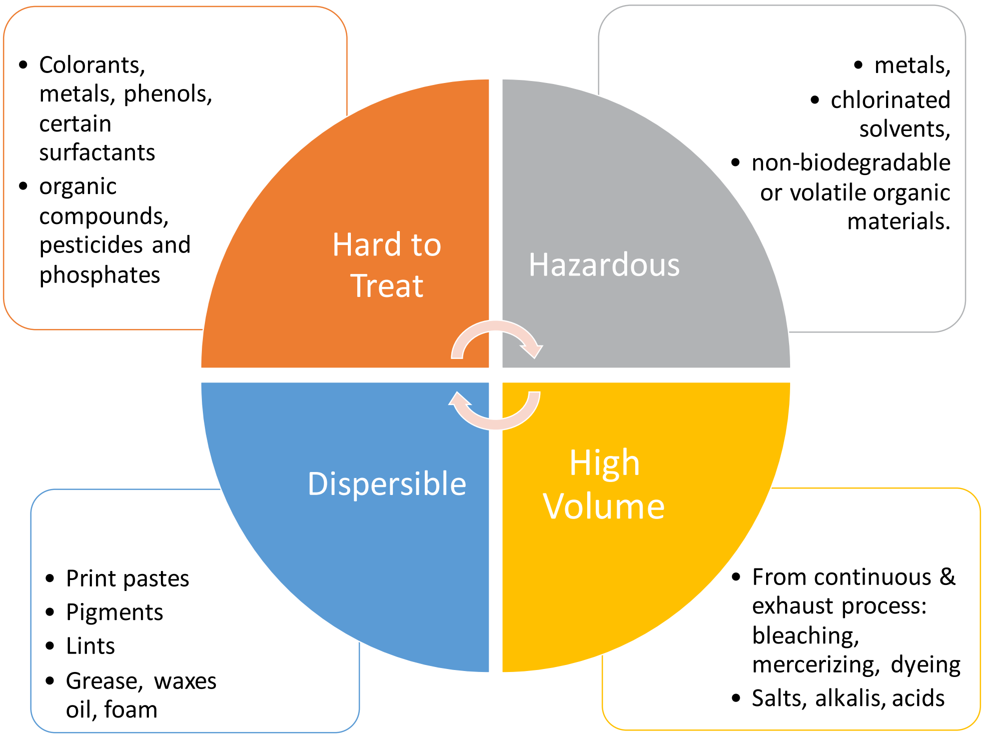


Fig. 2.11 Classification of textile industry wastewater.

3. MATERIALS AND METHODS

The main approaches were to explore the possibilities by which the water consumption could be effectively managed and conserved at source and further to develop the wastewater treatment techniques by which the quality and amount of the reclaimed water could be improved for the effective reuse in textile processes; approaching towards zero water discharge. To achieve these targets, each process at ATI was analyzed for ongoing water usage, actual water requirements, and adjusting the water consumption accordingly. Moreover, to manage the operation of the effluent treatment plant for maximum recovery of reclaimed water, analyses of the generated wastewater characteristics of each process in relation to the mixed effluent wastewater characteristics were made. In upcoming sections, the adopted approaches are discussed in detail.

3.1 Improving Water Use Efficiency at Source (Objectives 1 and 2)

The textile wet processing industry includes a sequence of various continuous and exhaust processes, where water is extensively used, such as bleaching, dyeing, printing, and finishing, also shown in the textile processing layout of ATI in Fig. 3.1. The consumption of water, wastewater generation, and intensity vary from process to process. Therefore, initially, each process performed at ATI was analyzed for the average water requirements. This included analysis of existing water consumption and its comparison with the actual and standard requirement of each process, and monitoring of water flows and cosumption trends in accordance to the processing v/s production rate. Secondly, the available water and wastewater for on-site recycling, recovery and reuse possibilities, chemical/process modification, and water-related maintenance were explored, in order to improve the water use efficiency of each

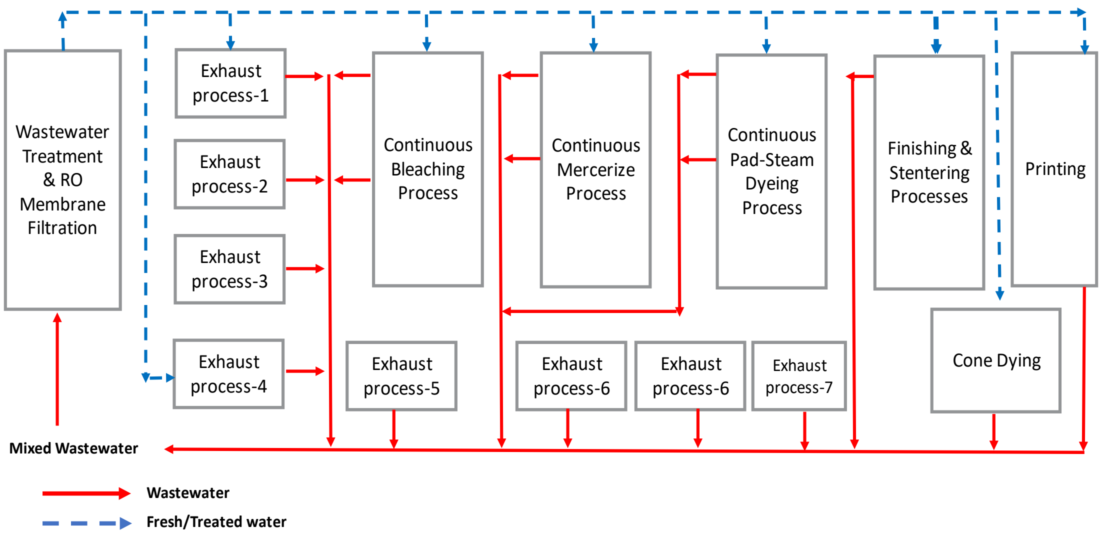


Fig. 3.1: Process layout of Al-Rahim Textile Industry (ATI) processing section

process and to minimize excessive freshwater consumption at the source. These activities led to development of the process water management system (PWMS), by which the consumption of the water and wastewater generation could be minimized and controlled at source. For the PWMS to be effective, five key areas were focused, and activities were followed to work on each:

1. Knowing and adjusting the actual process water requirement
2. Adoption and management of on-site water reuse
3. Adoption and management of cooling water and steam condensate recovery
4. Effective water-related maintenance
5. Water consumption control through process/chemical modification

After the adoption of the developed PWMS, water consumption patterns were compared and evaluated with previous consumption, i.e., before the adoption of PWMS, to assess the quantity of conserved water and minimized wastewater generation.

3.2 Wastewater Sampling and Analysis (Objective 3)

Regular field visits were made for the collection of wastewater samples from the specified outlet/discharge locations of each process, and the mixed effluent; the sampling locations and on-field analyses images are given in Fig. 3.2. The complete layout of textile processes being performed in ATI is shown in Fig. 3.1, along with the specified wastewater sampling ports/outlets, shown as arrows, respective to each process. The wastewater samples were collected from the outlets location of each process and at the point where the effluent wastewater gets mixed after discharge from each process. Also, the wastewater samples were collected from different locations of the combined wastewater treatment plant; the sampling points are shown in Fig. 3.3 that includes before and after equalization tank, after primary clarifier, aeration tank, and before and after clarifier. Some of the wastewater sample analyses viz. pH, conductivity, TDS (total dissolved solids), and turbidity were made on-site, while other analyses were performed at USPCAS-W which included COD, BOD_5, TOC (total organic carbon), heavy metals, MLSS (mixed liquor suspended solids), MLVSS (mixed liquor volatile suspended solids), volatile fatty acids (VFA), NO_3^- (nitrate), PO_3^-, and microbial analysis using plate count and fluorescence microscopy. The details of the analyses, standard methods, and analytic instruments are summarized in Table. 3.1. After the evaluation of wastewater characteristics, the generated wastewater was characterized and distinguished based on the composition, quality, and waste intensity associated with each process.

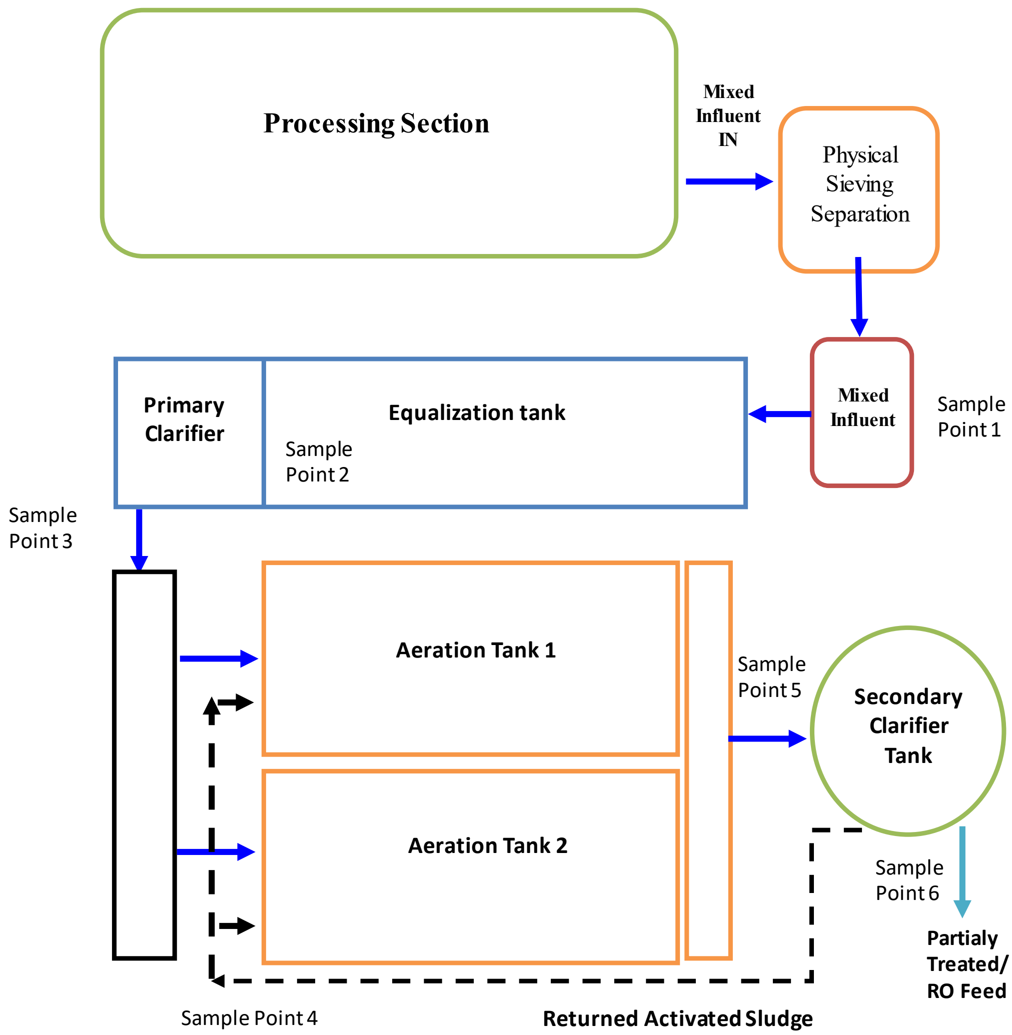


Fig. 3.2: Effluent wastewater treatment plant (ETP) layout and wastewater sampling points

Afterward, certain on-site techniques like wastewater sieve filtration and heat exchangers at bleaching and dyeing processes were explored and brought in operation to reduce the waste intensity, i.e., reduction of suspended solids before discharge and mixing with the main effluent. The wastewater samples were analyzed before and after implementation of the waste reduction techniques, to make the comparison, and to assess the progress of the planned project.

