Water Conservation in Textile Industry through Treatment Plant Modification and Rainwater Harvesting

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Sustainable Development Goals

(Please tick the relevant SDG(s) linked with FYDP)

SDG No	Description of SDG	SDG No	Description of SDG
SDG 1	No Poverty	SDG 9	Industry, Innovation, and Infrastructure
SDG 2	Zero Hunger	SDG 10	Reduced Inequalities
SDG 3	Good Health and Well Being	SDG 11	Sustainable Cities and Communities
SDG 4	Quality Education	SDG 12	Responsible Consumption and Production
SDG 5	Gender Equality	SDG 13	Climate Change
SDG 6	Clean Water and Sanitation	SDG 14	Life Below Water
SDG 7	Affordable and Clean Energy	SDG 15	Life on Land
SDG 8	Decent Work and Economic Growth	SDG 16	Peace, Justice and Strong Institutions
		SDG 17	Partnerships for the Goals

Range of Complex Problem Solving			
	Attribute	**Complex Problem**	
1	Range of conflicting requirements	Involve wide-ranging or conflicting technical, engineering and other	

		issues.	
2	Depth of analysis required	Have no obvious solution and require abstract thinking, originality in analysis to formulate suitable models.	
3	Depth of knowledge required	Requires research-based knowledge much of which is at, or informed by, the forefront of the professional discipline and which allows a fundamentals-based, first principles analytical approach.	
4	Familiarity of issues	Involve infrequently encountered issues	
5	Extent of applicable codes	Are outside problems encompassed by standards and codes of practice for professional engineering.	
6	Extent of stakeholder involvement and level of conflicting requirements	Involve diverse groups of stakeholders with widely varying needs.	
7	Consequences	Have significant consequences in a range of contexts.	
8	Interdependence	Are high level problems including many component parts or sub-problems	
Range of Complex Problem Activities			
	Attribute	**Complex Activities**	
1	Range of resources	Involve the use of diverse resources (and for this purpose, resources include people, money, equipment, materials, information and technologies).	
2	Level of interaction	Require resolution of significant problems arising from interactions between wide ranging and conflicting technical, engineering or other issues.	
3	Innovation	Involve creative use of engineering principles and research-based knowledge in novel ways.	
4	Consequences to society and the environment	Have significant consequences in a range of contexts, characterized by difficulty of prediction and mitigation.	
5	Familiarity	Can extend beyond previous experiences by applying principles-based approaches.	

DEDICATION

Our work is solely dedicated to our parents who have been a major support for us, laid our strong foundations.

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ABSTRACT

Disposing wastewater without or with less than the required treatment is deteriorating the water bodies, which ultimately affects the environment. Pakistan, where only 1% of wastewater is treated prior to disposal, Pakistan is facing significant water scarcity and is currently ranked as the 4th most water-stressed country in the world, according to the World Resources Institute. Depletion of existing water sources, extracting the available freshwater without considering alternatives, and poor water management are major drawbacks in our system and sustainable plans. It has also been observed that the industrial sector uses a lot of water, which is also contributing to water scarcity, and the textile industry is among the major water consumers. It extracts freshwater from underground sources and uses abundant amounts of it in its manufacturing processes. In order to ensure the sustainable use of water, it is required to decrease the water footprint of the industry. The approaches used for the sustainable use of water for industrial sector involves the reuse of the wastewater generated and the rainwater harvesting. The current study was hence devised comprising these two parts. The first part includes the design of treatment plant for the selected textile industry for the reuse of the wastewater within the same industry. The second part includes the conservation of water through rain harvesting.

The industry is currently discharging the waste in the sewers after secondary treatment through submerged membrane bioreactor (sMBR). The current treatment plant was thoroughly studied, issues In this thesis, modifications to the existing treatment plant of a selected textile industry were proposed focusing the reuse of treated wastewater within the industry. For this, raw and treated wastewater samples were collected from the selected industry for its complete characterization. Based on the characteristics of raw wastewater and considering its intended use in the same industrial process, the existing treatment plant is slightly modified. To meet the quality specifications of color and COD removal, ozonation, an advanced treatment process was added in the existing treatment plant. All the units of the treatment plant were designed considering the reuse of wastewater in the same process. Furthermore, the cleaning mechanism of the membrane was also modified. It was changed from chemical cleaning to biological cleaning to solve the issue of increased total dissolved solids (TDS) concentration after secondary treatment. To conserve more water and decrease the water footprint of the industry rooftop rainwater harvesting system was also designed, which can also be a good source of water for the industry. Afterward, cost estimation was done for the existing and modified treatment plants. Water reclamation by modification of the treatment plant and water conservation by rainwater harvesting show a 70% reduction in water bill cost, reduce water consumption, and minimize the overall water footprint, contributing to sustainable and responsible water management.

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1 INTRODUCTION

1.1 Background

Nothing is more necessary for life on Earth than water. (1) Our globe is 70% covered by water. Freshwater, however, is exceedingly rare. Fresh water makes up only 3% of the world's total water supply, and two-thirds of that amount is hidden in frozen glaciers or inaccessible to humans in other ways. Access to clean drinking water is decreasing as the world's population rises and the ecosystem is increasingly harmed by climate change. In order to maintain the standard of life on Earth, water is necessary. Utilizing available water resources effectively and efficiently is essential for the sustainability of socially important resources like water. (2) (1) 733 million people live in high and critically water-stressed countries out of the 2.3 billion people who live in water-stressed countries. (UN-Water 2021)

Regarding the ratio of water withdrawals to available water resources, Pakistan is placed 160th, better than only 18 other nations. More than 80% of the people in the nation experience "severe water scarcity" (3) Pakistan was among the countries with the worst groundwater depletion, according to NASA satellite maps. The Punjab is the province most severely impacted by groundwater depletion, as shown on the NASA satellite map.

The main causes of water scarcity in Pakistan are a combination of climate change, rapid population growth, and poor water management practices. Over the years, due to overexploitation of aquifers groundwater level and recharge have both dropped in the majority of the country. The need for water in the home, industrial, and agricultural sectors is strongly impacted by rapid urbanization and high population growth rates (3).

Table 1-1 is showing the decrease in the per capita availability of water in Pakistan over the years and also predicts the future situation.

Table 1-1 Per Capita Water Availability (adopted from *Pakistan Bureau of Statistics*

Year	Per Capita Water Availability
1962	5229 per capita
2017	903 per capita
2025	May fall to less than 830 per capita

1.2 Problem Statement

About 1.2 million tube wells in Pakistan collect 50 million acre feet of water annually, with 96 percent going to agriculture, 2 percent going to industry, and the remaining 2 percent going to domestic consumption. (3) Additionally, the nation treats barely 1% of wastewater, which is among the lowest percentages in the world. Here, our concern is about the water consumption of industries and their effluent. In 2020, industrial water withdrawal for Pakistan was 1.4 billion cubic meters per year. Pakistan gradually reduced its annual industrial water withdrawal from 3.21 billion cubic meters in 2001 to 1.4 billion cubic meters in 2020. (4)

The production of textiles, as well as wet processing and finishing of textile materials, is major consumers of high-quality water. Large amounts of polluted water are released as a result of these many processes. Water is used extensively in the textile industry. Throughout the entire production process, water is used for several flushing procedures as well as for cleaning the raw materials. 1 kilogram of textile is produced using approximately 200 L of water. (5)

Textile dyeing is the second-largest polluter in water worldwide (6). According to a 2019 report, the World Bank stated that “Some studies have shown that the textile industry is responsible for about one-fifth of global water pollution”. Pollutants such as BOD, COD, dyes, dissolved solids, suspended particles, and toxic metals are commonly found in textile effluent. Numerous colors are frequently used in the textile industry thus it is also a main constituent of its wastewater if this contaminated water is not treated before being added to the reservoir, the quantity of oxygen in the wastewater may decrease, endangering aquatic life and the aquatic ecosystem as a whole. (6)

Considering the water scarcity condition of Pakistan, we focused on industrial sector of the country particularly textile industry keeping in view the above stated information as it is one of the major consumers of water in Pakistan also. Lahore based industry having a daily water consumption rate of 7000 m3/day was selected for the current study. While a submerged membrane bioreactor (sMBR) system has been installed for wastewater treatment, it is not achieving the required efficiency for some parameters, required for water reuse. As a result, the industry is currently disposing of its wastewater instead of reusing it. This has led to a potential waste of a significant water resource and may have negative environmental and economic consequences. Therefore, there is a need to evaluate the current sMBR system's performance, identify the reasons behind its inefficiency, and implement appropriate measures to optimize the system's performance. By changing the system’s chemical cleansing to biological cleansing and adding an ozonation unit, the industry can reuse the wastewater. Furthermore, by rainwater harvesting, industry can reduce the fresh water consumption and use the rain water in their miscellaneous processes and minimize its overall water footprint, contributing to sustainable and responsible water management.

1.3 Objectives

The objectives of the current study are given below;

- Design of modified wastewater treatment plant for the selected textile industry for the reuse of wastewater
- Design rainwater harvesting system for the selected industry to conserve water.

1.4 Scope and Utilization of Work

Water reuse by plant modification requires wastewater characterization to study what type of treatment was needed to make the water reusable. For this, the collection and characterization of wastewater effluents from the selected industry was done. Then the shortcomings of the treatment plant were identified. By using the reuse guidelines, modification of the plant or further treatment was suggested. When the required efficiency to reuse the textile wastewater is achieved, a storage tank will be designed to store the treated water for the purpose of reusing it afterward. Water conservation by rainwater harvesting requires the rain data of previous years in the selected industrial area to design the rainwater harvesting system. Reusing guidelines will also be applied to the rainwater, and a storage tank will be provided to collect rainwater after physical treatment that will be used afterward by the industry. This water conservation and water reuse will reduce their water footprint; reduce the water cost and contributing to sustainable and responsible water management.

2 LITERATURE REVIEW

One of the broadest and most intricate industrial networks in the manufacturing sector is the textile industry. The mechanical processing steps involved in producing a textile, such as spinning, knitting, weaving, and garment manufacturing, appear to be isolated from the wet treatment processes, such as sizing, de-sizing, scouring, bleaching, mercerizing, dyeing, printing, and finishing operations, but there is actually a significant relationship between the two. All phases of the processing of fibers, textiles, and clothing production result in the textile sector emitting a wide range of pollutants. These include air pollutants, noise pollution, solid wastes, and wastewater. The amount of water discharged and the chemical load it contains are the primary environmental concerns in the textile industry. (6)

Our literature review has the following major parts:-

- Wastewater treatment for textile industry
- Rainwater harvesting

2.1 Wastewater Treatment of Textile Industry

2.1.1 Textile Industry Processes

2.1.1.1 Sizing

The technique of sizing involves covering the warp yarn with a protective material to reduce yarn breakage during weaving. The most crucial process in getting warp yarn ready for weaving, especially with cotton yarn, is sizing. The slightest mistake in the sizing procedure could be highly detrimental.

2.1.1.2 De-Sizing

After a cloth has been woven, the process of de-sizing involves removing the size material from the warp yarns. Before undergoing any more care for the garment, de-sizing is done to remove the size from the warp yarn of the woven cloth.

2.1.1.3 Scouring

A preparation process for some textile materials is scouring. Oils, waxes, fats, dirt, and other soluble and insoluble impurities found in textiles as well as natural, added, and accidental impurities are all removed by scouring.

2.1.1.4 Bleaching

It is a procedure to get clear white for completed fabric or as a base for dyeing and finishing by removing the natural and artificial imperfections in fabrics.

2.1.1.5 Mercerizing

To enhance qualities including fiber strength, shrink-age resistance, luster, and dye affinity, textiles (usually cotton) are subjected to the mercerization process, which uses a caustic (NaOH) solution.

For these modifications to occur, the cellulose molecules in the fiber must be rearranged by the caustic.

2.1.1.6 Dyeing

The flow of dye into the interior of the fiber as well as the interaction between a dye and a fiber are both components of the dyeing process. In a dying process, dyes are typically adsorbed (transferred from the aqueous solution to the fiber surface) and diffused (into the fiber).

2.1.1.7 Printing

The process of adding color to fabric in specific patterns or designs is known as textile printing. The color is linked to the fiber in correctly printed fabrics, making them resistant to washing and rubbing.

2.1.1.8 Finishing

In the production of textiles, "finishing" refers to the procedures that turn woven or knitted fabric into a useful product, and more specifically, to any procedure carried out after the yarn or fabric has been dyed to enhance the appearance or functionality of the finished textile or article of clothing.

2.1.2 Problem Imposed by Dye-waste

Pollutants include hazardous metals, dyes, dissolved solids, and suspended particles are commonly found in textile wastewater. Total dissolved solids (TDS) should be the primary factor taken into account when analyzing textile effluent. The amount of TDS in textile wastewater rises as a result of the use of common salt and Glauber salt. (7)

2.1.3 Characteristics of Textile Wastewater

Depending on the dyeing procedure and the type of fabrics produced, the amount of water used by various types of fabrics varies from industry to industry. According to research, 38% of water is actually utilized during the bleaching process, 16% during dyeing, 8% during printing, 14% during boiler use, and 24% for other purposes. Quite a bit of contaminated water is released as a result of numerous processes. The truth is that the water discharged after the creation of textiles is well beyond the recommended amount and contains a significant amount of chemicals that are bad for the environment. (5)

The chemical makeup of wastewater utilized in the textile industry varies from mill to mill and country to country based on the manufacturing process, factory equipment, fabric type produced, chemicals used, and fabric weight, season, and fashion trends. Textile wastewater contains metals such manganese, sodium, lead, copper, chromium, and iron as well as significant levels of suspended particles, chlorides, nitrates, and BOD and COD. (8)

2.1.3.1 Typical characteristic of textile effluents

Table 2-1 on next page shows the typical characteristic of textile effluent.

