DESIGN OF GROUNDWATER RECHARGE FACILITY FOR TREATED EFFLUENT OF ATTOCK REFINERY LIMITED

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CERTIFICATE

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DEDICATION

This thesis is wholeheartedly dedicated to our beloved parents, who have been our source of inspiration and gave us strength when we thought of giving up, who continually provide their moral, spiritual, emotional, and financial support.

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First, we bow before Allah Almighty for His endless blessings and rewards, which gave us the strength and ability to complete this thesis. Words cannot express our gratitude to our respective supervisor and co-supervisor for their invaluable patience and feedback. We express our sincere gratitude to our supervisor **Dr. Syed Rafay Hussain Jafri,** and co-supervisor **Dr. Ameen Shahid** for their guidance, enthusiastic support, constructive suggestions, and ever-helping supervision. We are thankful to **Attock Refinery Limited, Pakistan,** for reducing the student-industry gap, giving us industrial exposure, and a chance to apply our knowledge and learning to practical industry problems and situations. Lastly, we are thankful to our parents; without their assistance and encouragement, it was not possible to complete the project successfully.

ABSTRACT

Effluent treatment plants serve as vital necessities for both industrial operations and the preservation of our environment. Their significance lies in their ability to facilitate the safe discharge or reuse of wastewater. Our current project focuses on a distinctive endeavor: designing a state-of-the-art water treatment and groundwater recharge facility exclusively tailored for Attock Refinery Limited (ARL). The primary objective of this facility is to adhere to the stringent standards outlined in the Punjab Environmental Quality Standards (PEQS) for groundwater discharge. A meticulously planned process comprising three crucial unit operations has been devised to achieve this: pH control, BOD removal, and membrane operation. In stark contrast to zero liquid discharge systems, which entail the complete elimination of wastewater, our approach allows for groundwater discharge. This approach grants a broader scope of water usage, encompassing drinking purposes, irrigation for agricultural fields, and integration into secondary processes within the refinery. Simultaneously, it ensures that water disposal into natural water bodies remains within acceptable limits, thus striking a balance between water conservation and maintaining a harmonious ecological equilibrium.

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CHAPTER 1

INTRODUCTION

1.1 Problem Statement

Attock Oil Refinery, also known as Attock Refinery Limited (ARL), is a prominent oil refinery located in Rawalpindi, Pakistan. Established in 1922, it is one of the oldest and largest oil refineries in the country.

Attock Refinery plays a vital role in the energy sector of Pakistan by processing crude oil into various petroleum products. The refinery has a processing capacity of approximately 45,000 barrels per day. It receives crude oil from both domestic and international sources, which is then refined into products such as gasoline, diesel, jet fuel, furnace oil, liquefied petroleum gas (LPG), and various other petroleum by-products. The refinery utilizes advanced technology and processes to ensure the production of high-quality petroleum products that meet international standards. It has modern facilities and infrastructure, including state-of-the-art refining units, storage tanks, pipelines, and a laboratory for quality control.

Attock Refinery has a strong commitment to safety, health, and environmental conservation. It adheres to stringent safety measures and environmental regulations to minimize the impact of its operations on the surroundings. The refinery strives to continuously improve its processes and invests in research and development to enhance efficiency and reduce its environmental footprint.

In addition to refining operations, Attock Refinery is also involved in the marketing and distribution of its petroleum products. It supplies its products to a wide range of customers, including commercial and industrial sectors, as well as retail outlets across Pakistan. With its long-standing presence and contributions to the energy sector, Attock Oil Refinery has established itself as a reputable and reliable entity in Pakistan's petroleum industry. It plays a crucial role in meeting the country's energy needs and supporting its economic development. As an oil refinery, it requires significant amounts of water for various processes, including cooling, steam generation, and as a medium for transporting materials. Ensuring an adequate and uninterrupted water supply is essential for refinery operations. However, water scarcity or limitations in the local water infrastructure can pose challenges.

A comprehensive strategy that includes effective water management techniques, observance of environmental laws, and the use of cutting-edge technology for water treatment and conservation is needed to address these water-related concerns. Attack Oil Refinery can lessen its environmental effect and support the wise use of water resources by employing sustainable water management practices. Significant amounts of effluent from refineries are contaminated with chemicals, heavy metals, and hydrocarbons. It is essential to handle this wastewater properly in order to prevent environmental pollution and meet legal requirements.

Recharging of subsurface aquifers, which act as natural reservoirs for storing groundwater, is referred to as groundwater recharge. It is a crucial organic activity that contributes to the maintenance of freshwater supplies. When water from a variety of sources, including irrigation, surface water bodies like rivers and lakes, and precipitation, seeps into the soil and percolates through the unsaturated zone until it reaches the water table, groundwater recharge takes place.

1.1.1 Problem Scope

The project scope is to:

1. Design of an effluent treatment system to meet the groundwater-specific requirements set by Punjab Environmental Quality Standards (PEQS). It mainly Includes:
   a. pH control
   b. Organic material removal
   c. Total Dissolve Solids (TDS) removal
2. Design of Recharge Facility for the treated effluent

1.2 Literature Review

1.2.1 Effluent Treatment

In designing of effluent treatment plant following methods were studied in order to control pH, remove BOD and remove dissolved solids.

1.2.1.1 Organic Content Removal

1. Chlorination:

The process of chlorinating refers to the addition of chlorine or chlorine compounds to water or other substances for chemical treatment or disinfection. Because of its potent antibacterial qualities, chlorine is frequently employed as a disinfectant. It can eliminate or inactivate a variety of pathogens, such as bacteria, viruses, and protozoa, lowering the risk of contracting illnesses transmitted by water.

To preserve water quality throughout the distribution system, chlorine can be added at various phases of the water treatment procedure, like during primary disinfection, secondary disinfection, or as a residual disinfectant. To obtain the appropriate degree of disinfection while avoiding excessive levels that might cause problems with taste and odor or the creation of potentially dangerous disinfection byproducts, it is crucial to carefully monitor the chlorine dose.

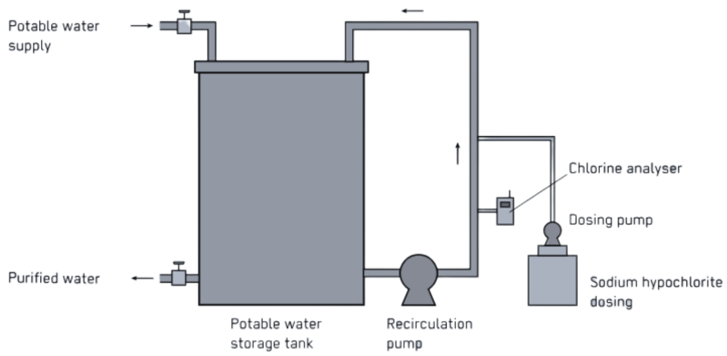


Figure 1. Working Principle of Chlorination

2. Bio Reactor:

The removal of pollutants and toxic substances from wastewater is made possible by bioreactors, which are essential for the treatment of wastewater. They use microorganisms' ability to decompose organic material and change dangerous compounds into less dangerous or even useful byproducts. In comparison to conventional wastewater treatment techniques, bioreactors are more effective, use less energy, and use fewer chemicals.