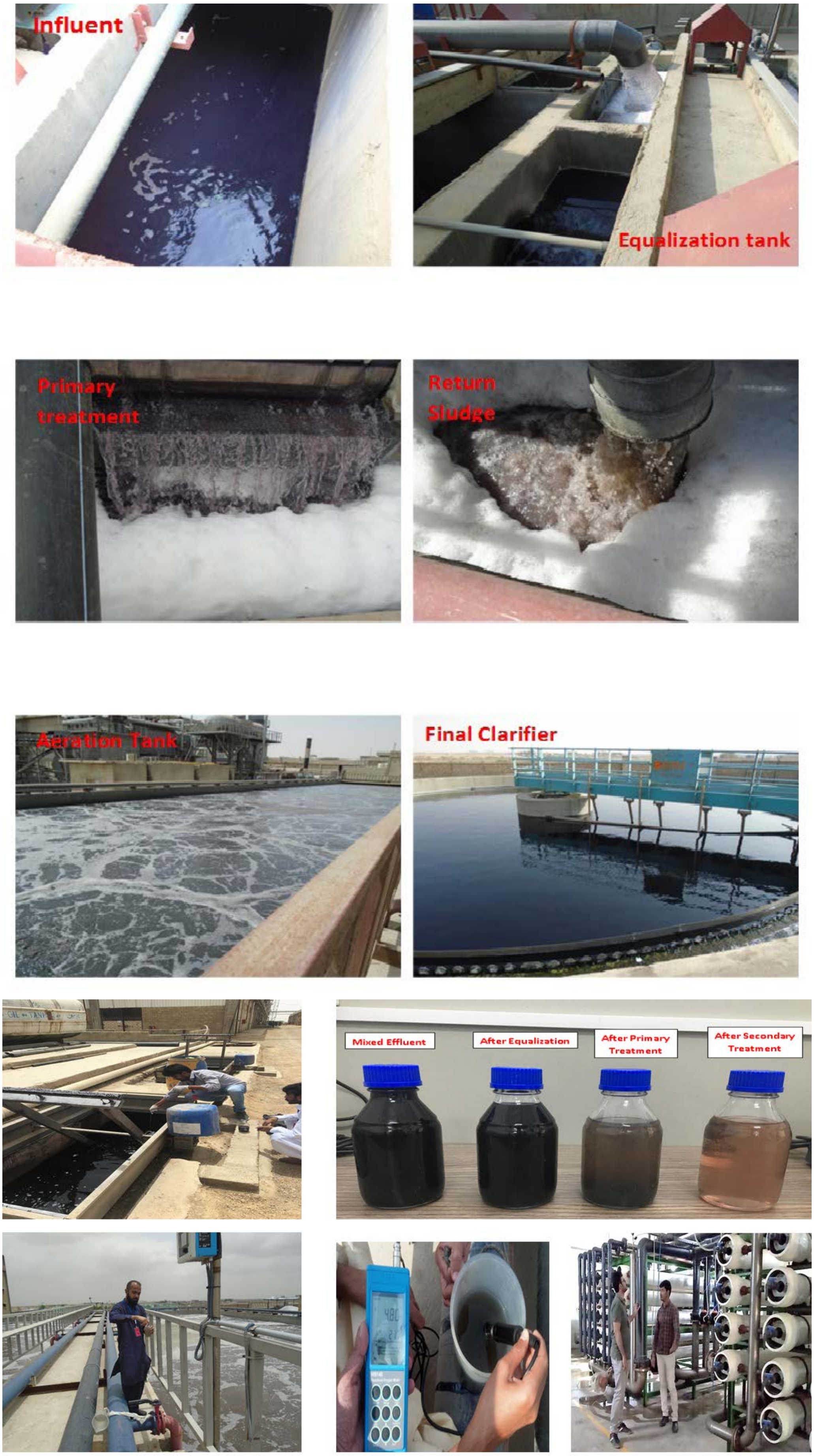


Fig. 3.3 Different sections of ETP operation, influent sampling, and on-field analyses

Table 3.1 Analytical methods followed for analyses of the wastewater samples

Test/Analysis	Standard method	Applied instrument/ equipment
pH	Electrode Method	HI 8424 pH meter, Hanna.
TDS/EC	Electrode Method	HI 8734, Hanna.
Turbidity	APHA Standard Method 2130 turbidity	HI93703 Portable Turbidity Meter
COD	5220 D. Closed Reflux, Colorimetric Method APHA Standard Method	COD Colorimeter
BOD	5210 B APHA Standard Method	HI9146 Portable Dissolved Oxygen Meter
TOC	5310 B. High-Temperature Combustion Method APHA Standard Method	TOC Analyzer
Metals and elemental analysis	APHA 3125 B. Inductively coupled Plasma-Mass Spectrometry (IC-PMS) Method	NexION 350 ICP-MS, Perkin Elmer
MLSS	2540 G APHA Standard Method	Muffle Furnace
MLVSS	2540 G APHA Standard Method	Muffle Furnace
VFA	5560 C. Distillation APHA Standard Method	NA
Nitrate (NO_3^-)	US-EPA Method 352.1 Nitrate Colorimetric Brucine method.	Lambda 365, UV/ Vis spectrophotometer (PerkinElmer)
Phosphate (PO_3^-)	Method 365.3: Phosphorus, All Forms (Colorimetric, Ascorbic Acid, Two Reagent)	Lambda 365, UV/ Vis spectrophotometer (PerkinElmer)
HPC (heterotypic plate count)	9215 APHA Standard Method	NA
Fluorescence microscopy	LIVE/DEAD® BacLight™ Bacterial Viability Kit Protocol	Zeiss fluorescence microscopy
Scanning electron microscopy	Morphology through detection of secondary electron	

3.3 Wastewater Treatment Development (Objective 4)

Based on the preliminary investigation and outcomes of wastewater analyses performed at the processing section and ETP, the operating conditions of ETP were developed that included pump flows, coagulant dose, and stabilization of food to microbes (F/M) ratio. These conditions were developed to make the ETP operation effective for RO membrane treatment to maximize the recovery rate of treated water and reduction of RO reject water. After stabilizing the primary and secondary treatments of ETP, the RO membranes were brought in operation, and the samples were collected before and after RO membranes to compare the performance and recovery rate. The collected reclaimed water after RO operation was analyzed in terms of biological (presence of selective microbes), chemical (COD, TOC, TDS, pH, total nitrogen, metals) and physical (color, temperature) parameters, to assess its feasibility for reuse in textile processes.

Based on the evaluation of ETP and RO treatment analyses and variations in properties (pH, temperature, TDS, COD, BOD, MLSS, MLVSS) of the incoming effluent from processing section, different scenarios were developed in which the standard operating conditions and procedures were explored to mitigate and stabilize the variation of incoming influent and to avoid disturbance in ETP and RO operations.

3.4 Treatment and Handling of RO Membranes Reject Water (Objective-5)

For treatment and handling of RO membranes reject water, a combined adsorption-distillation (AD) technique was adopted, and a lab-scale distillator was designed and developed to separate the distillate from concentrated salts, minerals, and elements; the scheme is given in Fig. 3.4. For easy separation, a mixed adsorbent media is introduced within the distillation chamber that could adjust and enhance the rate of vaporization and could allow distillate and solid separation. Moreover, for energy input, the lab-scale reactor was operated on-field using saturated steam. The steam was introduced through a half-inch coil, inside of which the steam was allowed to pass for heating of reject water to obtain distillation, scheme in Fig. 3.4. The mixed adsorbent media of 6 kg weight, comprising of 50% commercial coconut biochar and 50% sand, was placed below the heating coil. Before applying the mixed adsorbent to the adsorption study, it was washed thoroughly to avoid cross-contamination and any associated input, which is not related to the reject water, i.e., in the form of TDS, etc. For lab scale validation, 60 liters of RO rejected water was tested, at the proportion of 6:1 (RO reject quantity in liters: adsorbent weight in kg). The adsorbent bed was recharged after five cycles of 60 liters reject water distillation and continued up to 2 rounds, i.e., ten cycles. The water quality of reject water and distillate were analyzed for TDS, basic elements (Ca, Mg, Na, Cl, Ni), pH, alkalinity and hardness, to validate the performance of designed distillator and treatment of reject water. After five cycles of distillation, 300 g of the mixed adsorbent material was drawn from the adsorbent bed and tested for recharging at normal room-temperature with 1 liter of de-ionized water at static (recharge condition-1, RC-1) and stirring (300 rpm condition, RC-2), and thirdly with hot water at temperature of 60°C under stirring condition (RC-3), to analyze the release of the accumulated dissolved salts, i.e., measurement of TDS before and after recharge, at each applied condition.

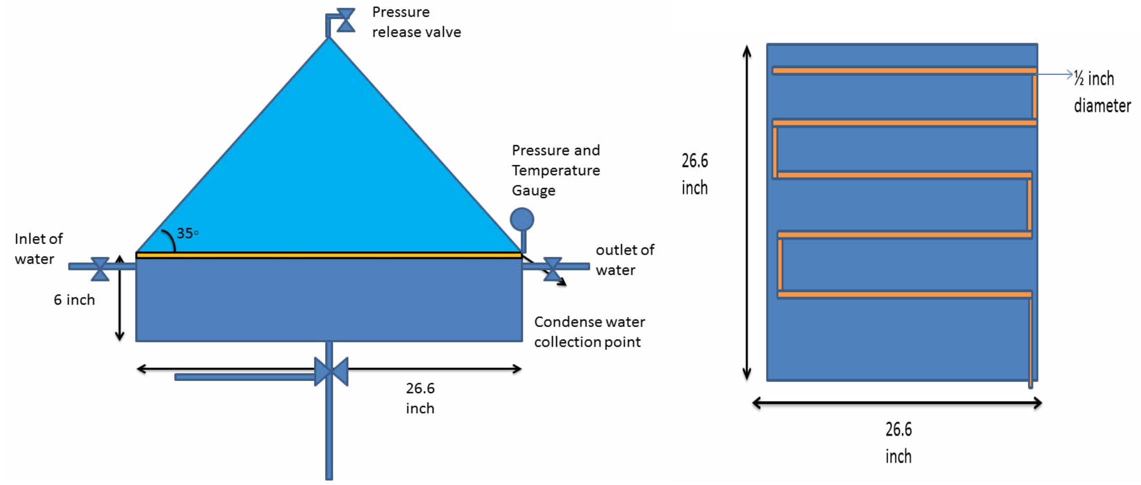


Fig. 3.4: Scheme of the designed and fabricated adsorption-distillator (AD) with equipped accessories and bed and heating coil dimensions

4. RESULTS AND DISCUSSION

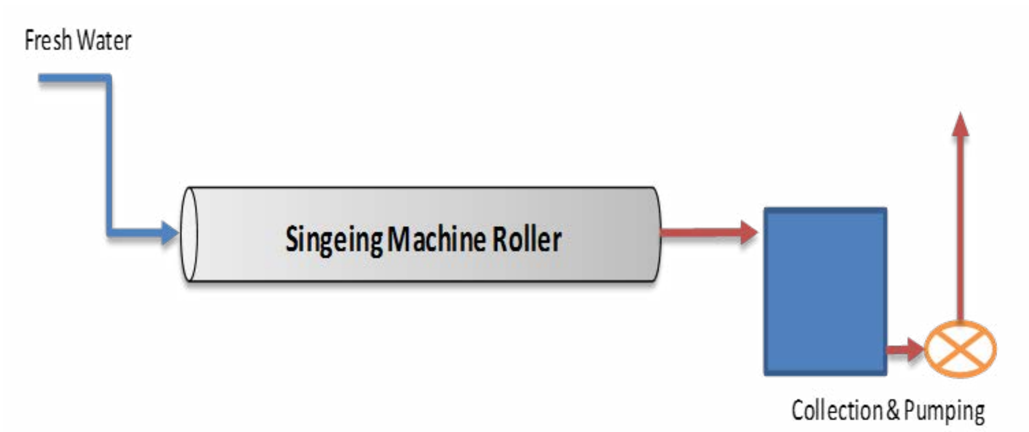
4.1 Improving Water Use Efficiency at Source (Objectives 1 and 2)