Table 2-1 Typical Characteristics of Textile Effluents (adopted from (7))**Parameters**	**Typical Range from Literature Review**	**Pakistan Range of raw textile wastewater from 7 textile mills from different steps (Imtiazuddin et al. (2012))**
Temp. (°C)	35-40	36-49.2
pH	6-10	7.5-11.5
Color (Pt.-Co)	50-2500	
COD (mg/l)	150-10,000	115.66–705.25
BOD (mg/l)	80-6000	125.55–653.75
TSS(mg/l)	15-8000	934–1619
TDS(mg/l)	2900-3100	2469–7295
Chlorine (mg/l)	1000-6000	-
Chlorides (mg/l)	200-6000	-
Total alkalinity (mg/l) as $CaCO_3$	500-800	-
Total hardness 9mg/l) as $CaCO_3$	-	-
TKN (mg/l)	70-80	-
Total nitrogen (mg/l)	10-30	-
Na_2CO_3 (mg/l)	20	-
NaOH (mg/l)	10	-
NaCl (mg/l)	300	-
Phosphate (mg/l)	< 10	-
Suphates (mg/l)	600-1000	-
Oil and grease (mg/l)	10-30	-
Dye (mg/l)	-	-
Zinc (mg/l)	<10	-
Nickel (mg/l)	<10	-
manganese (mg/l)	<10	-
Iron (mg/l)	<10	-
Copper (mg/l)	<10	-
Boron (mg/l)	<10	-
Arsenic (mg/l)	<10	-
Silica (mg/l)	<15	-
Mercury (mg/l)	<10	-
Fluorine (mg/l)	<10	-
Chromium (mg/l)	<10	-
Potassium (mg/l)	<10	-
Sodium (mg/l)	7000	-

2.1.3.2 The component of major pollutants involved at various stages of a textile manufacturing industry

Table 2-2 on next page shows the major pollutants involved at various stages of a textile manufacturing industry.

Table 2-2 Components of major pollutants involved at various stages of a textile manufacturing industry (adopted from, (2))

Process	Wastewater (Nature of Effluent)	Possible Pollutants
Fiber Preparation	Little or none	
Yarn Spinning	Little or none	
Sizing	BOD, COD, metals, cleaning waste, size	yarn waste, unused starch based sizes
Weaving	Little or none	-
Knitting	Little or none	-
Tufting	Little or none	-
De-Sizing	high BOD (30-50% of total), high COD, PVA	Starch, sizes lubricants, glucose, PVA, resins, fats and waxes.
Scouring	oily fats, BOD (30% of total), high pH, dark color	Disinfectants, insecticide residues, NaOH, detergents oils, knitting lubricants, spin finishes, spent solvents
Bleaching	TDS, high pH	H_2O_2, AOX, NaCl, organics
Singeing	Little or none	-
Mercerizing	BOD, High pH	NaOH
Heat Setting	Little or none	-
Dyeing	high toxicity, high PH, BOD, high dissolved solids	Dye stuff, colors, metal, mordant and reducing agents like sulphides, salts, acidity/alkalinity, formaldehyde and soap
Printing	high toxicity, high COD, high BOD, high dissolved solids, high PH, strong color	urea, solvents, color, metals
Finishing	low alkalinity, low BOD, high toxicity	Chlorinated compounds, resins, softeners, spent solvents, waxes, acetate.

2.1.4 Conventional Technologies Used by Textile Industries

Conventional technologies for textile wastewater treatment mainly comprise:-

- Biological treatment
- Precipitation
- Coagulation/flocculation
- Flotation
- Oxidation
- Adsorption

Anaerobic pretreatment can be used for large COD loads, such as those caused by starch de-sizing or wool washing and scouring, though it doesn't seem to have been implemented on a commercial basis yet. Coagulation is also widely utilized, frequently followed by sand filtration. (5) See Table 2-3 on next page shows different technologies for textile effluent treatment.

Table 2-3 Technologies for textile effluent treatment (adapted from Vandevivere et al., 1998)

Process	Stage	Status	Performance	Limitations
Biodegradation				
Activated sludge	Main treatment	Widely used	Bulk COD removal; partial nitrification	High residual COD, ammonia, color
Sequential anaerobic–aerobic	Main treatment	Few reports of full-scale use	Better COD and color removal than AS alone	High residual COD, color
Fixed bed	Main treatment	Pilot trials in China	Better COD and color removal than AS	Some residual color
Fungi/H_2O_2	Main treatment	Bench-scale	Full de-colorization	
Physicochemical treatment				
Coagulation-flocculation	Pre-, main or post-treatment	Extensive use	Almost full de-colorization; water reuse	Unreliable performance; sludge disposal
Adsorption	Pre- or post-treatment	Bench- to full-scale depending on adsorbent	Water reuse with newer adsorbents	Sludge disposal or adsorbent regeneration
Membrane filtration	Main or post-treatment	Extensive use in South Africa	Reliable performance; water reuse	Concentrate management
Oxidation				
Ozonation	Post-treatment	Full-scale	Full de-colorization; water reuse	Expensive; aldehydes formed
Fenton's reagent	Pre-treatment	Several full-scale plant in South Africa	Full de-colorization	
Photo catalysis	Post-treatment	Pilot-scale	Near complete color removal	For final polishing only
Electrolysis	Pre-treatment	Pilot-scale	Full de-colorization	Foaming; limited electrode life

2.1.5 Conventional biological treatments

Conventional biological treatment technologies used for textile industry are given below:

- Activated Sludge Process (ASP)
- Trickling Filtration
- Membrane bio reactors (MBR)
- Rotating biological contactors (RBC)
- Sequencing batch reactor (SBR)

2.1.5.1 *Activated Sludge*

Utilizing a multi-chamber reactor unit with highly concentrated microorganisms, the activated sludge process creates high-quality effluent by removing nutrients and degrading organics from wastewater. Maintaining aerobic conditions and keeping the activated sludge suspended are the objectives. A consistent and scheduled supply of oxygen is needed to do this. In an aerated tank, flocs of bacteria are suspended and combined with wastewater. The bacteria use the organic pollutants to grow and convert them into energy, water, CO2, and new cell material. Gravity settling can be used to remove the flocs in the secondary clarifier, and some of the clarifier's sludge is recycled back to the reactor. The final polishing can then be done using the effluent. (8)

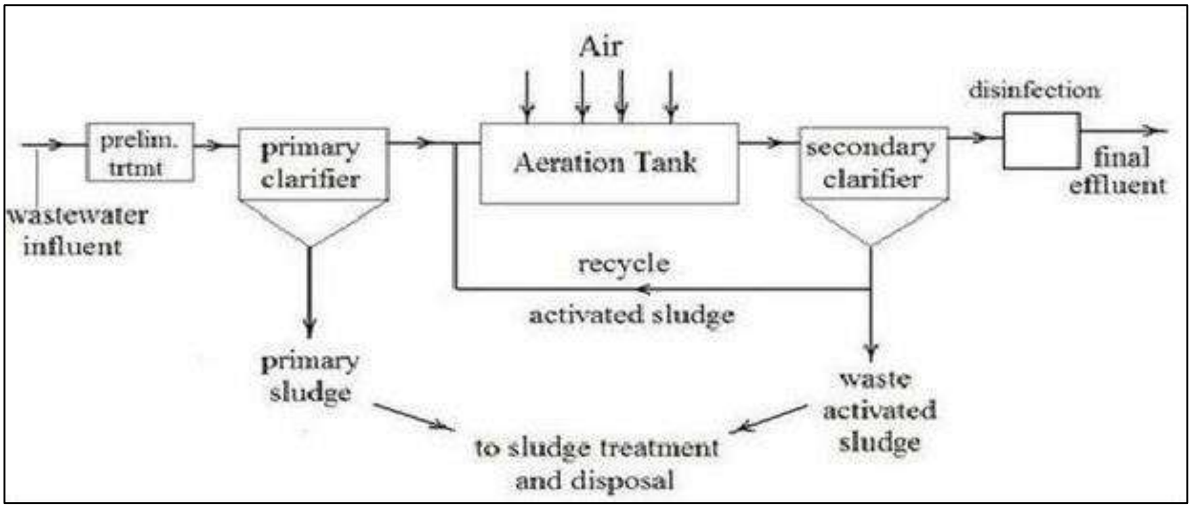


Figure 2-1 Flow Diagram of ASP

2.1.5.2 *Trickling Filtration*

TFs allow a population of bacteria, fungi, algae, and protozoa (including facultatively anaerobic, aerobic, and facultatively anaerobic bacteria), which are adhered to the medium as a biological film or slime layer (about 0.1 to 0.2 mm thick), to adsorb organic material from the wastewater. Microorganisms already present in the wastewater progressively cling to the rock, slag, or plastic surface and form a film as it passes over the medium. The aerobic microorganisms in the outer portion of the slime layer then decompose the organic material. (9)

Because oxygen cannot reach the medium face when the layer thickens due to microbial development, anaerobic organisms flourish there instead. The microorganisms at the surface lose their capacity to adhere to the medium as the biological film thickens, and some of the slime layer peels off the filter as a result. The action in question is called sloughing. The under-drain system collects the sloughed solids and delivers them to a clarifier where they are removed from the wastewater. (9)

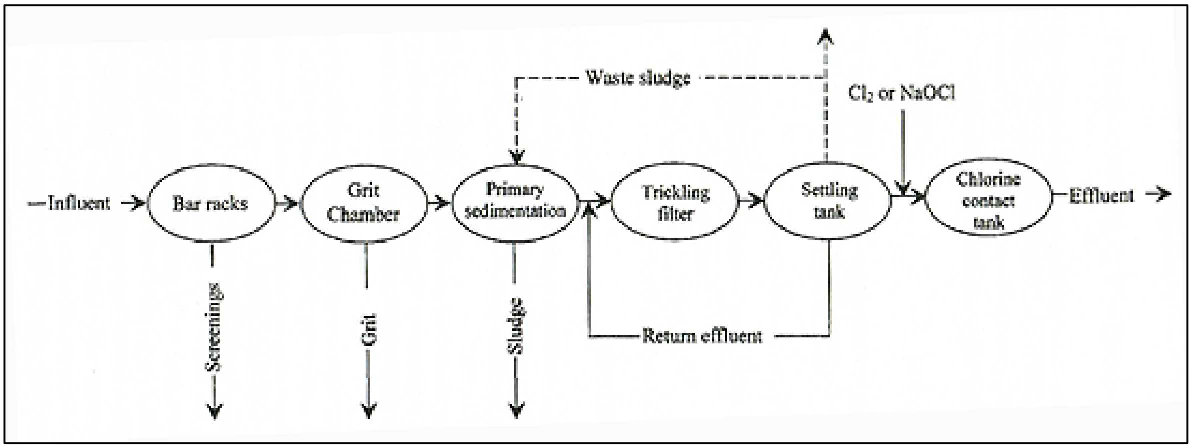


Figure 2-2 Flow diagram of Trickling Filter

2.1.5.3 *Sequencing batch reactor (SBR)*

A fill-and-draw activated sludge technology for wastewater treatment is the sequencing batch reactor (SBR). This approach involves adding wastewater to a single "batch" reactor, treating it to get rid of unwanted elements, and then releasing it. Using a single batch reactor, equalization, aeration, and clarifying can all be accomplished. Two or more batch reactors are utilized in a preset order of operations to maximize the system's performance. Industrial and municipal wastewater have been effectively treated using SBR systems. They are particularly well suited to wastewater treatment applications with low or irregular flow conditions. (10)

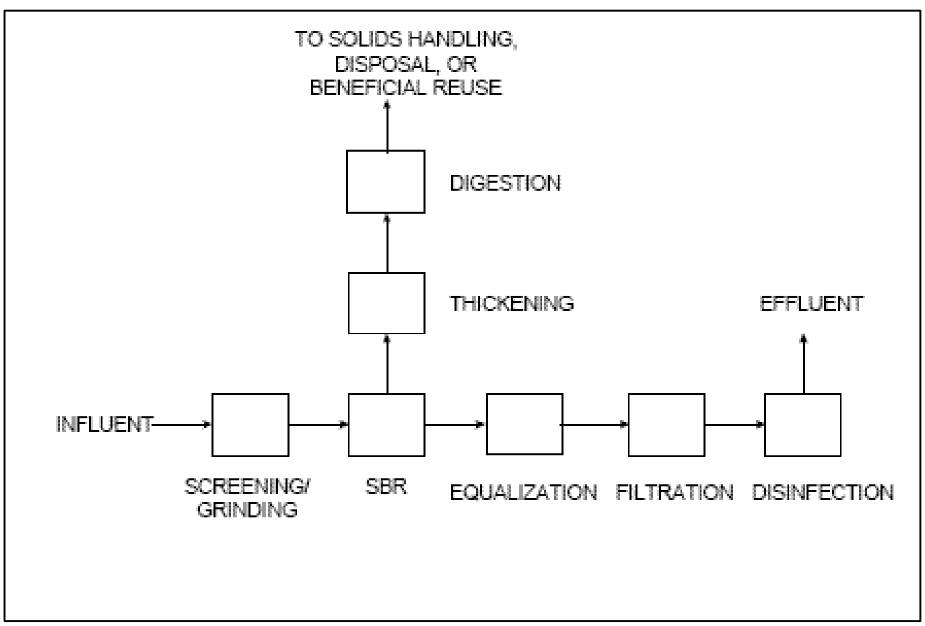


Figure 2-3 Flow Diagram of Sequencing Batch Reactor

2.1.5.4 Membrane bio reactors (MBR)

In both municipal and commercial wastewater treatment plants (WWTPs), membrane bioreactors (MBRs) are a method that combines a microfiltration or ultrafiltration membrane unit with a suspended growth bioreactor. Membranes serve as a solid-liquid separation mechanism in the MBR process, keeping the biomass inside the bioreactor before releasing the treated effluent to the environment. In essence, they replace the clarifiers that are employed in the traditional activated sludge (CAS) process. (11)

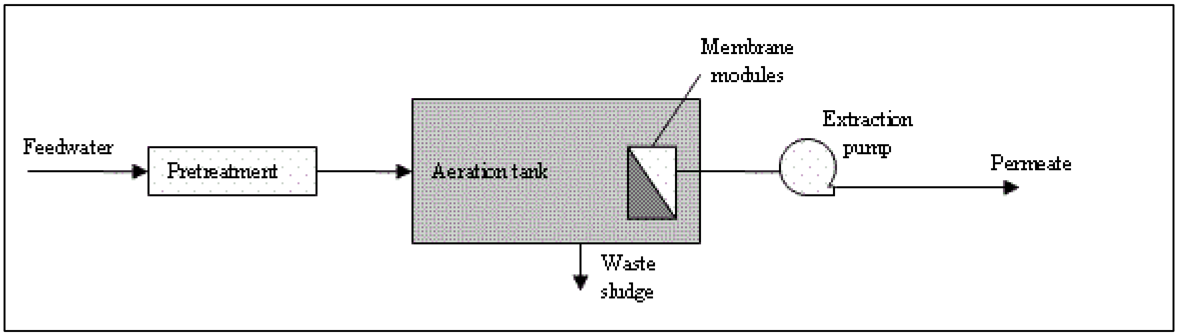


Figure 2-4 Flow Diagram of MBR

2.1.6 Possible Reason of MBR selection by Industry

Compared to conventional wastewater treatment methods, such as activated sludge systems, MBRs offer several advantages:

- High-quality wastewater: MBRs generate effluent of a high caliber that satisfies or surpasses legal requirements for disposal or recycling. A clear, odorless, and secure effluent is produced by the membrane filtration process, which removes suspended particles, bacteria, viruses, and other contaminants from the treated water.