In the field of the treatment of wastewater, a bioreactor is a regulated setting where biological interactions take place to speed up the breakdown of organic material and get rid of contaminants. These reactors offer the best conditions for bacteria and fungi to flourish and perform their metabolic functions. The organic content in the wastewater serves as a food supply for the microbes, which employ multiple biochemical procedures to break it into simpler chemicals. The bioreactor specifically used for this project is a suspended growth bioreactor.

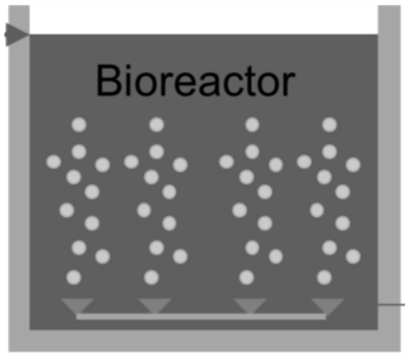


Figure 2. Schematic of Bio Reactor Tank

Suspended Growth Bioreactors are those bioreactors that treat wastewater by using suspended microorganisms, frequently in the form of sludge that has been activated. The bacteria multiply and generate flocs, which aid in the extraction of organic materials and suspended particles. Aeration is frequently used in suspended growth bioreactors to supply oxygen for bacteria respiration.

Chemical Reaction:

$$C_{24}H_{48}O_{24} + 4O_2 + 4NH_3 \rightarrow 4C_5H_7NO_2 + 4CO_2 + 16H_2O$$

For the simulation in Aspen HYSYS, we used the following reaction:

$$C_6H_{12}O_6 + 6O_2 \xrightarrow{\text{Bacterial activity}} 6CO_2 + 6H_2O$$

1.2.1.2 Total Dissolved Solids Removal

1) Membrane Distillation:

Membrane distillation is a separation process that utilizes a semi-permeable membrane to separate and purify liquids. It operates on the principle of phase change and relies on the differences in vapor pressure between the feed solution and a permeating stream to achieve separation.

A hydrophobic membrane, which in this process rejects dissolved particles and other contaminants while allowing only water vapor to travel through, is employed. On one side of the membrane, which can be a solution of saline or wastewater, the feed solution is heated and brought into contact with it, while a cold stream is pumped on the opposite side.

The water molecules in the feed solution evaporate and permeate across the membrane as a result of the difference in vapor pressure, leaving the pollutants behind. The resultant purified liquid stream, known as the permeate, is created when the water vapor condenses on the cold side of the membrane. The driving force behind vapor movement is maintained and effectively separated, thanks to the temperature difference across the membrane's surface.

Compared to traditional water treatment methods, membrane distillation devices can be rather pricey. For some applications, particularly in large-scale operations, it may not be economically feasible due to the cost of membrane materials, system design, and energy needs.

2) Ion Exchange Method

Second comes the ion exchange method for the removal of dissolved solids. The process of removing undesired ions from water by exchanging them with more desirable ions contained in an ion exchange medium is known as ion exchange, and it is a common technique for treating water. Ions in the water are drawn in and substituted with ions of similar charge existing in the exchange medium according to the reversible ion exchange principle.

The ion exchange medium, commonly known as resin, is usually composed of tiny, porous beads or granules made from a polymer matrix. These resins are chemically engineered to possess specific functional groups that attract and bind certain ions. The functional groups can be negatively charged (anion exchange resin) or positively charged (cation exchange resin), depending on the type of ions targeted for removal.

In the ion exchange process, water to be treated passes through a column or vessel containing the resin bed. As the water flows through the resin, the undesirable ions in the water come into contact with the resin's functional groups. The undesirable ions are attracted to and captured by the resin, while the desirable ions on the resin are released into the water, effectively swapping places.

Once the resin bed becomes saturated with undesirable ions, the ion exchange process is no longer effective, and the resin needs to be regenerated. Regeneration involves flushing a solution containing a high concentration of desirable ions through the resin bed, which displaces the captured undesirable ions and restores the resin's original capacity for ion exchange. The captured undesirable ions are typically washed away or treated separately to prevent their release back into the environment.

It's crucial to remember that ion exchange has some restrictions. Non-ionic pollutants and dissolved organic matter might not be successfully removed from the water. The cost of the ion exchange resin and the disposal of used regeneration chemicals can also be taken into account when evaluating the viability of using ion exchange as a water treatment technique.

3) Reverse Osmosis:

Reverse Osmosis (RO) is a water purification technology that utilizes a semi-permeable membrane to remove impurities and contaminants from water. It is a highly effective and widely used process for desalination, water treatment, and purification. The inherent osmosis process, in which water molecules pass across a semi-permeable membrane to migrate from a region of lower solute concentration to an area of greater solute concentration, serves as the basis for reverse osmosis. By exerting external pressure to counteract the osmotic pressure and drive water molecules through the membrane, reverse osmosis reverses this natural process, leaving behind dissolved pollutants and toxins.

Reverse osmosis employs a semi-permeable membrane that is intended to let water molecules through while obstructing the flow of dissolved salts, minerals, bacteria, viruses, and other contaminants. Purified water is produced as a result of the membrane's minuscule pores, which can reject particles bigger than water molecules.

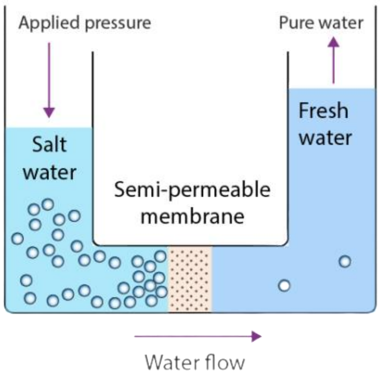


Figure 3. Working Principle of Reverse Osmosis Process

The reverse osmosis process typically involves several stages. First, the water to be treated is passed through a pre-filter to remove larger particles and sediment. Then, it is pressurized and forced through the semi-permeable membrane, where the majority of impurities and contaminants are rejected and separated from the water. The rejected impurities, known as brine or concentrate, are then flushed away, while the purified water, known as permeate, is collected for use.

Reverse osmosis systems come in a variety of sizes and capacities, from little home units to massive industrial facilities. They are employed in a number of processes, including the generation of ultrapure water for use in industrial operations, saltwater desalination, wastewater treatment, and the purification of drinking water. Numerous pollutants, including dissolved solids, heavy metals, germs, viruses, and organic substances, are effectively removed using RO technology.

Reverse osmosis is a dependable and often-used method for desalinating and purifying water, providing a practical way to get clean, safe drinking water from a variety of sources. Its uses keep growing, and continuing research attempts to boost its effectiveness, cut down on energy use, and overcome its drawbacks.

1.2.2 Groundwater Recharge

The process through which water permeates the Earth's surface and refills the subterranean aquifers—natural underground reservoirs that hold water—is referred to as groundwater recharge. It is an essential part of the hydrological cycle and significantly contributes to the preservation of freshwater supplies and the health of ecosystems.

The quantity and intensity of precipitation, the features of the soil, the amount of vegetation present, the kind of land used, and geological characteristics all have an impact on how quickly groundwater recharges. Recharge rates might range dramatically between places and throughout various seasons.

1. Direct Recharging

Direct groundwater recharging, also known as artificial groundwater recharging or managed aquifer recharge, refers to the intentional and controlled process of replenishing groundwater reserves by human intervention. It involves the deliberate addition of water to the subsurface, allowing it to infiltrate and replenish aquifers.

