Treatment of nitro-phosphate plant effluent

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This thesis is submitted as a partial fulfillment of the requirements for the degree of

BE Chemical Engineering

Supervisor Name: Dr. Abdul Qadeer Malik

Co-Supervisor Name: Dr. Muhammad Taqi Mehran

School of Chemical and Materials Engineering (SCME)

National University of Sciences and Technology (NUST)

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May, 2019

Certificate

This is to certify that work in this thesis has been carried out by **Mr. Muhammad Abdullah Akhtar, Mr. Rana Talha Ali** and **Mr. Umar Rafique** completed under my supervision in School of Chemical and Materials Engineering, National University of Sciences and Technology, H-12, Islamabad, Pakistan.

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Dedication

We dedicate our work to our parents and to SCME where we learned some valuable lessons of life.

Acknowledgements

We are thankful to Allah Almighty, Who is the most beneficent and the most merciful. We are grateful to Him and without His constant help we wouldn’t have been able to complete this project.

We would like to acknowledge Dr. Taqi Mehran, our co-supervisor, who helped us a lot throughout the project, without him this project wouldn’t have been possible. We are also thankful to Dr. Abdul Qadeer Malik for his constant support and help throughout the project.

We are also grateful to our respectable IPO (Lec Zaeem Aman, Dr. Waqas Cheema and Sir Sajjad Rahim), for getting us in contact with the industry and providing us with this project.

We would like to mention Engineer Asad Ahmed, our industrial supervisor, we thank him for guiding us and providing us with the data from the industry without which our project was not possible.

We are extremely indebted to our parents for believing in us, and for helping us achieve our dreams.

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Abstract

The effluent of nitro-phosphate plant contains very high amounts of total dissolved solids (TDS), total suspended solids (TSS), chemical oxygen demand (COD) and biochemical oxygen demand (BOD). These amounts are not in accordance to the standard of Government of Pakistan as mentioned in NEQs (National Environmental Quality Standards). The purpose of this project report is to design an industrial waste water treatment process for the effluent from Fatima Fertilizers Industries. The process includes equalization and neutralization (for flow and pH control), coagulation and sedimentation (for TSS removal), membrane bioreactor (for COD and BOD removal), ultrafiltration (for sludge and TSS removal) and reverse osmosis membrane system (for TDS removal). After the processing of the effluent TDS, TSS, COD and BOD are brought down to required NEQ standards.

CHAPTER 1: INTRODUCTION

Develop treatment process for reuse of Liquid effluent from Nitro-Phosphate plant as cooling water make up.

1.1 About the company

Fatima group has a significant importance in economic sector of Pakistan. First established as a trading company they got into a manufacturing business of different products. Fatima Group has now established business ventures in manufacturing of fertilizers, textiles, sugar, mining and energy.

Pak-Arab Fertilizer is also a venture of Fatima Group and it is the only company in Pakistan that produces Urea, Calcium Ammonium Nitrate and Nitro-Phosphate. We've been assigned to treat liquid effluent stream coming from Nitro-Phosphate production plant so that this treated water can be reused as cooling tower make-up.

1.2 Cooling water

Cooling requirements in industries are met through the use of cooling water. Cooling water is used to control and maintain the temperature of streams. Cooling towers are set-up to fulfill the cooling water requirements of the plant. A cooling tower needs a blow down due to accumulation of salts in the water that reduces the heat transfer properties of the water which in result reduces cooling effect of the water. So to accommodate this blow-down, make up water is required that is basically fresh water with low TDS. Our objective is to treat the effluent to conditions at which it can be used as a cooling tower make-up.

1.3 Why is treatment important?

High level of nutrients like Nitrate and Phosphate cause eutrophication which is one the most problematic kind of water pollution. Water is polluted because of the fertilizer plant effluent as well as the fertilizer run-off from agriculture sector. This polluted water harms the sea-life and ultimately affects the eco-system. Apart from its adverse effects on sea-life, drinking water containing nitrates and phosphate can cause harmful effects on health as well. The major aim of water treatment processes is to remove these ions from the effluent stream.

Recycling of water is also an effective way to tackle the water pollution problems.

1.4 Essentials of water treatment

1.4.1 Total Dissolved Solids (TDS)

The salts and minerals that are completely dissolved in water and can't be removed by simple separation processes are known as total dissolved solids. Ion exchange method or membrane separation at Nano scale is required to remove this dissolved content

1.4.2 Total Suspended Solids (TSS)

The particles or minerals that are not dissolved in water and can be separated out by a relatively easier separation processes. Water having high turbidity contains more TSS. Ultrafiltration, Coagulation, Flocculation and Sedimentation are some TSS removal processes.

1.4.3 Chemical Oxygen Demand (COD)

Some chemical compounds in water require oxygen to decompose. The total demand of oxygen by these chemical compounds is represented by chemical oxygen demand. When oxygen interacts with water that has a chemical oxygen demand the compound decomposes and forms sludge. COD is treated using activated sludge process with clarifier or membrane bio-reactors.

1.4.4 Biological Oxygen Demand (BOD)

Microorganisms in water require oxygen to decompose. The requirement of oxygen by these micro-organisms is called Biological Oxygen Demand. BOD can be treated just like COD is treated.

1.4.5 pH Balance

pH represents acidity or alkalinity of water. pH 7 is considered to be the neutral pH that is neither basic nor acidic. Acidic nature of water can cause corrosion and damage of equipment while fouling is caused by alkaline water. Hence, pH needs to be balanced in a treatment process. Neutralization is used to balance out the pH.

1.5 Treatment guidelines

To have the most successful cooling water treatment program requires all of the following elements.

1. Optimized chemical treatment and automated system control programs must be combined.

2. Plant personnel – including operators, supervisors, engineers, and managers – must understand the value of the cooling water system in relation to production and must be committed to maintain and control the program.

3. Monitoring and control must be continuous and must utilize the proper techniques, equipment, and supplies.

4. A complete system approach combining these aspects will optimize TDS.

1.6 Reasons for handing over this project

- Reduction in water consumption (full plant)
- Cost savings from recycling treated water
- Sustainability

1.7 Our goals

- Reduction in Total Dissolved Solids and Total Suspended Solids
- Reduction in Chemical Oxygen Demand and Biological Oxygen Demand

1.8 Treatment of wastewater

Flow Rate: 814 m^3/day

Table 1: Objectives of the project

Parameter Checked	**Test Result**	**Requirement**
Temperature (Degrees Celsius)	25	25
pH	4-8	7.1
Total Dissolved Solids (ppm)	52765	300-500
Total Suspended Solids (ppm)	2205	-
COD (ppm)	205	Negligible
BOD (ppm)	150	Negligible

CHAPTER 2: LITERATURE REVIEW

2.1 Equalization and Neutralization of Feed

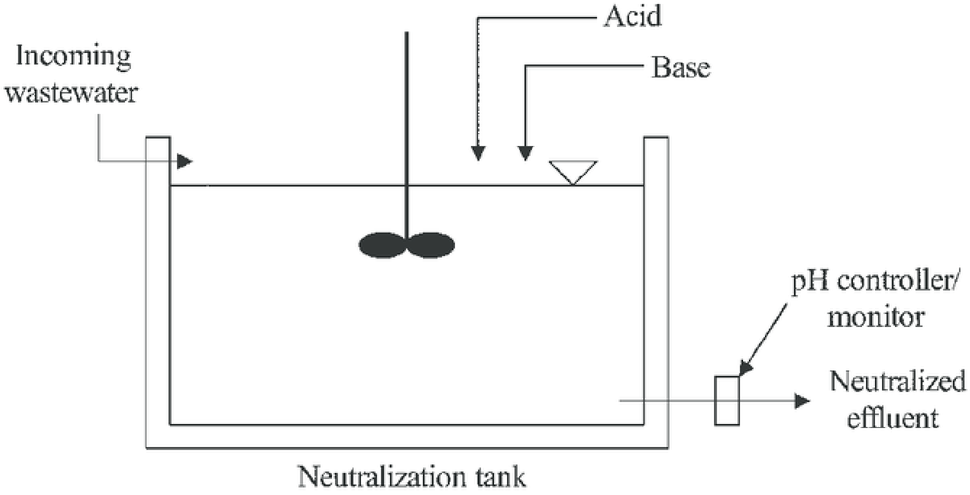


Figure 1 Neutralization Tank

Flow equalization and neutralization can be done in a same tank. Neutralization is necessary for controlling the pH. This is done in a CSTR in which acid (H_2SO_4) or a Base (NaOH) is added to neutralize the incoming stream. A pH sensor first indicates the pH of the inlet stream which sends a signal to the controller which controls the flow control valve for the acid or base (according to pH). Acid or base is added then mixed by impellers present inside a tank. This is the only suitable process for pH control hence it is used in almost every water treatment plant to maintain a pH. Since neutralization reaction is an extremely fast reaction, residence time required is quite less which ultimately means that there is no requirement for a vessel. This CSTR can also act as an equalization unit as agitators are present. Volumetric flow-rate can also be stabilized.

2.2 Processes for TSS Removal

2.2.1 Ultrafiltration:

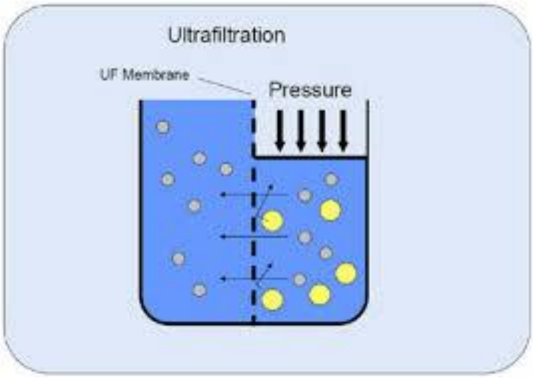


Figure 2 Ultrafiltration System

Ultrafiltration can be used to separate out the Total Suspended Solids. Ultrafiltration requires membranes with pore size less than micrometers and greater than nanometers. This process is only used for low TSS levels as high TSS values may lower the recovery of water or the membrane may choke. This is an expensive process as compared to other processes like coagulation and flocculation.

2.2.2 Coagulation, Flocculation and Sedimentation:

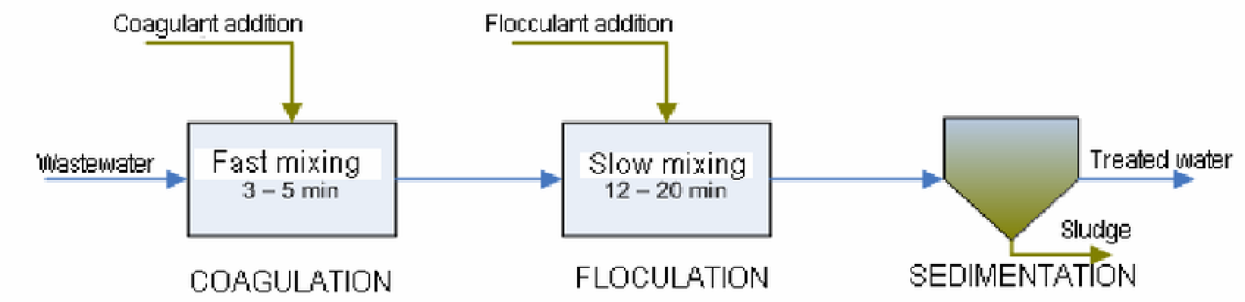


Figure 3 Coagulation, Flocculation and Sedimentation

Coagulation and flocculation are two separate methods that are used to remove suspended solids from the effluent stream. In Coagulation, coagulants with opposite charges to those of the suspended solids are added (mostly alum). This neutralizes the charges and the suspended solids form a settling tendency. Flocculation is a gentle mixing stage in which the particles get attached to each other and floccs of larger size are formed. The particles are brought together by slight collisions due to agitation inside the flocculation tank. Flocculants are also added to enhance the adhesive properties of the floccs so that their size increases. Once, the size increases to a point where the floccs are stable on their own and can settle down the stream is moved towards the sedimentation tank. Sedimentation is a process in which gravitational forced is used to settle down the particles in order to remove them. Sedimentation tanks are often large in dimensions to reduce the settling time. The big floccs formed in the previous step settle down here due to gravitational attraction. Pure water carries onwards while the floccs are removed as sludge from the bottom.

TSS in our effluent stream is above 2200 ppm so it cannot be separated out by ultrafiltration. Hence coagulation and sedimentation will be preferred over membrane filtration (UF).

2.3 BOD and COD removal methods

Following are some common methods to remove BOD and COD from the effluent stream.

1) Chemical Treatment: Hydrogen peroxide and ozone can be used to remove the COD and BOD in the effluent stream as they are oxidizing in nature. This method require further filtration.
2) Advanced oxidation: In this technique, UV radiation is used to oxidize BOD and COD compounds. Rest of this process is similar to that of chemical treatment and further filtration is required.
3) Activated sludge process with clarifiers: In this method air is used to oxidize BOD and COD compounds. To remove the sludge produced by this oxidation a clarifier is

necessary which requires enough time for the sludge to settle down and be removed.

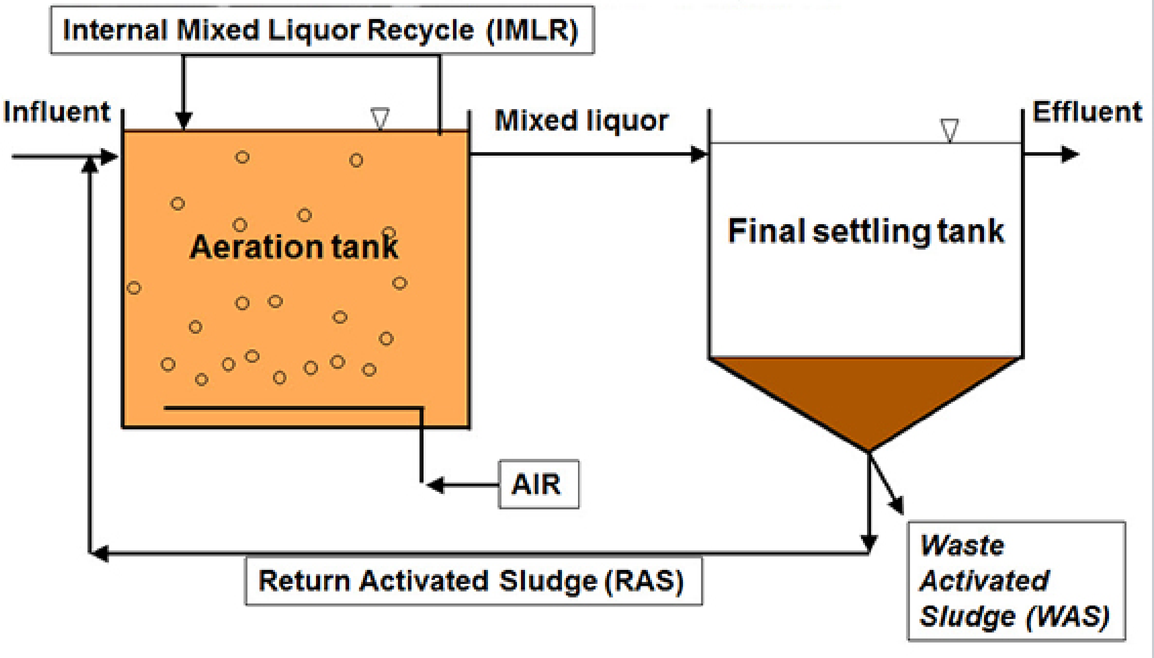


Figure 4 Activated Sludge Process

4) Membrane Bio Reactor: A combination of activated sludge process and membrane filtration is basically membrane bio-reactor. A blower is used to provide the air for oxidization of COD and BOD. This sludge-water mixture then passes through a micro-membrane. Sludge is removed by the membrane unit and pure water passes through. This process removes the need for clarifier, hence making it more time efficient and cost efficient.