- Small footprint: MBRs require less space than conventional treatment systems because the membrane filtration process replaces the need for a separate clarifier. This makes them ideal for urban and densely populated areas where space is limited.

- Flexible design: MBRs are appropriate for a variety of applications, including municipal, industrial, and decentralized wastewater treatment since they can be tailored to fulfil individual site requirements.

- Enhanced treatment performance: MBRs provide enhanced treatment performance, including higher removal efficiencies for organic matter, nitrogen, and phosphorus. This makes them ideal for treating high-strength or complex wastewaters.

- Reduced sludge production: MBRs produce less sludge than conventional treatment systems because the membrane filtration process retains the solids in the bioreactor. This results in lower disposal costs and reduces the environmental impact of sludge disposal.

Overall, MBRs are superior to traditional wastewater treatment techniques in a number of ways, including high-quality effluent, a small environmental footprint, flexible design, improved treatment efficacy, and less sludge generation (12)

2.1.7 MBR

MBR is a hybrid technology that combines an ultrafiltration- or microfiltration-based membrane filtration process with a biological treatment process (i.e., the traditional activated sludge process, CAS). Activated sludge is effectively retained within the bioreactor by the integration of a membrane separation process, producing clarified treated effluent that is suitable for water reuse applications even though the biological treatment process in MBR is similar to that in CAS (conventional activated sludge) process (12) (13)

Different forms of wastewater can be treated with MBRs. MBR can sustain changes in organic loading rates better than CAS process because the integrated membrane separation process enables MBR to be run at greater mixed liquor suspended solids (MLSS) concentration and solids retention time (SRT). The MBR method has gained popularity for wastewater treatment, especially when the treated effluent is destined for water reuse applications, and its market is expanding quickly with an annual growth rate of up to 15%. Over 200 nations have deployed complete MBR plants as of now. By 2019, it is anticipated that the MBR technology industry would grow to $3 billion (13)

2.1.7.1 Type of membranes in MBR

Membranes serve as a solid-liquid separation mechanism in the MBR process, keeping the biomass inside the bioreactor before releasing the treated effluent to the environment. In essence, they replace the clarifiers that are employed in the traditional activated sludge (CAS) process (11)

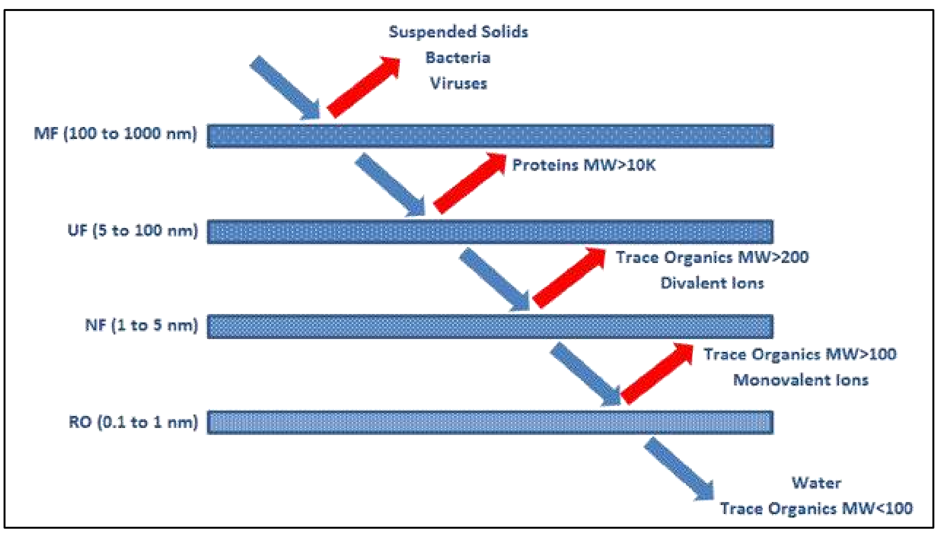


Figure 2-5 Classification of membranes according to pore size

MBR applications can employ both micro- (MF) and ultrafiltration (UF) membranes. Because of their superior separation properties (which allow them to remove certain colloids and viruses as well) and lower tendency to foul (because to their smaller pore size, they have a lesser likelihood of pore clogging), UF membranes are typically the favored option (11)

2.1.7.2 Geometry of membrane in MBR

There are three types of membrane geometries used for MBRs:

- Hollow fiber (HF)
- Tubular (or multi-tubular, MT)
- Flat sheet (FS)

Due to their sensitivity to suspended particles contents, other configurations, such spiral-wound (SW), are not appropriate for MBR applications.

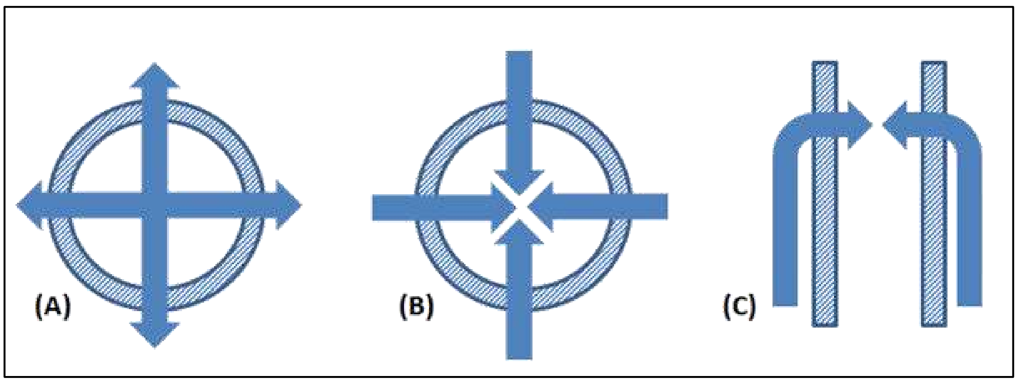


Figure 2-6 MBR membrane configurations, A) Hollow Fiber, B) Multi-tube, C) Flat Sheet

2.1.7.3 MBR configurations

MBR membrane filtration has two major configurations;

Vacuum-driven membranes immersed directly into the bioreactor (iMBR)

The filtering element is put in either the primary bioreactor vessel or a different tank in the immersed membrane bioreactor (iMBR) arrangement. The modules serve two purposes—supplying oxygen and cleaning the membranes—and are positioned atop the aeration system. The membranes can have an online backwash system that lowers membrane surface fouling by pushing membrane permeate back through the membrane. They can be flat sheets, tubular, or a combination of both. IPC membranes, created by Blue Foot Membranes, can improve the backwash system.
Due to its low energy consumption level, excellent biodegradation efficiency, and low fouling rate compared to side stream membrane bioreactors, immersed MBR has been the chosen option additionally; larger SSLM concentrations can be handled by iMBR devices. (14)

Pressure-driven filtration in side-stream MBRs (sMBR)

The filtering modules are located outside the aerobic tank in sMBR technology, therefore the name side-stream configuration. The aeration system is utilised to clean and provide oxygen to the bacteria that break down the organic compounds, just like the iMBR arrangement. Either the biomass is pumped directly through a bank of membrane modules in series before returning to the bioreactor, or the biomass is pumped to a bank of modules before being circulated through the modules in series by a second pump. With the use of an installed cleaning tank, pump, and pipes, the membranes can be cleaned and soaked in place. Because of the filtration power of the micro- and ultrafiltration membranes, the quality of the finished product is such that it can be recycled in process applications.

The ability to size and construct the tank and membrane separately, with benefits for the unit's operation and maintenance, is the fundamental benefit of the external/side stream layout. The internal/submerged configuration provides the shear through the aeration in the bioreactor, and since there is an energy requirement to promote the shear, this configuration shows this additional cost. As in other membrane processes, a shear over the membrane surface is needed to prevent or limit fouling; the external/side stream configuration provides this shear using a pumping system. Due to the greater fluxes involved in this design, the MBR module fouling is also more consistent. (14)

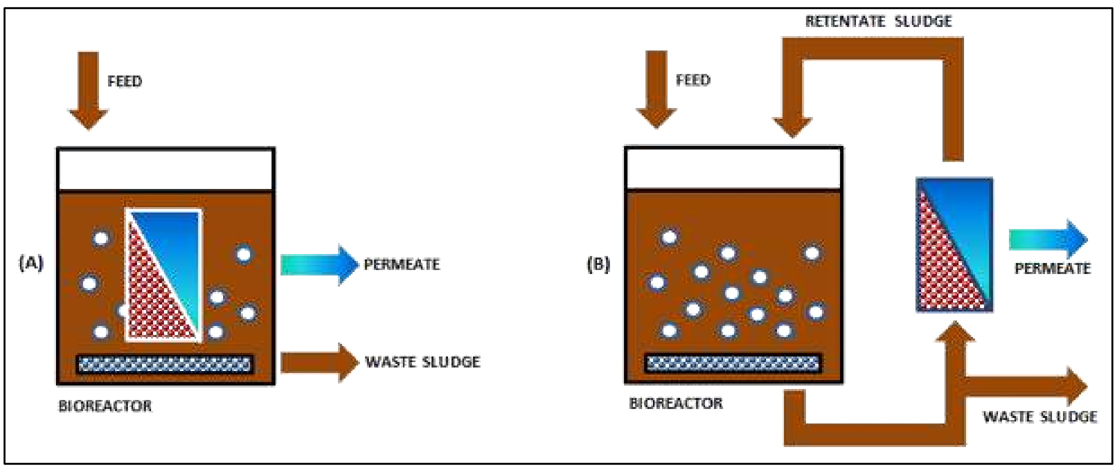


Figure 2-7 MBR configurations; (A) Immersed MBR, (B) Side-stream MBR

2.1.7.4 Removal efficiency of MBR

Table 2-4 given below showing the removal efficiency of MBR.

Table 2-4 Removal Efficiency of MBR (adopted from different literature review)

Parameter	Removal (%)
Chloride	18.8
Alkalinity	41.8
Hardness	55.08
Calcium	68.97

Parameter	Removal (%)
Magnesium	45
pH	5.7
Conductivity	17.1
TDS	6.7
Turbidity	98.1
TSS	100
Sulphates	-
COD	94.8
Nitrogen	28.9
NO3	28.9
NO2	28.9
NH3	28.9

2.1.7.5 Limitation of MBR

The performance and durability of a membrane are greatly decreased by membrane fouling, which raises maintenance and operating costs. These fouls can be solutes, colloids, or suspended particles (microorganisms and cell detritus) in the MLSS. Membrane fouling is the outcome of physio-chemical interactions between the contaminants and the membrane material. These substances accumulate on the membrane surface and fill its pores, decreasing the membrane's permeability as a result and clogging the pores. Membrane fouling is an unavoidable problem that is challenging to address in long-term MBR applications due to the heterogeneous nature of suspended solids and active microorganisms in mixed liquid suspended solids (MLSS)(12) (15)

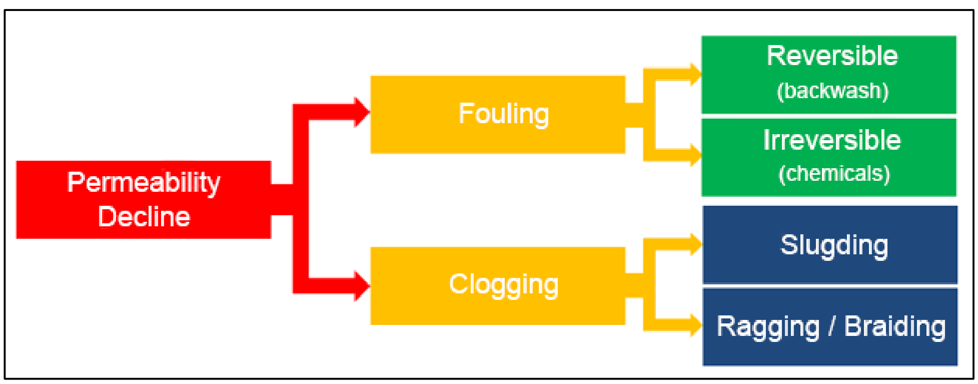


Figure 2-8 Reasons for permeability decline in MBR

<u>Classification of Foulants</u>

In the textile industry, possible membrane contaminants is a combination of organic and inorganic materials

- Organic contaminants
- Inorganic contaminants

Organic Contaminant- Organic contaminants are typically composed of artificial or natural organic compounds and are made up of carbon-based materials. Oils, greases, lubricants, dyes, pigments, finishing agents, and chemical byproducts from various textile processing steps are examples of organic contaminants in the textile processes.

Inorganic Contaminants - Minerals and salts are dominate in the composition of inorganic contaminants, which are non-carbon-based compounds. Scale deposits made by hard water minerals like calcium carbonate or magnesium silicate are examples of inorganic foulants in the textile industry. These deposits accumulate on equipment surfaces and obstruct efficient heat transfer. Chemical cleaning, which is more efficient than physical cleaning, it is frequently used to remove inorganic precipitate from the membrane surface.