Direct groundwater recharge techniques seek to improve existing recharge mechanisms or provide fresh channels for groundwater infiltration. These techniques may be used to complement natural recharge and guarantee a sustainable water supply in a variety of contexts, including metropolitan areas, agricultural fields, and water-scarce regions.

2. Surface Method

Groundwater recharge techniques used on the surface are intended to replicate or improve natural recharge processes. They entail gathering and diverting surface water—like rain or river water—to places where it may seep into the earth and percolate into the aquifer below. To increase groundwater supplies, these techniques may be used in a variety of environments, including urban, agricultural, and natural settings.

CHAPTER 2

PROCESS OVERVIEW

2.1 Process Flow Diagram

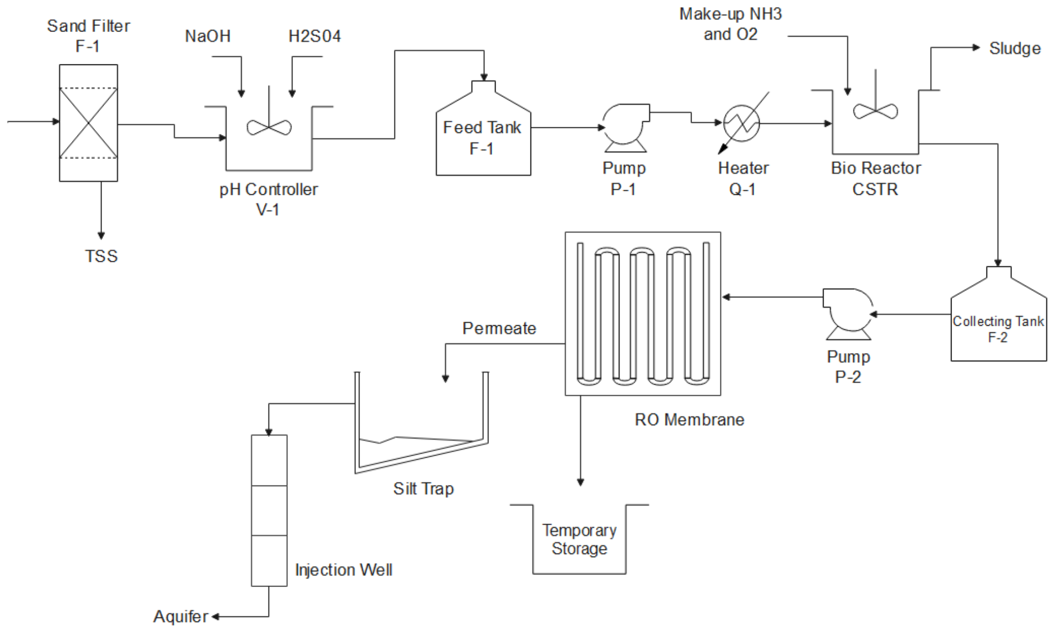


Figure 4. Process Flow Diagram

2.2 Process Description

Sand Filter:

The function of the Sand Filter is suspended solids removal. The primary purpose of the sand filter is to remove suspended solids from the wastewater. Suspended solids can include organic matter, debris, sediment, and other particulate matter. The filter bed's porous structure allows the wastewater to flow through while retaining the solids. Over time, the accumulation of solids on the top layers of the filter forms a layer called the filter cake, which enhances the filtration process.

pH Controller/Equalization Tank:

The feed water initially flows into an equalization tank which serves two purposes:

1. Equalizing the variable feed flow rate to a steady flow rate value so as to prevent the oversizing of the downstream equipment.

2. Act as a dosing point for the acid/base into the water stream to attain the desired pH level and to provide sufficient mixing to ensure neutralization reaction completion.

There is a pH sensor before the Equalization Tank, which senses the inlet pH and sends that value to the controller. Additionally, a flow sensor record the inlet flow rate and sends that value to the controller as well. The controller, using the set value of pH 7–7.5, determines the difference in H^+ moles and decides the amount of acid or base that needs to be added to the water stream. Consequently, the controller sends signals to the control valves to open proportionally to add the required amount of acid or base.

Feed Tank:

Feed tanks are used in wastewater treatment processes to provide a controlled and regulated supply of wastewater to the treatment system. The purpose of a feed tank is to store and regulate the flow of influent wastewater before it enters the treatment process.

Pump:

The Pump provides the water with such an amount of pressure so that when the water enters the next unit, it does not flow back due to the height difference present in going toward the membrane bioreactor.

Heat Exchanger**:**

There are two reasons why heat exchanger is being used in water treatment processes:

1. Temperature control: Heat exchangers help regulate the temperature of the water being treated.
2. Process optimization: In our water treatment processes, maintaining specific temperature conditions is critical for achieving optimal chemical reactions as well as microbial activity. Heat exchangers assist in maintaining the desired temperature range, ensuring effective treatment and consistent process performance.

Membrane Bio Reactor (MBR):

The MBR is a combination of a bioreactor and a separator. It serves to provide Oxygen to the water, which is given sufficient residence time for the oxidation reaction to take place. The microorganisms in the water use the provided Oxygen to break down the organic matter. Additionally, the Oxygen is used by other chemical compounds, which add to COD, to oxidize themselves. Hence, in this manner, the COD and BOD are eliminated. Furthermore, the microorganisms that reduce the BOD are prevented from flowing ahead with the water stream with the help of an ultrafiltration membrane, which has a pore size small enough to prevent the microorganisms from flowing along with it.

Filter Press:

A filter press is used in the treatment of sludge that comes from a membrane bioreactor (MBR). Its primary function is to separate solids from liquids in sludge by using pressure-driven filtration.

Storage Tank:

Storage tanks help to regulate flow, provide backup capacity, and facilitate efficient treatment processes by optimizing the timing and balance of wastewater flow throughout the plant. It is installed before the RO membrane for flow regulation.

High-Pressure Pump:

The High Pressure (HP) Pump provides the water with such an amount of pressure that when the water enters the RO unit, it does not flow back due to the osmotic pressure generated because of the salts present across the membrane there.

RO Membrane:

The RO Membrane unit is used to rid the water of dissolved salts so as to achieve freshwater standards. When the water containing high amounts of TDS flows into the RO unit, it passes through membrane elements that have such small pores (smaller than nano size) that only water is allowed to pass through the membrane while the salts are retained. However, the process is not 100% efficient, and some number of salts pass along with the product stream. The product stream, essentially known as the permeate water, contains significantly low amounts of TDS, while the salts retained in the RO are simultaneously rejected from the RO unit along with reject water as not all of the water passes as the product water due to the crossflow in the RO unit.

Slit Trap:

Slit trap is used for two basic functions:

1. Sedimentation: Slit traps promote the settling of heavier solids by providing a quiescent zone within the wastewater flow. When the wastewater enters the slit trap, the velocity decreases, allowing particles to settle and accumulate at the bottom. This sedimentation process helps separate the solids from the liquid phase.
2. Maintenance and Cleaning: Slit traps also facilitate easier maintenance and cleaning of the wastewater treatment system. Since the solid materials are retained in the trap, they can be periodically removed, preventing them from clogging or damaging downstream equipment or processes. Regular cleaning and removal of the accumulated sludge help maintain the overall efficiency of the wastewater treatment plant.

Injection Well:

Water, after being treated by all units and slit trap, moves to the injection well for its disposal into the ground. This effluent goes to the subsurface layers of Earth. Injection wells allow for the safe and controlled disposal of treated wastewater into deep underground formations, such as porous rock layers.