Based on the analysis of the water consumption trend of each process and exploring the possibilities of water and wastewater recovery and reuse, the findings were summarized and reported to ATI. And at later stages, activities were followed to adopt the best practices towards improved water efficiency and effective PWMS. The findings were as follows:

1. Various wet textile processes at ATI were observed, and water consumption data were recorded from the water flow meter. The flowmeter data and required machines/processing water consumption were compared to identify excess water consumption. It was found that continuous bleaching machine consumed excess water of around 4.5 m^3/hr than the actual requirement, due to improper functioning of automatic water control valves. The actual water requirement was estimated from the feed water program setting at the machine (details in the upcoming section), which is used to set the water input feed for any process.
2. It was found that water distribution at the mercerize machine was manual, whereby water feed was managed by throttling the manual water valves. Therefore the mercerize machine/process consumption of water was higher (estimated around 6-7 m^3/hr) than the actual requirement due to uncontrolled water flow during machine stop or due to lot change or due to sudden error that caused machine to stop leading to the fresh water wastage.
3. Regarding the exhaust bleaching and dyeing processes, it is was noted that during final washing and pH neutralization, freshwater loading was higher by around 600 liters per rinse/flush because the textile good is already wet and rinsing/neutralization could be done at lower liquor ratio. After reporting these concerns to ATI, batch trials were arranged for a small lot, and the quality of the washed fabric and fabric neutralization were observed at a lower amount of water for flushing/rinsing. It was revealed that processed textiles' quality remained uncompromised even at a lowering of 300 liters of fresh water intake per rinse/flush.
4. At the pad steam dyeing machine, excessive water consumption was observed for cooling water bath placed after the steamer, i.e., due to failure of the automatic feedwater control valve. At a later stage, the valve was brought in operation, which allowed a reduction of freshwater of around 2.2 m^3/hr, based on the observed water flow meter data.
5. The continuous machines/processes, i.e., desizing, bleaching, mercerizing, and dyeing, were analyzed for any provision of process water recycling and re-use.

- It was observed that except mercerize machine, all the other machines had integrated water recycling/recovery systems, provided by the machine manufacturer. At the singeing-desizing machine, the cooling water recovery system (Fig. 4.1 A) could recover cooling water and pump it back to the main water supply tank, but due to pump failure (that pumps water from desizing machine to boilers), the freshwater was continuously being drained (Fig. 4.1 B). At a later stage, the pump was brought in operation, and an estimated freshwater recovery of 4.7 m^3/hr was achieved.
- At the bleaching machine, the recycling system provided for collection and screen filtration of drained water from post washing chambers and then its

A



B

Fig. 4.1: A) Schematic layout of cooling water recovery at singeing machine B) Cooling water recovery pump failure and wastage of cooling water.

recycling in pre-washing chambers, as shown in Fig. 4.2 A. With the adoption of this practice, around 8-10 m^3/hr of water could be saved and reused. However, it was observed that due to chocking of filtration sieves, some amount of water was not reused properly during recovery, as shown in Fig. 4.2 B. At a later stage, the machine workers were instructed to clean the filtration assembly during each shift change (after 12 hrs) to avoid wastage of reuse water during recovery.

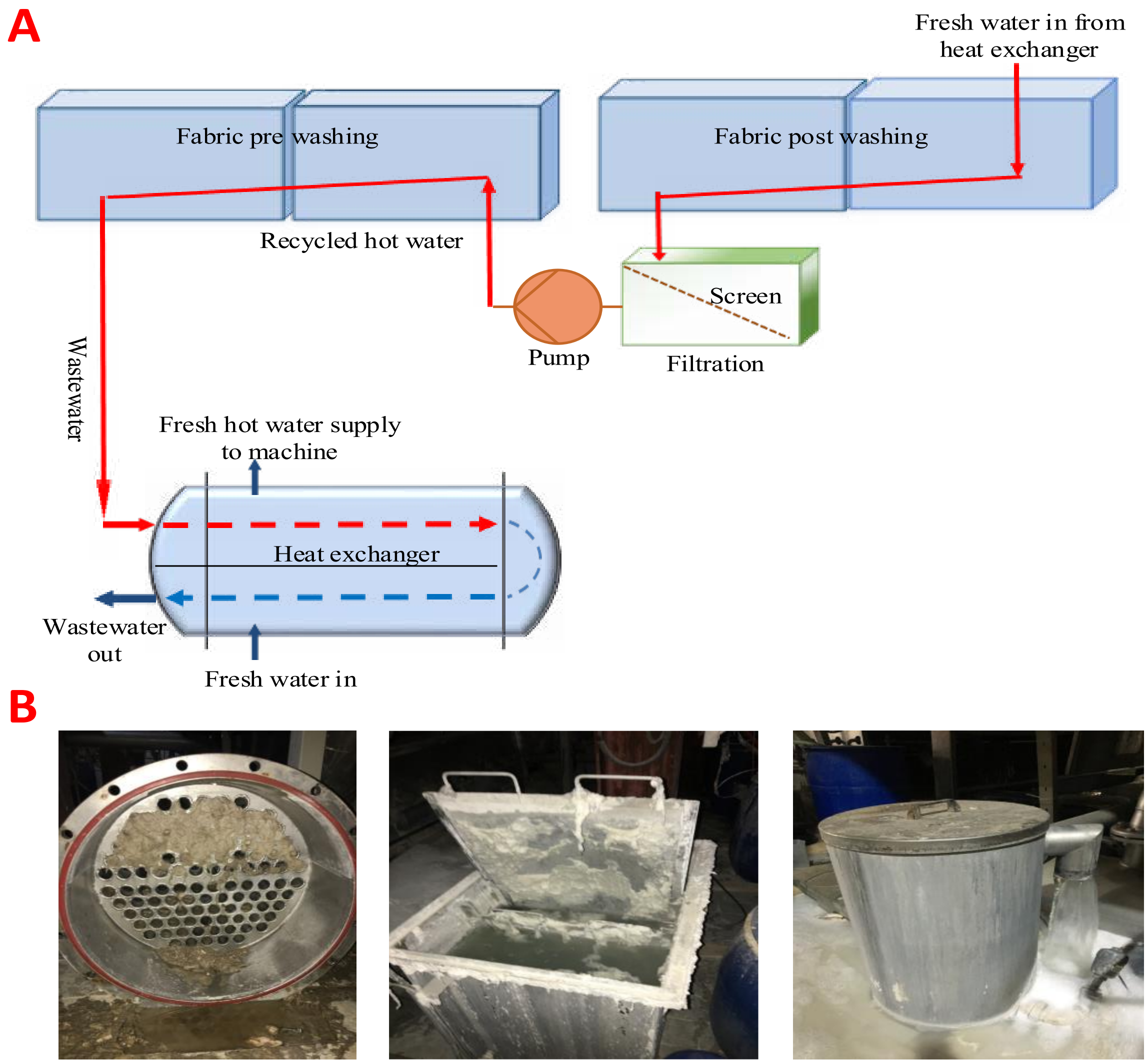


Fig. 4.2: A) Schematic layout of on-site wastewater recovery and reuse at continuous range machine B) Failure of on-site recovery and reuse due to sieves and heat exchangers chocking.

- At the mercerize machine, no water reuse system was found, but it was noted that rinsing water from the last two chambers was drained without being counter flown to earlier three chambers, which resulted in an excessive water feed in these three chambers estimated to around 2.5 m^3/hr. At a later stage, the water was brought in counterflow to earlier chambers, and the freshwater intake was thus reduced. With this practice, on average, 1.5-2 m^3/hr was conserved.
- On-site hot water recirculation system at the pad steam dyeing continuous machine (provided by the machine manufacturer) was not in operation due to maintenance problems. At a later stage, the water recirculation system was put into operation, and recirculation in earlier chambers reduced an excess consumption of 1.5 m^3/hr, based on the observed data from the water flow meter.

- The filtration assemblies and heat exchangers at bleaching machines had a chocking problem, due to which wastewater recovery and reuse was low. These assemblies were cleaned with acidic water, i.e., descaling of organic film cleared the passage of wastewater flowing from these assemblies, which increased the rate of water reuse.
- The sieve screens of mesh size 0.5-1 mm were introduced at the outlet drains of bleaching, mercerization, and pad steam dyeing machines, that allowed separation and removal of suspended solids at their sources. Normally, the sieve screens in earlier use had a mesh size of 2 mm and were not effective in separating the fine suspended particles, fibers, and lints. After the introduction of fine sieve screens of mesh sizes 0.5-1 mm, the TSS load was reduced to 10-15%.
- The saturated steam is mainly used for heating process water. During usage, the latent heat is utilized, and steam is condensed into freshwater commonly termed as steam condensate. This steam condensate being hot and distilled in nature is the significant feed water source of the steam boiler; therefore, it is recovered from various processes through steam condensate return lines and further supplied to the steam boilers feedwater system, as shown in scheme given in Fig. 4.3 A. Most of the washing baths/chambers and steam dryers at ATI are heated using saturated steam, and a huge amount of condensate is produced. During an early observation, the steam condensate recovery pumps at pad steam dyeing and cylinder dryers were found out of order (Fig. 4.3 B), which caused wastage of steam condensate and, as a result, excess fresh/ make up water was being consumed at steam boilers feedwater system. This wastage also caused an increase of mixed wastewater effluent and resulted in

A

B

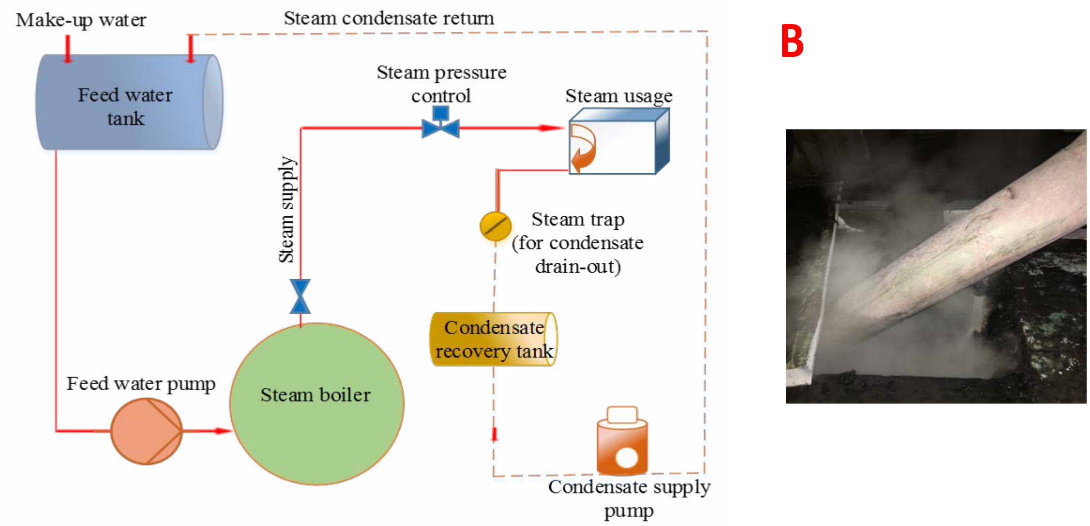


Fig. 4.3: A) Schematic layout of steam condensate recovery and reuse as steam boiler feed water B) Failure of steam condensate recovery pump and wastage of condensate

low microbial growth during ETP operation (detailed discussion in upcoming sections). At a later stage, all the steam condensate recovery pumps were brought into operation, and their regular maintenance was ensured for steady operation. Overall, the 8% (33 m^3/day) steam condensate was recovered to the total steam generation.