Factors affecting membrane fouling in membrane bioreactors (MBR)

Table 2-5 given below, showing factor that affects the membrane fouling in MBR

Table 2-5 factors affecting the fouling in membrane (adopted, (15))

Factor	Effect on Membrane Fouling
Membrane Characteristics	
Membrane Material	Ceramic membranes are hydrophilic, hence they foul less. Polymeric membranes are mostly hydrophobic and exhibit more fouling
Water affinity	Increasing hydrophilicity indicates less membrane fouling propensity while hydrophobicity correlates well with increase propensity for membrane fouling
Membrane surface roughness	Membrane fouling tends to increase with increasing surface roughness as the rough surface provides a valley for the colloidal particles in the wastewater to accumulate on. However, higher projections on the membrane surface exhibit higher antifouling property and better permeability recovery after backflushing than gentle roughness.
Membrane surface charge	The colloidal particles depositing on the membrane makes them negatively charged, hence they can attract cations in the MLSS, such as Ca2+ and Al3+ leading to inorganic fouling
Membrane pore size	Increasing membrane pore size increases the tendency for pore blocking mechanism
Operating Conditions	
Operating mode	Operating in cross-flow filtration mode reduces cake layer formation on the membrane surface
Aeration	Increasing aeration rates results in a reduction in membrane fouling
Solids retention time (SRT)	Operating at high SRTs reduces the production of EPS, hence reduced fouling. However, extremely high SRTs rather increase membrane fouling due to the accumulation of MLSS and increased sludge viscosity

Factor	Effect on Membrane Fouling
Hydraulic retention time (HRT)	Decreasing HRTs results in increasing rate of membrane fouling. However, extremely high HRTs leads to an accumulation of foulants
Food-microorganisms (F/M) ratio	The rate of membrane fouling in MBRs increases with increasing F/M ratio due high food utilization by biomass resulting in increased EPS production
Organic loading rate (OLR)	Membranes foul more as OLR increases
COD/N ratio	Operating at higher COD/N ratio reduces rate of membrane fouling, improved membrane performance and a longer operation period before membrane cleaning. On the contrary, other studies found that low COD/N ratio results in lower MLSS concentration, lower SMPs production, lower carbohydrates, proteins, and humic acids in LB-EPS; hence, low membrane fouling
Temperature	Low temperatures increase the propensity for membrane fouling as more EPS are released by bacteria and the number of filamentous bacteria increases. Sudden temperature changes also increase fouling rate due to spontaneous release of SMPs
Feed/biomass characteristics	
Mixed liquor suspended solids (MLSS)	Increasing MLSS correlate with increased rate of membrane fouling. Other studies report no (or little) effect of MLSS on membrane fouling
Sludge apparent viscosity	Increasing the viscosity results in increased membrane fouling.
Extracellular polymeric substances (EPS)	Increase in the concentration of EPS (bound EPS and SMPs) result in membrane fouling.
Floc size	Decrease in floc size increases membrane fouling
pH	Decrease in pH results in increased rate of membrane fouling
Salinity	Increasing salinity increases membrane fouling by altering biomass characteristic like more release of bound EPS and SMPs, floc size and zeta potential

2.1.8 Ozonation (Advance Oxidation Technology)

Ozonation is a method that is known to be quite successful in treating wastewater. It is a process where ozone (a molecule containing three oxygen atoms) is generated in situ by an ozone generator, this ozone gas is dissolved in water to kill microorganisms and remove organic and inorganic pollutants. The ozone acts as a powerful oxidizing agent, breaking down organic compounds and neutralizing harmful bacteria and viruses by a safe chemical reaction. It is a widely used method in both industrial and municipal wastewater treatment. Once the ozone is in the water, the ozone molecules attach to the pollutants or microorganisms and oxidize them, effectively destroying them. Ozone can be applied in various stages of the process, providing a high degree of flexibility for wastewater treatment plants. Also, Ozone can be combined with other oxidants like hydrogen peroxide to create Advanced Oxidation Processes (AOPs) in any water purification process. (16)

Ozone can be used as the last step in the wastewater treatment because of its effectiveness in purifies the water. For instance, ozonation decreases BOD/COD to safe levels at a lower cost In addition to lowering processing costs, ozone systems are also helpful in removing the penalties related to disposing of contaminated water. Adding a clean, ecologically friendly technology, raising oxygen demand, and enhancing the aesthetic qualities due to a decrease in turbidity are additional benefits. (16)

2.1.8.1 Sizing of Ozone Equipment

Ozone Generators

Ozone is generated by oxygen (O2) molecules being broken down into single atoms, which are then joined with additional oxygen molecules to form ozone (O3). This process is known as an ozone generator. As air passes through ozone generator equipment, oxygen molecules (O2) are electrically charged. This leads to the oxygen atoms to split apart and simply recombining with other oxygen molecules. Enriched oxygen is then fed into the oxygen concentrator, resulting in a high concentration of ozone and high ozone production. The ozone created in grams per hour is used to categorize the ozone generators. (16)

Dependences of size ozone generator

The following information is necessary to determine the right size Ozone Generator for Water Treatment:

- Water quality and Ozone demand (via water sample analysis)
- Ozone dosage
- Flow rate
- Inline pressure
- The volume of water (for recirculating systems)

Dosage

Dosage is the required amount of ozone that is necessary which is measured in mg/l (milligrams per liter) or ppm (parts per million).

2.2 RAIN HARVESTING

Rainwater runoff from roofs, parks, highways, open spaces, etc. is collected and stored by rainwater harvesting. It is possible to store or recharge the groundwater using this runoff water (17)

Benefits to Consumers	Benefits to Environment
Less cost.	Rainwater collection may reduce a storm water flow from a property.
Helps in reducing the water bill.	The elimination of runoff can reduce contamination of surface water with pesticides, sediment, metals, and fertilizers.

Decreases the demand for water.	By reducing storm water runoff, rainwater harvesting can reduce a storm's peak flow volume and velocity in local creeks, streams, and rivers, thereby reducing the potential for stream bank erosion.
Reduces the need for imported water.	Maintaining the Quality of Watershed and Prevent Flooding
Promotes both water and energy conservation.	Mitigate the Changes in Climate and Reduction in Carbon Footprint.
Improves the quality and quantity of groundwater.	Rainwater harvesting can reduce storm water runoff from a property.
Does not require a filtration system for landscape irrigation.	The elimination of runoff can reduce contamination of surface water with pesticides, sediment, metals, and fertilizers.

2.2.1 Importance of RWH for Industrial Use

Growth in population, industrialization and urbanization severely impacts the water resources. Many processes in industries make more use of water than their counterparts; e.g. power generation, textiles and garments, beverages, car-wash businesses, construction, refueling areas etc. Hence, it makes complete sense to opt for alternatives for harnessing water and one such way of using the raindrops to their full potential is – rainwater harvesting (RWH) (17)

- Direct cost-savings on lengthy water bills
- Availability of freshwater cuts down carbon footprints by saving power used in freshwater processing
- Catchment areas in commercial centers can collect and store water to be used in times of shortage.
- Water recycling systems receive better quality water; thereby increase their shelf life.
- Harvested rainwater is soft, thus it minimizes the cycles of filtration.
- It can reduce mains water supply by 40-50%
- It reduces run-off and its harmful impacts
- RWH promotes both water and energy conservation
- Can be used for several non-drinking purposes
- It also helps towards a company's sustainability credentials
- The ever-increasing demand for water can be satisfied

2.2.2 Techniques of Rainwater Harvesting

There are two major techniques of rainwater harvesting.

2.2.2.1 Surface runoff harvesting

In this method, rainwater flows away as surface runoff and can be stored for future use. Surface water can be stored by diverting the flow of small creeks and streams into reservoirs on the surface or underground. It can provide water for farming, for cattle and also for general domestic use. Surface runoff harvesting is most suitable in urban areas. (18)

2.2.2.2 *Rooftop rainwater harvesting*

Rooftop Rain Water Harvesting is the technique through which rain water is captured from the roof catchments and stored in reservoirs. Collecting and storage of rooftop rainwater harvesting can be used for direct use or for ground water recharging. (19)

2.2.3 Process:

A rainwater harvesting system has three main stages;

2.2.3.1 *Collecting and Transporting Rain Water*

This is done through catchment areas & conduits. The catchment of a water harvesting system is the surface which receives rainfall directly. It can be a paved area like the terrace or courtyard of a building. Conduits are the pipelines that carry rainwater from the catchment or rooftop to the harvesting system.

2.2.3.2 *Filtration*

A filter unit is a chamber filled with filtering media to remove debris and dirt from water before it enters the storage tank or recharge structure.

2.2.3.3 *Storage in Tank for Reuse:*

The harvested water can now be stored in storage tanks for immediate usage, which are designed according to the water requirements of the society. Existing non-potable water storage tanks in the society can also be used to store the harvested rainwater.

2.2.4 Installation Process

- Obtaining the rainfall data
- Obtaining the number of personnel or people supplied with water
- Estimation of water demand
- Calculation of total roof area
- Determination of volume of water that can be harvested
- Sizing and selection of filters
- Design of delivery system
- Cost estimation
- Calculation of annual savings and payback period

2.2.5 Essentials for Rainwater Harvesting

- Catchment area
- Water pump
- Water filter
- Storage tank
- Conduit pipes
- Rooftop filters

2.2.6 Cost Effectiveness

Installing a rainwater harvesting system leads to **80%** direct costs saving on lengthy water bills. (20)

3 METHODOLOGY

3.1 SCOPE

The methodology followed for the treatment plant design for the textile industry is briefly described in this chapter. This chapter discusses the proper sampling strategies used, the data collected from the respective industry, and the identification of the streams that need treatment.

3.2 Selection of Textile Industry

The selected industry is one of the world's leading textile and apparel manufacturers, with a vertically integrated supply chain that straddles from greige fabric to apparel. They have partnerships with world-famous brands including Adidas, Nike, and Reebok. The group members visited the factory. The possible sources of water usage and wastewater generation were identified. The site location and surrounding area were visited to ensure the reuse of treated wastewater. The processes involved in the manufacturing of textiles were observed, and waste streams of different effluents were analyzed. It was also observed that the industry has already installed a secondary treatment plant, a membrane bioreactor, to treat their effluent before discharge. Each unit of the treatment plant was also observed, and data was collected about their wastewater before and after treatment.

3.3 Collection of Data

After visiting, wastewater was collected from the inlet and outlet of the treatment plant. After the wastewater was collected, different experiments were performed in the university lab to identify the pollutants in the industry's wastewater and observe the removal efficiency of their treatment plant. These experimental results served as the foundation for the improvement of the treatment units in the industry.

3.4 Characterization of Waste Effluents

Table 3-1 given below showing the processes and the type of effluents generating from the specific process.

Table 3-1 Type of Effluent Generating from Different Process of Textile Industry

Process	Nature of Effluent
Sizing	BOD, COD, metals, cleaning waste
De-Sizing	high BOD, high COD, PVA
Scouring	oily fats, BOD (30% of total), high pH, dark color
Bleaching	TDS, high pH
Mercerizing	BOD, High pH

Process	Nature of Effluent
Dyeing	high toxicity, high PH, BOD, high dissolved solids
Printing	high toxicity, high COD, high BOD, high dissolved solids, high PH, strong color
Finishing	low alkalinity, low BOD, high toxicity

3.5 Quantity of Parameters Wastewater Effluents at Inlet and Outlet of Mbr

The following Table 3-2 shows the quantity of the above discussed effluents that are generated during the process and the quantity of the pollutants remained after treatment through MBR. The required criteria for reuse in Textile Industry show the amount of effluent that must be achieved after treatment for the purpose of reuse.

Table 3-2 Quantity of Different Parameter in Wastewater Effluents after Lab Testing

Parameters	Units	Inlet	Primary Treatment Outlet	MBR Outlet	%age removal
Chlorides	mg/L	**299.9**	-	**399.7**	
Alkalinity	mg/L	656.6	-	274.46	58
Hardness	mg/L	345	-	155	55
pH	pH	8.8	-	8.3	5.7
Conductivity	mg/L	940	-	780	17
TDS	mg/L	1480	-	817.3	30
Turbidity	NTU	147	-	2.80	98.1
TSS	mg/L	1067	32	11	66
Sulphates	mg/L	**86.8**	**-**	**97**	
COD	mg/L	1333	-	43.41	97
Nitrogen	mg/L	14.56	-	5.73	61
BOD	mg/L	520	390	12	97
Color	Pt-Co	487	-	341	30

The data clearly shows that most of the pollutants are treated enough through MBR for reusing in textile industry. It has been identified from the experimental values obtained from lab performances that salts are getting rich during treatment due to some fault in the plant. The possible cause is the addition of sodium hydroxide and sodium hypochlorite for the removal of organic fouling in membrane.

3.6 Limitation for Industrial Water Reclamation

Table 3-3 given below showing the limitation for industrial reuse.

Table 3-3 Limitation for Industrial Reuse

Parameters	Unit	Outlet	*Required Guidelines for Reuse in Textile Industry (adopted from *Inspection and quarantine of the PRC, 2005)*	Further removal required (%age)
Chlorides	mg/L	**399.8**	250	17
Alkalinity	mg/L	274.5	350	-
Hardness	mg/L	155	450	-
pH	pH	8.3	6.5-8.5	-
Conductivity	mg/L	780	1000	-
TDS	mg/L	**817.3**	800	22
Turbidity	NTU	2.8 NTU	5	-
TSS	mg/L	11	30	-
Sulphates	mg/L	97	250	-
COD	mg/L	43	60	-
Nitrogen	mg/L	5.7	5	
BOD	mg/L	**12**	10	16
Color	Pt-Co	**341**	30	91

Another problem was arising that colour is not getting treated up to the mark by MBR. Same is for the TDS as MBR does not have enough removal efficiency to make these constituents lower enough so they can reach to the criteria of reuse.