CHAPTER 3

MATERIAL AND ENERGY BALANCE

3.1 Sand Filter

3.1.1 Material Balance

Formula Used:

$$Accumulation = In - Out + Generation - Consumption$$

Table 1. Sand Filter Material Balance

Parameter	IN	OUT
Flow Rate (L/hr) or (kg/hr)	68137.4	68127.53
TSS (kg)	9.87	0
H_2O	68127.53	68127.53

3.2 pH Controller

3.2.1 Material Balance

Formula Used:

$$Input = Output + Accumulation \pm Generation/Consumption$$

$$[H^+]\ conc.\ (\frac{mol}{L}) = 10^{-pH}$$

$$NaOH\ Required\ (\frac{g}{hr}) = NaOH\ Required\ (\frac{mol}{hr})\ x\ 40$$

$$H_2SO_4\ Required\ (\frac{g}{hr}) = H_2SO_4\ Required\ (\frac{mol}{hr})\ x\ 98$$

$$Water\ Flow\ Rate = 68.1372\ m^3/h$$

$$Water\ Flow\ Rate = 68137.2\ Litre/h$$

3.2.2 Acidic Medium Calculations

Table 2. Acidic Inlet Calculations for pH Controller

Inlet						
Parameters	**Units**	**10^{-6} (mol/dm^3)**	**10^{-6} (mol/dm^3)**	**10^{-6} (mol/dm^3)**	**10^{-6} (mol/dm^3)**	**10^{-6} (mol/dm^3)**
pH	-	5.65	5.8	5.95	6.1	6.25
H^+ Conc	-	2.23872	1.58489	1.12202	7.94328	5.62341
H^+ Flow	-	6813.72	6813.72	6813.72	6813.72	006813.72

Table 3. Acidic Outlet Calculations for pH Controller

Outlet						
Parameters	**Units**	**10^{-6} (mol/dm^3)**	**10^{-6} (mol/dm^3)**	**10^{-6} (mol/dm^3)**	**10^{-6} (mol/dm^3)**	**10^{-6} (mol/dm^3)**
pH	-	7	7	7	7	7
H^+ Conc	-	1	1	1	1	1
H^+ Flow	-	6813.72	6813.72	6813.72	6813.72	006813.72

Table 4. Overall Balance of pH Controller

Balance: In - Out + Gen - cons = 0					
Units	**10^{-6} mol/h**	**10^{-6}mol/h**	**10^{-6}mol/h**	**10^{-6} mol/h**	**10^{-6} mol/h**
H+ to be consumed	208655	145726.47	101176.464	0.069637476	47309.582
NaOH	208655	145726.47	101176.464	0.069637476	47309.582
NaOH(g/h)	8346201	5829058.7	4047058.577	2.785499033	1892383.272

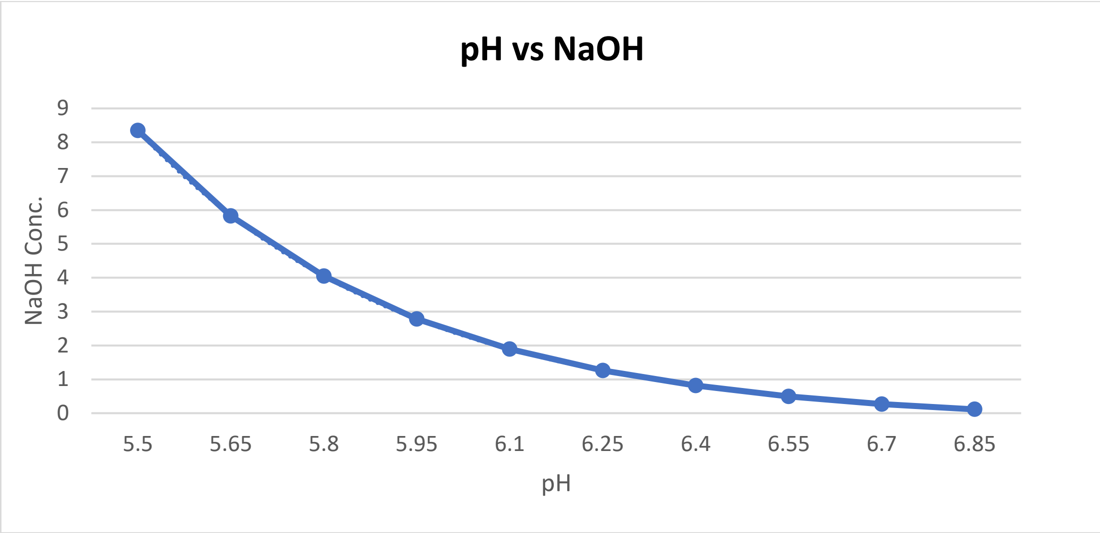


Figure 5. Acidic Medium Graph for pH Controller

3.2.3 Basic Medium Calculations

Table 5. Basic Medium Calculations

Inlet										
pH	8.8	8.65	8.5	8.35	8.2	8.05	7.9	7.75	7.6	7.45
H+ conc (mol/lr)	1.58489E-09	2.23872E-09	3.16228E-09	4.46684E-09	6.30957E-09	8.91251E-09	1.25893E-08	1.77828E-08	2.51189E-08	3.54813E-08
H+ flowrate (mol/hr)	0.00010799	0.00015254	0.000215469	0.000304358	0.000429917	0.000607273	0.000857797	0.00121167	0.001711529	0.002417599
Outlet (mol/h)										
pH	7	7	7	7	7	7	7	7	7	7
H+ conc	0.0000001	0.0000001	0.0000001	0.0000001	0.0000001	0.0000001	0.0000001	0.0000001	0.0000001	0.0000001
H+ flowrate	0.00681372	0.00681372	0.00681372	0.00681372	0.00681372	0.00681372	0.00681372	0.00681372	0.00681372	0.00681372

Table 6. Overall Balance for pH Controller

Balance: In - Out + Gen - cons = 0						
H+ to be generated mol/h	0.006705	0.00666118	0.00659825	0.00650936	0.00638380	0.00620644
H2SO4 mol/h	0.003352865	0.00333059	0.003299126	0.003254681	0.003191902	0.00310322
H2SO4 to add g/h	0.32858076	0.32639781	0.32331431	0.31895875	0.31280636	0.30411588