6. With continuous efforts in line with the project objectives and implementation of the recommendations as highlighted to the ATI management, the processing water consumption was reduced up to 18% (around 200,000 gallons/day). The main follow-ups were made on reducing the liquor ratio at exhaust processes from 1: 6.5 to 1: 5.5, maintenance of water automatic regulating valves, reducing the rinsing cycles at bleaching and pad steam dyeing machines, water usage as per process and textile goods processing requirements, effective recovery and reuse of post-washing wastewater into pre-washing stages, cooling water recovery at singeing machine, and effective steam condensate recovery.

After preliminary work on improving water-use efficiency at processing machines and recovery and reuse of water and wastewater, PWMS was developed to maintain and ensure the long term water sustainability and efficiency in processing, which comprised of five key areas discussed in upcoming sections.

4.1.1 Knowing and adjusting the actual process water requirement

To fix and adjust water feed setting at processing machines, water balance tool was developed and shared with ATI management, in which the water efficiency of any process/machine could be analyzed by providing the input of machine production per day or per month, water flowmeter consumption data and the average weight of the textile good. The tool is fixed with formulae and quantifies the average consumption per kg textile goods processed, which could be used for estimation of water efficiency as per water feed setting for any process. The water balance tool for the continuous bleaching process is shown in Fig. 4.4 for bleaching process chambers-3, 6 and 10, and 11, which are used for freshwater feed with total and average water requirement of 9-12 liters/kg fabric for washing chambers and an additional 1 liter for chemical recipe and showering. Therefore, total water consumption is estimated to 13 liters/kg on bleaching of a towel, and if 1500 kg towel is bleached in one hour, then total water requirement is estimated to 19,500 liters/hr (~20 m^3/hr). The water balance tool will reveal excess water consumption in case of any failure. Similarly, the water balance tool was developed for the pad steam dyeing process, as given in Fig. 4.5. The estimated average consumption of pad steam dyeing process was recorded as 14 liters/kg of a dyed towel, and if 1200 kg towel is dyed per hour, then total consumption will be 16,800 liters/hr (~17 m^3/hr). Any excess water consumption could be easily assessed in case of any failure of the pump, automatic feed valves, etc.

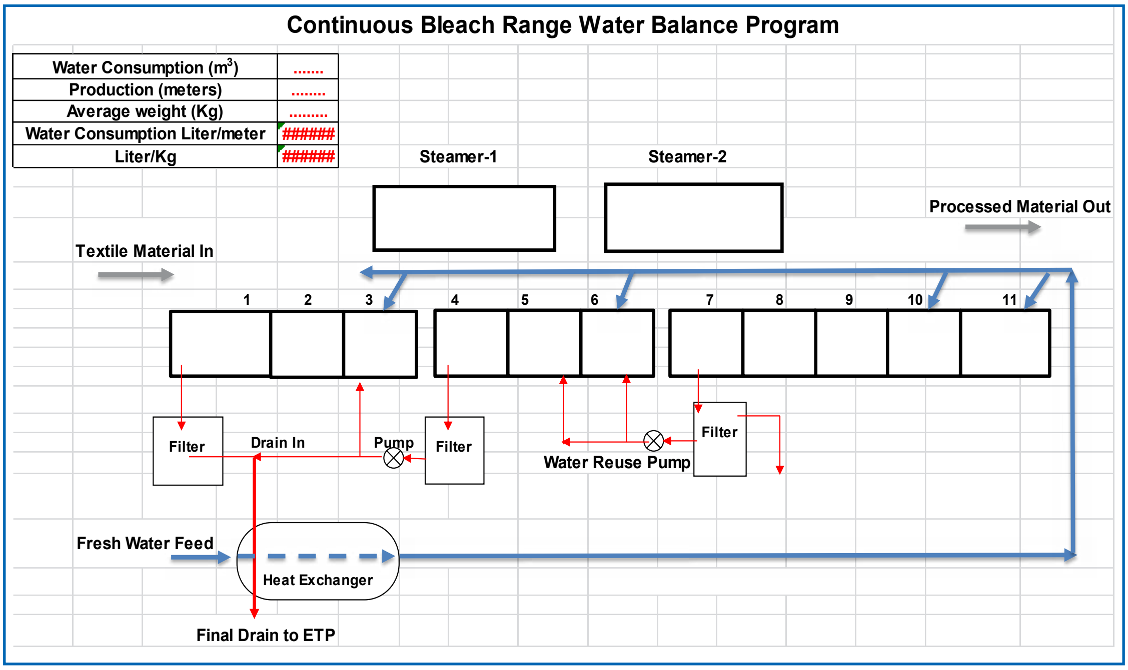


Fig. 4.4: Water balance tool for continuous bleaching range machine

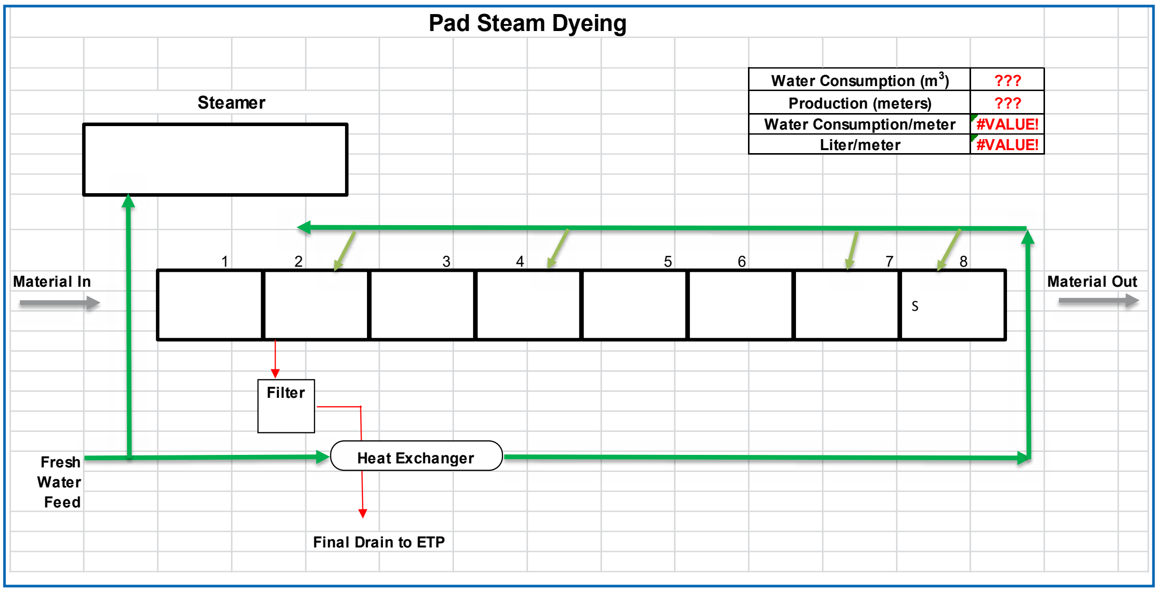


Fig. 4.5: Water balance tool for continuous pad steam dyeing machine

Moreover, a water balance program (shown in Fig. 4.6) was developed for all the exhaust processes, i.e., bleaching, dyeing, washing, and combined bleaching-dyeing-washing, for estimation of water consumption as per requirement. Based on the liquor ratio, the consumption of exhaust combined bleaching-dyeing-washing processes were estimated as given in the example below:

If a textile lot of 800 kg is to be dyed at 1:6 liquor ratio then,

- 800 kg towel: 800*6 = 4800 liters (initial water loading in exhaust vessel)
- Rinsing after bleach = 4800 liters (2nd loading)
- Neutralization after bleach = 4800 liters (3rd loading)
- Loading for dyeing = 4800 liters (4th loading)

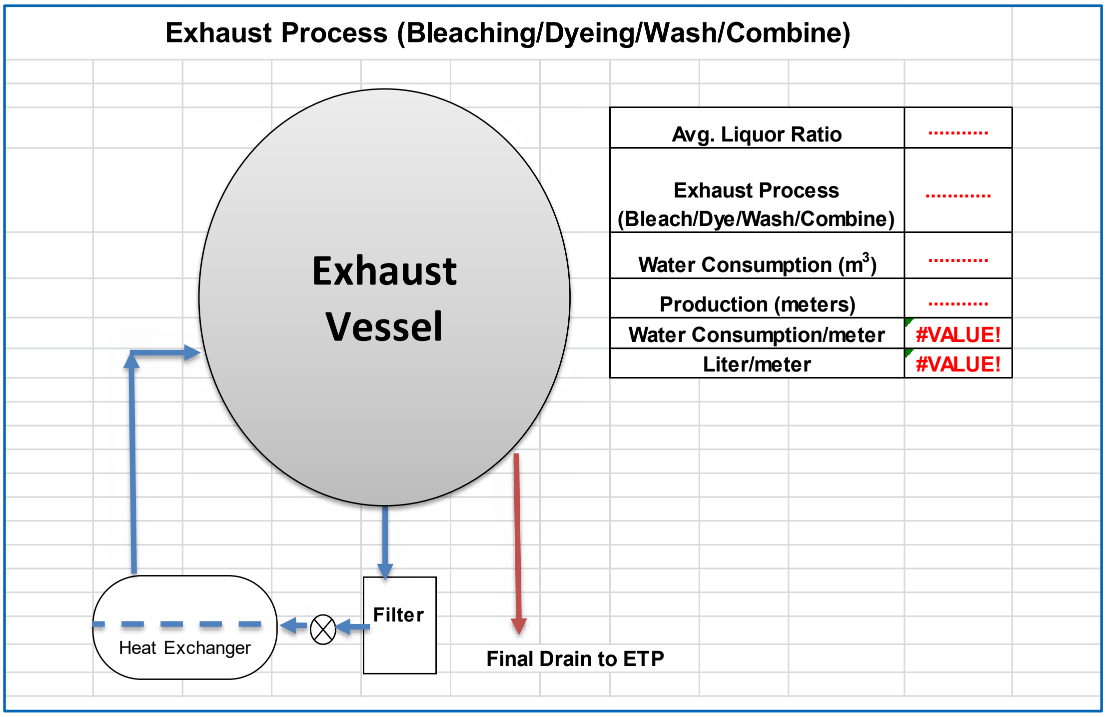


Fig. 4.6: Water balance tool for exhaust bleaching/dyeing/washing/combine processes

- ☐ Rinsing after dyeing = 4800 liters (5th loading)
- ☐ Final neutralization after dyeing = 4800 liters (6th loading)
- ☐ Chemical bathwater amount = 500 liters
- ☐ Total water consumption = 29,300 liters (~ 30,000 liters)
- ☐ Around 37.5 liters /kg dyed fabric

Even after using the required setting of water feed at the machine, sometimes excess water consumption trends were observed. Therefore, to track the excess water consumption, the following checklist was made to ensure water-use efficiency:

- ☐ Proper functioning of water flowmeters
- ☐ Computation of water balance, i.e., consumed water/processed fabric
- ☐ Checking of water leakages
- ☐ Checking proper functioning of automatic water controlling/regulating valves
- ☐ Referring to any major changes of process route/sequencing

4.1.2 Effective management of on-site water reuse

Given the above water balance and management tools, it is now the part of the responsibility of each process staff to ensure and regularly monitor effective management of on-site water reuse with the collection, screen filtration of produced wastewater from post-washing and its reuse/recirculation in pre-washing, and further in-time cleaning and maintenance of filtration screen/sieve, i.e., after every 12 hrs duration.