3.7 Selection for Unit Modification in Treatment Plant

3.7.1 Removal of Salts

3.7.1.1 Solution for the limitation of chemical cleaning for membrane fouling

It was observed that chlorides were increasing because of the chemical added for cleaning of fouls in membrane. If chemical cleaning is not a suitable option due to concerns about increasing salt levels in the MBR, there are other methods that can be used to mitigate membrane fouling, including: (15)

- **Physical cleaning:**
  Physical cleaning involves the use of physical forces such as pressure, shear, and ultrasound to remove fouling from the membrane surface. This method is less likely to increase salt levels compared to chemical cleaning.

- **Bio augmentation:**
  Bio-augmentation involves introducing specialized microorganisms into the MBR to break down or metabolize the foulants. This method can be effective for organic fouling but may not be effective for inorganic fouling.

- **Membrane relaxation:**
  Membrane relaxation involves reducing the trans-membrane pressure (TMP) or stopping the aeration of the MBR to allow the fouling layer to swell and become easier to remove. This method can be effective for removing biofilms or other loosely attached fouling.

- **pH adjustment:**
  pH adjustment involves changing the pH of the feed water to create conditions that discourage the growth or accumulation of foulants on the membrane surface. This method can be effective for reducing inorganic fouling.

3.7.2 BOD, TDS, and Dye treatment

3.7.2.1 Post - Ozonation

Ozone is one of the most powerful commercially available oxidants and is commonly used for municipal water and wastewater treatment. In addition to its oxidizing capabilities, it is an environmentally friendly method of treatment wherein the pollutants, including color, odor and microorganisms are directly destroyed by oxidation, without creating harmful chlorinated by-products or significant residues. The instability of ozone makes it powerful oxidizing agent with oxidation potential of 2.08 eV. Among the most common oxidizing agents, it is only surpassed in oxidation power by fluorine and hydroxyl radicals as atomic oxygen is very much unstable. Ozone has a low solubility and is a highly reactive gas. It is usually generated on-site from dry air or pure oxygen through high-voltage corona discharge. The ozonation of dissolved compounds in water can only constitute an Advanced Oxidation Process (AOP) by itself when the hydroxyl radicals are the oxidizing agents of the process. As the pH rises, the decomposition rate of ozone in water increases. Thus, ozonation is considered an AOP when carried out at alkali conditions (above pH 9). Oxidation of organic species may occur due to combination of reactions with molecular ozone and reactions with hydroxyl radicals. Ozone molecule is selective and attacks preferentially the unsaturated bonds of chromophores. The chromophore groups generally are organic compounds with conjugated double bonds that can be broken by ozone directly or indirectly forming smaller molecules that decreases the effluent color. See Figure 3-1 showing the systematic diagram of post ozonation treatment plant working.

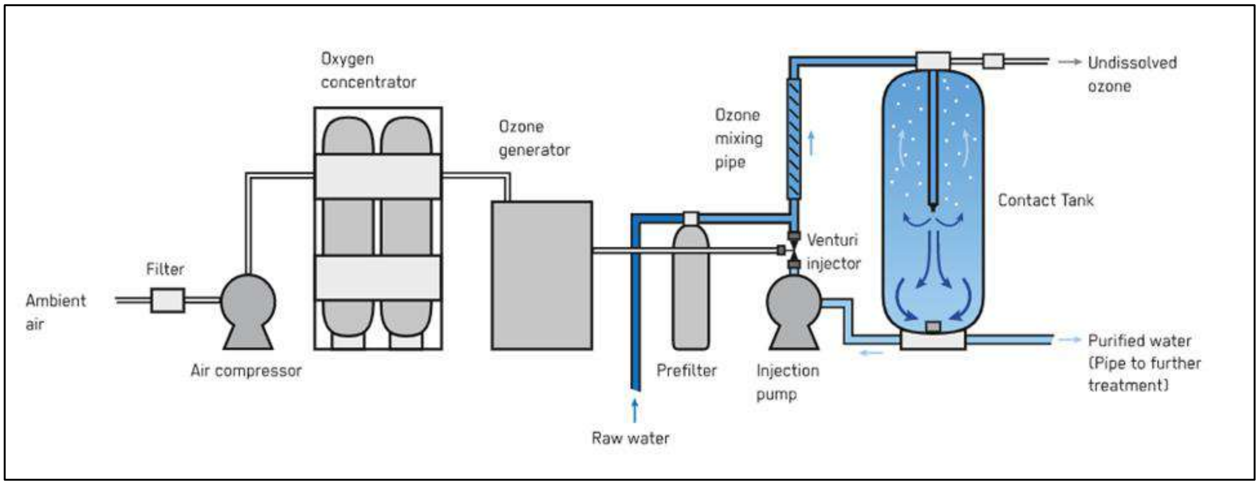


Figure 3-1 Ozonation Process

Mechanism of Ozonation

Ozone chemistry is complex; it is characterized by driving the oxidation in two mechanisms; the direct reaction with the dissolved molecular ozone (O3) and the indirect reaction with the radical species (HO, HO2) that are formed when ozone decomposes in water. The combination of both pathways of mechanism for the removal of the compound will depend on pH of the medium and ozone dose. The reaction between hydroxide ions and ozone leads to the formation of super-oxide anion radical O2 and hydroperoxyl radical HO2. Two hydroxyl radicals are formed from three ozone molecules as, shown in equation

$1.3\ O_3 + OH— + H+2OH + 4O_2$

The O3/UV process makes use of UV photons to activate ozone molecules, thereby facilitating the formation of hydroxyl radicals. Because the maximum absorption of ozone molecules is around 260 nm, the light source commonly used is a medium pressure mercury lamp wrapped in a quartz sleeve. It can generate the UV light at a wavelength of 200-280 nm. The reaction mechanism starts with activating the ozone molecule by UV to form oxygen radical, which then combines with water to form hydroxyl radical.

3.8 Flow Diagram of Treatment Processes

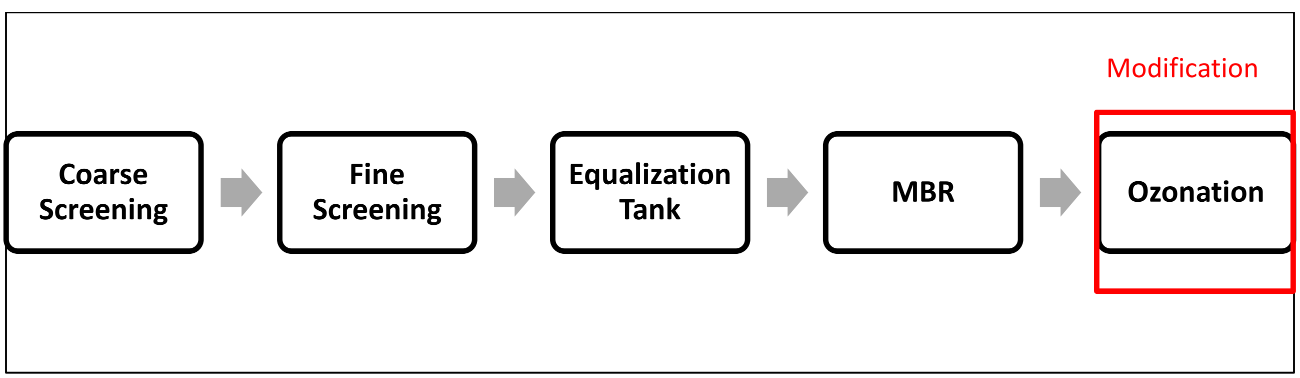


Figure 3-2 Flow Diagram of Treatment Processes

3.9 Rainwater Harvesting

3.9.1 Rainwater Characterization

Table 3-4 given below shows the rainwater characterization adopted from (21) and using guidelines adopted from (22) to directly use the rainwater in industry after collecting and storing the rainwater.

Table 3-4 Rainwater Characterization and Guidelines for Reuse (adopted from (21), (22))

Parameters	Unit	Rainwater Sample Values	*Reuse Guidelines for Textile Industry
pH	-	6.6	6.5-8.5
Electric Conductivity	(m.s)	0.1	1000
TDS	(mg/l)	78.2	700
Hardness	(mg/l)	53.3	450
Cl^-	(mg/l)	54.7	250

3.9.2 Methodology for the rainwater Harvesting

Rainwater is collected from the rooftop of the industry and stored in a cistern, from which it can be directly used in the industry for different purposes. From the above Table 3-4, we can see that all the parameters of rainwater characteristics are under reuse guidelines for the textile industry. Screening is only required for solid waste removal. First flush diversion equipment and screens can be purchased from the market to design the rainwater harvesting system. Systematic picture of rainwater harvesting proposed for the industry as shown in figure 3-3

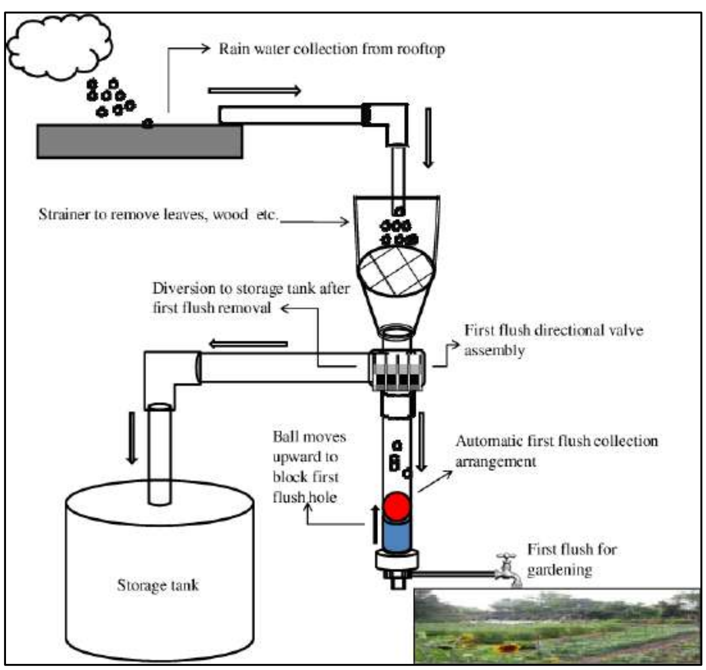


Figure 3-3 Systematic Diagram of Rainwater Harvesting for Industry

4 DESIGN CALCULATIONS

In this chapter the detail design of different unit of treatment process is carried out. First we have design coarse and fine screening, equalization tank and sMBR. Then for advance treatment we have designed ozonation.

Original Flow = 7000 m^3/day

Design Flow = Q = 10,000 m^3/day = 416.67 m^3/hr = 0.1157 m^3/sec

Note: We have taken higher design flow as a safety factor and to incorporate factor for future development.

4.1 Design of Screens

4.1.1 Design of Coarse Screen

Two bar racks were designed.

4.1.1.1 Design Criteria

Table 4-1 given below shows the criteria for designing the screens

Table 4-1 Design Criteria for Screens (adopted from (23))

Parameters	Range	Selected Values
Angle of inclination	0-30°	45°
Bar Size	Width of bars 5-15 mm Depth 25-38 mm	10 * 30 mm
Clear spacing between bars	15 – 75 mm for coarse screen	35 mm
Velocity through screens	-	0.9 m/s
Free Board	-	0.5
Aproach Velocity	0.6 – 0.1 m/s	0.6 m/s

4.1.1.2 Clear Area of Screens

Area through which flow will pass means spaces between bars.

$$A = \frac{Q}{Vs}$$ **Equation 4-1**

By using**Error! Not a valid bookmark self-reference.**

$A = \frac{0.1157}{0.9} = 0.128\ m^2$

Clear area for single opening of screen is 0.128 m^2

4.1.1.3 Clear Width

$$\textbf{Clear Width} = \frac{\textbf{\textit{Area}}}{\textbf{\textit{Total Depth}}} \qquad \textbf{Equation 4-2}$$

Total Depth

Total Depth = Dip + Sewer Dia = 0.5 + 0.45 = 0.95 m

By using

$$\textbf{Clear Width} = \frac{\textbf{\textit{Area}}}{\textbf{\textit{Total Depth}}} \qquad \textbf{Equation 4-2}$$

Clear Width $=\frac{0.128\ m2}{0.95\ m}$ = 0.133m

4.1.1.4 No of Bars

$$\textbf{No of Spaces} = \frac{\textbf{\textit{Clear Width}}}{\textbf{\textit{Spacing between bars}}} \qquad \textbf{Equation 4-3}$$

By using Equation 4-3

No of Spaces = $\frac{0.135}{0.035}$ = 3.87 m

No of Bars

No of Bar = No of Spaces – 1 = 3.867 − 1 = 3

4.1.1.5 Total Width of Bar Screen

$$\textbf{Total width of bars screen} = \textbf{\textit{No of bar}} * \textbf{\textit{Width}} \qquad \textbf{Equation 4-4}$$

By Using Equation 4-4

Total width of bars screen = 3 ∗ 0.01 = 0.0286 m

4.1.1.6 Total Width of Bar Rack

$$\textbf{Total width of bars racks} = \textbf{Clear Width} + \textbf{Total Width of Bar Screen} + \textbf{Total Thickness of Iron Bar Rack} \qquad \textbf{Equation 4-5}$$

By Using Equation 4-5

Total width of bar rack = 0.135 + 0.0286 + 0.3 = 0.464 m

4.1.1.7 Total Gross Width

$$\textbf{Total gross width} = (\textbf{Total Width of Bar Racks} * \textbf{No of Chamber}) + \textbf{Width of Separating Wall} \qquad \textbf{Equation 4-6}$$

By Using Equation 4-6

Total gross width = (0.464*2) +0.34 = 1.268 m

4.1.1.8 Length of Screen Chamber

$$\textbf{Length of screen chamber} = \frac{Total\ Depth}{\tan 45 + 2} \qquad \textbf{Equation 4-7}$$

By using Equation 4-7

Length of screen chamber = $\frac{0.95}{(\tan 45)+2}$ = 2.586m

4.1.1.9 Head Loss

Head loss considering approach velocity (V) = 0.6 m/s as maximum.

$$\mathbf{H_L} = \frac{(1/Cd)*((V2-V2)}{2g} \qquad \textbf{Equation 4-8}$$

Cd= 0.7

Self-cleansing velocity V = 0.9m

By putting the values in Equation 4-8 we can calculate the allowable head loss

Allowable head loss = 0.03m < 0.15m (Ok)

4.1.1.10 Design Summary

Table 4-2 given below shows the design summary of screens

Table 4-2 Design Summary of Screens

Design Summary	
Parameters	**Values**
Area	0.1286 m^2
Depth of Screens	0.95 m
Length of chamber	2.586 m
Head Loss	0.03279m

4.1.2 Design of Fine Screening

4.1.2.1 Design Criteria

Table 4-3 given below shows the criteria for designing the fine screens.