We will be choosing membrane bio reactor due to its high recovery rate, high efficiency and time efficiency. The need for clarifier is diminished hence making this it a fast process.

2.3.1 Types of Membrane Bio Reactors:

There are two MBR system configurations namely Immersed (Submerged) MBR and Sidestream MBR.

In the Immersed MBR (IMBR) system, the membranes are placed in the bio-reactor vessels in which the aeration is provided. This is done to the waste water to reduce the efforts of cleaning and to reduce the need of an additional vessel. The flow is essentially dead end which results in high water recovery, i.e., permeate water is generally equal in amount to the feed water. This driving force in this system is created by the trans-membrane pressure which is essentially the drop in pressure across the membrane. There is a suction pump on the permeate side that helps in pulling the water from the MBR system. Hence, the pump is a centrifugal type where vacuum is created at the eye of the impeller so as to draw liquid from the MBR and which can pump the liquid to a higher pressure, if desired.

In the Side-stream MBR (SMBR) system, the membranes are placed in a pressure vessel separate from the one used for aeration of the waste water. The mixed liquor flows into the pressure vessel where cross flow is used for separation. This system also requires the employment of a high pressure pump. The driving force here is the pressure provided by the pump. The pressurized water flow through the membrane and the permeate flows out of the MBR and is pumped further ahead.

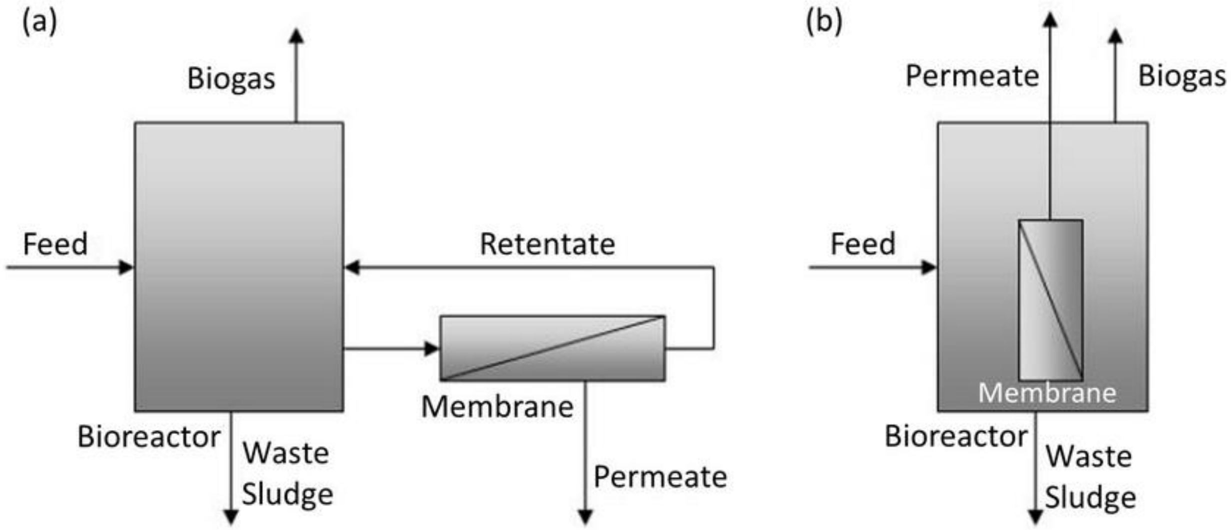


Figure 5Side Stream and Immersed MBR Configuration

The system selected was IMBR because:

- Unlike the SMBR, the IMBR doesn't require an additional pressure vessel reducing the required capital.
- the IMBR doesn't require a high pressure pump before the membrane separation, unlike the SMBR (which increase the operational costs)

- The IMBR employs dead end flow where recovery (permeate flow as a percentage of feed flow) is essentially 100% unlike the lower recovery of the cross flow of SMBR.

2.3.2 Selection of Membrane Configuration

Membrane configuration essentially refers to the shape or construction of membrane in a specific manner. There are 4 basic membrane configurations that can be employed:

- Hollow Fiber (HF): In this configuration, many fibrous membranes that are hollow from the inside are bundled together and attached to epoxy blocks at each end. The water flows in to the hollow part from the outside and is collected in the epoxy blocks from where it is moved forward.

- Spiral wound: In this configuration, membrane sheets are wound around a perforated tube through which the permeate flows. These membranes are normally used for Nano-Filtration and Reverse Osmosis applications.

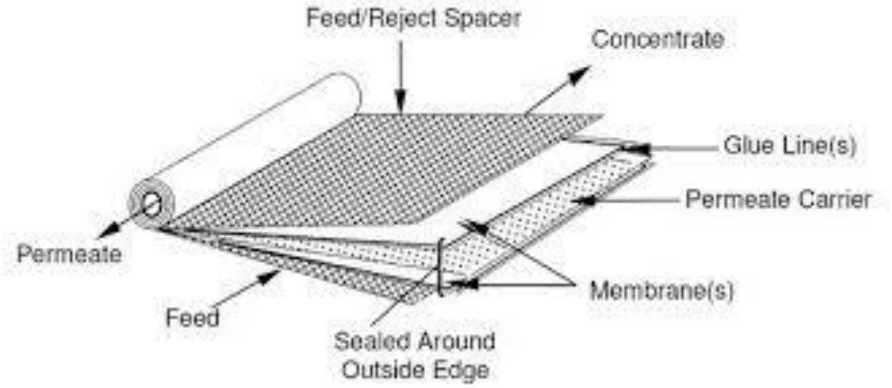


Figure 6 Spiral Wound Configuration

- Plate and Frame (Flat Sheet): In this configuration, flat membrane sheets are clamped on to plates and separated by support material. The water flows through the membrane, i.e., right across it, and permeate is then collected using pipes starting from inside the membrane modules.

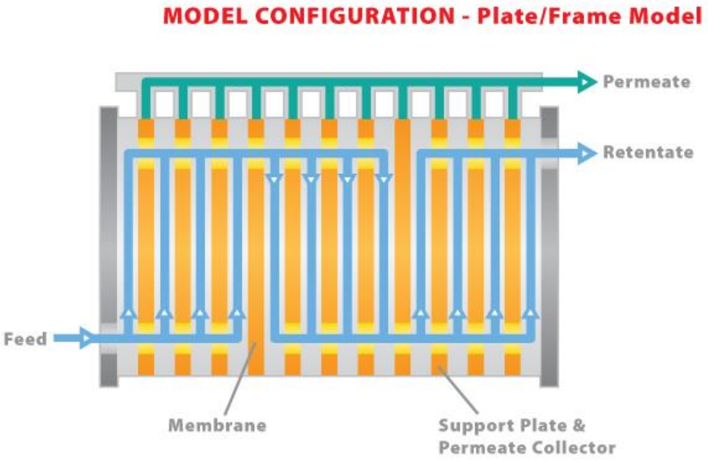


Figure 7 Plate and Frame Configuration

- Tubular: In this configuration, the membranes are in a tubular form and are contained in pressure vessels. So, they generally require that the mixed liquor be formed in one vessel where aeration is provided and be sent to these membranes in the pressure vessel, thereby creating a side-stream configuration.

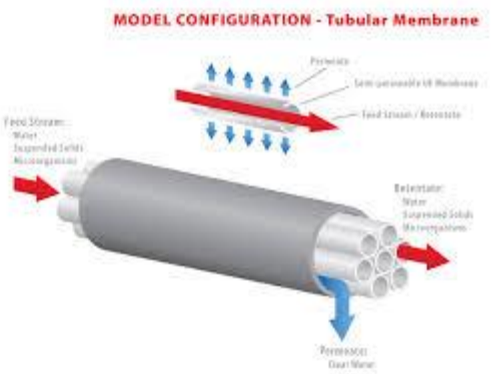


Figure 8 Tubular Configuration

The selected membrane configuration was the HF configuration because of their high packing density, high permeability, lower cost and use of dead end flow allowing greater separation efficiency.

2.4 TDS Removal methods

Total dissolved content can be removed by two methods, one is ion exchange method and the second one is through RO filtration. Our TDS limits matches that of the seawater i.e. greater than 50000ppm hence seawater desalination method can be applied where two step RO units are placed to reduce the TDS to ultimately less than 500. If we use the conventional ion-exchange method instead of the RO system our desired efficiency and results would not be obtained and the chemical requirements for ion exchange would result in increased costs. Hence, an RO system similar to seawater desalination was employed.

CHAPTER 3: Process Flow Diagram

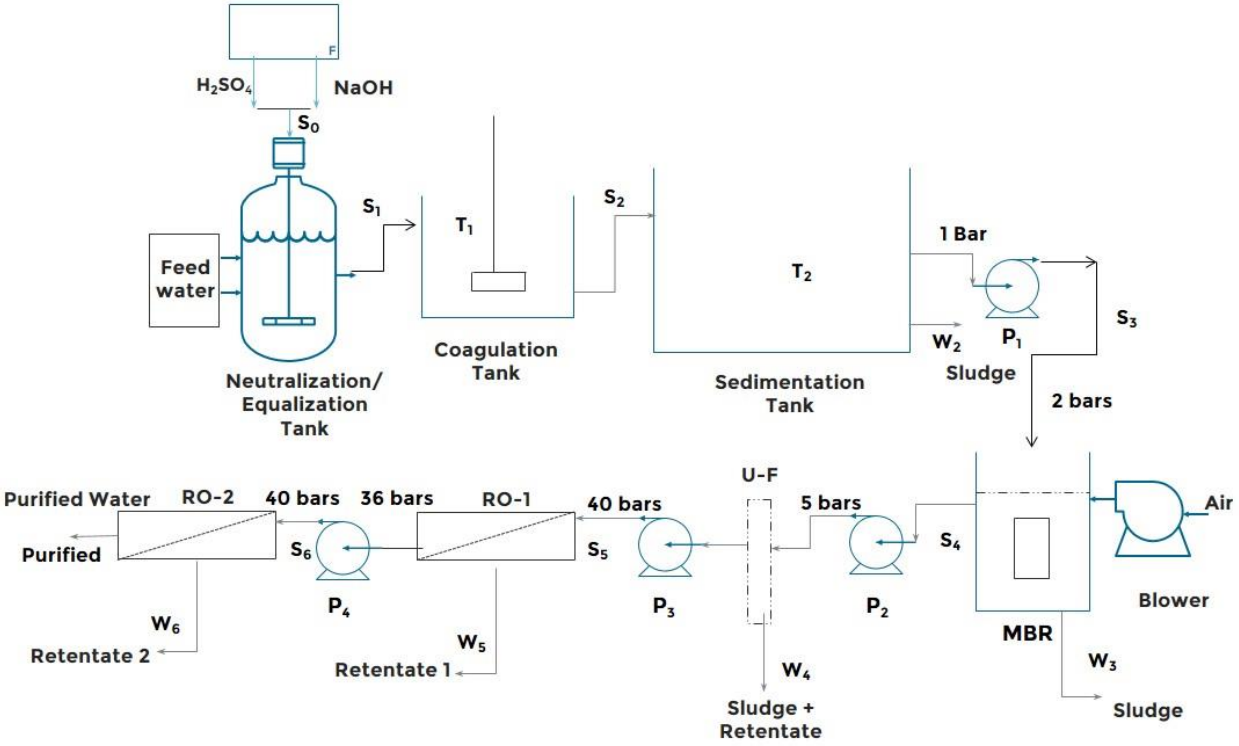


Figure 9 Process Flow Diagram of Process

3.1 Equalization and Neutralization Tank

This tank serves two purposes;

- Equalization of the fluctuating incoming flow of plant effluent.
- Neutralization of the acidic/basic nature of the incoming plant effluent.

Hydraulic velocity and the flow rate of any liquid or in our case the effluent is controlled by process of flow equalization, and this is achieved by installing a flow equalization basin or tank in the process. It is necessary in cases where there are fluctuations in the flow with time and this unsteady may disturb the units ahead.

So the effluent is collected in the equalization tank which acts as buffer area, equalization tank stores the effluent, and gives out a steady and stable flow at the non-peak and peak hours.

This equalization tank also serves the purpose of neutralization, therefore also termed as neutralization tank, here required amount of base (sodium hydroxide) or acid (sulphuric acid) is added depending upon the pH of the incoming feed water from the plant. There is a sensor at the inlet of the pH tank, which senses the pH of the influent and sends the signal to the analyze controller, which analyzes the difference in the H+ ions concentration and the amount of acid or the base to be added is calculated and fed.

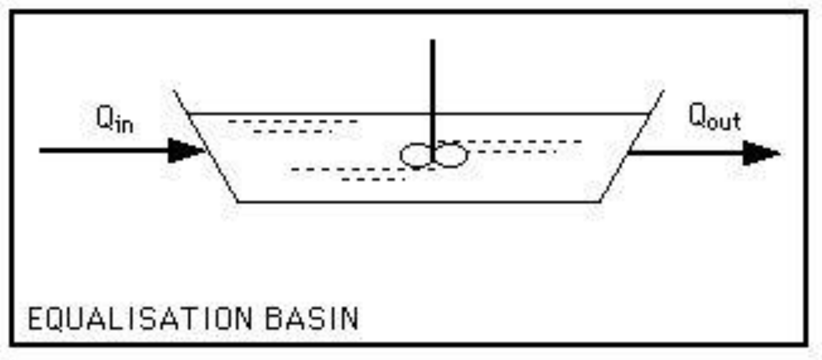


Figure 10 Equalization Basin

3.2 Coagulation Tank

Coagulation is a water treatment procedure normally applied before sedimentation and filtration (for example sand filtration) to upgrade the capacity of a treatment procedure to remove the suspended particles. Coagulation is a procedure used to neutralize the charges and form bigger coagulants from the suspended particles with the addition of coagulant, these bigger coagulants can be easily settled down afterwards. It’s a relatively time consuming process but it’s advantages overcome this time consuming disadvantage, it’s a relatively simple process and very efficient in removing different types of suspended solids.

The total suspended solids are removed by the addition of required amount of coagulant (alum) and the sludge produced is removed from the bottom, impellers installed in the coagulation tank stirs the effluent and helps to speed up the coagulation process by rapid mixing.

3.3 Sedimentation Tank

Sedimentation is a typical method for treating water. It is a procedure that expels solids that float and settle in the water after they are given retention time. This settled mass is then removed from the bottom of the sedimentation tank.