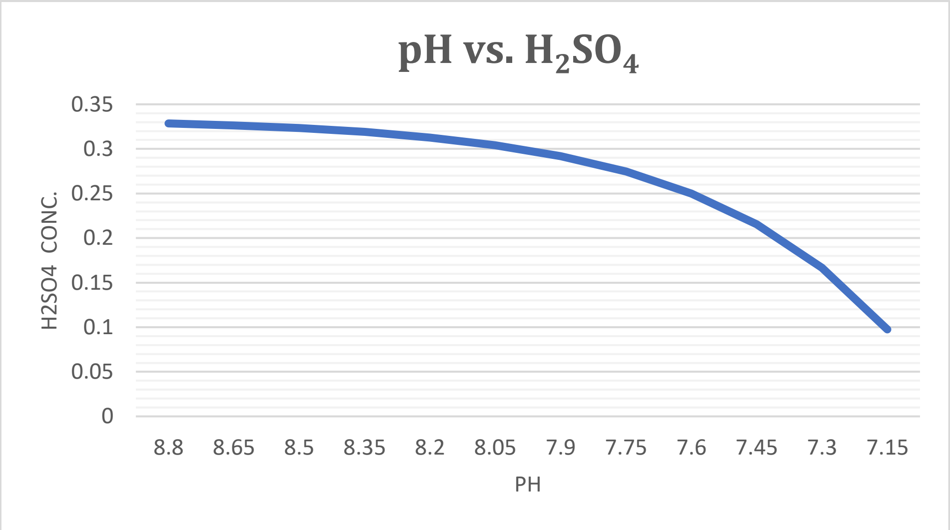


Figure 6. Basic Medium Graph for pH Controller

3.3 Heat Exchanger

3.3.1 Material Balance

The material balance for heat exchanger was required to evaluate the amount of steam necessary for heating the effluent stream. This was done by using the equation:

$$Total\ Duty = Q = \ mCp\Delta T$$

$$m = \ \frac{Q}{c_p\ \Delta T}$$

$$m = \ \frac{3132479}{4.9\ x\ 26}$$

$$m = 5116.4\frac{kg}{h} = 5.4\ m^3/h$$

Table 7. Heat Exchanger Material Balance

Parameters	Shell Side	Tube Side
Flow Rate (m3/h)	5.4	68.2
Stream	Steam	effluent
Inlet Temperature (^{0}C)	180	25
Outlet Temperature (^{0}C)	133	35

3.3.2 Energy Balance

The purpose of the heat exchanger is to rise the effluent temperature so the total duty required to rase the temperature will be supplied by the steam at 180^{o}C and 3 bar pressure from the shell side (since effluent).

$$Total\ Duty = Q = \ mCp\Delta T$$

$$= 68137.4\ x\ 4.5\ x\ (35 - 25)$$

$$= 3132479\ \text{kJ} = 870\ \text{kW}$$

3.4 Bio Reactor

3.4.1 Formulas and Reactions

$$C_{24}H_{48}O_{24} + 4O_2 + 4NH_3 \rightarrow 4C_5H_7NO_2 + 4CO_2 + 16\ H_2O$$

For CSTR

$$L_iQ = L_eQ + k_1L_eV$$

where L_i = Initial BOD

L_e = Outlet BOD

Q = Volumetric Flow Rate (L/min)

k_1 = Reaction Constant (1^{st} Order)

V = Volume of Reactor

$$V = \frac{(Li - Le)Q}{k_1L_e}$$

$$Q = 1135.54 \text{ L/min}$$

$$k_1 \text{ (at } 36^oC) = 0.0723 \text{ min}^{-1}$$

$$V = 10101 \text{ L} = 10.1 \text{ m}^3$$

$$\text{Retention Time} = \frac{V}{Q} = 8.89 \text{ hr}$$

$$1 \text{ mg/L BOD} = 0.089 \text{ mg } O_2\text{/L consumed}$$

3.4.2 Material Balance

Table 8. Bio Reactor Material Balance

BOD (mg/L)		
Inlet	100	8.9
Outlet	60	5.34

3.4.3 Energy Balance

The main energy required in bioreactor will be supplied by heat exchanger and. Therefore, formula we will be using for the pump is as follows:

$$Pump\ Duty = \frac{\Delta P.V.density}{Efficiency}$$

$$Pump\ Duty = \frac{1x\ 68.14\ x\ 1000}{0.75}$$

$$= 136{,}340\ kJ = 37.8\ kW$$

Table 9. Bio Reactor Energy Balance

Energy Balance		
	IN	**OUT**
Flow Rate (m^3/min)	1135.54	1135.54
Pump Duty	98.3600	0.027
Heater Energy Requirement		
Heater Exchanger Duty	3132479 kJ	870 kW

3.5 RO Membrane

3.5.1 Material Balance

Recovery = 80 %

Table 10. RO Membrane Material Balance

Parameters	In	Permeate	Retentate
Flow Rate (L/hr)	68137	54373	13762.565
TDS (kg)	238	54.3	183.7
H_2O (L or kg)	67898.91	54319.14	13578

3.5.2 Energy Balance

The main energy required in reverse osmosis will be supplied by membrane pump. Therefore, formula we will be using is as follows:

$$Pump\ Duty\ = \frac{\Delta P.V.}{density\ x\ Efficiency}$$

$$Pump\ Duty\ = \frac{8.6\ x\ 68.14\ x\ 1000}{0.75}$$

$$= 136{,}340\ kJ = 37.8\ kW$$

3.6 Overall Balance

3.6.2 Material Balance

Table 11. Overall Material Balance of Process

Equipment	In	Out
Sand Filter (ppm)	30 - 145	0
pH Tank	6 - 8.5	7
Bio Reactor (ppm)	100	60
Membrane (ppm)	2500	600

3.6.3 Energy Balance

Table 12. Overall Energy Balance of Process

Equipment	Energy Requirement
Heat Exchanger (kW)	800
Pump (kW)	2.381
Membrane Pump (kW)	20.2
Total Energy Required (kW)	822

CHAPTER 4

EQUIPMENT DESIGN

4.1 pH Controller and Storage Tanks

4.1.1 Volume Calculations

The purpose of a pH controller is the neutralization of water by adding sodium hydroxide and sulphuric acid.

It is an agitated tank that will use a sensor to evaluate pH in steady or dynamic stages. The calculations regarding design are as follows:

The volume of a cylindrical vessel is given by the formula:

$$V = \pi r^2 h$$

The volume used in the volume with a one-fourth extra hold-up.

Which implies

$$\text{Volumetric flow rate} = 68.17\ m^3/h$$

$$\text{Extra Hold up} = 68.17 + (68.17 \times \tfrac{1}{4})$$

$$\text{Extra Hold up} = 68.17 + 17.0425 = 85.212\ m^3/h$$

Assumption:

$$h = 1.5\ d$$

$$85.2 = \pi \frac{d^2}{4}\ 1.5d$$

$$d^3 = \frac{85.2 \times 4}{3.14 \times 1.5} = \frac{340.8}{4.71} = 72.3$$

Taking cube root on both sides:

$$d = \sqrt[3]{72.3} = 4.16\ m$$

And for height

$$h = 1.5(4.16) = 6.24\ m$$

This height and diameter are held for all storage tanks and pH tanks.

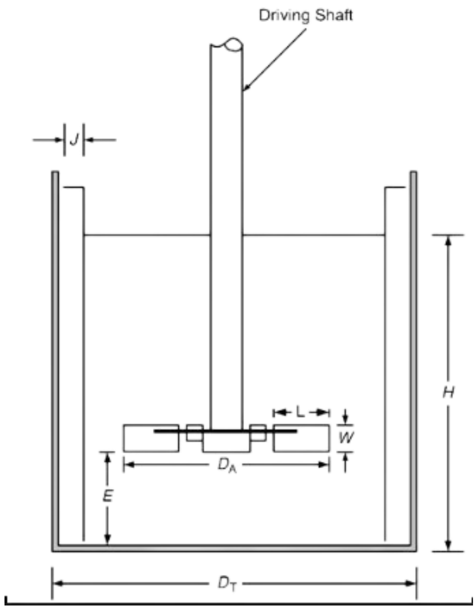


Figure 7. Tank Volume Specifications

4.2 Bio Reactor

The bioreactor is a continuously stirred tank reactor. Which uses the following design equations of CSTR.

$$Volume = Volumetric\ flow\ rate \times Residence\ time$$

$$Volume = 1.135 \times 60\ m^3/min \times 9\ hr$$

$$Volume = 10.21\ m^3$$

4.2.1 Calculation of Diameter and Height

The volume of a cylindrical vessel is given by the formula:

$$V = \pi r^2 h$$

Assumption:

$$h = 1.5\ d$$

$$10.1 = \pi \frac{d^2}{4}\ 1.5d$$

$$d^3 = \frac{10.1 \times 4}{3.14 \times 1.5} = 8.49$$

Taking cube root on both sides:

$$d = \sqrt[3]{8.49} = 2\ m$$

And for height

$$h = 1.5(2) = 3\ m$$

4.2.2 Agitator Design

Impeller Diameter = D_a *= 0.4 x Tank Diameter (general assumption from "Unit Operation by Smith")*

$$D_a = 0.4 \times 2 = 0.8$$

Number of impellers = 2

Number of impeller blades = 4

Tip Velocity = 3 to 6 m/sec.