4.1.3 Effective management of cooling water and steam condensate recovery

On average, the singeing machine needs 1050 gallons of water/hr (at 2 bar water line pressure), which, if not collected, will be wasted. Therefore, this is now the part of the responsibility of singeing machine staff, to ensure the recovery of cooling water and proper functioning of delivery pump, and further in-time reporting to maintenance staff, in case of pump failure.

Moreover, the maintenance staff was bound to regularly monitor the steam condensate recovery pumps located at bleaching, dyeing, exhaust vessels, and cylindrical dryer for their proper functioning and in-time maintenance to avoid steam condensate wastages.

4.1.4 Effective water-related maintenance

For validation of water-related maintenance, a checklist was made that includes:

- ☐ Checking on water leaks, faulty valves
- ☐ Turning off running taps, hoses and manual valves
- ☐ Turning off water feed when machines are not running/stand-by
- ☐ Checking machine automation related to water, i.e., feed controlling valves, water flow meters, level sensors, and reporting to concern in case of any failure.
- ☐ Checking and in-time maintenance of steam traps, water control valves, steam condensate pumps, water re-use/recirculation pumps, water flow meters, water leakages, etc.

4.1.5 Water consumption control through process modification

The process modification is critical for any textile industry because of the already established process routes, chemical recipe, and risk of losing textile goods processing quality. However, to approach the planned targets, i.e., improved water-use efficiency and water conservation in processing, the following initiatives were taken:

- ☐ Reduced single washing/rinsing step during continuous bleaching and dyeing, minimized 2-4 m^3 of freshwater consumption/1000 kg processed towel
- ☐ During the exhaust process after initial water loading and lot feeding in the vessel, the textile goods already got wet. Therefore liquor ratio adjustment could be made during later washing and neutralization cycle, i.e., after 1st loading. Therefore, the liquor ratio was adjusted from 1:6 to 1:5 after 1st water loading, and the adverse effects of processed goods quality (whiteness degree, color shade and depth, washing efficiency) were observed. As a result, 5 m^3 water was conserved /1000 kg dyeing of textile good/towel

- Improved process scheduling employing continuous sequencing of the same shades helped to avoid repeated machine preparation and freshwater feeding in washing and chemical chambers.

Other methods under consideration

- Dye bath reuse from darker shades to lighter shades
- Combined neutralization and rinsing during exhaust dyeing
- Identification and use of chemical fixers that could improve color exhaustion and reduce washing cycles
- Use of metal-free and biodegradable dyes, chemicals, and finishing agents.

4.2 Wastewater Sampling and Analysis (Objective 3)

Various samples of the generated wastewater at different processes/machines were frequently collected and analyzed at USPCAS-W. The samples were characterized in terms of pollutant intensity and wastewater amount. It was observed that pretreatment processes like desizing, bleaching, and mercerize discharged a huge amount of wastewater with high pollution load because these processes remove the natural and artificial impurities from the textile fabric, and high use of chemical compounds is involved. The average TDS of the bleached wastewater was in the range of 2500-4000 mg/L, while average COD was in the range of 870-5300 mg/L. The average TDS of the mixed mercerized wastewater was in the range of 3200-3800 mg/L, while COD was in the range of around 350-600 mg/L.

The mercerizing process is normally carried with the use of only sodium hydroxide (NaOH). Due to the presence of this single compound in wastewater, its recovery is easy through the separation of water from NaOH, due to difference in boiling temperatures of both. The separated water distillate could be reused again in processing or as boiler feed water, while NaOH could be again reused for mercerize process. However, the NaOH recovery system/plant is not present at ATI, therefore highly alkaline and saline wastewater is being disposed and mixed with other effluent. At a later stage, the NaOH recovery plant was purchased; however, the installation will be followed at the end of the project period.

The pollution load of dyeing wastewater was also found on a higher side, with an average TDS of around 2200-3600 mg/L, and COD of around 1400-3250 mg/L. This high pollutant loading was due to the presence of hydrolyzed unfixed dyes and other dyeing auxiliaries in wastewater, i.e., Na_2CO_3, NaCl, and leveling agents, which were used in the dyeing liquor/recipe for color fixation.

In comparison to continuous bleaching and dyeing processes, the exhaust processes have a lesser amount of drained water, i.e., one batch of 400-800 kg textile fabric took around 4-5 hrs to process the textile goods and afterward concentrated water is drained. This wastewater after exhaust bleaching/dyeing is polluted compaired to continuous processed wastewater due to low volume of water associated to the concentrated pollution load. However, after the exhaust process, the processed batch is washed and neutralized with freshwater that dilutes the earlier concentrated waste in the equalization tank. The cone dyeing produced wastewater had similar characteristics as also observed for exhaust dyeing of a towel, while silica-based softener finishing produced wastewater was low in COD but higher in TDS, as compared to the other processes. However, it drained a lesser amount of water (800-850 liters) of the chemical bath after finishing the operation (at stenter machine).

Table 4.1 Average wastewater characteristic of different processes at ATI

Sample ID	COD (mg/L)	BOD_5 (mg/L)	TDS (mg/L)	pH	Temperature (°C)
Continuous bleaching pre chambers	5073	1420	3620	7.7	58
Continuous bleaching mid chambers	2010	833	1740	10.2	56
Continuous bleaching post chambers	2320	340	1560	10.8	61
Mercerizing	1870		12310	11.9	54
Exhaust bleaching	5730	1513	11158	10.3	54
Exhaust dyeing	3217	435	8120	9.6	52
Exhaust washing	872		1365	7.8	57
Pad steam dyeing	1205	317	2240	9.3	59
Softener finishing	1230		6300	7.4	35
Cone dyeing	2640	660	7715	9.75	53

During the project period, one problem of wax/fatty compounds precipitates was observed in the secondary clarifier of the wastewater treatment plant (WWTP), which was creating a problem, i.e., separation of these precipitates. It was identified that the dosage of the wax/lube chemical was high. The dosage was reduced and optimized to resolve the issue of precipitates.

After starting the ETP operation in May 2018, it was under continuous observation by ATI personnel and the USPCAS-W team. Water samples from the defined locations were collected and analyzed regularly. The water quality characteristics of the samples, observations, and recommendations were shared with concerned ATI staff from time to time, to improve the ETP operations parameters and further to increase water recovery at RO membranes and reuse of treated water at processing. Some of the key characteristics of collected and analyzed wastewater samples are given in Tables 4.2 and 4.3.

Table 4.2 ETP wastewater analyses

Sample ID	COD (mg/L)	BOD (mg/L)	TDS (mg/L)	Turbidity (NTU)	Temp. (°C)	pH	MLSS (mg/L)	MLVSS (mg/L)
Mixed influent	590-1540	109-263	1540-8900	37-126	43-56	6.9-10.3		
After equalization	567-965	137-192	1950-3280	35-96	38-43	7.8-9.7		
After primary clarifier	339-537	83-116	2250-3240	29-93	36-42	7.38-8.9		
After aeration	65-227	30-92	2360-3090	630-697	36-39	7.76-8.1	443-2931	180-1992
Return sludge			2410-3140	1220-1840	34-38	7.87-8.83	717-9750	230-3412
After secondary clarifier	63-191	8-17	2371-2930	0.5-8	32-37	7.86-8.7		

Table 4.3 Water analyses of RO feed, permeate compared to reclaimed water reuse limits (Ali *et al.*, 2016)

Analysis	Units	RO feed avg. values	Permeate avg. values	Reuse limits (Ali *et al.*, 2016)
COD	mg/L	60	5	<50
BOD	mg/L	13	0	<10
TDS	mg/L	2650	120	65-300
Turbidity	NTU	3	0	0
pH		8.1	6.7	6.5-7.5
Chloride	mg/L	415	13	
HCO_3^-	mg/L	211	-	
Total Hardness	mg/L	425	0	<10
Calcium	mg/L	141	8	
Magnesium	mg/L	58	5	
Nitrate (NO_3^-)	mg/L	13	-	
Phosphate (PO_3^-)	mg/L	12	-	
Total Alkalinity		491	0	

Some of the key observations and initiatives related to ETP performance and mixed wastewater quality are summarized as:

i. The recorded temperature of the mixed effluent coming from the various textile processes was high, i.e., around 53-58°C and after equalization and primary tank the temperature slightly reduced to 38-42°C in the aeration tank, which is considered high and could negatively affect coagulation and flocculation of influent and stabilization of the bacterial growth in the aeration tank (He *et al.*, 2018; Xia *et al.*, 2018). The high temperature in the aeration tank, i.e., up to 38°C, resulted in reduced biological growth, and low and disturbed MLSS. To reduce the temperature below 35°C, initially, the heat exchanger was installed (Fig. 4.7A), through which the influent was brought in direct contact with fresh cold water, to perform heat exchange before the primary treatment. However, the amount of freshwater required to cool down influent wastewater below 35°C was very high, and heated freshwater was not of any use. Therefore, it was recommended to install a cooling tower to lower the temperature and stabilize the biological growth and optimized coagulation. The installation of cooling water was completed in July 2019 (Fig. 4.7B) but before that, the ETP plant was under observation for maintaining the temperature lowering with a heat exchanger to optimize the operating conditions based on the variation in influent quality and hydraulic flows from primary treatment to the secondary clarifier.

Fig. 4.7: A) Heat exchanger for cooling of mixed influent after equalization and B) Installed cooling tower for cooling of mixed influent.

ii. The problem of low BOD/COD ratio (less than 0.3), which was below the recommended BOD/COD ratio of 0.3 for effactive biological treatment with suficient food to microbes ratio (Chen *et al.*, 2018; Duc, 2019). The designed organic load of the ETP is 2500 mg/L of COD, and 1200 mg/L of BOD, based on which the operation of ETP was supposed to perform. However, after equalization of mixed influent, the average load of COD was observed to be in the range of 900 mg/L, BOD less than 200 mg/L, and MLSS in the range of

800-1400 mg/L, which were very low to stabilize the biological activity with the desired food to microbes (F/M) ratio. To resolve this issue, additional nutrient loading was recommended by adding urea and buffalo dung to stabilize and maintain required microbes for biological activities. The bacterial plating count was performed on aeration tank water sample to see if microbes could grow at lower F/M and BOD/COD ratio, before and after adding nutrients supply. As can be observed from Fig. 4.8A, very little microbial growth was observed with low microbial count for the aeration tank sample without nutrient, however a good growth was observed for the sample with added nutrients in the aeration tank. Some of the identified microbes in the nutrient-supplied plates were domain bacteria (70.4%) and gram positive bacteria (23.5%) (Fig. 4.8B), which were identified using FISH (fluorescent in-situ hybridization) technique based on fluorescence microscopy, similar microbial strains were also identified on textile industry wastewater treatment in reported literature (Franca *et al.*, 2015; Li *et al.*, 2017).