Table 4-3 Design Criteria for Fine Screens

Types of Screening Devices	Size Classification	Size Range (mm)	Screen Medium	Application
Inclined	Medium	0.25 – 2.5	Stainless Steel Wedge wire Screen	Primary Treatment
Drum	Coarse	2.5 – 5	Stainless Steel Wedge wire Screen	Preliminary Treatment
	Medium	0.25 – 2.5	Stainless Steel Wedge wire Screen	Primary Treatment
	Fine	6 – 35 µm	Stainless Steel and Polyester Screen Cloths	Removal of residual secondary suspended solids
Horizontal Reciprocating	Medium	1.6 – 4	Stainless steel bars	Combined sewer overflows
Tangential	Fine	1200 µm	Stainless steel mesh	Combined sewer overflows

Stainless steel and polyester screen cloths (rotary drum) is used as fine screen.

4.1.2.2 Submerged area of screen openings

Area through which flow will pass means spaces between bars and can calculate by using Equation 4-1

$A = \frac{Q}{Vs} = \frac{0.1157}{1} = 0.1157\ m^2$

Submerged area of screen openings is 0.1157 m^2

4.1.2.3 Dimensions

Clear width can calculate by using Equation 4-2

Total Depth

By taking Depth to Width Ratio **1:5**

Depth = 0.416m

Width = 0.358 m

Clear Width = $\frac{Area}{Total\ Depth}$ =$\frac{0.1157\ m2}{0.416m}$ = 0.278m

4.1.2.4 Area of Holes

$$\textbf{Area} = \frac{\pi}{4} * D^2 \qquad \textbf{Equation 4-9}$$

By using Equation 4-9

Area = $\frac{\pi}{4}$ * D^2 = $\frac{3.14*(0.000035)^{\wedge}2}{4}$ = 9.62 x 10^{-10} m^2

No of Holes

$$\textbf{No. of holes}= \frac{Clear\ Area}{Area\ of\ Holes} \qquad \textbf{Equation 4-10}$$

By using Equation 4-10

No. of holes= $\frac{0.1157}{9.62 \text{ x } 10^{-10}}$ = 120298239

4.1.2.5 Total Area

By using Equation 4-1 we can find total area

Total area = $\frac{Q}{Approch\ Velocity}$ = $\frac{0.1157}{0.6}$ = 0.1929 m^2

4.1.2.6 %age of Holes on sheet

$$\textbf{Percentage of holes on sheet} = \frac{Clear\ Area}{Total\ Area} \qquad \textbf{Equation 4-11}$$

By using Equation 4-11

Percentage of holes on sheet = $\frac{0.1157}{0.1929}$ = 0.6 = 60 %

4.1.2.7 Total Gross Width

$$\textbf{Total gross width} = (width \times no. of\ chamber) + width\ of\ separating\ wall \qquad \textbf{Equation 4-12}$$

By using Equation 4-12

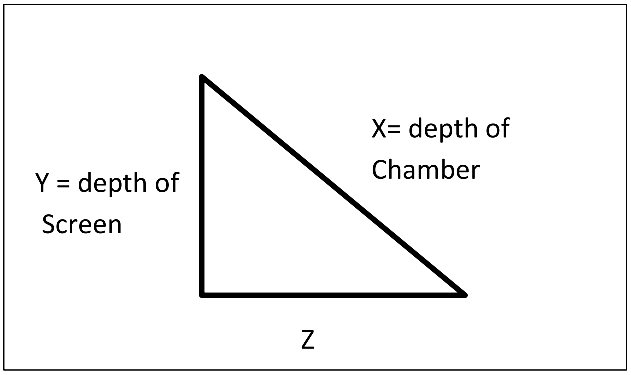
Total gross width = $(0.358 \times 2) + 0.3$ = 1.057m

4.1.2.8 Length of Screen Chamber

$$\textbf{Depth} = \frac{Q}{Velocity\ through\ screens*Width} \qquad \textbf{Equation 4-13}$$

By using Equation 4-13

$$\text{Depth} = \frac{0.1157}{(1*0.3856)} = 0.323\text{m}$$



Length Chamber= 1+0.5+0.5 = 2 m

4.1.2.9 Head Loss

Head loss considering approach velocity (V) = 0.6 m/s as maximum.

By using Equation 4-8 we can calculate the allowable head loss

Cd= 0.7

Allowable head loss = 0.14m < 0.15m (OK)

4.1.2.10 Design summary

Table 4-4 given below shows the design summary of fine screens

Table 4-4 Design Summary of Fine Screen

Design Summary	
Parameters	**Values**
Total Depth	0.416 m
Width	1.057 m
Length	2 m
Head loss	0.14 m

4.2 Equalization Tank Design

4.2.1 Volume of tank

Taking the detention time 8 hours (adopted from (24))

$$\boldsymbol{Volume = \frac{Flow}{time}}$$ **Equation 4-14**

By using Equation 4-14

$Volume = \frac{416.67}{8} = 52\ m^3$

4.2.2 Dimensions of Tank

Assume Depth **4m**

$$\textbf{Area} = \frac{\boldsymbol{Volume}}{\boldsymbol{Depth}}$$ **Equation 4-15**

By using Equation 4-15

Area $= \frac{52}{4} = 13.02\ m^2$

Length to Width Ratio **1:1**

$Length = \sqrt{Area}$

$Length = \sqrt{13.02}$

$Length = 3.6\ m$

$Width = 3.6\ m$

4.3 Design Of sMBR

This design calculation is for sMBR. sMBR shows the position of MBR that will show that MBR is submerged in the sedimentation tank; otherwise, it requires the same criteria and calculation for design as MBR.

4.3.1 Design Criteria for MBR

Table 4-5 shows criteria for designing the MBR

Table 4-5 Design Criteria for MBR (adopted from (25))

Design Criteria of MBR	
Parameters	**Values**

Design Criteria of MBR	
Depth	4-5 m
L:W	1
Flux for Zenon membrane	12 LMH
Total Retention time	2-5 days
K_n	0.26
K_d	0.06
K_0	0.5
K_{dn}	0.06
Factor of Safety (FS)	1.5
f_d	0.15
μ_{nm}	0.26
N	1
ρ_A	1.2

4.3.2 Design Parameter

Table 4-6 given below shows the design parameter after getting the lab result

Table 4-6 Design Parameter (adopted from lab testing)

Parameter	Value
Influent BOD (S_o)	982 mg/L
Required Effluent BOD (S)	12 mg/L
Oxygen requirement of Biomass ($M_{x,bio}$)	1156.8
NO_x	19.04
NO_e	8.49
$O_{A,m}$	0.232
DO	1.5
Yield	0.4
Nitrogenous Yield (Y_n)	0.26
nbVSS	3
Mass of Volatile Suspended Solids (X_{vss})	8000
Biomass (X_b)	195.1

4.3.3 Area of membrane

$$\textbf{Area of membrane} = \frac{Flow}{Flux} \quad \text{Equation 4-16}$$

By using Equation 4-16

Area of membrane = $\frac{10,000}{288}$ = 34.72 × 1000 = 34722.2 m^2

Area of 1 unit of Zenon membrane = 1651.2 m^2

$$\textbf{Total number of units} = \frac{\textit{Area of membrane}}{\textit{Area of 1 unit}} \quad \textbf{Equation 4-17}$$

By using Equation 4-17

Total number of units = $\frac{34722.2}{1651.2}$ = 21 units

4.3.4 Specific Aeration Demand (SAD) according to membrane area

For Membrane type, Zenon ZW500D, (25)

SAD_m = 0.29 $Nm^3/m^2/h$

4.3.5 Specific Aeration Demand according to permeate

$$\textbf{SAD}_p = \frac{Flux}{SADm} \quad \textbf{Equation 4-18}$$

By using Equation 4-18

$SAD_p = \frac{12}{0.29} \times 1000$ = 24.17 m^3 air/ m^3 permeate

4.3.6 Membrane Air Scouring Capacity

$$\textbf{Oxygen requirement for biological treatment} = M_o = Q(S_0 - S) - 1.42M_{x,bio} + 4.33QNOx - 2.86Q(NOx - NOe) \quad \textbf{Equation 4-19}$$

By using Equation 4-19

Oxygen requirement for biological treatment = M_o

$$= \frac{10,000(982-12)-(1.42\times1156.8)+(4.33\times10,000\times19.04)-(2.86\times10,000(19.04-8.49)}{1000} = 424.3 \text{ kg/hr}$$

$$\textbf{Oxygen transferred by membrane aeration} = M_m = Q_{A,M} \times \rho_A(SOTE_{coarse} \times y_{coarse})O_{A,m} \times \alpha\beta\varphi \quad \textbf{Equation 4-20}$$

By using Equation 4-20

Oxygen transferred by membrane aeration = M_m =10,000×1.2×0.02×2.3×0.232×0.43×0.95×0.83

= 43.42 kg O_2/day = 1.81 kg O_2/hour

$$\textbf{Net air flow} = \frac{M_O - M_m}{\rho_A(SOTE_{fine}y_{fine})O_{A,m}\alpha\beta\varphi} \quad \textbf{Equation 4-21}$$

By using Equation 4-21

Net air flow = $\frac{424.3-1.81}{1.2\times0.05\times5\times0.232\times0.51\times0.95\times0.83}$ = 15095.2 Nm^3/hour

4.3.7 Membrane Tank Volume

$$\textbf{Volume} = \frac{A_m}{\varphi_{tank}} \qquad \textbf{Equation 4-22}$$

By using Equation 4-22

Membrane packing density of Zenon = 253 m^{-1}

Volume = $\frac{34722.2}{253}$= 137.24 m^3

4.3.8 Aerobic SRT

$$\textbf{Specific growth rate of nitrifying bacteria} = \mu_n = \left(\frac{\mu_{nm}N}{K_n+N}\right)\left(\frac{DO}{K_o+DO}\right) - k_{dn} \qquad \textbf{Equation 4-23}$$

By using Equation 4-23

Specific growth rate of nitrifying bacteria = μ_n = $(\frac{0.26\times1}{0.26+1})(\frac{1.5}{0.5+1.5})$-0.06 = 0.095 g new cells/ g cells.day

$$\textbf{Theoretical SRT} = \frac{1}{\mu_n} \qquad \textbf{Equation 4-24}$$

By using Equation 4-24

Theoretical SRT = $\frac{1}{0.095}$= 10.55 days

$$\textbf{Design SRT} = FS \times theoretical\ SRT \qquad \textbf{Equation 4-25}$$

By using Equation 4-25

Design SRT = 1.5 × 10.55 = 15.83 days

4.3.9 Sludge Production

$$P_{x,bio} = \frac{QY(S_o-S)(\frac{1kg}{10^3g})}{1+k_dSRT} + \frac{(f_d)QY(S_o-S)SRT(\frac{1kg}{10^3g})}{1+k_dSRT} + \frac{QY_n(NO_x)(\frac{1kg}{10^3g})}{1+k_{dn}SRT} \qquad \textbf{Equation 4-26}$$

By using Equation 4-26

$P_{x,bio}$= $= \frac{10,000\times0.4(982-12)\left(\frac{1kg}{10^3g}\right)}{1+(0.06\times15.83)} + \frac{(0.15)10,000\times0.4(982-12)15.83\left(\frac{1kg}{10^3g}\right)}{1+(0.06\times15.83)} + \frac{10,000\times0.26(19.04)\left(\frac{1kg}{10^3g}\right)}{1+(0.06\times15.83)}$

= 32.1049 kg/day

$$P_{x,vss} = P_{x,bio} + Q(nbVSS)(\frac{1kg}{10^3g}) \qquad \textbf{Equation 4-27}$$

By using Equation 4-27

$P_{x,vss}$ = $32.1049 + 10{,}000(3)(\frac{1kg}{10^3 g})$ = 62.1049 kg/day

$$\mathbf{P_{x,tss}} = \frac{P_{x,bio}}{0.8} + P_{x,vss} + (Q \times 18.3)\left(\frac{1kg}{10^3 g}\right) \quad \textbf{Equation 4-28}$$

By using Equation 4-28

$P_{x,tss} = \frac{32.1049}{0.8} + 62.1049 + (10{,}000 \times 18.3)\left(\frac{1kg}{10^3 g}\right)$= 285.236 kg/day

4.3.10 Aerobic Volume

$$\textbf{Mass of MLVSS} = Px, vss \times\ design\ SRT \quad \textbf{Equation 4-29}$$

By using Equation 4-29

Mass of MLVSS = 62.1049 × 15.83 = 983.1 kg

$$\textbf{Volume} = \frac{P_{x,vss}\left(\frac{1kg}{10^3 g}\right)SRT_{design}}{X_{vss}} \quad \textbf{Equation 4-30}$$

By using Equation 4-30

Volume = $\frac{62.1049(10^3 g)15.83}{8000}$= 122.9 m^3

4.3.11 Recirculation ratio

r_{int} = $(\frac{19.04}{4.55})$-1 = 3.18

4.3.12 Active biomass in Anoxic Zone

$$\mathbf{X_b} = (\frac{Q(SRT)}{V})(\frac{Y(S_o - S)}{1 + k_d SRT})(\frac{r_{int}}{r_{int}+1}) \quad \textbf{Equation 4-31}$$

By using Equation 4-31

X_b = $(\frac{10{,}000(15.83)}{122.9})(\frac{3880/10{,}000}{1+(0.06\times15.83)})(\frac{3.18}{3.18+1})$ = 195.1 g/m^3

4.3.13 Nitrate load to anoxic zone

$$\textbf{NO – loading in g/day} = \mathbf{Qrint(TKN - Ne - 0.12Mx, bio/Q)} \quad \textbf{Equation 4-32}$$

NO – loading in g/day = 33.8 – 8.49 – $\frac{(0.12\times1156.8)/10{,}000}{1000}$ = 25.31 kg/day

4.3.14 F/Mb ratio

$$\mathbf{F/M_b} = \frac{QS_o}{V_{annox}X_b} \quad \textbf{Equation 4-33}$$

By using Equation 4-33

$V_{annox} = Q\tau = 10000 \times \frac{3}{24} = 1250\ m^3$

$F/M_b = \frac{QS_o}{V_{annox}X_b} = \frac{10{,}000 \times 982}{1250 \times 195.1} = 40.3$ gBOD/gTSS.day

4.3.15 Total Retention Time

$$\mathbf{T} = \frac{VX_{vss} + (V_{annox} \times 2908.02)}{0.011QX_{vss}} \quad \textbf{Equation 4-34}$$

By using Equation 4-34

$T = \frac{122.9 \times 8000 + (1250 \times 2908.02)}{0.011 \times 10{,}000 \times 8000} = 5$ days

4.3.16 Total process volume

$$\mathbf{V} = V_{\text{annox}} \times V_{\text{aerobic}} \quad \textbf{Equation 4-35}$$

By using Equation 4-35

$V = 1250 \times 122.9 = 1372.9\ m^3$

4.3.17 Area Requirement & Dimensions

Let depth = 5m

By using Equation 4-15

Area $= \frac{V}{d} = \frac{1372.9}{5} = 274.6\ m^2$

Assume L: W = 1

Thus Length & Width= 16.5m

4.3.18 Design summary of SMBR

Table 4-7 given below shows the design summary of sMBR.