Tip Velocity = 4 m/s

$$Tip\ velocity = \pi \times D \times N$$

$$4 = 3.142 \times N \times 0.8 \times (1/60)$$

$$N = 4/\ (\pi \times 0.8 \times 0.017)$$

$$N = 94\ RPM$$

4.2.3 Power Requirement

$$Power = Power\ Number \times density \times N^3 \times D^5$$

For radial impellers:

Power Number = 5

$$Power = 5 \times 1000 \times (94/60)^3 \times 0.32 = 6222.2\ W = 6.2\ kW$$

4.3 RO Membrane

4.3.1 Feed and Permeate Specifications

Feed Source = Wastewater Effluent

Feed flowrate = 68.14 m^3/h

Feed TDS concentration = 2500 ppm

Permeate flowrate = 154 m^3/h

Permeate TDS concentration = 37.5 ppm

$$Recovery = (Permeate\ Flow)/(Feed\ Flow) \times 100$$

$$Recovery = 47.6/68.14\ \times 100 = 68\ \%$$

4.3.2 Flow Configuration and Number of Passes

Plug flow in spiral wound configuration.

Number of passes = 1

4.3.3 Membrane Module and Type

The table below shows the typical specifications of different membrane elements.

Membrane Type	Feed TDS (ppm)	Permeate Quality (ppm)
TW	<5000	<50
XLE, LE	<1000	<50
BW, FR	<5000	<50
SW	3000 - 15000	<150
SWHR, SWHR LE	10000 - 50000	Varies (<500)
NF	<1000	<150

Figure 8. System recoveries w.r.t number of stages

Membrane element BW30-400/34i is selected given the brackish feed water and large-scale application. The active area of this element is 40.8 m^2.

4.3.4 Average Membrane Flux

Flux = 23.8 LMH (based on the effluent feed to the RO unit passing through conventional pre-treatment)

4.3.5 Number of Elements

$$N_e = Q_P/(F \times A)$$

where Ne is the number of elements

Qp is the permeate flow rate.

F is the average membrane flux

A is the active element area.

$$N_e = (47.6\ m^3/h \times 1000\ L/m^3)/(23.8\ L/(m^2\ h) \times 40.81 m^2)$$

$$N_e = 49$$

4.3.6 Number of Stages

System Recovery (%)	Number of Serial Element Positions	Number of Stages (6-elements vessels)
40 – 60	6	1
70 – 80	12	2
85 – 90	18	3

Figure 9. System recoveries w.r.t number of stages

Given that our system has a recovery of 68 % with 7 elements in a single pressure vessel, we can reasonably assume that we would require a 1-stage RO system.

4.3.7 Pressure Vessels

No of Pressure Vessels = 6

Capacity of each vessel = 68/6 = 11.36 m^3

4.4 Heat Exchanger

Design Considerations

1. Tube Layout and Size:

To meet the appropriate fluid flow rates and to offer adequate heat transfer area, the tube layout and size must be carefully determined. Pressure reduction and the efficiency of heat transmission are influenced by tube diameter, length, and pitch.

2. Baffles and passes:

By controlling fluid flow and creating turbulence, baffles are used to enhance heat transmission. The quantity and kind of baffles, as well as the arrangement of several tube passes, all have an impact on the overall heat transfer coefficient and pressure drop.

3. Shell Side:

The fluid characteristics, flow rates, and pressure drop on the shell side should be considered in the design. The choice of shell-side baffles, inlet and outlet arrangements, and flow topologies (such as parallel or counter-flow) all have an impact on the efficiency of heat transmission.

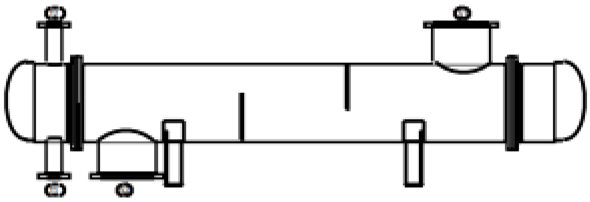


Figure 10. Shell and Tube Heat Exchanger Schematic

4.4.1 Kern’s Method

A popular method for the thermal design of shell and tube heat exchangers is Kern’s method, often known as Kern's method of heat exchanger design. It was created by renowned engineer Donald Q. Kern, who also wrote the book "Process Heat Transfer."

Kern's approach offers a methodical process for calculating the pressure drop, heat transfer area, and total heat transfer coefficient in a shell and tube heat exchanger. In order to create a design that is both effective and efficient, it takes into account a number of variables, including fluid characteristics, flow configuration, and heat transfer correlations.

Kern's method follows the following steps:

1. Determine the heat duty: Calculate the amount of heat that needs to be transferred between the hot and cold fluids. This is usually specified by the process requirements or can be calculated based on the temperature difference and flow rates of the fluids.
2. Select the fluids and determine their properties: Identify the properties of the hot and cold fluids involved in the heat transfer process, such as specific heat capacity, density, viscosity, and thermal conductivity. These properties are essential for calculating the heat transfer coefficients.
3. Determine the temperature difference: Calculate the logarithmic mean temperature difference (LMTD) based on the temperature profiles of the hot and cold fluids. The LMTD is a driving force for heat transfer and is used in subsequent calculations.

4. Choose the flow arrangement: Select the appropriate flow arrangement for the hot and cold fluids in the heat exchanger. Options include parallel flow, counterflow, and crossflow configurations. The choice depends on factors such as temperature difference, pressure drop constraints, and thermal performance requirements.
5. Calculate correction factors: Determine the correction factors based on the flow arrangement, fluid properties, and heat transfer correlations. These factors account for non-uniform fluid flow, temperature cross conditions, and other effects that deviate from ideal conditions.
6. Calculate the overall heat transfer coefficient: Use the correction factors and appropriate heat transfer correlations to calculate the overall heat transfer coefficient. The overall heat transfer coefficient represents the combined thermal resistance of the fluid films and the tube material.
7. Calculate the required heat transfer area: Use the calculated overall heat transfer coefficient and the heat duty to determine the required heat transfer area. The heat transfer area represents the surface area available for heat transfer between the hot and cold fluids.
8. Determine the pressure drop: Calculate the pressure drop on both the hot and cold fluid sides of the heat exchanger using appropriate pressure drop correlations. This information is essential for ensuring proper fluid flow and sizing of pumps or fans.