The efficiency of this physical water treatment process is dependent on the retention time, the nature (size and weight) of the particles. Only the particles whose specific gravity is greater than water settle down on the other hand particles with specific gravity equal or less than that of water remain suspended in the sedimentation tank and are removed in the subsequent processes.

Tanks of various shapes are employed for the sedimentation process depending upon the amount of suspended solids present, flow rate of influent, footprint limitation and the capital budget of the process. There are a number of advantages of the sedimentation process, they include;

- Fewer chemical additives are required for subsequent water treatment units.
- Makes the consequent process simpler and effective.
- The cost is lower as compared to similar different techniques for removal of suspended solids.

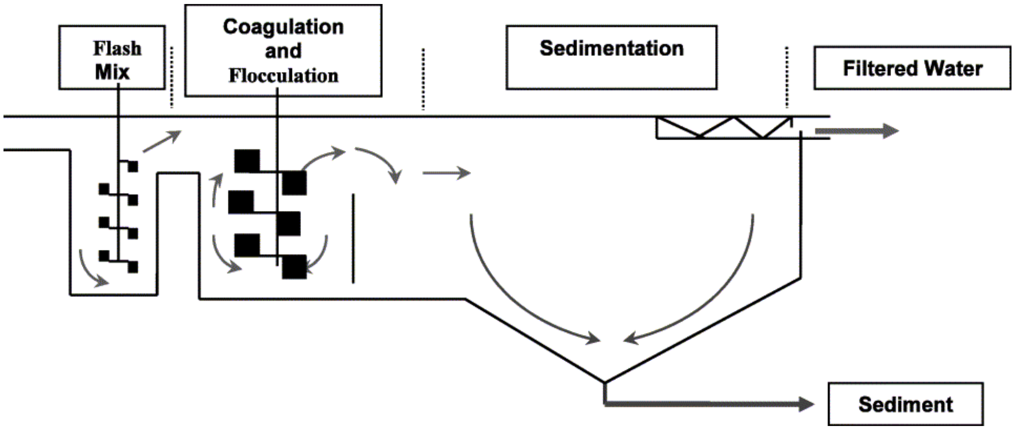


Figure 11 Coagulation and Sedimentation Process

3.4 Membrane Bio Reactor (MBR)

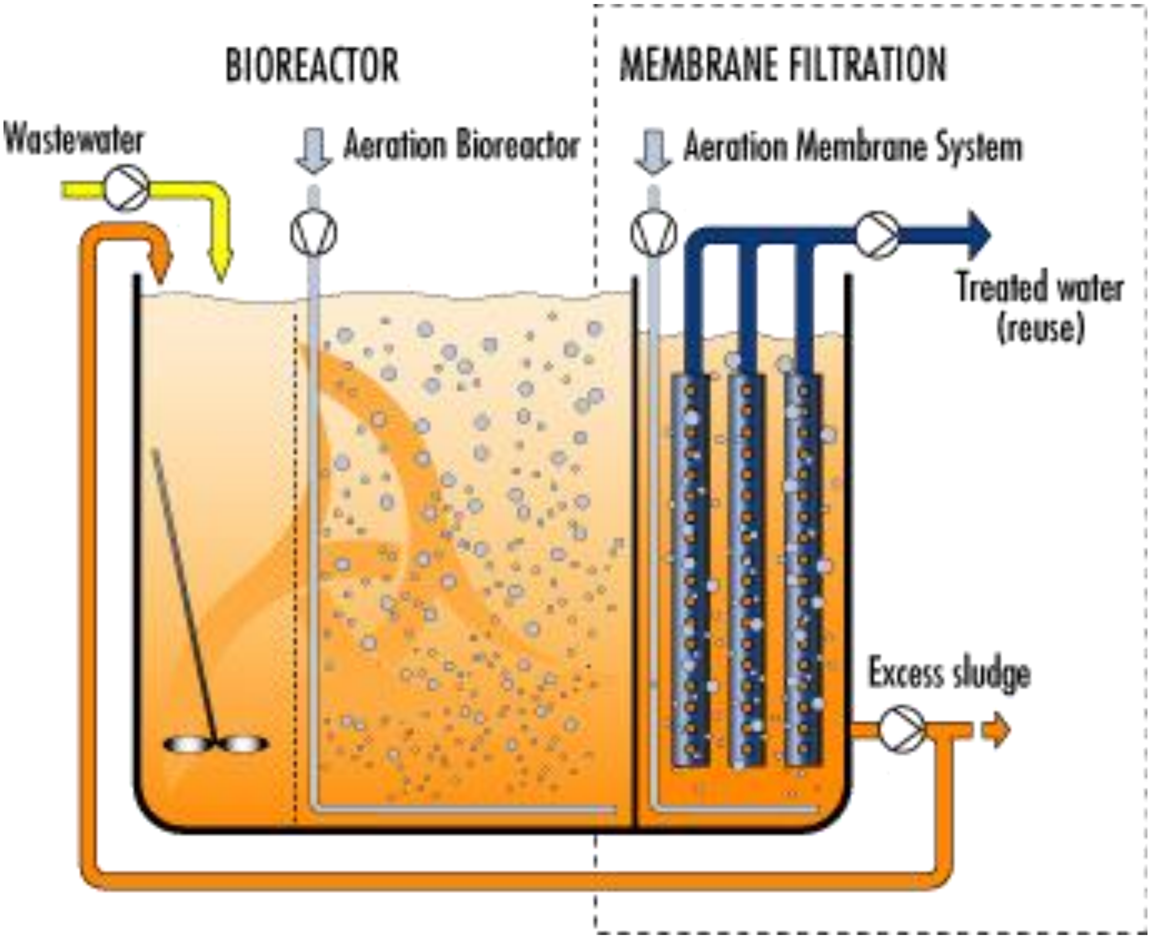


Figure 12 Membrane Bio Reactor

Membrane bioreactor is the hybrid of two processes; waste water treatment process that is the activated sludge process followed by a membrane process which can be microfiltration or ultra-filtration. This is relatively a new technology which is being implemented for the treatment of municipal and industrial waste water treatment.

Air is introduced in the MBR's tank through a blower which serves as a source of oxygen for the oxidation of the organic matter. The microorganisms that reduce the BOD are not allowed to move to the subsequent units and this is achieved by the membrane separation process which blocks the passage of microorganisms.

Factors Influencing the Filtration in MBR:

- MEMBRANE CHARACTERISTICS
    - Pore size
    - hydrophobicity
    - surface roughness
    - surface charge
- SLUDGE CHARACTERISTICS
    - Biomass concentration
    - rheology
    - particle size
    - particle structure
    - SMP/Colloids concentration
- OPERATING CONDITIONS
    - temperature
    - trans membrane pressure
    - cross flow or dead-end flow
    - flux

3.5 Ultrafiltration

Size exclusion principle is utilized in ultrafiltration process, water is forced through the semipermeable membrane by the hydrostatic pressure. The pore size of ultrafiltration membrane is around 0.01 micron. Suspended solids, viruses, bacteria and other pathogens are removed through this membrane process.

Although the membrane system in the membrane bioreactor is highly efficient and removes almost all of the sludge produced in the removal of COD and BOD is discarded, but there is a chance of carryover of very small amount sludge and for the removal of this small amount we have installed a UF system. It helps in the efficient removal of sludge coming from MBR and the remaining TSS which was not removed in the coagulation and sedimentation process. Ultrafiltration gives the effluent that is free from sludge and TSS which is then fed to the RO membrane system.

3.6 RO System

Since the TDS in our effluent is comparable to that of seawater so we have incorporated a two step RO system for the maximum removal of TDS and maximum recovery. The incoming feed to the RO system has passed through a thorough pretreatment process, so life of RO system would be longer.

The feed water is pressurized so that the osmotic pressure is overcome and the process of reverse osmosis is possible, this pressurized feed water flows into the pressure vessels of the RO system which contains the membrane elements (process of Nano filtration takes place). Permeate stream contains a very less amount of TDS since major amounts of ions, unwanted particles, dissolved solids are removed while the retentate is highly concentrated in TDS. Then permeate of this first stage RO is introduced as a feed to the second RO system.

CHAPTER 4: MATERIAL BALANCE

4.1 Neutralization Tank

Formulae Used:

- [H+]Conc. (mol/L) = $10^{(-pH)}$
- Mass = Volume x Density
- Moles = Molar concentration x volume
- NaOH Required (g/day) = NaOH Required (mol/d)*40
- H_2SO_4 Required (g/day) = H_2SO_4 Required (mol/d)*98

Minimum pH = 4.854	
[H+]	$10^{-4.854}$
Inlet Flow Rate (m^3/hr)	33.92
Inlet H^+ Flow Rate *(mol/hr)*	*0.4747*
Desired Outlet pH	7
Outlet [H+] (mol/L)	10^{-7}
Outlet [H+] Flow (mol/hr)	0.003392
Consumption of [H+] (mol/hr)	0.4713
NaOH Required (mol/hr)	0.4713
NaOH Required (g/d)	452.4

Table 2 : Equalization Tank Material Balance when pH<7

Max pH = 8	
Inlet [H+] (mol/L)	10^{-8}
Outlet H^+ Flow Rate *(mol/hr)*	3.392×10^{-4}
Desired Outlet pH	7
Outlet [H+] (mol/L)	10^{-7}
Outlet [H+] Flow (mol/hr)	0.003392
Outlet Flow Rate H^+ Required (mol/hr)	3.052×10^{-3}
H_2SO_4 Required (mol/d)	0.03664
H_2SO_4 Required (g/d)	3.59

Table 3: Equalization Tank Material Balance when pH>7

Variation of Inlet pH									
Inlet pH	**Inlet [H+] (mol/L)**	**Inlet Flow Rate (L/hr)**	**Inlet H+ Flow Rate (mol/hr)**	**Desired Outlet pH**	**Outlet [H+] (mol/L)**	**Outlet [H+] Flow (mol/hr)**	**Required of [H+] (mol/hr)**	**H_2SO_4 Required (mol/d)**	**H_2SO_4 Required (g/d)**
7.4	3.98107E-08	33920	0.0013	7	0.0000001	0.0033	0.00204	0.0244	2.40
7.6	2.519E-08	33920	0.0008	7	0.0000001	0.0033	0.0025	0.0304	2.98
7.8	1.5848E-08	33920	0.00053	7	0.0000001	0.0033	0.0028	0.0342	3.35

Table 4: Variation in H_2SO_4 dosage according to inlet pH

Inlet pH	**Inlet [H+] (mol/L)**	**Inlet Flow Rate (L/hr)**	**Inlet H^+Flow Rate (mol/hr)**	**Desired Outlet pH**	**Outlet [H+] (mol/L)**	**Outlet [H+] flow (mol/hr)**	**Consumption of [H+] (mol/hr)**	**NaOH Required (mol/hr)**	**NaOH Required (g/d)**
4.854	1.39959E-05	33920	0.474	7	0.0000001	0.0033	0.4713	0.4713	452.4
5.054	8.8308E-06	33920	0.299	7	0.0000001	0.0033	0.29614	0.296	284.30
5.254	5.57186E-06	33920	0.18	7	0.0000001	0.0033	0.1856	0.185	178.1
5.454	3.5156E-06	33920	0.11	7	0.0000001	0.0033	0.11585	0.1158	111.2
5.654	2.2182E-06	33920	0.07	7	0.0000001	0.0033	0.07184	0.0718	68.9
5.854	1.39959E-06	33920	0.047	7	0.0000001	0.003	0.04408	0.0440	42.3
6.054	8.8308E-07	33920	0.029	7	0.0000001	0.0033	0.02656	0.026	25.4
6.254	5.57186E-07	33920	0.018	7	0.0000001	0.0033	0.0155	0.0155	14.8
6.454	3.5156E-07	33920	0.011	7	0.0000001	0.0033	0.0085	0.0085	8.1
6.654	2.2182E-07	33920	0.007	7	0.0000001	0.0033	0.0041	0.0041	3.9

Table 5: Variation in NaOH dosage according to inlet pH

4.2 Coagulation Tank

TSS Removed (kg/day)	17770.9
Sludge Produced and Removed (kg/day)	18050
Coagulant Amount (kg/day)	279

Table 6: Remover of TSS

4.3 Membrane bioreactor

BOD In (kg/day) = Water Flow Rate * BOD In Concentration

COD In (kg/day) = Water Flow Rate * COD In Concentration

Oxygen Required (kg/day) = BOD In + COD In

Air Required (m^3/day) = Oxygen Required/0.23

Air volume Required (m^3/day) = (Air to be supplied)/(Density of air)

Density of air (kg/m^3) = 1.184

Water flow rate = 814 m^3/day

BOD In (mg/l)	1501
BOD In (kg/day)	122.11
COD In (mg/l)	205
COD In (kg/day)	166.8
Oxygen Required (kg/day)	288.99
Air Required (m^3/day)	1376.18

Table 7: MBR Material Balance

4.4 Ultra Filtration Membrane

Recovery = Permeate water flow/Feed water flow

Water Inflow (m^3/day) = Rejected Water + Permeate Water

Feed In Flow Rate (m^3/day)	814
TSS In (kg/day)	22
Sludge In (kg/day)	5
Recovery	99%
TSS Out in Permeate (kg/day)	0
Sludge Out in Permeate (kg/day)	0
Permeate Flow Rate (m^3/day)	805.86
Retentate Flow Rate (m^3/day)	8.14

Table 8: UF Material Balance

4.5 Reverse Osmosis System

TDS in Rejects (kg/day) = TDS Inflow * Salt Rejection

TDS In Permeate (kg/day) = TDS Inflow – TDS Rejects

Recovery = Permeate water flow/Feed water flow

Water Inflow (m^3/day) = RO Rejected Water + RO Permeate Water

4.5.1 Reverse Osmosis Membrane 1

TDS In (kg/day)	42523
Salt Rejection	90%
TDS in Permeate (kg/day)	4252
TDS in Permeate (ppm)	7537
TDS in Retentate (kg/day)	38270
TDS in Retentate (ppm)	158293
Recovery	70%
Feed Water Flow Rate (l/day)	805900
Permeate Water Flow Rate (l/day)	564130
Rejected Water Flow Rate (l/day)	241770

Table 9: RO1 Material Balance

4.5.2 Reverse Osmosis Membrane 2

TDS In (kg/day)	4252
Salt Rejection	96%
TDS in Permeate (kg/day)	170
TDS in Permeate (ppm)	402
TDS in Retentate (kg/day)	4082
TDS in Retentate (ppm)	28945

Recovery	75%
Feed Water Flow Rate (l/day)	564130
Permeate Water Flow Rate (l/day)	423097
Rejected Water Flow Rate (l/day)	141032