Table 4-7 Design Summary of sMBR

Design Summary of MBR	
Parameters	**values**
Area of membrane	34722 m^2
Units of membrane	21 membranes
Membrane Tank Volume	137.24 m^3
Aerobic SRT	15.83 days
Depth	5 m
Area	274 m^2
F/M_b	40.3 gBOD/gTSS.day
Sludge Production	285 kg/day
Retention Time	5 days
Type of membrane	Polymeric micro-filtration membranes with a pore size of 0.1–0.4 μm

4.4 Design of Ozonation Unit

4.4.1 Design criteria for ozonation unit

Table 4-8 given below shows the design criteria for designing the ozonation unit.

Table 4-8 Design Criteria for Ozonation Unit (adopted from (26))

Design Criteria for Ozonation
For Contact Tanks: No. of tanks = minimum 2 Ozone concentration = 5-85 mg/L Water Depth= 18-20ft = 5.48 – 6.09 m Treatment time= Less than 120mins Freeboard = 4-6 ft = 1.2 – 1.8 m
For Destruction Unit: Type: Heat Catalyst Unit Temperature= 80-100 ^{0}F = 26.67-37.78^{0}C Catalyst: Metal or Metal Oxides

4.4.2 Design Parameters

Table 4-9 shows the design parameter adopted some of the values from criteria and some on the basis of pervious treatment plant effluent results

Table 4-9 design Parameters

Parameters	Values
COD after MBR	43.41 mg/L
Color after MBR	341 units
O3 conc.	85 mg/L
O3 flowrate	2 g ozone/hour
k	2.8
Depth	6.1 m (20ft)
Freeboard	1.22m (4ft)
L:W	1:1

4.4.3 Ozonation rate

$$\textbf{Rate} = \frac{O_3 conc. \times O_3 flowrate}{Q} \qquad \text{Equation 4-36}$$

By using Equation 4-36

Rate = $\frac{85 \times 2}{416.67}$ = 0.408 g/m^3.hour

4.4.4 Ozone Demand

$$\textbf{For COD} = \frac{COD\ conc. \times 2.66}{k \times O_3 conc.} \qquad \text{Equation 4-37}$$

By using Equation 4-37

For COD = $\frac{43.41 \times 2.66}{2.8 \times 85}$= 0.48 g ozone/g COD

$$\textbf{For Color} = \frac{color\ conc. \times 2.66}{k \times O_3 conc.} \qquad \text{Equation 4-38}$$

By using Equation 4-38

For Color = $\frac{341 \times 2.66}{k \times 85}$= 3.81 g ozone/unit color

4.4.5 Treatment time

$$\textbf{t = ozone rate × ozone demand} \qquad \text{Equation 4-39}$$

By using Equation 4-39

t_{COD} = 0.408 × 0.48 = 0.2 hours = 11.88 minutes

t_{color} = 0.408 × 3.81 = 1.55 hours = 93.3 minutes (selected)

4.4.6 Dimensions of contact tank

By using Equation 4-14 and Equation 4-15

Volume = Qt = 416.67 × 1.55 = 647.9 m^3

For 2 tanks, V = $\frac{647.9}{2}$= 323.95 m^3

Area = $\frac{V}{d}$= $\frac{323.95}{6.1}$= 53.1 m^2

Length = $\sqrt{Area}$= $\sqrt{53.1}$= 7.29 m

Width = 7.29 m

Length with freeboard = 7.29+1.22 = 8.51 m

4.4.7 Design Summary

Table 4-10 given below showing the design summary of ozonation unit.

Table 4-10 Design summary for Ozonation Unit

Design Summary for Ozonation Unit	
Parameter	**Values**
Ozonation rate	0.408 g/m^3.hour
Ozone demand for COD	0.48 g ozone/g COD
Ozone demand for color	3.81 g ozone/unit color
Recommended treatment time	93.3 minutes
Area	53.1 m^2
Length	8.51 m
Width	7.29m

4.5 Design of Sludge Dewatering Unit

The design calculations for sludge produced in primary treatment and sMBR are given below:

4.5.1 Design Criteria for Sludge Treatment

Table 4-11 given below shows the design criteria for sludge dewatering.

Table 4-11 Design Criteria for Sludge Dewatering Unit (adopted from (23))

Design Criteria for Sludge Treatment	
Parameters	**Values**
Solid Loading Rate	6 kgTSS/m^2.day
SOR	20-30 m/day
Primary sludge	3%
Secondary Sludge	1.5%
Depth	3m (Minimum)
Hydraulic Retention Time	2-10 days

4.5.2 Design Parameters

Table 4-12 given below shows the design parameter for sludge dewatering.

Table 4-12 Design Parameters for Sludge Dewatering

Parameters	Values
Sludge production	285.2 kg/day
Density of water (ρ_w)	1000 kg/m^3
Specific Gravity SG_{sludge}	1.03
Mass of sludge	30 gSS/day
Depth	4 m
No. of gravity thickener	3

4.5.3 Flow

Flow = 10,000 m^3/day

No. of chambers = 8

Flow for 1 chamber = $\frac{10,000}{8}$= 1250 m^3/day

4.5.4 Surface Area

$$A = \frac{total\ solid\ load}{solid\ loading\ rate} \quad \text{Equation 4-40}$$

By using Equation 4-40

$A = \frac{285.2}{6} = 47.54\ m^2$

4.5.5 Surface Overflow Rate

$$\textbf{SOR} = \frac{Q}{A} \qquad \textbf{Equation 4-41}$$

By using Equation 4-41

$SOR = \frac{1250}{47.54} = 26.3\ m/day$

4.5.6 Influent Sludge Volume

$$\textbf{Volume} = \frac{mass}{SG_{sludge} \times P_s \times P_w} \qquad \textbf{Equation 4-42}$$

By using Equation 4-42

$P_w = \frac{3}{100} + \frac{1.5}{100} = 0.045$

$Volume = \frac{mass}{SG_{sludge} \times P_s \times P_w} = \frac{285.2}{1.03 \times 1000 \times 0.045} = 6.15\ m^3$

4.5.7 Recycled Water

$$\textbf{Recycled Water} = \textbf{\textit{Flow – Influent Sludge Volume}} \qquad \textbf{Equation 4-43}$$

By using Equation 4-43

Recycled Water = 1250-6.15 = 1243.8 m^3/day

4.5.8 Gravity Thickener

$$\textbf{Area} = \frac{Total\ surface\ area}{No.\ gravity\ thickener} \qquad \textbf{Equation 4-44}$$

By using Equation 4-44

$Area = \frac{47.54}{30} = 1.6\ m^2$

$$\textbf{Diameter} = \sqrt{\frac{4A}{\pi}} \qquad \textbf{Equation 4-45}$$

By using Equation 4-45

Diameter = $\sqrt{\frac{4(1.6)}{\pi}}$= 0.8m

By using Equation 4-15

Volume = V = Ad = 1.6×0.8 = 4.75 m^3

Volume for all thickeners = 14.26 m^3

4.5.9 Hydraulic Retention Time

$$t = \frac{V_{GT}}{Influent\ sludge\ volume} \qquad \textbf{Equation 4-46}$$

By using Equation 4-46

t = $\frac{14.26}{6.15}$ = 2.32 days

4.5.10 Dimensions

By using Equation 4-14 and Equation 4-15

V= $\frac{Q}{t}$= $\frac{1250}{2.32}$= 539.4 m^3

A = $\frac{V}{d}$= $\frac{539.4}{4}$= 134.8 m^2

Area for 8 chambers = 1079 m^2

4.5.11 Design Summary

Table 4-13 given below shows the design summary of sludge dewatering unit

Table 4-13 Design Summary of Sludge Dewatering Unit

Design Summary for Sludge Dewatering Unit	
Parameter	**Values**
Surface Area	47.54 m^2
Surface Overflow Rate	26.3 m/day
Influent Sludge Volume	6.15 m^3/day
Recycled Water	1243.8 m^3/day
Volume of all gravity thickeners	14.26 m^3

Design Summary for Sludge Dewatering Unit	
Parameter	**Values**
Hydraulic Retention Time	2.32 days
Area of 8 dewatering chambers	1079 m^2

4.6 Storage Tank:

To store the reclaimed water a storage tank is design.

4.6.1 Volume of tank

Assume Detention time= 3 days

By using Equation 4-14

Volume = $\frac{Q}{Time}$ = $\frac{10,000}{3}$ = 3333.3m^3

4.6.2 Area of tank

Assume Depth = 5 m

By using Equation 4-15

$Area = \frac{Volume}{Depth} = \frac{3333.3}{5}$ = 666.67 m^2

4.6.3 Dimensions

Length to width ratio **1:1**

Area = $Length * \quad Width$

Length = $\sqrt{Area}$

Length = $\sqrt{666.67}$

Length of tank = 25.8 m

Width of tank = 25.8 m

4.7 Design of Rain Water Harvesting System

Average calculated from peak values of 60-year rainwater data for Lahore as per (27)

Rainfall Intensity = 52mm/month

$$\boldsymbol{Volume = Rainfall\ Intensity \times Area\ of\ 1st\ Building \times 0.8 \times 0.95 \times 0.05}$$ **Equation 4-47**

By using Equation 4-47

4.7.1 Volume of 1st Cistern:

$$Volume = Rainfall\ Intensity \times Area\ of\ 1st\ Building \times 0.8 \times 0.95 \times 0.05$$

$$Volume = 52 \times 16129 \times 0.8 \times 0.95 \times 0.05$$

Volume of Tank = 31676 l
Volume of Tank = 32 m^3

4.7.2 Volume of 2nd Cistern:

$$Volume = Rainfall\ Intensity \times Area\ of\ 2nd\ Building \times 0.8 \times 0.95 \times 0.05$$

$$Volume = 52 \times 15745 \times 0.8 \times 0.95 \times 0.05$$

Volume of Tank = 30922 l
Volume of Tank = 31 m^3

4.7.3 Volume of 3rd Cistern:

$$Volume = Rainfall\ Intensity \times Area\ of\ 3rd\ Building \times 0.8 \times 0.95 \times 0.05$$

$$Volume = 52 \times 15745 \times 0.8 \times 0.95 \times 0.05$$

Volume of Tank = 32123.8 l
Volume of Tank = 32.1 m^3

4.7.4 Design Summary of Rainwater Harvesting

Table 4-14 given below shows the summary of design

Table 4-14 Design Summary of Rainwater Harvesting System

Parameters	Building 1	Building 2	Building 3
Area	16129 m^2	15745 m^2	16357 m^2
Volume of Cisterns	31 m^3	31 m^3	32 m^3
Cistern Diameters	6.09 m	6.02 m	6.13 m
Diverted water	7 L	7 L	7 L

5 COST ESTIMATION

5.1 Cost Estimation Uptil sMBR

5.1.1 Capital Cost of sMBR

Table 5-1 given below shows the Preliminary cost estimate of MBR is

Table 5-1 Preliminary Cost Estimation of MBR (adopted from (24))

sMBR Preliminary Cost Estimate		
Parameters		**Cost ($)**
MBR Equipment		3,000,000
Concrete + Equalization Tank		750,000
Yard Piping		250,000
Excavation		50,000
Electrical		400,000
Disinfection		30,000
Headworks		350,000
Contractors Overhead and Profit	10%	516175
Primary treatment		257,267.50
Equalization Tank		74,483.68
Total Cost ($)		**5,677,926**

Use US $ 5,677,926 for O & M cost:
Take inflation rate= 18.6% (Avg inflation rate of Pakistan 2023) (28)
For 2023:
$ 5,677,926 *1.186 = US $ 6,734,020
For Our flow rate = 1.5 MGD* 6,734,020
= US $ 10,101,030
This is the expected preliminary cost estimate for membrane bioreactor.

5.1.2 Operation and Maintenance Cost of sMBR

The operational and maintenance cost of MBR is $1.77 per 1,000 gallons of wastewater treated (29). So, the annual operational cost of MBR for our project is:

For 2023:
Take inflation rate= 18.6% (Avg inflation rate of Pakistan 2023)

$O\&M\ cost\ per\ thousand\ gallon = inflation\ rate\ \times cost\ per\ thousand\ gallons$

=1.77×1.18 = US $ 2.0886

For Our flow rate = 1,849,204 G/D × 2.0886

= $ 3.8 M

This is the approximate O & M cost of MBR.