After performing the above-mentioned steps following data was obtained:

Table 13. Shell and Tube Heat Exchanger Process Parameters

Cold Fluid - Tube Side		**Hot Fluid - Shell Side**	
Parameters	**Value**	**Parameters**	**Value**
Inlet Temperature (°C)	25	Inlet Temperature (°C)	180
Outlet Temperature (°C)	35	Outlet Temperature (°C)	133
Mass flowrate (kg/hr)	68137	Mass Flowrate (kg/hr)	485

Avg. C_p (kJ/kg K)	4.5	C_p (kJ/kg K) vapor	4.7
Avg. density (kg/m^3)	994	Density (kg/m^3) vapor	881.77
Avg. viscosity (C_p)	0.9122	Viscosity (C_p) vapor	0.2016
Thermal conductivity (W/mK)	0.6044	Thermal Conductivity (W/mK)	0.6866

Calculated Parameters:

Table 14. Shell and Tube Heat Exchanger Parameters Value

Parameters	**Tube Side**	**Shell Side**
Duty (kW)	802.46	
LMTD (°C)	123.09	
Reynold number	9373.78	9682
Prandtl number	6.83	1.38
h (film coefficient)	797	14577
U_c (W/m^{2}K)	5363.5	
U_d (W/m^{2}K)	5363.5	
R_d (m^{2}K/W)	0.0002	
Area (m^2)	49.8	
Pressure Drop (kPa)	0.21569	0.20684

The exchanger geometry was chosen based on Aspen Exchanger Design and Rating (EDR) recommendation. The design was modified considering operation warnings provided by EDR.

Table 15. Exchanger, Design and Rating (EDR) Data

Tube Side	
Number	176
Length (m)	2.438
OD (m)	0.01905
ID (m)	0.015
Pitch	0.02381
Passes	2
Material	Stainless Steel

Shell Side	
OD (m)	0.4572
ID (m)	0.438
Baffle spacing (m)	0.25
Passes	1
Material	Stainless Steel

CHAPTER 5

PROCESS MODELLING AND SIMULATION

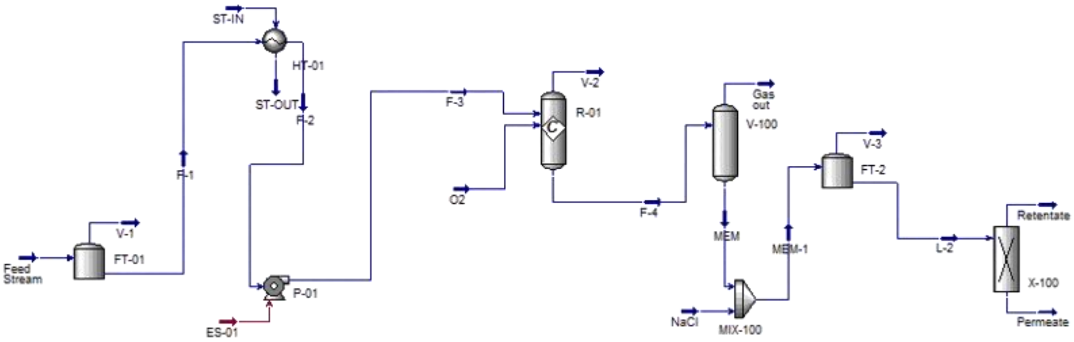


Figure 11. Process Simulation

5.1 Composition List

In selecting the components for the simulation, compounds such as $C_{24}H_{48}O_{24}$ and $C_5H_7NO_2$ (bacterial cells) were replaced by glucose to replicate bacterial activity. The assumption is taken from the wastewater engineering book from Eddy.

Source Databank: HYSYS

Component	Type	Group
H2O	Pure Component	
Inositol	Pure Component	
Oxygen	Pure Component	
NACL	Pure Component	
CO2	Pure Component	

Figure 12. Component Lists

5.2 Fluid Package

A fluid package in Aspen is a collection of mathematical models and parameters used to simulate the behavior of various fluid types within the Aspen software package. Aspen is an extensive collection of process modeling software that is frequently used in domains like chemical engineering, petroleum refinery, and other related ones.

The information and computations required to simulate the behavior of fluids in various process units, including distillation columns, heat exchangers, reactors, and separators, are provided by Aspen's fluid packages. These software programs provide equations and techniques for computing many characteristics, including density, viscosity, phase equilibria, enthalpy, and entropy.

Aspen offers a number of fluid packages, each of which is intended to represent a particular class of fluid and its unique thermodynamic properties.

The package we have used is NRTL. Aspen HYSYS, a program used to simulate processes, has a fluid package called NRTL (Non-Random Two-Liquid) that is used in fields like chemical engineering, oil & gas, and refining. The NRTL fluid program was created primarily to model and simulate non-ideal behavior in complicated chemical systems as well as liquid-liquid phase equilibria.

Activity coefficients are used in NRTL to explain the non-ideality of liquid mixtures and are based on the principle of the non-randomness of molecular interactions. Systems having azeotropes or substantially non-ideal liquid behavior are particularly suited to it. The package employs programmable binary interaction parameters to increase prediction accuracy while accounting for component-to-component interactions.

Engineers and scientists may correctly simulate and analyze liquid-liquid phase equilibria using the NRTL fluid package in Aspen HYSYS, enabling them to design and optimize chemical processes involving complicated mixtures.

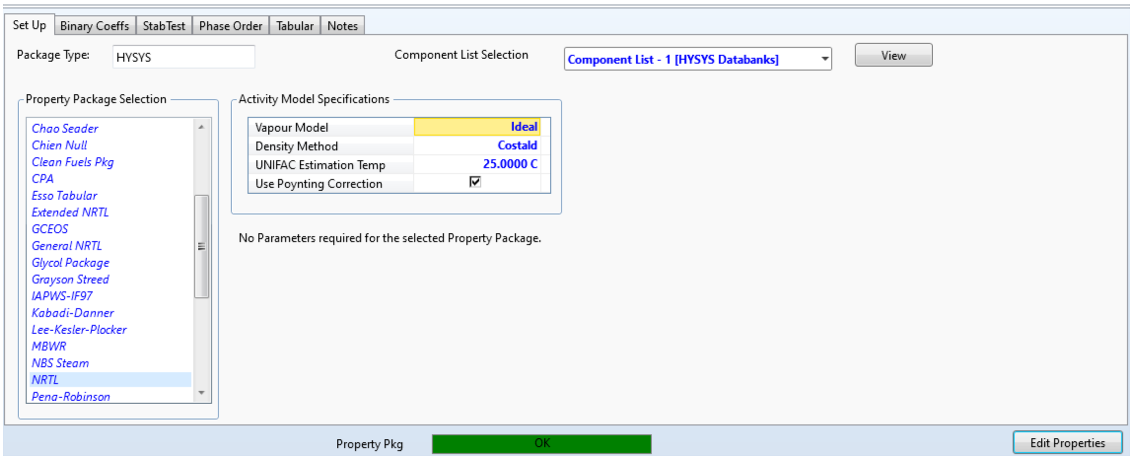


Figure 13. Fluid Package

5.3 Reaction Set

A reaction set in Aspen HYSYS is a group of specified and simulated reactions that are used to depict the chemical changes taking place throughout a process. Aspen HYSYS is a popular process simulation tool used to study and optimize diverse chemical processes in sectors including chemical engineering, oil & gas, and refining.