Table 10: RO2 Material Balance

Overall Material Balance

Table 11 Summarized Material Balance

Equipment		**In**						**Out**				
	Flow In (m3/day)	**TSS (mg/L)**	**TDS (mg/L)**	**COD (mg/L)**	**BOD (mg/L)**	**SLUDGE (kg/day)**	**Flow Out (m3/day)**	**TSS (mg/L)**	**TDS (mg/L)**	**COD (mg/L)**	**BOD (mg/L)**	**SLUDGE (kg/day)**
Neuralization Tank	814	2205	52765	205	150	0	814	2205	52765	205	150	0
Coagulation and Sedimentation	814	2205	52765	205	150	0	814	22.025	52765	205	150	18050
MBR	814	22.025	52765	205	150	0	814	22.025	52765	2.05	1.5	5
Ultra-Filtration	814	22.025	52765	2.02	1.5	5	805.9	0	52765	2.05	1.5	0.1
RO-1	805.9	0	52765	2.05	1.5	0.1	564.1	0	7537	2.05	1.5	0
							241.7	0	158293	2.05	1.5	0.1
RO-2	564.1	0	7537	2.05	1.5	0	423.09	0	402	2.05	1.5	0
							141.0	0	28945	2.05	1.5	0

CHAPTER 5: ENERGY BALANCE

The main energy balance equation used for energy change on each equipment is as follows:

$$m_{in}\left(H_{in}+gz_{in}+\frac{v_{in}^{2}}{2}\right)+\dot{Q}+W=m_{out}\left(H_{out}+gz_{out}+\frac{v_{out}^{2}}{2}\right)$$

Energy balance on each equipment is as follows:

5.1 Neutralization Tank

Energy balance for neutralization tank is as follows:

Energy Out= Energy In + Energy of reaction

pH	NaOH required	Energy of reaction kJ/mol	Energy of reaction kJ
4.854	452.494099	-99.52	-1125.805318
5.054	284.3027541	-99.52	-707.3452523
5.254	178.1811898	-99.52	-443.3148002
5.454	111.2230094	-99.52	-276.7228473
5.654	68.97525366	-99.52	-171.6104311
5.854	42.3187219	-99.52	-105.2889801
6.054	25.49958741	-99.52	-63.44297348
6.254	14.88743098	-99.52	-37.03992828
6.454	8.191612937	-99.52	-20.38073299
6.654	3.966837366	-99.52	-9.869491366

Table 12: Equalization Tank Energy Balance

5.2 Coagulation Tank

Energy In=Energy Out

Table 14: Pump Energy Balance

Volumetric Flow Rate m3/s	P inlet (Pa)	P outlet (Pa)	Coefficient of thermal expansion (1/K)	Temperature C	Efficiency	Delta P	V*delP	(1-BT)	Power kW
0.009422	500000	4000000	0.00248	25	1	3500000	32977	0.938	30.93243
0.009422	500000	4000000	0.00248	25	0.9	3500000	32977	0.938	34.36936
0.009422	500000	4000000	0.00248	25	0.8	3500000	32977	0.938	38.66553
0.009422	500000	4000000	0.00248	25	0.7	35000	32977	0.938	44.18918
0.009422	500000	4000000	0.00248	25	0.6	3500000	32977	0.938	51.55404
0.009422	500000	4000000	0.00248	25	0.5	3500000	32977	0.938	61.86485
0.009422	500000	4000000	0.00248	25	0.8	200000	1884.4	0.938	2.209459

5.3 Sedimentation Tank

Energy In=Energy Out

5.4 Pump balance:

An example of RO1 pump is shown below

Formula:

$$\boldsymbol{Energy\ Required} = \boldsymbol{Water\ Inflow} * (\boldsymbol{P_{out}} - \boldsymbol{P_{in}}) * (\mathbf{1} - \boldsymbol{\beta T})/(\boldsymbol{Pump\ Efficiency})$$

5.5 MBR Unit

Energy In = Energy out

1) Ultra Filtration and RO Energy Balance:

$$\text{Energy in permeate} = \frac{Permeate\ Flow}{Feed\ Flow} \times \text{Energy of Feed}$$

Energy in Retentate= Energy of Feed – Energy of Permeate

5.6 Overall Balance

Equipment	Enthalpy In (kJ/day)	Energy Added (kJ/day)	Energy Removed (kJ/day)	Enthalpy Out (kJ/day)
Neutralization Tank	85.4×10^6	-	171.48	85.4×10^6
Coagulation Tank	85.4×10^6	-	-	85.4×10^6
Sedimentation Tank	85.4×10^6			85.4×10^6
Pump 1	85.4×10^6	101088	-	85.5×10^6
MBR	85.5×10^6	-	-	85.5×10^6
Blower	-	159840	-	-
Pump 2	85.5×10^6	303264	-	85.8×10^6
Ultra-Filtration	85.8×10^6	-	870000	84.93×10^6

Pump 3	84.93 x 10^6	3.34 x 10^6	-	88.27 x 10^6
RO-1	88.27 x 10^6	-	26.48 x 10^6	61.79 x 10^6
Pump 4	61.79 x 10^6	304992	-	62.09 x 10^6
RO-2	62.09 x 10^6	-	15.52 x 10^6	46.57 x 10^6

Table 15: Overall Energy Balance

CHAPTER 6: EQUIPMENT DESIGN

6.1 Equalization/Neutralization Tank:

Volume

Time (hrs)	Flow Rate (m3/hr)	Cumulative Volume (m3)
1	35	35
2	32	67
3	35	102
4	38	140
5	39	179
6	42	221
7	40	261
8	35	296
9	32	328
10	30	358
11	28	386
12	24	410
13	24	434
14	28	462

15	30	492
16	34	526
17	38	564
18	40	604
19	35	639
20	32	671
21	30	701
22	25	736
23	38	774
24	40	814
Average Flow	33.91	-

Table 16: Hourly flow data of feed

Time in hours and the cumulative flow can be plotted against each other to obtain a hydrograph, which is usually used to determine the volume/capacity of the equalization tank. So a hydrograph is shown below according to the hourly data, and the capacity of the tank can be determined by summing up the vertical distances from the average flow rate line to the tangent to the curve.

Capacity of the equalization tank comes out to be 45 m^3, and the average flow rate is 33.91 m^3/hr.

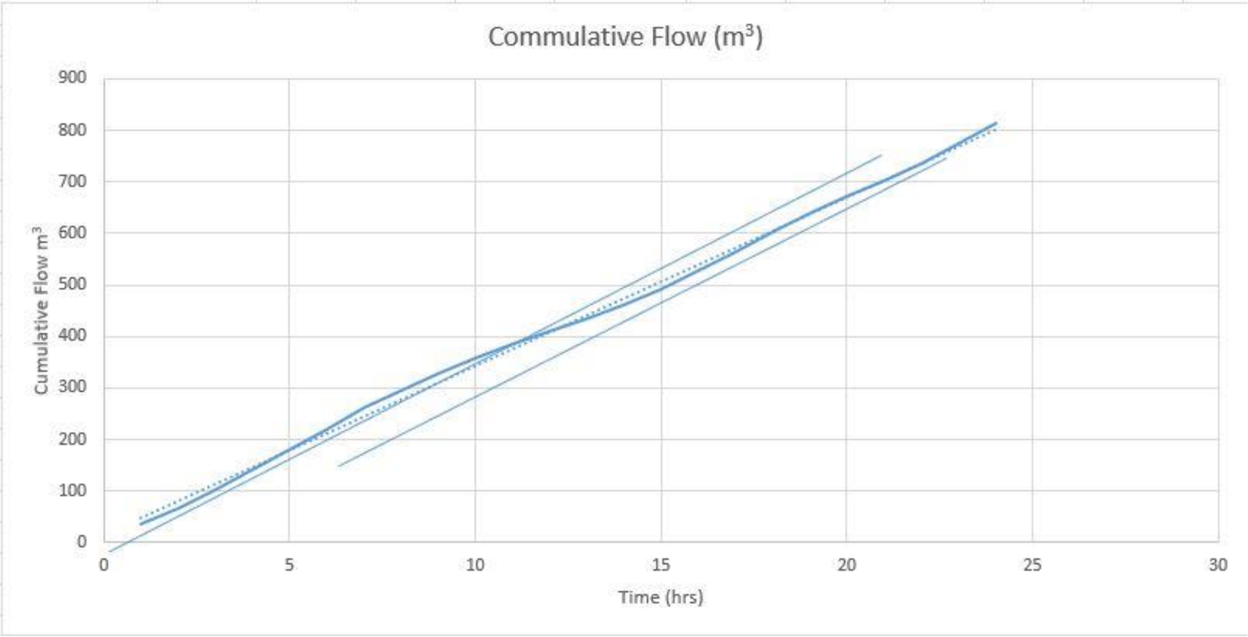


Figure 13 Hydrograph of Hourly Flow

6.1.1 Diameter

Diameter of the equalization tank can be easily determined by using the realtion that height of the tank is double to that of its diameter. So by using the found volume of the tank we can determine the height and diameter of the tank. The tank is cylindrical in shape.

$$D{:}H = 1{:}2$$

$$H = 2 * D$$

$$V = \frac{\pi}{4} D^2 H$$

$$V = \frac{\pi}{2} D^3$$

$$45 = \frac{\pi}{2} D^3$$

$$D = 3.06\ m$$

$$H = 6.12\ m$$

So the height of the tank and he diameter of the tank is 6.12 m and 3.06 m respectively.

6.1.2 Impellers:

Di = 0.3D = 0.3 x 3.06= 0.918 m

Impeller Spacing = Di = 0.918 m

Average height of liquid in equalization tank is given by;

$$H_L = \frac{Average\ Flow\ Rate}{Capacity} * H_T$$

$$H_L = \frac{33.9}{45} * 6.12$$

$$H_L = 4.61\ m$$

Now we will be calculating the minimum and the maximum number of impellers required for the equalization tank and then determine the idea number of impellers for the tank.

Minimum number of impellers;

$$n_{min} = \frac{H_L - 2\mathrm{Di}}{2\mathrm{Di}} = 5$$

Maximum number of impellers required;

$$n_{min} = \frac{H_L - \mathrm{Di}}{\mathrm{Di}} = 2$$

Ideal number of impellers required are therefore 3.

Typical speed of impeller with diameter of 0.272 m is around 6 m/s. Now the RPM is calculated as follows;

$$v = \pi N D_i$$

$$N = 124$$

Design of the equalization/neutralization tank is summarized below;

Neutralization/ Equalization Tank	
Capacity	45 m^3
Diameter	3.06 m
Height	6.12 m
Average flow rate	33.92 m^3/hr
Impellers	
Minimum number of impellers	2
Maximum number of impellers	5
Ideal number of impellers	3
Impeller diameter	0.272 m
Rpm	124

Table 17: Design summary Equalization Tank

6.2 Sedimentation Tank:

Volume of the tank can be calculated by the product of volumetric flow rate and the hydraulic residence time.

Hydraulic residence time for industrial waste water in sedimentation tank is around 4 hours.

So;

$$volume = HRT * Volumetric\ flow\ rate$$

$$volume = 4\ hr * 814 \frac{m^3}{day} * \frac{1day}{24hr}$$

$$volume = 135\ m^3$$

Now we can calculate the diameter and height of the tank by the relation used in the equalization tank;

$$D : H = 1 : 2$$

$$H = 2 * D$$

$$V = \frac{\pi}{4} D^2 H$$

$$V = \frac{\pi}{2} D^3$$

$$135 = \frac{\pi}{2} D^3$$

$$D = 4.42\ m$$

$$H = 8.84\ m$$

Design of the sedimentation tank is summarized below;

Sedimentation tank	
Volume	135 m^3
Diameter	4.42 m
Height	8.84 m

Table 18: Design of Sedimentation Tank

6.3 Membrane Bioreactor

Volume

Volume of the tank can be calculated by the product of volumetric flow rate and the hydraulic residence time.

Hydraulic residence time for industrial waste water in MBR tank is around 6 hours. So;

$$volume = HRT * Volumetric\ flow\ rate$$

$$volume = 6\ hr * 814 \frac{m^3}{day} * \frac{1day}{24hr}$$

$$volume = 203\ m^3$$

Diameter and Height

Now we can calculate the diameter and height of the tank by the relation used in the equalization tank;

$$D: H = 1: 2$$

$$H = 2 * D$$

$$V = \frac{\pi}{4} D^2 H$$

$$V = \frac{\pi}{2} D^3$$

$$203 = \frac{\pi}{2} D^3$$

$$D = 5.05\ m$$

$$H = 10.11\ m$$

Membrane Specifications

Product specifications

The MexFil™ MP025 MF100 microfiltration modules can be used for pilot trials to test:

- Applications for the Food & Beverage industry;
- The removal of sand, silt, clays, yeast, algae, and bacteria;
- Inside-out operation, typically in a semi dead-end or crossflow filtration mode, cleaning regularly by a combination of forward flush and a backwash supported by a chemically enhanced backwash, providing perfect control of the membrane fouling rate.

These modules can be used in the NX Filtration MexPlorer Test Unit. A connector set can be provided to connect the modules.

Membrane specification

Membrane material	Modified PES
Nominal pore size	95 nm
Membrane charge	Negative charge @ pH=7
Nominal fiber ID	1.5 mm

Table 19: Membrane specification of MBR

Module specification

Dimensions Length (L1)	300 mm
Outer diameter housing (D1)	25 mm (1 inch)
Permeate outlet diameter (d1)	6 mm (4 outlets each side)
Permeate connector position (l1)	23 mm
Nominal membrane area	0.045 m^2

Table 20: Module specifications of MBR

Materials of constructions

Housing PSU	Transparent
Internals	None
Potting material	Epoxy resin

Table 21: Material of constructions of MBR membrane

Trans membrane pressure = 1 bar

Flux = 233 l/m^2 hr.

Required area of membrane = 145 m^2

Permeability of membrane = 233 l/m^{2}hr bar

$Flux = Permeability * Transmembrane\ Pressure$

$$Flux = 233\ l/m^2hr$$

$$Required\ area\ of\ the\ membrane = \frac{Flow\ Rate}{Flux}$$

$$Required\ Area\ of\ membrane = \frac{814\frac{m^3}{day} * 1000\frac{l}{m^3} * \frac{1day}{24hr}}{233\frac{l}{m^2hr}}$$

$$Required\ Area\ of\ Membrane = 145\ m^2$$

Design of the Membrane Bioreactor is summarized below;

Membrane Bio Reactor	
Hydraulic Resistance time	6 hrs
Volume	203.5 m^3
Diameter	5.05 m
Height	10.11 m
Membrane	
Pore size	95 nm
Configuration	Hollow fiber

Model	MexFil™ MP025 MF100
Material	Polyether sulfone (PES)
Transmembrane pressure	1 bar
Required Area	145 m^2

Table 22: Design summary of membrane bioreactor

6.4 Reverse Osmosis System

The configuration of the two stage RO system is Permeate Staged (double pass) system where the permeate obtained from the first RO is fed as feed to the second RO system. Both RO systems may be of the single-stage or multi-stage type, flow configuration is plug flow.