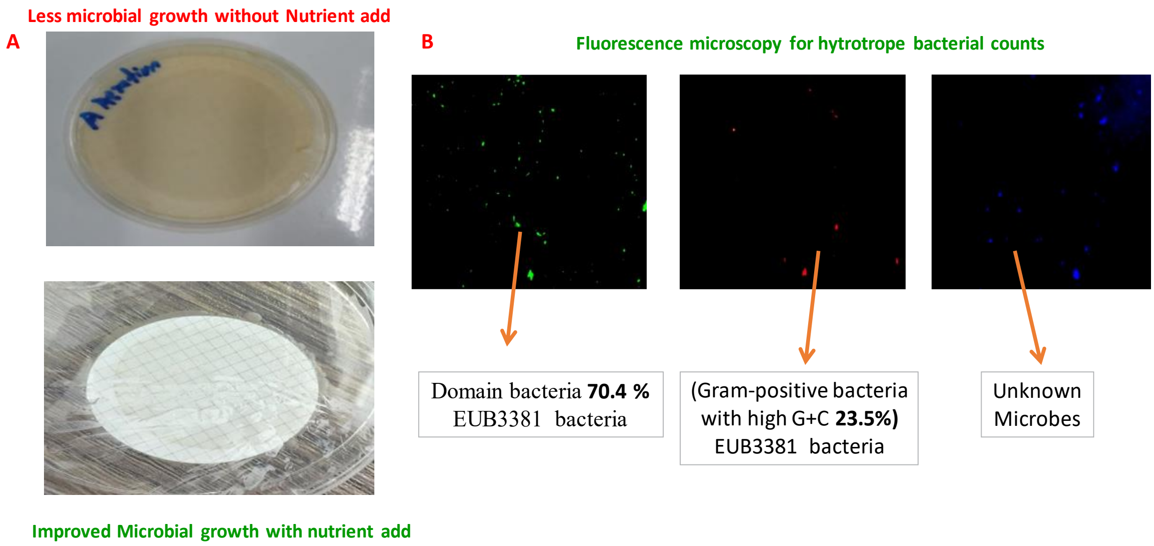


Fig. 4.8: A) Microbial growth analyses with and without added nutrients and B) Identified microbes using the FISH technique based on fluorescence microscopy.

i. A batch study, consisting of 3 cycles, was performed at USPCAS-W, MUET, to determine biological activity at an average COD load of 1050 mg/L using a lab-scale aeration reactor of 100 liters containing mixed influent taken after equalization tank. A microbial culture was seeded on the mixed influent by adding manure dung, whereby 95% COD reduction was achieved within two days that confirmed the un-toxic nature of mixed influent and stabilized biological activity with added nutrients.

ii. Further work focused on optimizing the coagulant dose for maximum removal of organic and suspended load and the associated COD reduction. Jar test was performed to test coagulation and flocculation of 1 liter mixed influent, using different dosages of PAC (synthetic coagulant in use of ETP) and low-cost alum ($Al_2(SO_4)_3$) coagulant, i.e., 10, 15 and 20 mg/L. Alum showed the best results at 10 mg/L dosage in the quick formation and settling of flocs as compared to PAC. After the jar test with alum, there was a 53% reduction in COD. Therefore, to deal such effluent with low BOD/COD and F/M ratios, the efforts were focused to make primary treatment such that coagulation and flocculation and primary settling were more active as to minimize 60% of COD and BOD load through coagulation and flocculation, while remaining load (40%) was targeted to be reduced through biological/activated sludge process by maintaining the MLSS of returned sludge at 800-1200 mg/L of MLSS.

iii. The presence and accumulation of waxy precipitates and emulsion layers were observed in primary and secondary clarifiers and in the aeration tanks that ultimately may transport to RO membranes and could cause a fouling problem. It was identified that these waxy compounds were sourced into mixed influent from printing and finishing department, one was the PVA (polyvinyl alcohol) adhesive/glue applied at printing blanket to hold and stand smooth the textile goods during the printing process, the second identified source was the use of local silica-based softener in finishing process. At a later stage, the drain of the printing department was separated from the mixed influent line, while the local softener was replaced with a high-grade softener, to resolve the matter.

4.3 Wastewater Treatment Development (Objective 4)

Based on the variation of wastewater quality and the issues encountered at ETP, four scenarios were developed in which the standard and optimized operating conditions including pump flows, chemical dosages, blowers operation, additional nutrient add ups, operation of RO membrane, and sand filter backwashing sequence, etc., were defined to keep the ETP operation smooth and also to avoid any destabilization in bacterial growth and activity. The developed scenarios are given in Fig. 4.9 to 4.12. Each scenario suggested as to how to manage the ETP operation in a particular situation. For example, in case of low COD and BOD in influent (scenario-2), the operating conditions will emphasize on high influent flow, low hydraulic retention time (HRT), less dosage of coagulant, limited diffused aeration by blower and nutrients (Jiggery/dung) addition, besides the long-run backwashing of sand filter and RO membranes. While in scenario-3, which is signified by high temperature in the aeration tank, it could be managed by increased coagulant dosage, HRT, and diffused aeration. Similarly, scenario-3 will deal with the operation during the unavailability of chemical supplies, i.e., PAC/alum, through increased coagulant dosage, HRT, and diffused aeration and reduced influent flow for plant stability.

After developing and validating the optimized conditions of ETP, the RO membranes were brought in to operation, to treat the partially treated wastewater intensively and

Scenario-1

IF

- Availability of supplies/chemicals
- BOD: 150-250 mg/L
- COD: 800-1200 mg/L
- Equalization: 15 hours retention
- Influent Temperature: 50-55 °C
- MLSS: 700-1000 mg/L
- Influent pH: 9-12
- Aeration temperature: ≤ 35 °C

Then

- Two Air blowers in operation maintaining DO of 2-3 ppm
- PAC/Alum Coagulant doze: 10-15mg/L
- Acid Doze: as per achieved neutralization
- Influent pump flow: 95-110 m^3/h
- Hydraulic retention: 8-10 hrs
- One bag of 25 Kg Jiggery / Buffalo Dung/ Urea per day in each aeration basin or 10 bags after 5 days.
- Sand filter back wash after 12 hours.
- Cartridge Filter replacement as per need
- Membrane backwash: 8-10 hours (Depending upon permeate quality and flux rate).

Fig. 4.9: Developed scenario for normal wastewater characteristics and defined operating conditions

Scenario- 2

IF

- Chemical/Supplies availability
- **Low COD and BOD loads**
- Influent temperature: 50-55 °C
- Equalization Retention: 15hr
- pH: 8.5-12
- MLSS: 500-700 mg/L
- Aeration temperature: ≤ 35 °C

Then

- One air blower in operation maintaining DO of 2-3 ppm
- PAC/Alum Coagulant doze: 7-10 mg/L
- Acid Doze: as per achieved neutralization
- Influent pump flow: 100-110 m^3/h
- Hydraulic retention: 8 hrs
- Two bags of 25 Kg-Jiggery per day in each basin or 20 bags per week in each aeration basin
- Sand filter backwash 12-14 hr
- RO membrane backwashing 10-12 hr

Fig. 4.10: Developed scenario for wastewater at low COD and BOD loads and defined operating conditions

Scenario- 3

IF

- High Temperature of influent
  > 35 °C in aeration and primary basin

Then

- PAC/Alum Coagulant 15-20 mg/L
- Two blowers in operation
- Influent pump flow: 95 – 110 m^3/hr
- MLSS: 500- 700 mg/L
- Increased Activated sludge return flow: 75% to main influent
- Acid Doze: as per achieved neutralization
- Influent Pump flow: 95-110 m^3/h
- Hydraulic retention: 10-12 hrs
- RO membranes and sand filter flow and back washing as per

Fig. 4.11: Developed scenario for wastewater at high temperature and defined operating conditions

Scenario- 4

IF

- No consumables/supplies availability (PAC/ Alum/Acid)
- Average BOD and COD loads
- Influent Temperature normal (50-55 °C)
- Aeration basin temperature < 35 °C
- MLSS 400-700 mg/L

Then

- Two Air blowers in operation maintaining DO of 2-3 ppm
- Pump flow: 80-90 m^3/hr
- Hydraulic retention: 10-12 hrs
- Jiggery / low dung/urea per week as per requirement
- Returned activated sludge Flow: 60 m^3/hr
- Sand Filter backwash 8-10 hrs
- RO Membrane backwash: 5-6 hrs
- Cartridge Filter replacement as per need

Fig. 4.12 Developed scenario with no availability of chemical supplies at ETP and defined operating conditions.

to get reclaimed permeate for reuse in processing. The analysis of RO feed, i.e., after secondary clarifier, showed that the TDS and COD were in the range of 1760-3340 and 65-112 mg/L, respectively. Before RO membranes, the partially treated water was further put under pre-treatment using a multimedia sand filter and micron filter (5 microns), to avoid fouling or membrane chocking. Afterward, the pre-treated water was pumped to 3-stage RO membranes, in which 1^{st} stage permeate was directly collected, while reject of 1^{st} stage was pumped to 2^{nd} stage, whereas the reject of 2^{nd} stage followed further treatment in 3^{rd} stage. This 3-stage intensive treatment was designed to recover 70-75% permeate and rejection of 25-30%. But, during trial operation of one month, 60-65% permeate recovery was obtained, and membrane and sand filters were back-washed from time to time to maintain the flux and high permeate recovery rates.

The quality of RO permeate water was analyzed in terms of TDS, hardness, calcium, magnesium, sodium, nickel, chromium, and manganese and for the detection of selective microbes, i.e., *E.coli*, Salmonella, Shigella, Vibrio, and *Staphylococcus aureus*, which was done at USPCAS-W, MUET. The results (Table. 4.3) revealed a TDS concentration of around 120 mg/L, with no identification of selective microbes and acceptable limits of all the analyzed elements. After validation of the results as per processing quality criteria and reuse standard limits (Ali *et al.*, 2016), the reclaimed permeate was supplied to the main water tank for reuse in processing. Some of the explored key recommendations for smooth and efficient RO membranes operation are as follows:

- Reduction in chemical ionic/TDS load at processing: optimum use of salts, dyes, and alkali
- Replacement of microfilter with ultrafiltration (UF) membrane for efficient pre-treatment of RO feed and improved cyclic stability
- Drain/by-pass of 1^{st} stage RO-reject without further filtration at 2^{nd} and 3^{rd} stages, while the use of 2^{nd} and 3^{rd} stages for filtration of fresh RO feed rather than the reject of 1^{st} stage.
- The dose of coagulants and operating conditions of secondary processes were optimized for 90-95% organic load reduction to avoid membrane fouling and quick backwash.
- Proper use of an anti-scaling agent, i.e., dozing in the RO feed line, not in the storage tank of the secondary clarifier.
- Timely maintenance and backwashing of the sand filter and RO membranes following the monitored variations in processing influent and ETP operation i.e. COD, TDS, SDI (Silt Density Index).

- Use of caustic recovery for mercerization weak lye (mixed wastewater containing NaOH and water) to reduce the dissolved ionic load in RO feed and for improved permeate recovery.

4.3.1 Project aided improvements

At the start of the project, the amount of average WW generation at the ATI industry was around 5000 m^3 (1,100,000 gallons/day), while after project execution the amount was reduced to 4000-4200 m^3 (880,000-925,000 gallons/day), i.e., an overall reduction of 18% compared to the previous consumption. This reduction was mainly associated with the on-site source reduction, re-use at continuous machines, improved condensate, and cooling water recovery, i.e., after the implementation PWMS. The conserved amount of freshwater from each process is given in Table 4.4. On average, out of 4200 m^3 generated wastewater, 60-65% water is being treated and reused on daily bases (after intensive RO operation) and is being mixed with fresh water in the central storage tank and supplied to processing section.

Table 4.4 Volume of the water conserved/recovered after implementation of PWMS.