5.2 Cost Estimation of Ozonation Unit

5.2.1 Capital Cost of Ozonation Unit

The preliminary cost of ozonation is given below in Table 5-2:

Table 5-2 Preliminary Cost Estimation of Post Ozonation Unit (adopted from (29))

Preliminary Cost of Ozonation		
Parameters		**Cost ($)**
Ozonation Equipment		300,000
Contact tank		25,000
Yard Piping		250,000
Excavation		50,000
Electrical		400,000
Headworks		350,000
Ozone generation		200
Contractors Overhead and Profit	10%	137,520
Total Cost ($)		**1,512,720**

5.2.2 Operation and Maintenance Cost of Ozonation

The operational and maintenance cost of ozonation is $0.2 per 1,000 gallons of wastewater treated (29). So, the annual operational cost of ozonation for our project is:

For 2023:

Take inflation rate= 18.6% (Avg inflation rate of Pakistan 2023)

1.77*0.2 = US $ 0.354

For Our flow rate = 1,849,204 G/D* 0.354

= $ 0.6M

This is the approximate O & M cost of Ozonation.

5.3 Cost Estimation of Rainwater Harvesting System

Table 5-3 given below shows the cost estimation of rainwater harvesting. Cost estimation of screen, first flush diverter and cisterns are based upon the current market rate of these things.

Table 5-3 Cost estimation of Rainwater Harvesting System

Units	Cost ($)
Screen	57
First Flush Diverter	120
Cisterns	10,000
Total Cost ($)	**10,177**

6 RESULT AND RECOMMENDATIONS

6.1 Efficiency after Modification

6.1.1 By sMBR modification

It was observed that salts were increasing because of the chemicals added for the cleaning of fouling in membranes. So instead of chemical cleaning, we suggest biological cleaning for fouling, as they are not only more effective for membrane biofouling control but also milder and more environmentally friendly. Now there are various biological-based strategies, but according to removal efficiency and availability of biological organisms, quorum quenching with Rhodococcus bacteria is preferred as they reduce membrane fouling with a rate of 75.0–89.0%. Their source is Lactonase and their mode of action is signal molecule degradation. These micro-organisms are easily available at micro labs.

By this method, MBR will reach its optimum removal of chlorides i.e., 18.8% thus removing chlorides of 299.907 at inlet to 243.07 mg/L while required for reuse are 250 mg/L. In this way, chloride will no longer remain an issue while industrial reuse.

6.1.2 By Addition of Ozonation Unit

Effluent from the sMBR is then further treated by ozonation to achieve the guidelines for reuse. Efficiencies achieved after the modification of the treatment plant are given below Table 6-1**Error! Reference source not found.**. The first column shows the parameter we need to treat, and the second column shows the unit of each parameter. While the 3rd column shows the required efficacy we need to achieve after wastewater is treated with sMBR, the 4th column shows the values we achieved after treating sMBR effluent with ozonation, and the 5th column shows the required guidelines we need to achieve for reuse.

Table 6-1 Efficiency Achieved after Modification

Parameters	Unit	Required Removal Efficiency (%)	Achieved Values after Modification	Required Values According to Guidelines
Chlorides	mg/l	18.8	243.5	250
TDS	mg/l	6	792	800
Color	Pt-Co	92.2	26.6	30
Nitrogen	mg/l	30	4	5
BOD	mg/l	10	10.2	10
COD	mg/l	40	26	60

6.2 Graphical Representation of Results

The graphs represent the removal efficiencies achieved with and without ozonation in comparison to the required criteria for that parameter that need to be treated to achieve the guidelines for reuse

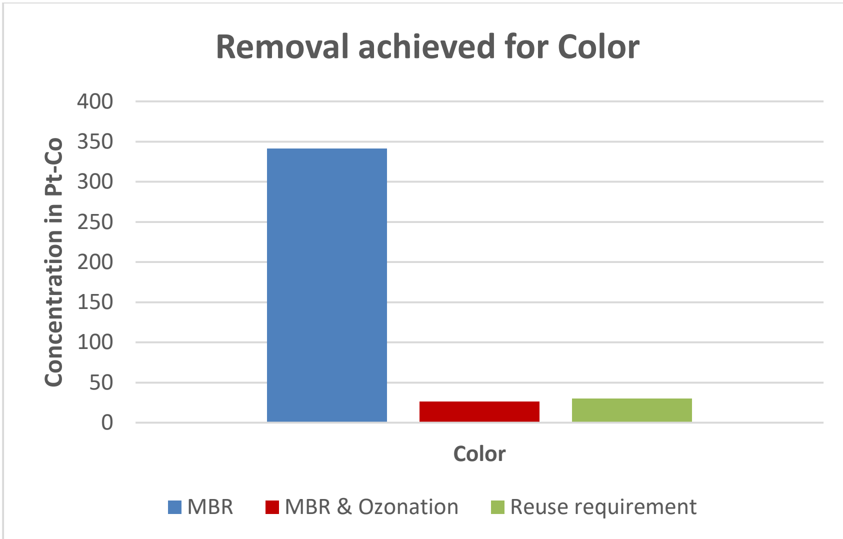


Figure 6-1 Removal achieved for color by ozonation

Figure 6-1 represents that the remaining color after only sMBR is much greater (as shown with the blue bar) than the amount required for reuse (as shown with the green bar). After our addition of an ozonation unit to enhance the treatment, the remaining colour will be even slightly less than required (as shown with the red bar), thus meeting the guidelines.

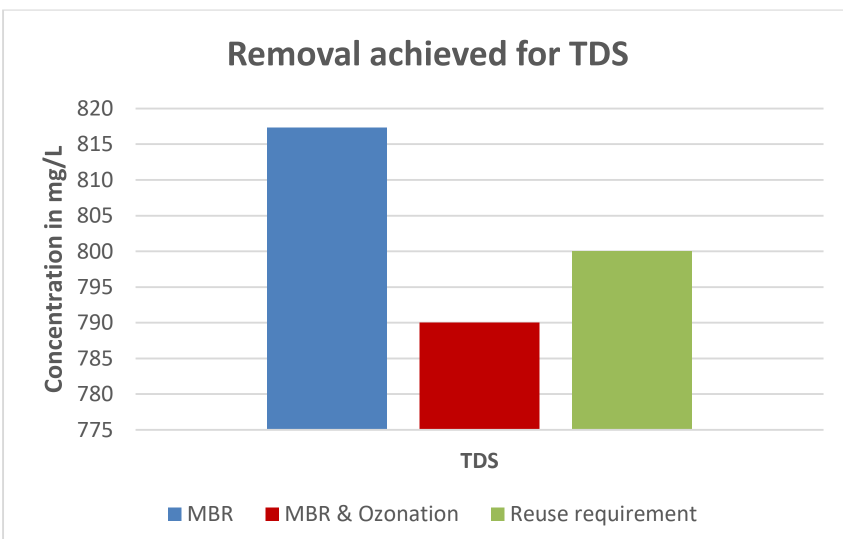


Figure 6-2 Removal achieved for TDS by ozonation

Figure 6-2 represents that the remaining TDS after only sMBR, even after using biological cleansing for membrane fouling, is slightly greater (as shown with the blue bar) than the amount required for reuse (as shown with the green bar). After our addition of an ozonation unit to enhance the treatment, the remaining TDS will be almost equal (as shown with the red bar), thus meeting the guidelines.

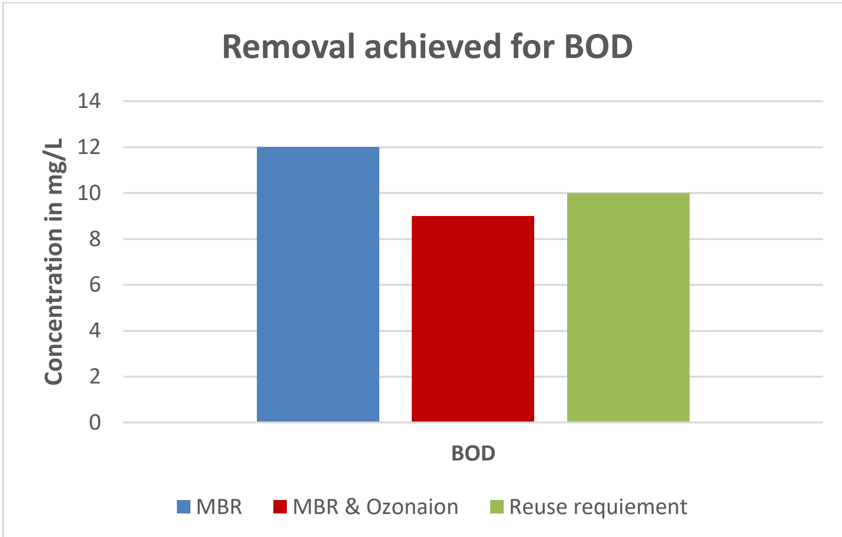


Figure 6-3 Removal achieved for BOD by ozonation

Figure 6-3 represents that the remaining BOD after only sMBR was already low (as shown with the blue bar) but still not meeting the guidelines (as shown with the green bar). After our addition of an ozonation unit to enhance the treatment, the remaining BOD will be even slightly less than required (as shown with the red bar), thus meeting the guidelines.

6.3 Water Conserved

Table 6-2 given below showing the amount of water conserved from treatment plant modification and rainwater harvesting.

Table 6-2 Amount of Water Conserved

Total Water For Re-Use	
From treated water	6650 m^3/day
From rainwater harvesting	93 m^3/month

Water conserved by rainwater harvesting can vary during the monsoon season. This conserved water can be used in different processes in the textile industry, such as sizing, de-sizing, scouring, bleaching, and mercerizing and can be used for other purposes instead of printing and dyeing, because a small amount of color is still present in the treated water. Printing and dyeing are important and sensitive unit processes in the textile industry. Following Table 6-3 and Table 6-4 shows the water consumption by industry.

Table 6-3 Water Consumption by Industry (adopted from industrial data)

Water Requirements for Textile Wet Finishing Operations		
Process	**Selected industry water usage m^3/1000 kg of product**	**Water usage for industry daily production (14000 kg/day)**
Sizing	7.8	109.2
De-sizing	20.5	287
Scouring	32.6	455.7
Bleaching	22.4	313.6
Mercerizing	31	434
Total consumptions	507.2	1599.5

Table 6-4 Water consumption by industry for other purposes (adopted from industrial data)

Water Usage in Textile Mills	
Purpose	**Percentage of water used**
Steam generation	8.2
Cooling water	6.4
Sanitary use	7.6
Miscellaneous and fire fighting	28.0

The Table 6-4 above shows that out of total amount of water, the above stated percentages can be used for each parallel listed process. Hence, we can see that conserved water can easily be used in the above-mentioned industrial processes and for some other industrial purposes too.

6.4 Cost Reduction

Lahore development authority (water and sanitation agency) aquifer charges on industrial water extracting trough tube-well are given below in Table 6-5 :

Table 6-5 aquifer charges on industrial water extracting trough tube-well (30)

Aquifer Charges on Industrial Water Extracting Trough Tube-Well		
Size of Tube Well	Rate per Month (Rs.)	Rate per Month ($)
1 cusec	3,00,000	1041.83
½ cusec	1,50,000	520.91

Industry required 3 cusecs of underground water pumping for their processes, which cost them 10 lacs ($ 3473) per month as per the WASA rating as shown in the above Table 6-5. After reuse, there will be a 70% reduction in water costs, as now they'll only require pumping 1 cusec of water for their sensitive processes. The comparison of cost is shown in the Figure 6-4 below:

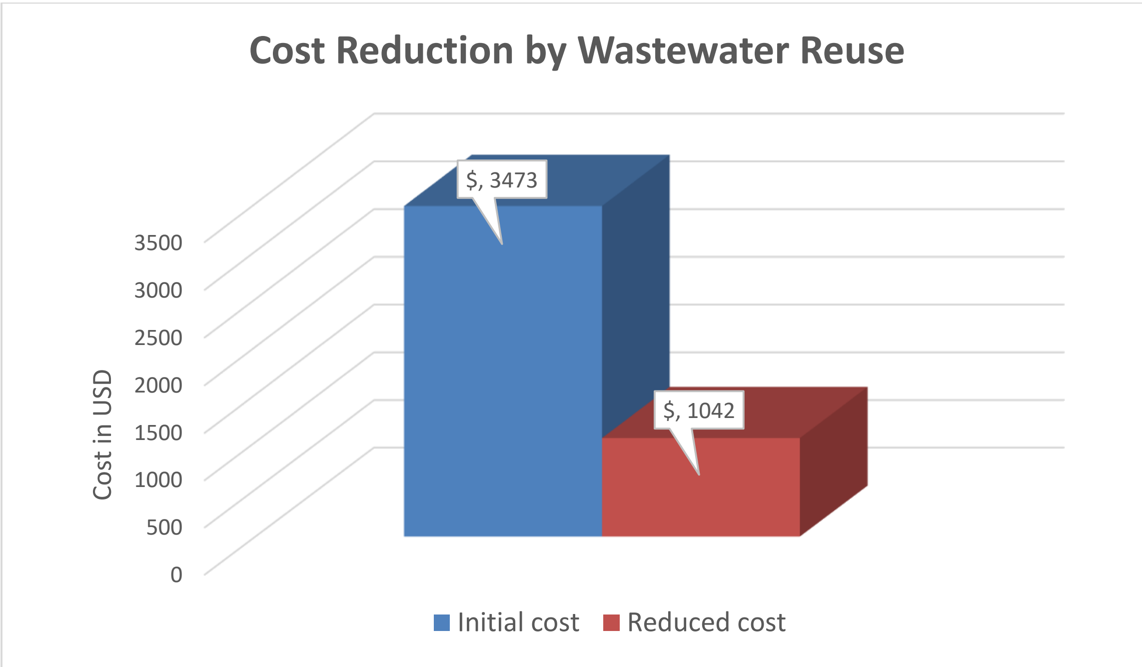


Figure 6-4 Cost Reductions by Wastewater Reuse

6.5 RECOMMENDATIONS

Following are some recommendations:-

- For membrane fouling cleansing, air flushing or air sparging can be used to avoid an increase in salts.
- Water conservation through surface runoff rainwater harvesting can conserve more water. If industry wants more conservation, they can conserve 103.3 m^3/month amount of water according to their area availability and rainfall data.

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