6.4.1 Reverse Osmosis Membrane 1:

$$Feed\ flow\ rate = 805.9\ \frac{m^3}{day}$$

$$Feed\ TDS = 42955\ \frac{kg}{day}$$

$$Permeate\ flow\ rate = 564.13\ \frac{m^3}{day}$$

$$Permeate\ TDS = 4295.5\ \frac{kg}{day}$$

$$Recovery = 70\%$$

$$Permeate\ flux = 13.5\ \frac{l}{m^2hr}\ (from\ literature)$$

$$Active\ area\ of\ membrane = 37\ m^2$$

Number of elements:

$$Number\ of\ elements = \frac{Permeate\ Flow\ Rate}{Flux * Area\ of\ single\ element}$$

$$Number\ of\ Elements = \frac{564.13\ \frac{m^3}{day} * 1000\frac{l}{m^3} * \frac{1\ day}{24\ hrs}}{13.5\frac{l}{m^2hr} * 37m^2}$$

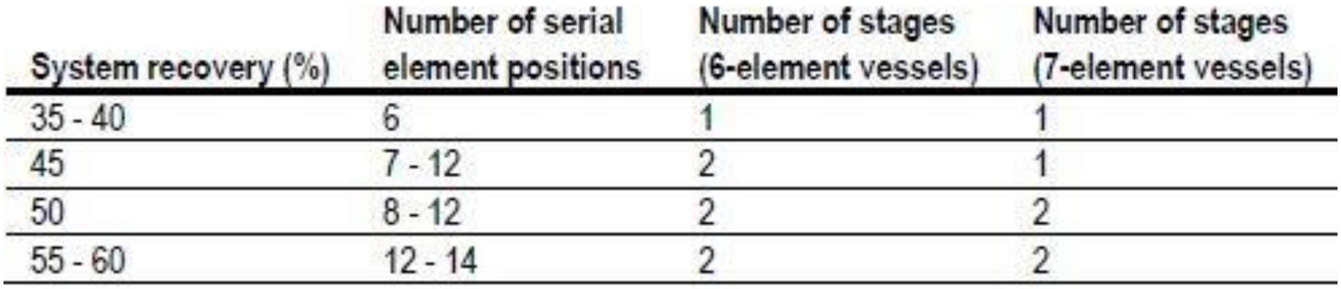
$$Number\ of\ Elememts = 43$$

Number of pressurfe vessels:

$$Number\ of\ pressure\ vessels = \frac{Total\ number\ of\ elements}{Number\ of\ elements\ per\ vessel}$$

$$Number\ of\ pressure\ vessels = \frac{43}{6} = 8$$

Number of stages:



System recovery (%)	Number of serial element positions	Number of stages (6-element vessels)	Number of stages (7-element vessels)
35 - 40	6	1	1
45	7 - 12	2	1
50	8 - 12	2	2
55 - 60	12 - 14	2	2

Figure 14 System Recovery and Number of Stages Chart

Table above shos the number of stages with elements required according to the system recovery. Since our recovery is relatiely high i.e 70% so for this purpose our RO system is a two stage system.

$$Number\ of\ Stages = N = 2$$

Staging Ratio:

$$R = \sqrt[N]{\frac{1}{1-y}}$$

Where R is the staging ratio, Y is the recovery and N is the number of stages.

$$R = \sqrt[2]{\frac{1}{1-0.7}}$$

So the staging ratio is 2.

Now;

$$N_{V1} = Number\ of\ vessels\ in\ first\ stage$$

$$N_{V2} = Number\ of\ vessels\ in\ second\ stage$$

$$N_{V1} = \frac{N_V}{1+R^{-1}} = \frac{8}{1+8^{-1}} = 5$$

$$N_{V2} = N_V - N_{V1} = 8 - 5 = 3$$

So in first satge there are 5 pressure vessels and in the second satge there are 3 pressure vessels. The two stages are connected in series and inside each stage the pressure vessels are connect in parallel manner. Membrane elements are also connected in series inside each pressure vessel.

Area of Pressure Vessel

$$Diameter\ of\ each\ vessel = D = 7.9\ in$$

$$length\ of\ each\ element = 40.5\ in$$

$$length\ of\ vessel = L = 6 * 40.5 = 243\ in$$

$$V = \frac{\pi}{4} D^2 L$$

$$V = \frac{\pi}{4} 7.9^2 * 243 = 11911\ in^3$$

$$V = 0.195\ m^3$$

Design of the RO-1 is summarized below;

RO-1	
Active area of membrane	37 m^2
Model	FILMTEC™ SW30ULE–400i
Number of elements	43
Number of pressure vessels	8
Recovery	70%
Number of stages	2
Number of pressure vessels in stage 1	5
Number of pressure vessels in stage 2	3

Table 23: Design summary of RO-1

6.4.2 Reverse Osmosis Membrane 2

Permeate staged with plugflow. The permeate of the RO-1 is the feed of the RO-2.

$$Feed\ flow\ rate = 423.097\ \frac{m^3}{day}$$

$$Feed\ TDS = 7537\frac{kg}{day}$$

$$Recovery = 70\%$$

$$Permeate\ flux = 13.5\ \frac{l}{m^2hr}\ (from\ literature)$$

$$Active\ area\ of\ membrane = 37\ m^2$$

Number of elements

$$Number\ of\ elements = \frac{Permeate\ Flow\ Rate}{Flux * Area\ of\ single\ element}$$

$$Number\ of\ Elements = \frac{423.097\ \frac{m^3}{day} * 1000 \frac{l}{m^3} * \frac{1\ day}{24\ hrs}}{13.5 \frac{l}{m^2hr} * 37m^2}$$

$$Number\ of\ Elememts = 36$$

Number of pressurfe vessels

$$Number\ of\ pressure\ vessels = \frac{Total\ number\ of\ elements}{Number\ of\ elements\ per\ vessel}$$

$$Number\ of\ pressure\ vessels = \frac{36}{6} = 6$$

Number of stages:

Since our recovery is relatiely high i.e 70% so for this purpose our RO system is a two stage system.

$$Number\ of\ Stages = N = 2$$

Staging Ratio:

$$R = \sqrt[N]{[1/(1-Y)]}$$

Where R is the staging ratio, Y is the recovery and N is the number of stages.

$$R = \sqrt[2]{[1/(1-0.7)]}$$

So the staging ratio is 2.

Now;

$$N_{V1} = Number\ of\ vessels\ in\ first\ stage$$

$$N_{V2} = Number\ of\ vessels\ in\ second\ stage$$

$$N_{V1} = \frac{N_V}{1 + R^{-1}} = \frac{6}{1 + 6^{-1}} = 4$$

$$N_{V2} = N_V - N_{V1} = 6 - 4 = 2$$

So in first satge there are 4 pressure vessels and in the second satge there are 2 pressure vessels. The two stages are connected in series and inside each stage the pressure vessels are connect in parallel manner. Membrane elements are also connected in series inside each pressure vessel. Design of the RO-1 is summarized below;

RO-2	
Active area of membrane	37 m^2
Model	FILMTEC™ SW30ULE–400i
Number of elements	36
Number of pressure vessels	6
Recovery	70%
Number of stages	2
Number of pressure vessels in stage 1	4
Number of pressure vessels in stage 2	2

Table 24: Design summary of RO-1

6.5 Pumps

In our process flow diagram there are 4 main pumps, and they are;

1) Before MBR.
2) Before UF membrane
3) Before RO-1
4) Before RO-2

All of these pumps are centrifugal pumps since our flow is consistant due to the installation of the equalization tank in the very start of the process.

Design of two of these pumps (pump 1 and pump 2) is given below.

The main formulae used are;

$$Differential\ Head = H = \Delta P * \frac{1000}{\rho g}$$

$$NPSH = (P_{SUCTION} - P_{VAPORATION}) * \frac{1000}{\rho g}$$

$$Hydraulic\ Power = \frac{H * Q * \rho * g}{\in}$$

Pump 1:

$$Pressure\ at\ suction = 100\ kPa$$

$$Pressure\ at\ Discharge = 200\ kPa$$

First calculating the differential head, putting the values;

$$Differential\ Head = H = (200\ kPa - 100kPa) * \frac{1000}{1000\frac{kg}{m^3} * 9.8\ \frac{m}{s^2}}$$

$$Differential\ Head = H = \ 10.2\ m$$

Now calculating the Net Positive Suction Head for pump 1, putting the values in the formula for NPSH;

$$P_{vaporation} = 3.17\ kPa$$

$$NPSH = (100\ kPa - 3.17\ kPa) * \frac{1000}{1000\frac{kg}{m^3} * 9.8\ \frac{m}{s^2}}$$

$$NPSH = 9.88\ m$$

Now calculating the hydraulic power required for the first pump;

$$Hydraulic\ Power = \frac{10.2 * 814 * 1000 * 9.8}{0.8}$$

(Hydraulic power required at different efficincies is calculated and is provided in the excel sheet attached)

$$Hydraulic\ Power = 1.223\ kW$$

$$Hydraulic\ Power = 1223\ W$$

Pump 2

$$Pressure\ at\ suction = 200\ kPa$$

$$Pressure\ at\ Discharge = 500\ kPa$$

First calculating the differential head, putting the values;

$$Differential\ Head = H = (500\ kPa - 200kPa) * \frac{1000}{1000\frac{kg}{m^3} * 9.8\ \frac{m}{s^2}}$$

$$Differential\ Head = H = \ 30.6\ m$$

Now calculating the Net Positive Suction Head for pump 1, putting the values in the formula for NPSH;

$$P_{vaporation} = 3.17\ kPa$$

$$NPSH = (500\ kPa - 3.17\ kPa) * \frac{1000}{1000\frac{kg}{m^3} * 9.8\ \frac{m}{s^2}}$$

$$NPSH = 20.08\ m$$

Now calculating the hydraulic power required for the first pump;

$$Hydraulic\ Power = \frac{30.6 * 814 * 1000 * 9.8}{0.8}$$

(Hydraulic power required at different efficincies is calculated and is provided in the excel sheet attached)

$$Hydraulic\ Power = 3.670 kW$$

$$Hydraulic\ Power = 3670\ W$$

Design of Pump 1 and Pump 2 is summarize below;

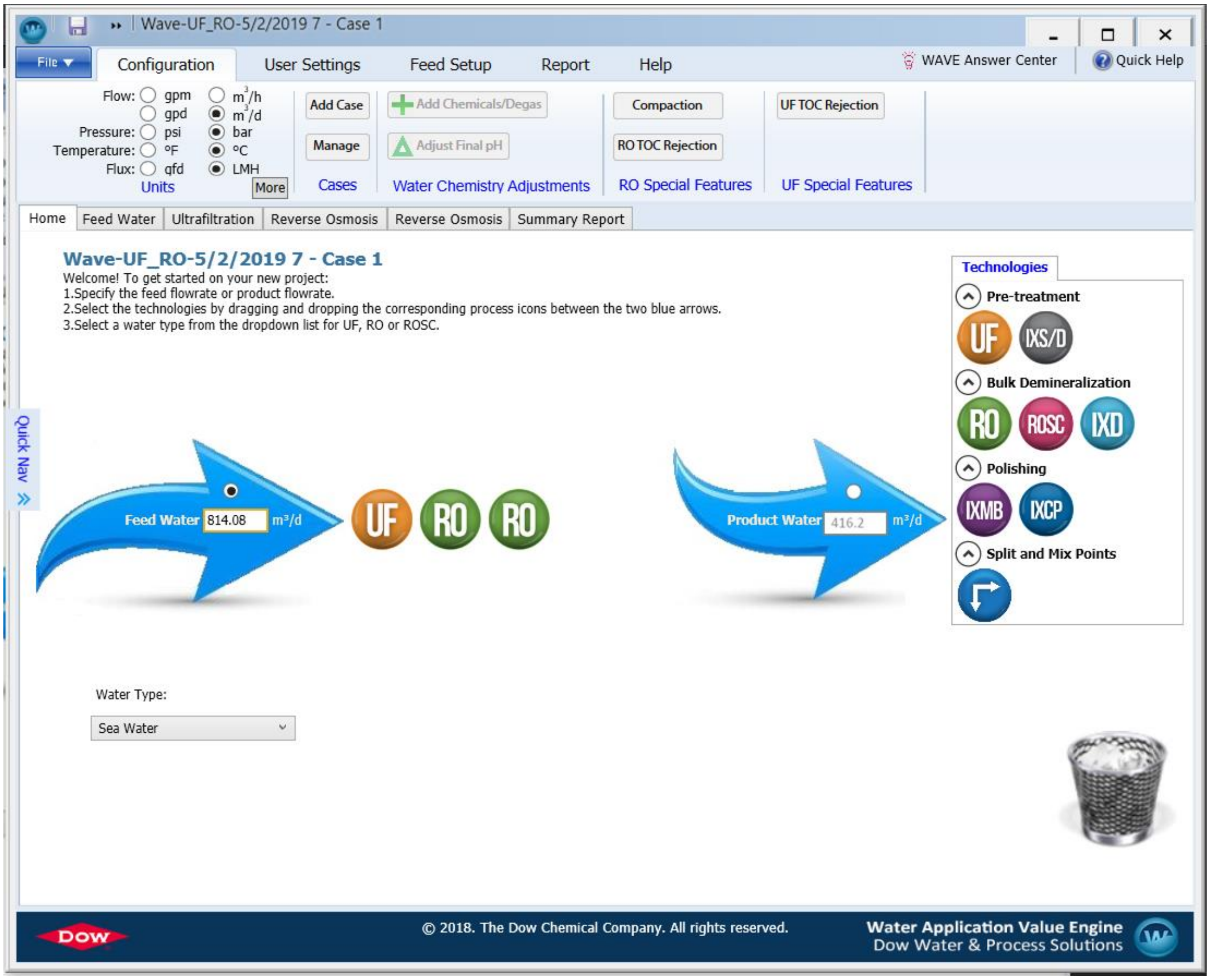
Pump 1	
Pump Type	Centrifugal Pump
Suction pressure	100 kPa
Discharge pressure	200 kPa
Differential head	10.2 m
NPSH available	9.88 m
Hydraulic power	1223 W

Pump 2	
Pump Type	Centrifugal Pump
Suction pressure	200 kPa
Discharge pressure	500 kPa
Differential head	30.6 m
NPSH available	20.08 m
Hydraulic power	3670.6 W

Table 25: Design summary of Pumps

CHAPTER 7: SIMULATION

Simulation of RO and Ultrafiltration unit is done on a software called WAVE. RO and Ultrafiltration were configured on our specifications and the results are as following:



Wave-UF_RO-5/2/2019 7 - Case 1

Units:
Flow: ○ gpm ○ m^3/h
○ gpd ● m^3/d
Pressure: ○ psi ● bar
Temperature: ○ °F ● °C
Flux: ○ gfd ● LMH

Wave-UF_RO-5/2/2019 7 - Case 1

Welcome! To get started on your new project:
1.Specify the feed flowrate or product flowrate.
2.Select the technologies by dragging and dropping the corresponding process icons between the two blue arrows.
3.Select a water type from the dropdown list for UF, RO or ROSC.