Process/Type of recovery	Avg. amount	Avg. operational hours	Avg. amount m^3/day
Singeing-esizing (cooling water recovery)	4.7 m^3/hr	16	75
Scour-Bleaching (improved reuse and rinsing cycles)	9 m^3/hr	16	144
Exhaust Bleaching (reduced liquor ratio)	5 m^3/ 1000 kg lot	20 (1 machine)	25
Mercerizing (improved reuse)	2 m^3/hr	8	16
Pad-Steam Dyeing (improved reuse and rinsing cycles)	3.5 m^3/hr	12	25
Exhaust Dyeing (reduced liquor ratio)	5 m^3/ 1000 kg lot	20 (1 machine)	25
Exhaust Washing (reduced liquor ratio)	5 m^3/ 1000 kg lot	20 (1 machine)	25
Steam Condensate (improved recovery)	-	-	33

4.4 Treatment and Handling of RO Membranes Reject Water (Objective-5)

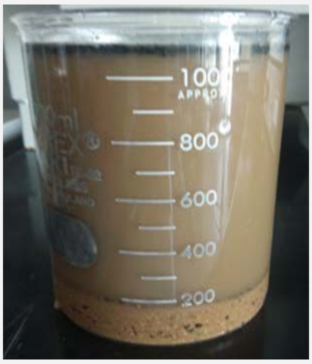
The fabricated lab-scale AD was experimentally tested on-field for treatment and handling of RO rejected water at an amount of 60 liters and up to 10 cycles. The saturated steam was provided to the AD set-up as an energy source for the vaporization of rejected water and the accumulation of salts on the composite adsorbent bed. The water quality analysis of RO rejects, and distillates are given in Table 4.5, which showed that a high quality of distillate with TDS ranging up to 300 mg/L after distillation of RO reject having TDS of 6990 mg/L. Besides, lower elemental concentrations were observed for chloride, sodium, calcium, and magnesium in the distillate.

Table 4.5 Water quality analysis of Ro reject and distillate after adsorption-desorption distillation

Parameter	Unit	Rejected water	Treated distillate
pH		8.21	7.6
TDS	mg/l	6990	310
EC	us/cm	15480	630
Turbidity	FTU	0.26	0
Chloride	mg/l	1617	75
Total alkalinity	mg/l	1120	117
Total hardness	mg/l	1580	-
Calcium	mg/l	381	22
Magnesium	mg/l	85	37
Sodium	mg/l	4220	53.3
Nickel	mg/l	0.08	Not detected

The desorption and recharge test revealed that at recharge condition-1 (RC-1), lower desorption of adsorbed solids (27%) was achieved, while in case of RC-2 and RC-3 when stirring and temperature were applied the desorption of solids was improved to 85 and 96%, respectively (Table 4.6, and Fig. 4.13). The results revealed that the adsorbed solids could be separated from adsorption bed using physical back-washing and/ or hot temperature water, and the adsorbent bed could be used for adsorption-distillation after recharge. Moreover, the separated solids after backwash/recharge could be easily handled through brine solidification, i.e., dewatering, drying, and solidifying the metals, salts, and minerals (Renew *et al.*, 2016).

Table 4.6 **Summarized results for mixed adsorbent recharge at different conditions**

	Recharge with room temperature de-ionized water without stirring (RC-1)	Recharge with room temperature de-ionized water under stirring (RC-2)	Recharge with hot (60 °C) de-ionized water under stirring (RC-3)
TDS after recharge (mg/L)	440	1310	1533
Desorption %	27%	85%	96%
Images			

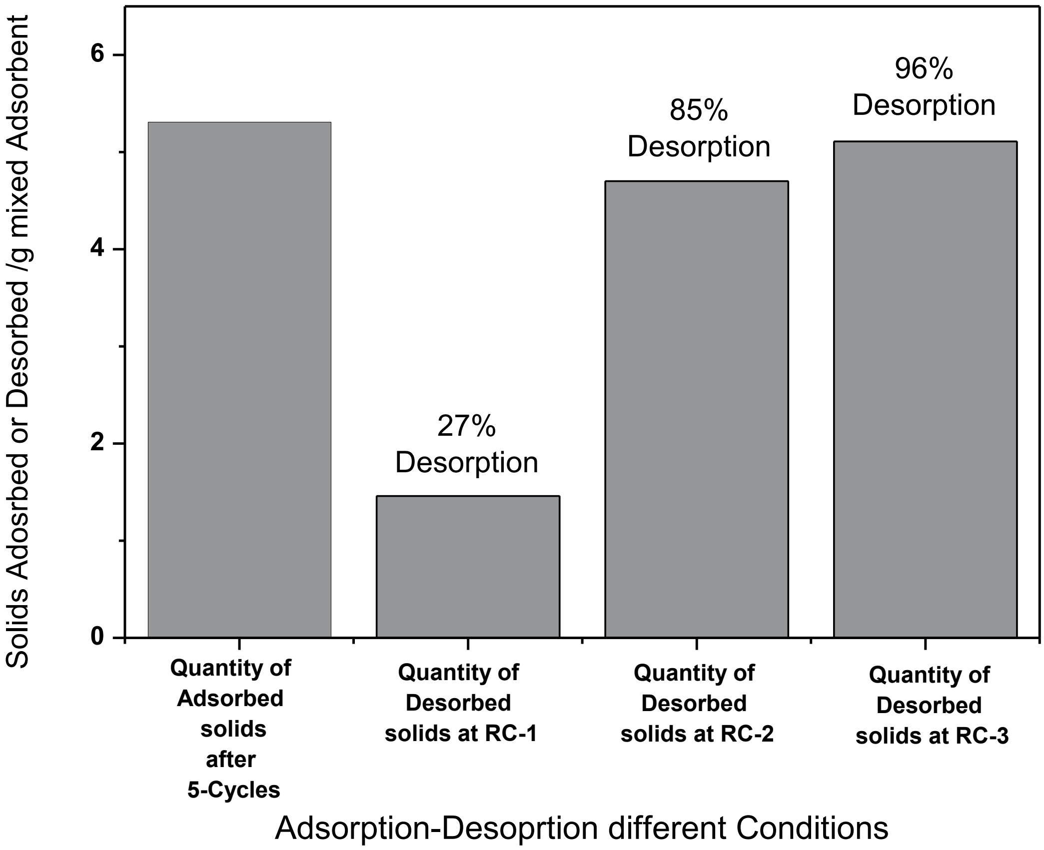


Fig. 4.13: Adsorption and desorption results at different conditions of recharge

4.5 Project Scientific/Collaborative Outcomes and Disseminations

3.4.1 MS thesis produced

1. Vinod Kumar: Health Risk Assessment of Textile Industry Reclaimed Water
2. Ayaz Ali Samejo: Treatment and Handling of RO Reject Water from Textile Industry
3. Aizaz Ali Qureshi: Photocatalytic Removal of Dye Colorant from Textile Industry Wastewater
4. Seher Haleema Dars: Antimicrobial and Photocatalytic Activity of Bismuth based Metal Oxides

4.5.2 Presentation of papers in conferences

1. The paper titled 'Health risk assessment of textile industry reclaimed water' was presented by Mr. Vinod Kumar, MS Student, in 3rd Young Researchers National Conference on Water and Environment, September 5-6, 2019
2. The paper titled 'Treatment and handling of RO reject water of textile industry' was presented by Mr. Ayaz Ali Samejo, MS Student, in 3rd Young Researchers National Conference on Water and Environment, September 5-6, 2019
3. The paper titled 'Photocatalytic removal of dye colorant from textile industry wastewater' was presented by Mr. Aizaz Ali Qureshi, MS Student, in 3rd Young Researchers National Conference on Water and Environment, September 5-6, 2019
4. The paper titled 'Antimicrobial and photocatalytic activity of bismuth based metal oxides' was presented by Ms. Seher Dars, MS Student, in 3rd Young Researchers National Conference on Water and Environment, September 5-6, 2019

4.5.3 Publications

1. Gadhi, T.A., Ali, I., Mahar, R.B.., and Maitlo, H.A. Waste heat and wastewater recovery in textile processing industry: A case study of adopted practices. Submitted for publication in Mehran University Research Journal of Engineering & Technology (HEC indexed journal).

4.5.4 Dissemination seminars

Three seminars have been presented on different forums to disseminate the project results and outcomes:

1. Project outcomes and consultative Seminar on 'Best Practices of Industrial Wastewater Treatment Focusing Textile Processing Industries', held at

Federation of Pakistan Chambers of Commerce and Industry (FPCCI), Karachi, on 27th June 2019 (Annex-1).

2. Project outcomes and consultative Seminar on 'Wastewater Treatment and Reuse at Al-Rahim Textile Industries Ltd.', held at Al-Rahim Textile Industries Ltd., on 27th August 2019 (Annex-2).
3. Project completion seminar on 'Wastewater Treatment and Reuse to Approach Zero Water Discharge at Al-Rahim Textile Industries Ltd.', held at USPCAS-W, MUET, Jamshoro, on 18th September 2019 (Annex-3).

4.5.5 Project Outcome/ Impact

1. Based on the successful completion of the project with Al-Rahim Textile Industry (ATI) and the experience and collaborative support of the industry, a project was submitted to HEC under the 3rd Call (2018-19) for proposals under the Technology Development Fund (TDF). The HEC has approved grant of PKR 14 million for another project in collaboration with ATI entitled: "Development and Upscaling of Indigenized Anaerobic Digester for the Biotransformation of Textile Sludge into the Production of Biogas and Biocompost".
2. Signed MoU between USPCAS-W, MUET and ATI on September 18, 2019 for three years collaborative work on industrial wastewater treatment research, and financial and technical support of participating students and faculty from USPCAS-W, MUET, Jamshoro.

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The textile wet-processes are water-intensive and are often neglected in managing water consumption, treatment of produced wastewater, and disposal. Therefore, to highlight the importance of water-use efficiency and wastewater treatment and reuse, this client-driven project was initiated through the collaborative support and active participation of the Al-Rahim Textile Industry (ATI). Various textile processes were analyzed and observed by evaluating the water consumption of each process; on-site water recovery and reuse were explored and adopted, including analyses of wastewater quality produced within each process and that of a mixed influent at ETP. For water-use efficiency, a comprehensive framework of process water management system (PWMS) was developed that provided guidance and management, focusing on five areas: i) knowing and adjusting the actual process water requirement, ii) adoption and management of on-site water reuse, iii) adoption and management of cooling water and steam condensate recovery, iv) effective water-related maintenance, and v) water consumption control through process/chemical modification. With the successful implementation of PWMS, 18% of water consumption was reduced at ATI.

Another phase of the project focused on the evaluation of process-related variation in produced water quality. It was observed that continuous bleaching and dyeing process generated a high volume of wastewater and concentrated pollutants load, i.e., COD in the range of 1700-3470 mg/L, TDS in the range of 1800-2700 mg/L, due to presence of dyes, salts and alkalis, and alkaline pH at temperature in the range of 50-58°C. The exhaust bleaching and dyeing processes produced a low volume of wastewater, but at a high pollutant load than continuous processes, however, the continuous bleaching-washing-dyeing-washing cycles diluted out the pollutant concentration in the mixed influent. During on-site wastewater recovery and reuse, the suspended load of produced wastewater, including lint, loose fibers, etc., was filtered out using filtration sieves of 0.5 -1.5 mm diameter. Some of the chemical agents were identified that caused adverse effects on ETP and RO operations, i.e., emulsion formation in aeration and fouling on RO membranes. These were the PVA glue used at printing and silica-based local softener used at finishing, which were then separated from the mixed stream to stabilize the ETP operation.

In the next project phase, the ETP and RO membrane operations were analyzed and observed to develop the standard operating conditions that could lead to smooth physico-chemical biological treatment of influent for maximum recovery of reclaimed permeate. Various issues were observed in terms of influent composition and characteristics that had adverse effects on ETP. The problem of high temperature of mixed influent, in the range of 53-58°C received from processing and 38-42°C in the aeration tank, caused difficulty in the stabilization of the bacterial growth in aeration tank and smooth coagulation and flocculation during primary treatment. The issue was resolved by installing the heat exchanger and cooling tower. The problem of low BOD to COD ratio (<0.3) and low food to microbes' ratio indicated enough supply of nutrient for bacterial growth and activity. This was resolved by supplying additional nutrients with the use of jiggery/animal dung and stabilization of bacterial growth, by reducing the water consumption i.e. excess dilution in processing section, the COD was improved from 950 to 1250 mg/L, that helped to maintain food to microbes' ratio.