Feed Water 814.08 m³/d

Product Water 416.2 m³/d

Water Type: Sea Water

UF and RO1 results:

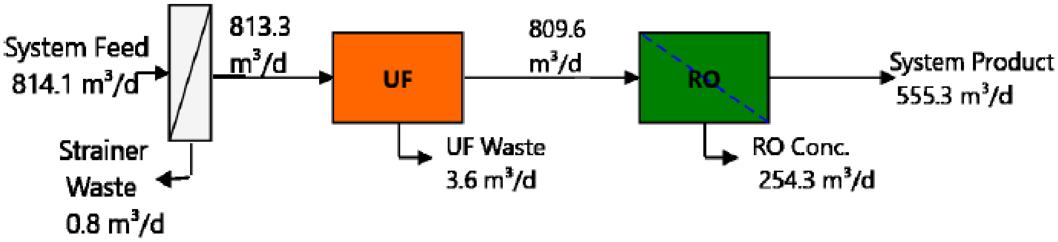


Figure 15 Results of UF and RO-1

		Strainer	Ultrafiltration	Reverse Osmosis
Feed	Flow Rate (m^3/d)	814.1	813.3	809.6
	TDS (mg/L)	52,848.2[b]	52,848.2[b]	52,848.0[a]
	pH	7.0	7.0	7.0
	Pressure (bar)	8.1	8.1	479.9
	Temperature (°C)	25.0	25.0	25.0
Product	Flow Rate (m^3/d)	813.3	809.6	555.3
	TDS (mg/L)	52,848.2[b]	52,848.2[b]	7,786.7[a]
	pH	7.0	7.0	5.1
	Recovery	99.9 %	99.55 %	68.6 %
	Operating Costs ($/h)	-	1.0	59.3
	Specific Energy (kWh/m^3)	-	0.30	24.35
	Operating Cost ($/$m^3$)	-	0.031	2.564
System	Specific Energy (kWh/m^3)	24.79		
	Operating Cost ($/$m^3$)	0.11		
	Feed Flow Rate (m^3/d)	814.1		
	Product Flow Rate (m^3/d)	555.3		
	Recovery	68.2 %		

UF System Overview

Module Type		Ultrafiltration SFD-2660			
# Trains		Online =	1	Standby =	0
				Redundant =	0
# Modules		Per Train =	1	Total =	1
System Flow Rate	(m^3/d)	Gross Feed =	814.1	Net Product =	809.6
Train Flow Rate	(m^3/d)	Gross Feed =	814.1	Net Product =	809.6
UF System Recovery	(%)	99.55			
TMP	(bar)	9.41 @ 10.0 °C		6.41 @ 25.0 °C	
Utility Water		Forward Flush:	Pretreated water	Backwash:	UF filtrate water
		CEB Water Source:	UF filtrate water	CIP Water Source:	UF filtrate water

UF Operating Conditions

	Duration	Interval	Flux/Flow
Filtration:	30.0 min	33.1 min	-
Instantaneous			
1 Online Trains			1155 LMH
1 Total Trains			1155 LMH
Average			1026 LMH
Net			1022 LMH
Backwash	3.1 min	33.1 min	120 LMH
Acid CEB	15.8 min	168 h	60 LMH
Alkali CEB	15.8 min	24 h	60 LMH
CIP	311.3 min	60 d	24.00 m^3/d
Membrane Integrity Testing	0.0 min	24 h	-

UF Water Quality

Stream Name		Stream 1	
Water Type		Sea Water (10.0 - 40.0 °C)	
		Feed	**Expected UF Product Water Quality**
Temperature	(°C)	25.0	25.0
TSS	(mg/L)	22.0	-
TDS	(mg/L)	52848	52848
pH		7.0	7.0

UF Configuration Options

Standby Option:	Constant module flux, variable plant filtrate flow
Storage Tank Option:	Storage Tank sized to maintain constant net filtrate flow
Forward Flush Water Source:	Pretreated water
BW Water Source:	UF filtrate water
CEB Water Source:	UF filtrate water
CIP Water Source:	UF filtrate water

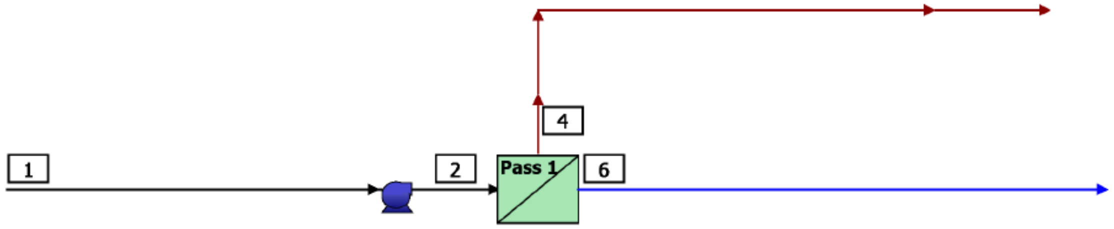
UF System Size and Module Details

Trains	
Online Trains	1
Standby Trains	0
Redundant Trains	0
Total Trains	1
Max Offine Trains	1
Modules/Train	1
Total Modules	1

Module Details		
Name: Ultrafiltration SFD-2660		
Membrane Area	33 m²	355 ft²
Length	1.863 m	73.3 in
Diameter	0.165 m	6.5 in
Weight (empty)	25 kg	55 lb
Weight (water filled)	41 kg	90 lb
Water Volume	16.0 L	4.2 gal

RO Detailed Report

RO System Flow Diagram



#	Description	Flow (m^3/d)	TDS (mg/L)	Pressure (bar)
1	Raw Feed to RO System	809.6	52,848	0.0
2	Net Feed to Pass 1	793.3	53,924	479.9
4	Total Concentrate from Pass 1	249.1	154,373	478.1
6	Net Product from RO System	555.3	7,787	0.0

RO System Overview

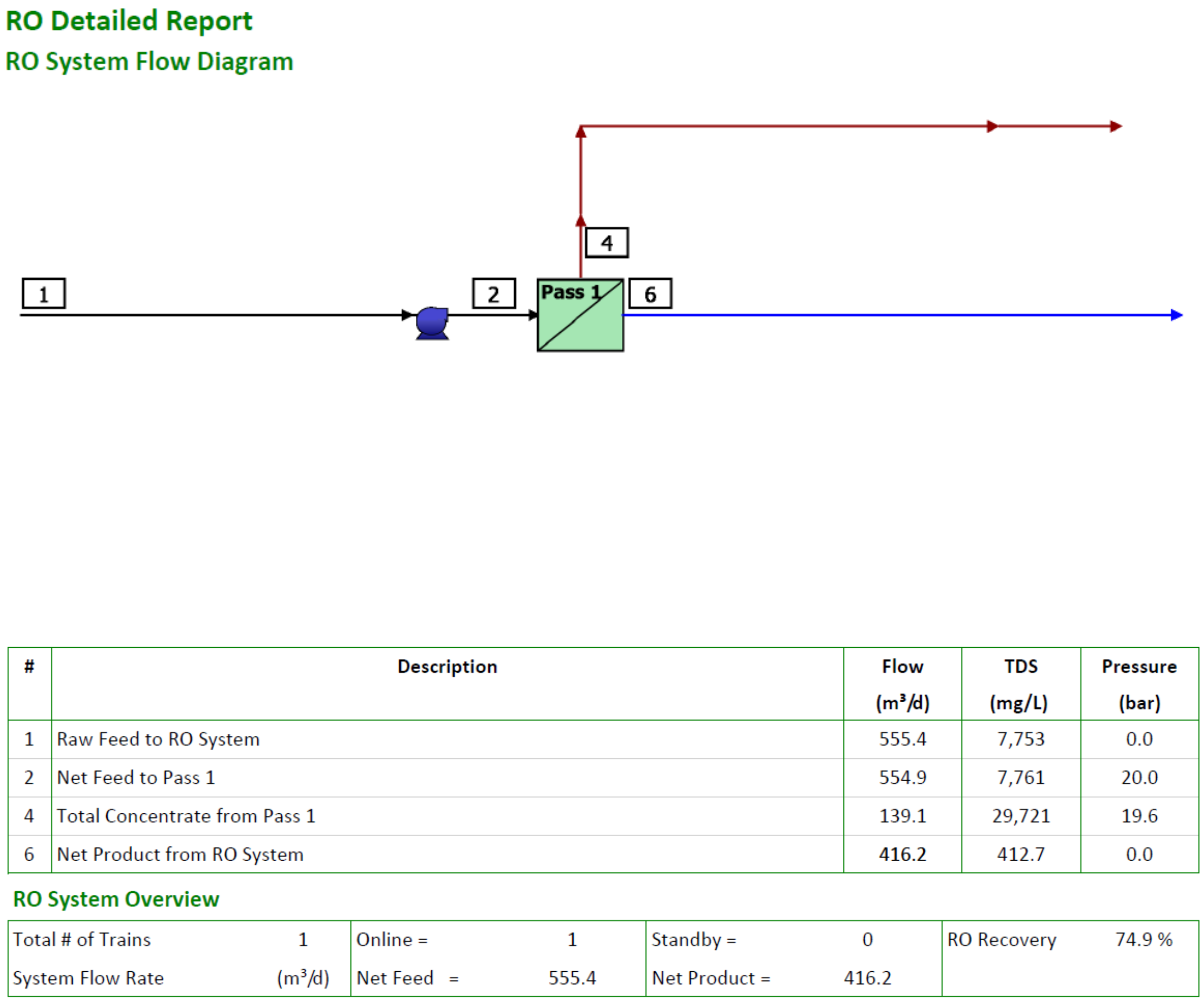
Total # of Trains	1	Online =	1	Standby =	0	RO Recovery	68.6 %
System Flow Rate	(m^3/d)	Net Feed =	809.6	Net Product =	555.3		

Pass		**Pass 1**
Stream Name		Stream 1
Water Type		Seawater With DOW UF, SDI ≤ 2.5
Number of Elements		8
Total Active Area	(m^2)	327
Feed Flow per Pass	(m^3/d)	793.3
Feed TDS^a	(mg/L)	53,924
Feed Pressure	(bar)	479.9
Flow Factor		0.85
Permeate Flow per Pass	(m^3/d)	555.3
Pass Average flux	(LMH)	70.8
Permeate TDS^a	(mg/L)	7,787
Pass Recovery		70.0 %
Average NDP	(bar)	394.6
Specific Energy	(kWh/m^3)	24.35
Temperature	(°C)	25.0
pH		7.0
Chemical Dose		
RO System Recovery		68.6 %
Net RO System Recovery		68.6%

RO Flow Table (Stage Level) - Pass 1

Stage	Elements	#PV	#Els per PV	Feed				Concentrate			Permeate			
				Feed Flow	Recirc Flow	Feed Press	Boost Press	Conc Flow	Conc Press	Press Drop	Perm Flow	Avg Flux	Perm Press	Perm TDS
			PV	(m^3/d)	(m^3/d)	(bar)	(bar)	(m^3/d)	(bar)	(bar)	(m^3/d)	(LMH)	(bar)	(mg/L)
1	SW30ULE-440i	2	4	793.4	0.00	479.6	0.0	249.1	478.1	1.5	555.3	70.8	0.0	7,787

RO 2 Results:



RO Detailed Report

RO System Flow Diagram

#	Description	Flow (m³/d)	TDS (mg/L)	Pressure (bar)
1	Raw Feed to RO System	555.4	7,753	0.0
2	Net Feed to Pass 1	554.9	7,761	20.0
4	Total Concentrate from Pass 1	139.1	29,721	19.6
6	Net Product from RO System	**416.2**	412.7	0.0

RO System Overview

Total # of Trains	1	Online =	1	Standby =	0	RO Recovery	74.9 %
System Flow Rate	(m³/d)	Net Feed =	555.4	Net Product =	416.2		

Pass		**Pass 1**
Stream Name		Stream 1
Water Type		Sea Water (With DOW UF, SDI < 2.5)
Number of Elements		72
Total Active Area	(m^2)	2943
Feed Flow per Pass	(m^3/d)	554.9
Feed TDS[a]	(mg/L)	7,761
Feed Pressure	(bar)	20.0
Flow Factor		0.85
Permeate Flow per Pass	(m^3/d)	416.2
Pass Average flux	(LMH)	5.9
Permeate TDS[a]	(mg/L)	412.7
Pass Recovery		75.0 %
Average NDP	(bar)	5.1
Specific Energy	(kWh/m^3)	0.93
Temperature	(°C)	25.0
pH		7.0
Chemical Dose		
RO System Recovery		74.9 %
Net RO System Recovery		74.9%

CHAPTER 8: HAZOP ANALYSIS

The following terms are considered during performing the HAZOP analysis.

Term	Definition
• **Study Nodes**	The points on streams/ equipments which are being considered.
• **Operating Steps**	The procedure that is analyzed by the HAZOP analysis team.
• **Intention**	The regular operations that are expected of the study nodes.
• **Process parameters**	Chemical or physical characteristics used to define the process.
• **Deviation**	Variation in operations from the desired intention.
• **Causes**	Reasons behind the deviations.
• **Consequences**	The results of deviations in the process/system.
• **Safeguards**	To ensure that system follows the intention.
• **Actions**	Steps to be taken after the deviations

Table 26: Meanings of different terminologies used in HAZOP Analysis

8.1 Equalization Tank

Deviation	Causes	Consequences	Safeguards	Recommendations
Low Flow Rate	• Tanker operator fails to control the pressure by closing a valve at wrong time. • Valve system fails closed.	• Leads to leakage, vibration in pump impeller.	• Level control valves and system must be inspected punctually.	• Install flow rate indicators in the filling lines.
High Flow Rate	• Operator sets the flow rate too high • Failure of control system.	• Over pressurize the tank during filling. • It could cause injury to operator in area.	• Tanker man monitoring to detect the problem • There is a reductant level control system.	• Verify that the relief valves on the tank are sized.

Table 27: Factors involved in HAZOP Analysis of Equalization Tank

8.2 Coagulation Tank

Deviation	Causes	Consequences	Recommendations
More flow	• Level control valves (LCV) fails open	• Pressurization of tank • Tank overflows	• Level indicator transmitter (LIT) installation at critical points
Less flow	• Blockage or leaking	• Pressurizes impeller • Material loss	• Install alarm on LIC, keep check of sizing and liquid overfilling.

High concentration water in stream	• Water level increases in storage tank	• Storage tank of water fills quickly	• Install alarm on sump
More Temperature	• High Intermediate in storage tank. • Summer conditions	• High pressure in tank.	• Install high temperature warning alarm
Less Temperature	• Winter conditions	• Freezing of pipelines	• Install TC on tank • Lag water sump down to drain system and drain line downstream.

Table 28: Factors involved in HAZOP Analysis of Coagulation Tank

8.3 Sedimentation Tank

Deviation	**Causes**	**Consequences**	**Recommendations**
More flow	• Level control valves (LCV) fails open	• Pressurization of tank • Tank overflows	• Level indicator transmitter (LIT) installation at critical points
Less flow	• Blockage or leaking	• Pressurize impeller • Material loss	• Install alarm on LIC, keep check of sizing and liquid overfilling.
More Temperature	• High Intermediate in storage tank. • Summer conditions	• High pressure in tank.	• Install high temperature warning alarm
Less Temperature	• Winter conditions	• Freezing of pipelines	• Install TC on tank • Lag water sump down to drain system and drain line downstream.

Table 29: Factors involved in HAZOP Analysis of sedimentation Tank

8.4 Membrane Bio-Reactor

Deviation	Causes	Consequences	Recommendations
Less flow	• Blockage of valves and pipelines • Membrane life decreased/ membrane blocked • Retentate side left open	• No efficient separation. • Pressurization caused.	• Check on lines and valves • Substitution with new membrane
More flow	• Membrane ruptured. • Feed flow rate and temperature increase.	• Less purity • Increased pressure • Zero Separation • Recovery increases	• Install relief valve • Maintenance of instrumentations. • Check of valves and lines.
More temperature	• Heat exchanger valve struck • Failure of heat exchanger controls	• Damaging of Membrane • No efficient separation. • High flow of permeate	• Install temperature alarm. • Maintenance of instrumentations/ controllers.

Low temperature	• Heat exchanger valve for steam partially closed • Failure of heat exchanger controls	• Film of condensate on membrane surface. • Inefficient separation	• Put temperature alarm. • Backwash membrane

Table 30: Factors involved in HAZOP Analysis of MBR

8.5 High Pressure Pump

Deviation	Causes	Consequences	Recommendations
Pressure	• Increased pressure due to overflow • Decrease in pressure due to restricted flow	• Pump damage. • Recirculation. • More pump power. • Cavitation in pump	• Flow regulation and control. • Install pressure gauge
Temperature	• High or low temperature of stream due to environment conditions	• Increased risk of cavitation.	• Temperature regulation and control of columns. • Install temperature sensor and controller • Flow regulation and control of tanks
Flow	• More or less flow due to valve failure • Possible leakage in pipeline if decreased flow	• Reduced pump efficiency. • Chances of cavitation.	• Flow regulation and transmittance through controller • Install relief valve • Regular patrolling of operators to

		• Chances of recirculation.	inspect for leakages

Table 31: Factors involved in HAZOP Analysis of HP Pump

8.6 RO Membrane

Deviation	Causes	Consequences	Recommendations
Low pressure	• Decreased level of raw water in tank • Obstruction of strainer • Corrosion of pump	• Tripping of line, and zero production of permeate water	• Manual controlling valves • Install moisture sensor over sand filter pump
No pressure	• Blockage of pump inlet and outlet • Pump system failure • Check valves fouling • Manual valve failure	• Tripping of line, and zero production of permeate water	• Installing switch system on manual valves for safety • Install auto vent on line
Low flow	• Incorrect installation of manual valve at raw water pump outlet	• Tripping of line, and zero production of permeate water	• Manual controlling valves installation • Orderly backwash of sand filter.

	• Pump Suction failed • Check valve blockage		• Periodical inspection & maintenance
High flow	• Manual valve irregularity. • Flange failure mechanically. • Start accidental pump	• Tripping of line, no production of permeate water, cracking of pipe	• Well programmed PLC to prevent starting additional pump when one pump is running.
Service failures	• Acid Pump corrosion. • Mechanical failure in Acid instrument	• No unloading of Acid, diffusion of Acid on place	• Maintenance & Periodical repairing

Table 32: Factors involved in HAZOP Analysis of RO

CHAPTER 9: CONTROL SYSTEM

A demonstration of control loop on neutralization tank is shown below:

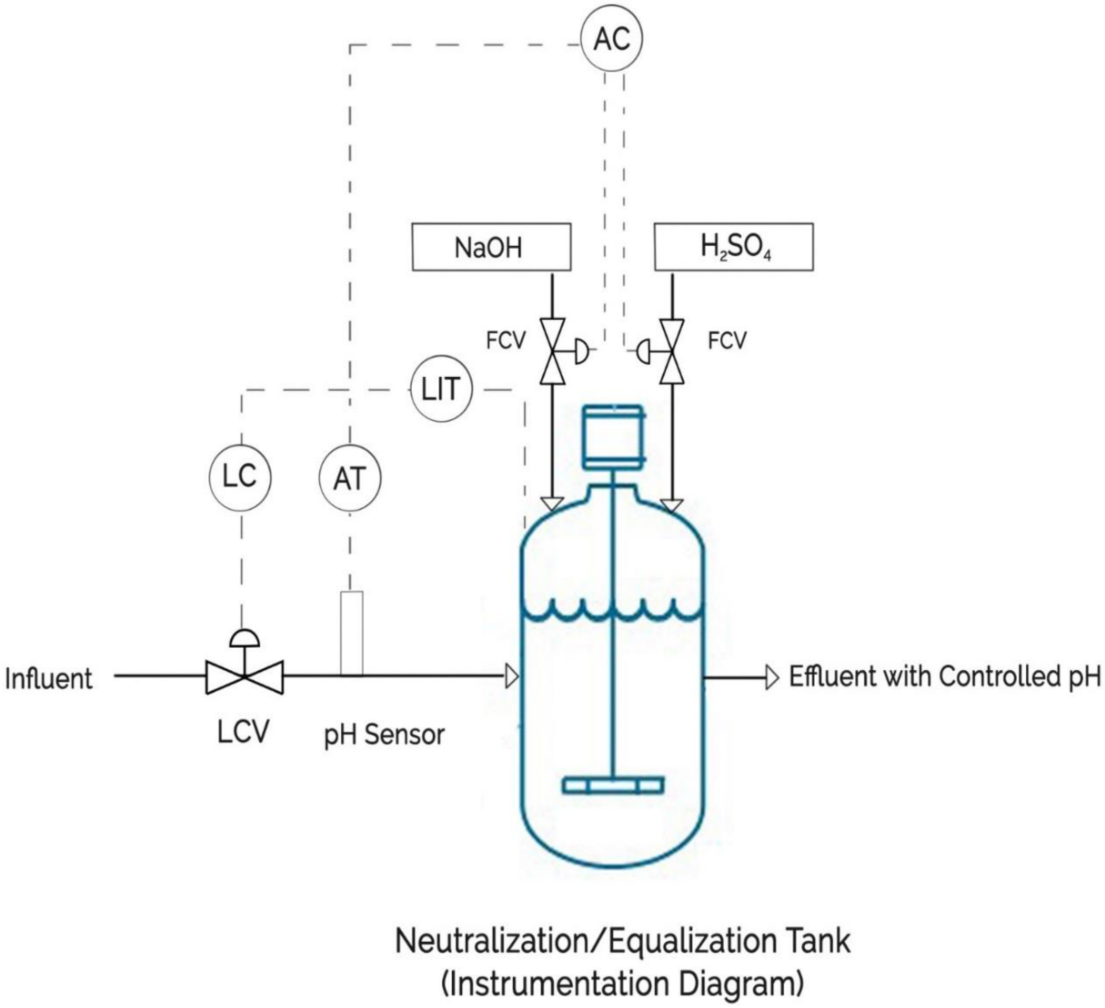
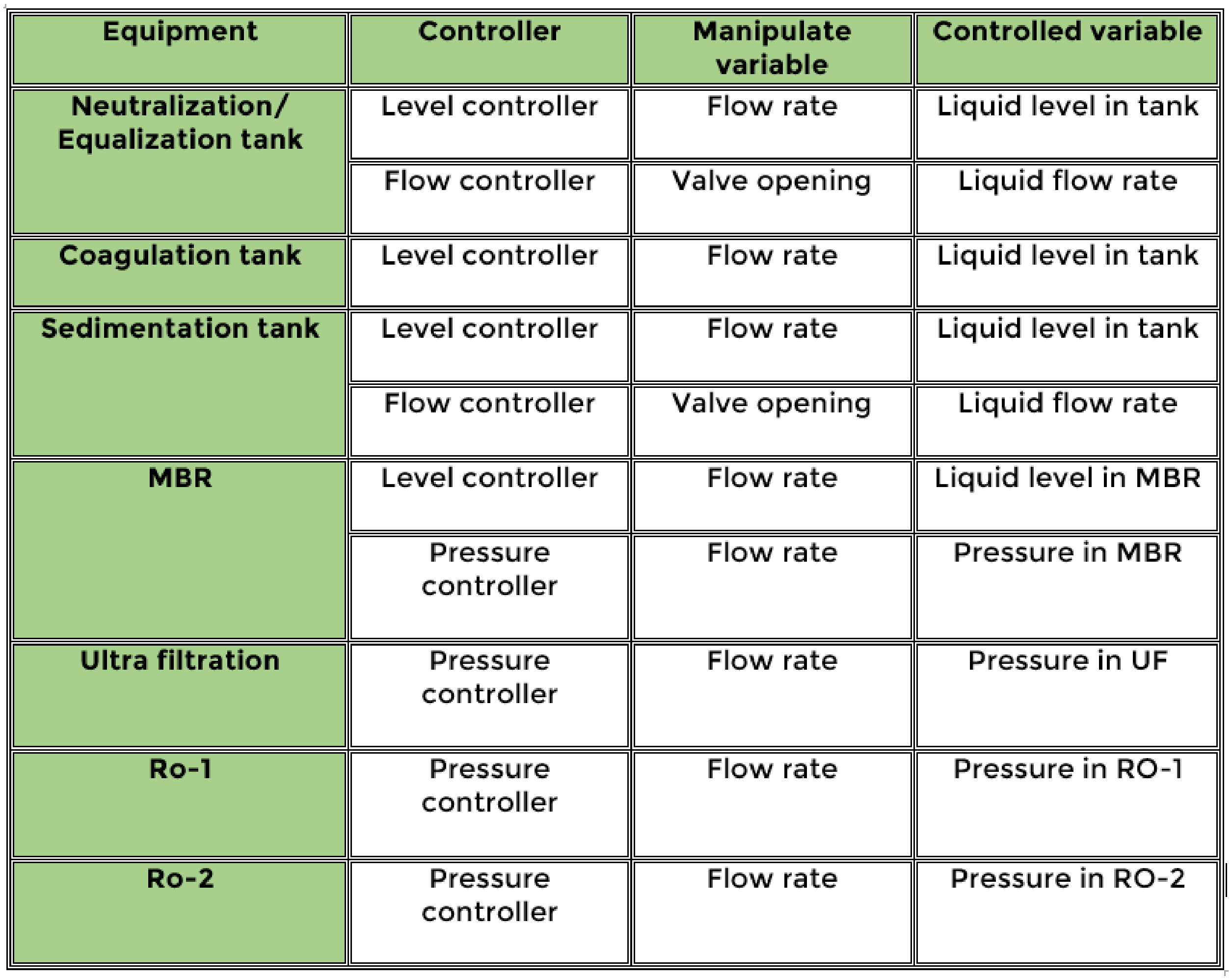


Figure 16 Control System on Neutralization Equalization Tank

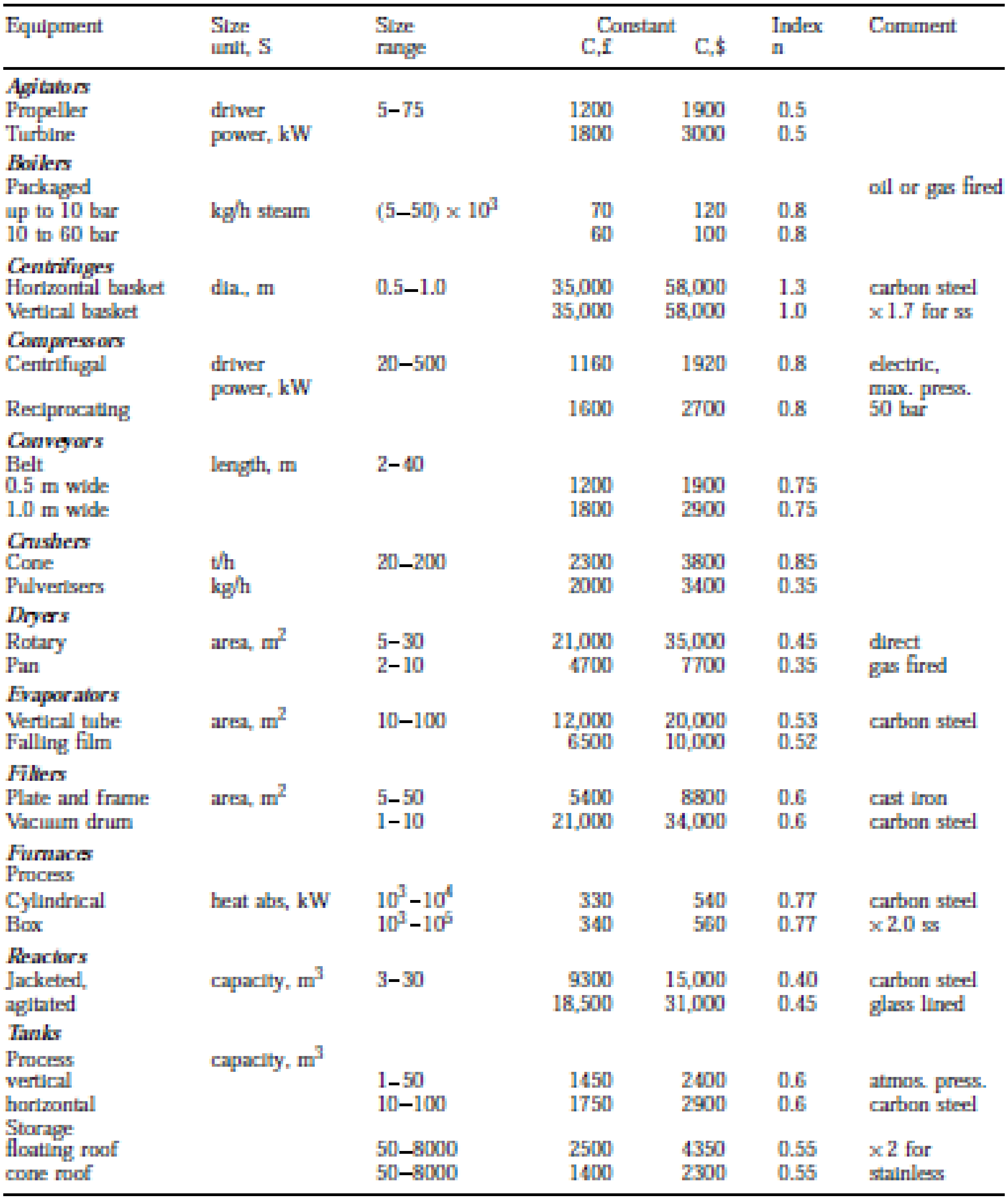
Necessary control loops for the entire plant are as following:



Equipment	Controller	Manipulate variable	Controlled variable
Neutralization/ Equalization tank	Level controller	Flow rate	Liquid level in tank
	Flow controller	Valve opening	Liquid flow rate
Coagulation tank	Level controller	Flow rate	Liquid level in tank
Sedimentation tank	Level controller	Flow rate	Liquid level in tank
	Flow controller	Valve opening	Liquid flow rate
MBR	Level controller	Flow rate	Liquid level in MBR
	Pressure controller	Flow rate	Pressure in MBR
Ultra filtration	Pressure controller	Flow rate	Pressure in UF
Ro-1	Pressure controller	Flow rate	Pressure in RO-1
Ro-2	Pressure controller	Flow rate	Pressure in RO-2