After stabilizing the ETP operation and biological activity, the COD load was reduced below 100 mg/L and RO membrane trails were started. Proper pre-treatment of RO feed water was ensured before its supply to 3-stage membranes. With effective operation, 60-65% permeate (TDS <20 mg/L) recovery was achieved. Furthermore, no selective microbes were observed in the permeate, which showed lower concentrations of selective elements, i.e., under acceptable limits. After validation of results as per processing fresh water requirements, the recovered RO permeate was supplied to the main water tank for reuse in processing.

Finally, the fabricated lab-scale adsorption-distillator (AD) was experimentally tested on-site for treatment and handling of RO reject. The water quality of separated distillate showed TDS ranging up to 300 mg/L and low presence of chloride, sodium, calcium and magnesium in the distillate, which confirmed that the AD could be applied on larger scale for RO reject treatment and reuse of recovered distillate. Further the separated solids on adsorbent bed of distillator could be easily separated and handled after backwashing.

5.2 Recommendations

Given below are the key recommendations and outcomes of the project, which could be useful for textile processing industries towards achieving water-use efficiency and effective wastewater treatment and membrane operations.

- Optimization of water-use efficiency with the development of a water management system that includes continuous water consumption patterns of each process ensures the proper adoption of water and wastewater recovery and reuse, in-time water-related maintenance, and doable process modification for water conservation.
- Regular monitoring of wastewater quality produced from processes and check on chemicals inventory could ensure the identification of add-ups with adverse effects on ETP and/or RO membranes operation.
- Development of standard operating conditions as per different scenarios and

variation of received influent, to sustain and stabilize the ETP operation

- Reduction in chemical ionic/TDS load at processing: optimum use of salts, dyes, and alkali
- Use of ultrafiltration (UF) membranes for efficient pre-treatment of RO feed and improved cyclic stability
- An optimum doze of coagulants and operating conditions of secondary processes for 90-95% organic load reduction to avoid membrane fouling and quick backwash
- In-time maintenance and backwashing of the sand filter and RO membranes following the regularly monitored variations in processing influent and ETP operation, i.e., COD, TDS, SDI (Silt Density Index)
- Use of caustic recovery for mercerization weak lye (mixed wastewater containing NaOH and water) to reduce the dissolved ionic load in RO feed and for improved permeate recovery.

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Annex-1: Presentation on the Project Outcomes at FPCCI, Karachi

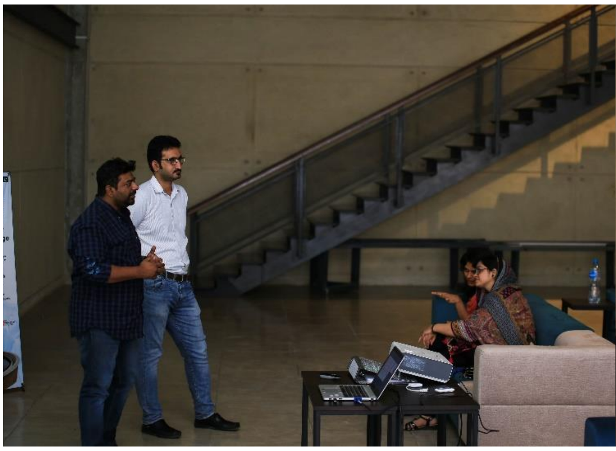
2nd Meeting of Federation of Pakistan Chambers of Commerce and Industry (FPCCI) Standing Committee Academia-Industry Collaboration on Water Resources was held on 27th June 2019. The meeting agenda was to discuss some of the outcomes achieved on ongoing collaborative projects of USPCAS-W with industries and led by Prof. Dr. Zubair Ahmed, Prof. Dr. Rasool Bux Mahar, and Dr. Tanveer Ahmed.

Prof. Dr. Rasool Bux Mahar, senior convener of the committee for the year 2019, whereas Prof. Dr. Zubair Ahmed (Committee member) and the Research Assistants from the USPCAS-W: Mr. Barkatullah, Mr. Shan Saleem, Mr. Bahadur, and Mr. Asif Jokhio also participated. The Committee Chairman Mr. Waseem Vohra, Deputy Convener Ms. Ainy Zehra and other participants from industry and consulting firms were also present during the meeting. Prof. Dr. Rasool Bux Mahar gave a presentation on “Wastewater Treatment and Reuse in Textile Processing and Production of Biogas and Biocompost from Wastewater” and briefed about the achievement of water conservation and improvement of a wastewater treatment plant and reuse of treated water at Al-Rahim Textile Industry with efforts and recommendation of the research team from the USPCAS-W, MUET Jamshoro.

Prof. Dr. Zubair Ahmed gave a presentation on “Treatment & Reuse of Wastewater of Shrimp Processing/Seafood Industry” and presented the results achieved and potential of fish wastewater treatment and reuse with the developed and installed electro-coagulation system at Mohammadi & Co. Fisheries, Karachi. The committee members appreciated the efforts of the research teams from MUET working with the industries for need-based solutions on water.

http://water.muet.edu.pk/2nd-meeting-of-federation-of-pakistan-chambers-of-commerce-and-industry-fpcci-at-karachi/

Annex-2: Dissemination Seminar held at Al-Rahim Textile Industries



US-Pakistan Center for Advanced Studies in Water collaborated with Al-Rahim Textile Industries (ATI) Pvt. Ltd. through the USPCAS-W-USAID funded research project on "Wastewater treatment and reuse: Approaching zero water discharge in textile wet-processing". At the completion of this project, one Workshop/Seminar was organized at ATI on 27th August 2019, with the participation of ATI executives, directors and managers, to disseminate the outcomes and further consultation on the recommendations drawn from the project. The project Principal Investigator Dr. Tanveer Ahmed and Co-Principal Investigator Dr. Rasool Bux Mahar, led the discussion and presented the outcomes.

With this project, effective Water Management System is developed at ATI to control water consumption, improve water use efficiency, development of processes for water balance, and adoption of on-site water recovery and reuse in textile processing.

Moreover, each textile process at ATI was analyzed in order to characterize wastewater load from individual process and its relationship with the mixed effluent reaching to effluent treatment plant (ETP), in order to develop efficient operating conditions of ETP. Various scenarios of ETP operations were developed through this research, to improve its efficiency and to provide organic-free raw water for tertiary treatment and RO membrane filtration, that aimed to enhance recovery rate of reclaimed/RO treated water. The project also covered development of operating conditions of RO plant at ATI and potential option for the sustainable treatment and handling of RO rejected water. During execution of this project, another research project proposal was developed on 'Anaerobic Co-Digestion of Industrial Wastewater Sludge' in collaboration with ATI, which has been awarded by HEC, Pakistan, with funding of PKR 14 million for 2 years research study.

http://water.muet.edu.pk/al-rahim-textile-industry-workshop-brief/

Annex-3: Project Completion/ Results Dissemination Seminar at USPCAS-W



The project completion seminar on "Wastewater treatment and reuse to approach zero water discharge at Al-Rahim Textile Industries" was held at the U.S.-Pakistan Center for Advanced Studies in Water (USPCAS-W), MUET Jamshoro on 18th September 2019. The seminar was given by Dr. Tanveer Ahmed, Principal Investigator (PI), and Dr. Rasool Bux Mahar, Deputy Director and Co-Principal Investigator (Co-PI) & Deputy

Director of the project. The seminar participants included, Prof. Dr. Bakhshal Khan Lashari Project Director USPCASW, Mr. Raheel Tabani, Industrial Partner and Director Al-Rahim Textile Industry (Pvt.) Ltd., Mr. Asif Bukhari of ATI, Dr. Imran Ali, Assistant Professor SMI University and Ex. Manager Utilities, Yunus Textile Mills, Dr. Kazi Suleman Memon, Manager Research USPCAS-W, as well as various stakeholders from textile industries, faculty members and students.

In his welcome address, the Project Director Dr. Lashari briefed the audience about the vision of USPCAS-W toward applied and need-based research with industry-academia collaboration. He added that students should approach industries to design their research as per industry needs and issues requiring solutions. In addition, he also emphasized the role of industrial stakeholders for allowing and facilitating the researchers and students from academia by extending the required technical and financial assistance.

The project PI Dr. Tanveer Ahmed briefed about the project objectives and the activities as followed at ATI and USPCAS-W for successful execution of the project plans. He narrated the challenges faced by Pakistan Textile Industries in managing the water consumption and treatment of the generated wastewater. He added that with the help of completed project various developments are made at ATI which include: adjustment of water consumption as per textile process requirement, identification and adoption of on-site water reuse and water conservation through processes modification and water-related maintenance.

Dr. Rasool Bux Mahar, project Co-PI described the development of treatment techniques that were implemented at Al-Rahim Textile Industries in order to extensively treat the generated wastewater and 60% recovery of reclaimed water through RO membrane operations. He highlighted the design and operating conditions that were explored, developed and validated at the industry through the execution of this project. He concluded that with the help of the completed project, a new technique is indigenously developed for the cost-effective treatment of RO reject water/brine.

Dr. Imran Ali shared his experiences in the successful execution of wastewater treatment and reuse at Yunus Textile Mills, since 2015, using membrane biological reactor technology. He added that the technological solutions are available for industrial wastewater treatment and the payback of invested cost is viable. He also highlighted that the selection of feasible technology should be validated with research in analyzing the characteristic and composition of industrial wastewater that is to be treated and reused.

Mr. Raheel Tabani, GM Business Excellence at Al-Rahim Textile Industries, appreciated the efforts of USPCAS-W and USAID for provide funding and conducting research for development of wastewater treatment and reuse at Al-Rahim Industries. He highlighted that the conventional industrial trend is changing towards research-based solutions, and to achieve this academic collaboration is important and could play major role for improvement and industrial progress. Furthermore, he offered technical and financial support to the students and researchers from USPCAS-W, MUET towards planned research to be applied at Al-Rahim Textile Industries.

Signing of the MoU between USPCAS-W and ATI

At the end of the seminar, a MoU was signed between USPCAS-W, MUET Jamshoro and Al-Rahim Textile Industries (ATI) to create and maintain an amicable working relationship through sharing of information and opportunities. Besides other multiple roles, the key role is to offer training, capacity building, employment, and internship for USPCAS-W faculty, researchers and students. Moreover, ATI would also offer financial assistance and facilitation of conducting need-based research or academic project at Al-Rahim Textile Industries.

http://water.muet.edu.pk/project-completion-seminar-on-wastewater-treatment-and-reuse-to-approach-zero-water-discharge-at-al-rahim-textile-industries/

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Syed Asif Ali Bukhari is working as Director Engineering at Al-Rahim Textile Industries (ATI), Nooriabad. He holds a B.Sc. degree and has over 20 years' experience of working in different textile groups including Towel, Denim, and Home textiles. At ATI, besides heading effluent treatment plant, he is directing utilities and engineering operations. He participated in this project as the industrial collaborator from the ATI, and will be the facilitator for the future collaboration between ATI and MUET, Jamshoro.

Main thrust of Applied Research component of the Water Center is to stimulate an environment that promotes multi-disciplinary research within the broader context of water-development nexus to support evidence-based policy making in the water sector. This is pursued using the framework provided by the six targets of the Sustainable Development Goal on Water i.e. SDG-6.

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