CHAPTER 10: COST ANALYSIS

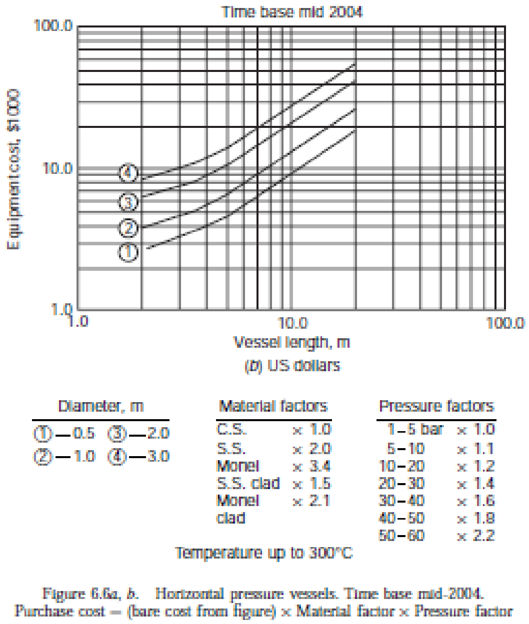
The table for base costs, size units, and indices for different equipments was used from Richardson Coulson's Chemical Engineering Volume 6. The table is as follows:



Equipment	Size unit, S	Size range	Constant C,£	Constant C,$	Index n	Comment
Agitators						
Propeller	driver	5–75	1200	1900	0.5	
Turbine	power, kW		1800	3000	0.5	
Boilers						
Packaged						oil or gas fired
up to 10 bar	kg/h steam	$(5–50) \times 10^3$	70	120	0.8	
10 to 60 bar			60	100	0.8	
Centrifuges						
Horizontal basket	dia., m	0.5–1.0	35,000	58,000	1.3	carbon steel
Vertical basket			35,000	58,000	1.0	× 1.7 for ss
Compressors						
Centrifugal	driver power, kW	20–500	1160	1920	0.8	electric, max. press.
Reciprocating			1600	2700	0.8	50 bar
Conveyors						
Belt	length, m	2–40				
0.5 m wide			1200	1900	0.75	
1.0 m wide			1800	2900	0.75	
Crushers						
Cone	t/h	20–200	2300	3800	0.85	
Pulverisers	kg/h		2000	3400	0.35	
Dryers						
Rotary	area, m^2	5–30	21,000	35,000	0.45	direct
Pan		2–10	4700	7700	0.35	gas fired
Evaporators						
Vertical tube	area, m^2	10–100	12,000	20,000	0.53	carbon steel
Falling film			6500	10,000	0.52	
Filters						
Plate and frame	area, m^2	5–50	5400	8800	0.6	cast iron
Vacuum drum		1–10	21,000	34,000	0.6	carbon steel
Furnaces						
Process						
Cylindrical	heat abs, kW	$10^3–10^4$	330	540	0.77	carbon steel
Box		$10^3–10^5$	340	560	0.77	× 2.0 ss
Reactors						
Jacketed,	capacity, m^3	3–30	9300	15,000	0.40	carbon steel
agitated			18,500	31,000	0.45	glass lined
Tanks						
Process	capacity, m^3					
vertical		1–50	1450	2400	0.6	atmos. press.
horizontal		10–100	1750	2900	0.6	carbon steel
Storage						
floating roof		50–8000	2500	4350	0.55	× 2 for
cone roof		50–8000	1400	2300	0.55	stainless

Table 33: base costs, size units, and indices for different equipments

For tanks and horizontal pressure vessels, we use the following table from Richardson Coulson's Chemical Engineering, Volume 6:



Diameter, m	
①—0.5	③—2.0
②—1.0	④—3.0

Material factors	
C.S.	× 1.0
S.S.	× 2.0
Monel	× 3.4
S.S. clad	× 1.5
Monel clad	× 2.1

Pressure factors	
1–5 bar	× 1.0
5–10	× 1.1
10–20	× 1.2
20–30	× 1.4
30–40	× 1.6
40–50	× 1.8
50–60	× 2.2

Temperature up to 300°C

Figure 6.6a, b. Horizontal pressure vessels. Time base mid-2004.
Purchase cost = (bare cost from figure) × Material factor × Pressure factor

Figure 17 Pressure Vessel Costing Graph

10.1

Neutralization Tank

10.1.1 Tank:

Capacity of Tank = 45 m^3

Cost = CS^n

= 2400 x $(45)^{0.6}$

= \$23,558.01

10.1.2 Agitator:

Agitator Power = 0.005 kW

Cost = CS^n

$= 3000 \times (0.005)^{0.5}$

= \$212.13

10.1.3 Total Cost:

Total Cost of Tank = Cost of Tank + Cost of Agitator

= 23,558.01 + 212.13 = \$23,770.14

10.2 Coagulation Tank

10.2.1 Tank

Capacity of Tank = 135 m^3

Cost = CS^n

$= 2400 \times (135)^{0.6}$

= \$45,541

10.3 Membrane Bio-Reactor

10.3.1 Vessel:

Capacity of tank = 203.5 m^3

Cost = CS^n

$= 2400 \times (203.5)^{0.6}$

= \$58,257.2

10.3.2 Membrane:

Area = 145 m^2

Cost = Cost per unit area x Total Area

= 25 x 145

= \$3625

10.3.3 Total Cost:

Total Cost = Cost of Vessel + Cost of Membrane

= 58,257.2 + 3625

= \$61,882.2

10.4 Ultra filtration Unit

The Ultra filtration unit will cost approximately 0.25 million dollars as has been derived from the literature.

Total Cost = \$0.25 Million = \$250000

10.5 Reverse Osmosis

There are two Reverse Osmosis Units being used in our process. According to the literature, the cost of a Reverse Osmosis Unit is 1 million dollars when the flow rate is 1000 m^3.

Our flow rate is 814 m^3, which results in a cost of 0.814 million dollars for one unit.

Total Cost of Reverse Osmosis (for 2 units) = 0.814 x 2 = \$1.628 million

10.6 High Pressure Pumps

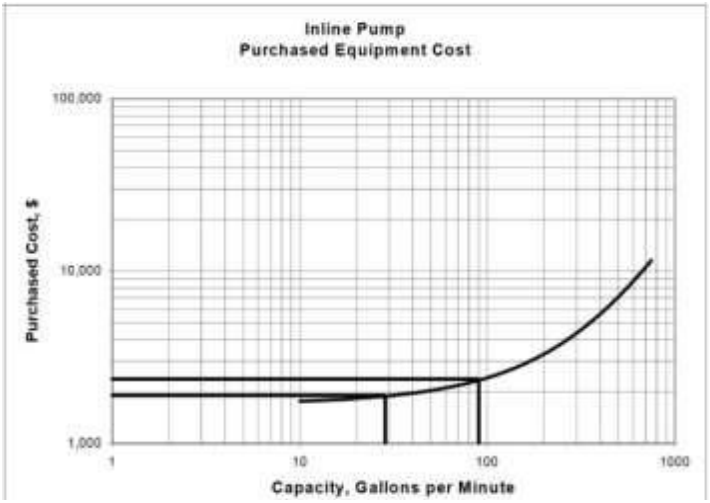


Figure 18 Pump Costing Graph

Pump 1:

Volumetric flow rate = 805 m^3

Cost from Graph = \$12,500

Pump 2:

Volumetric flow rate = 567 m^3

Cost from Graph = \$9,500

10.7 Storage Tanks

10.7.1 NaOH Tank:

Capacity of tank = 0.3164 m^3

Cost = CS^n

= 2400 x $(0.3164)^{0.6}$

= $1203.2

10.7.2 H_2SO_4 Tank:

Capacity of tank = 0.05124 m^3

Cost = CS^n

= 2400 x $(0.05124)^{0.6}$

= 403.6

10.7.3 Total Cost:

Total Cost of Storage Tanks = 1203.2 + 403.6

= $1605.8

10.8 Purchased Cost of Equipment

The total purchased cost would be the sum of all the equipment costs, which is as follows:

Equipment	**Cost(in Dollars)**
Neutralization Tank	23,770.14
Coagulation Tank	45,541

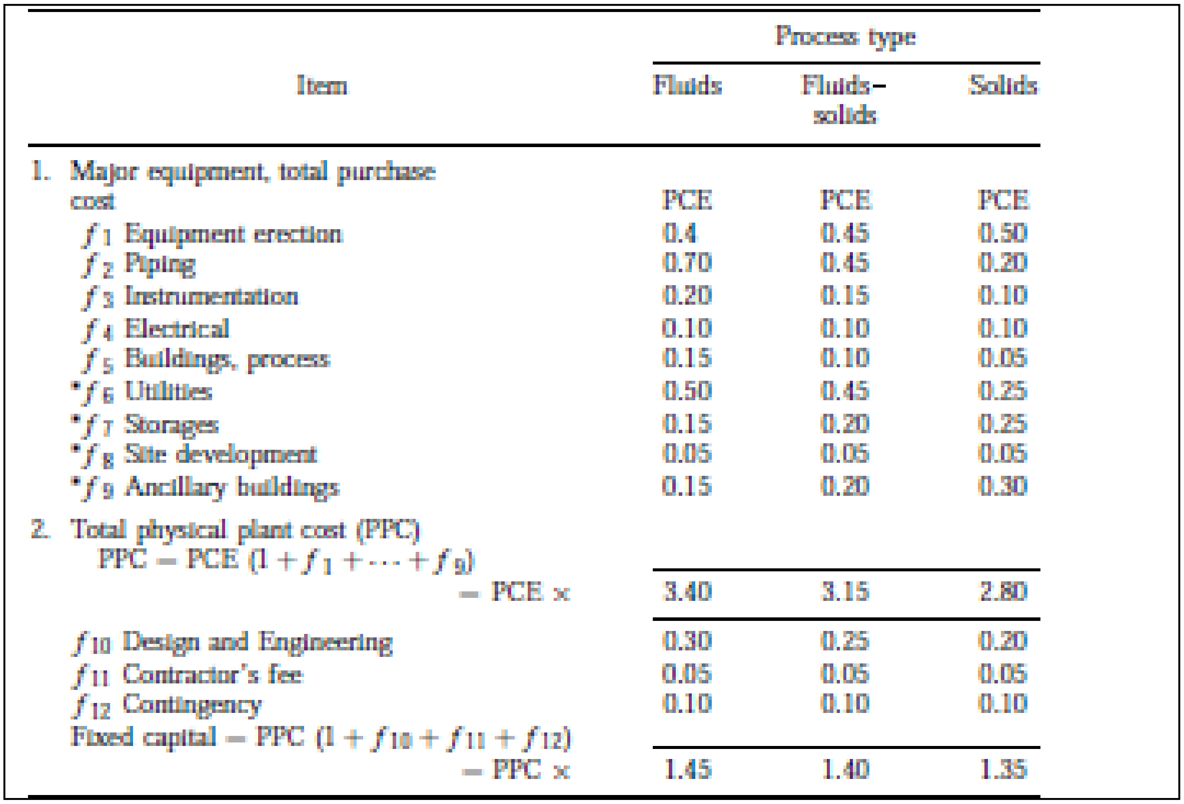
Membrane Bio-Reactor	61,882.2
Ultra filtration	0.25 million
Reverse Osmosis Units	1.628 million
Pressure Pumps	22000
Storage Tanks	1605.8
Total Cost	2,032,799

Table 34: Purchased cost

The total purchased cost of equipment is **2.03 million dollars.**

10.9 Physical Plant Cost

We use the following table from Richardson Coulson’s Chemical Engineering Volume 6 to determine the Physical Plant Cost and the Fixed Capital Cost.



Item	Process type		
	Fluids	Fluids–solids	Solids
1. Major equipment, total purchase cost	PCE	PCE	PCE
f_1 Equipment erection	0.4	0.45	0.50
f_2 Piping	0.70	0.45	0.20
f_3 Instrumentation	0.20	0.15	0.10
f_4 Electrical	0.10	0.10	0.10
f_5 Buildings, process	0.15	0.10	0.05
*f_6 Utilities	0.50	0.45	0.25
*f_7 Storages	0.15	0.20	0.25
*f_8 Site development	0.05	0.05	0.05
*f_9 Ancillary buildings	0.15	0.20	0.30
2. Total physical plant cost (PPC) PPC = PCE $(1 + f_1 + \cdots + f_9)$ = PCE ×	3.40	3.15	2.80
f_{10} Design and Engineering	0.30	0.25	0.20
f_{11} Contractor's fee	0.05	0.05	0.05
f_{12} Contingency	0.10	0.10	0.10
Fixed capital = PPC $(1 + f_{10} + f_{11} + f_{12})$ = PPC ×	1.45	1.40	1.35

The following table is used to calculate our Physical Plant Cost with the Lang factors suited to our process.

Factor	Value
f_1 Equipment Erection	0.45
f_2 Piping	0.45
f_3 Instrumentation	0.15
f_4 Electrical	0.10
f_5 Buildings	0.10

Table 35: Lang's factors to calculate PPC for system containing solids and liquids

Physical Plant Cost = Purchased Cost of Equipment x $(1 + f_1 + .. + f_9)$

f_6 Utilities	0.45
f_7 Storages	0.20
f_8 Site Development	0.05
f_9 Ancillary Buildings	0.20
Total	2.15

= \$2,032,799 x (1+2.15)

= \$6,403,316 = \$ 6.4 million.

10.10 Fixed Capital Costs

The following Lang factors are used to determine the Fixed Capital Cost:

Factor	Value
f_{10}Designing and Engineering	0.25
f_{11} Contractor’s Fee	0.05
f_{12} Contingency	0.10
Total	**0.40**

Table 36: Lang’s factors to calculate Fixed Capital for system containing solids and liquids

Fixed Capital Cost = Physical Plant Cost x $(1+f_{10} + f_{11} + f_{12})$

= 6,403,316 x (1 + 0.40)

= \$8,964,643 = \$8.9 million

10.11 Working Capital

The Working Capital of the process is taken as 5 percent of the Fixed Capital Cost of the process:

Working Capital = 5 % x FCC

= 5% x 8,964,643

= \$4,48,232

10.12 Total Investment

The Total Investment required is:

Total Investment = Fixed Capital + Working Capital

= 8,964,643 + 448,232

= \$ 9,412,875 = \$9.4 million

10.13 Operating Costs

Type of Cost	**Method of Calculation**	**Cost (in dollars)**
Maintenance	5 % of Fixed Capital	448232
Operating Labour	Estimate	100000
Laboratory Costs	20 % of Operating Labour	20000
Supervision	20 % of Operating Labour	20000
Plan Overheads	50 % of Operating Labour	50000

Capital Charges	10 % of Fixed Capital	896464
Local Taxes	2 % of Fixed Capital	179262
Total	Sum of all costs	1,713,958

Table 37: Fixed Operating Costs

The Total Operating Costs are **$ 1,713,958.**

Conclusion:

Effluent of Nitro-Phosphate Plant which had undesirable amounts of TDS, TSS, COD and BOD due to which it couldn’t be reused in industry and couldn’t be discharged into environment either because it was not meeting the NEQs provided by the government of Pakistan, this effluent has been treated effectively by our proposed plant which utilizes new technology like membrane bioreactor and a highly effective two step reverse osmosis membrane system. After this treatment, 423.790 m^3 of reusable water is produced each day, which is almost free from TSS, COD and BOD. TDS, which was the main target, is reduced to 402 ppm which is now safe to discharge in environment as it meets the NEQs, furthermore it can also be reused in the plant reducing the total expenditure.

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Membrane Desalination Technology by Mark Wilf

Metcalf and Eddy’s Wastewater Engineering