A reaction set in Aspen HYSYS allows you to define the chemical reactions taking place in your system, specify reaction stoichiometry, reaction kinetics, and other relevant parameters. By incorporating reaction sets into your simulation, you can accurately model the conversion of reactants into products, track the progress of reactions, and analyze the behavior of the overall process.

Elementary reactions, complicated reactions, reversible reactions, irreversible reactions, and user-defined reactions are just a few of the reaction types that Aspen HYSYS offers. The type of chemical changes taking place in your process will determine the best reaction type to use.

Engineers and researchers may model, analyze, and optimize chemical reactions inside a process by using reaction sets in Aspen HYSYS. This helps with process design, troubleshooting, and decision-making. A holistic perspective of the complete system is provided by this rich feature set, which enables the modelling of a variety of industrial processes, including chemical reactions, separation devices, heat exchangers, and more.

A form of chemical reaction where reactants are converted into products with a specific degree of conversion is represented by the conversion reaction type in Aspen HYSYS. This sort of reaction is frequently used to represent reactions in which the reactants only partially transform into the products. Since our reaction just needs simple conversion of glucose into carbon dioxide and water, we have used conversion reaction type.

When defining a conversion reaction in Aspen HYSYS, you specify the reactants, products, and the stoichiometric coefficients involved in the reaction. Additionally, you set the conversion factor, which represents the extent to which the reactants are converted into products.

The conversion factor in Aspen HYSYS is a dimensionless value ranging from 0 to 1, where 0 represents no conversion (all reactants remain unchanged), and 1 represents complete conversion (all reactants are converted to products). The conversion factor can also be set to values between 0 and 1 to represent partial conversion.

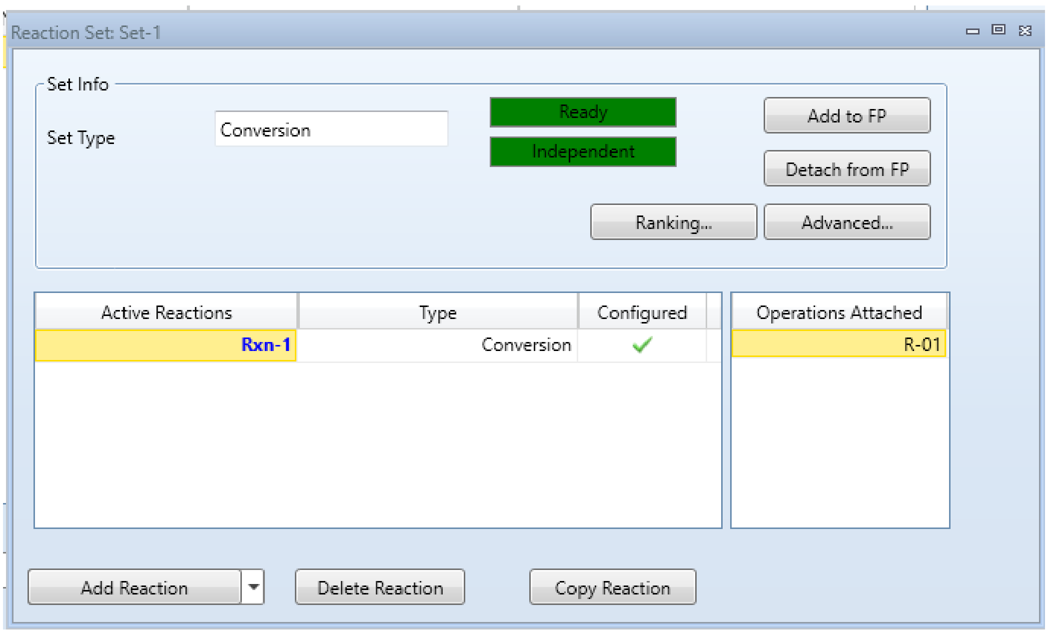


Figure 14. Reaction Set

The reaction equation is as follows:

$$C_6H_{12}O_6 + 6O_2 \xrightarrow{\text{Bacterial activity}} 6CO_2 + 6H_2O$$

The reaction equation just as imitation of bacterial activity since the compound such as C24H48O24 and C5H7NO2 (bacterial cells) cannot be added in HYSYS by using hypothetical compounds.

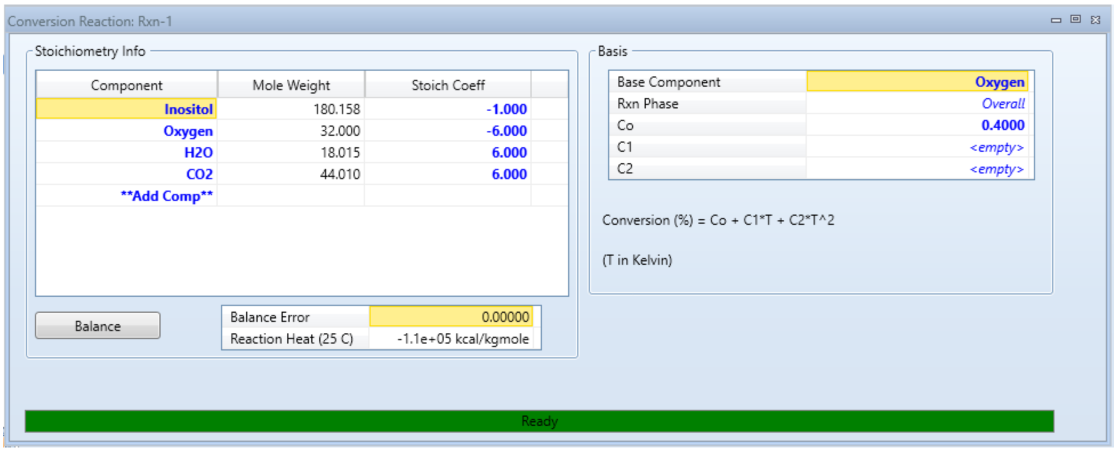


Figure 15. Conversion Reaction

5.4 Storage Tanks

The Storage tank purpose is just to hold the water or the effluent stream if there is any trouble shooting in the proceeding processes. The vessel model is used and given the feed stream with the desired designed dimensions and the tanks are simulated.

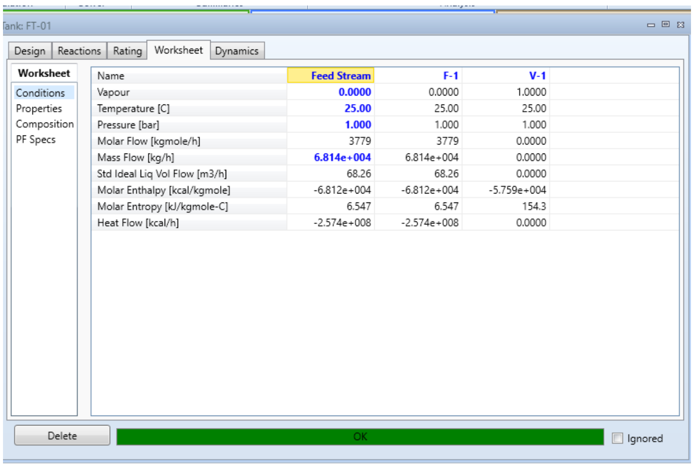


Figure 16. Storage Tank Worksheet

The dimensions of the tanks are obtained by adding the designed volume of 85 m^3.

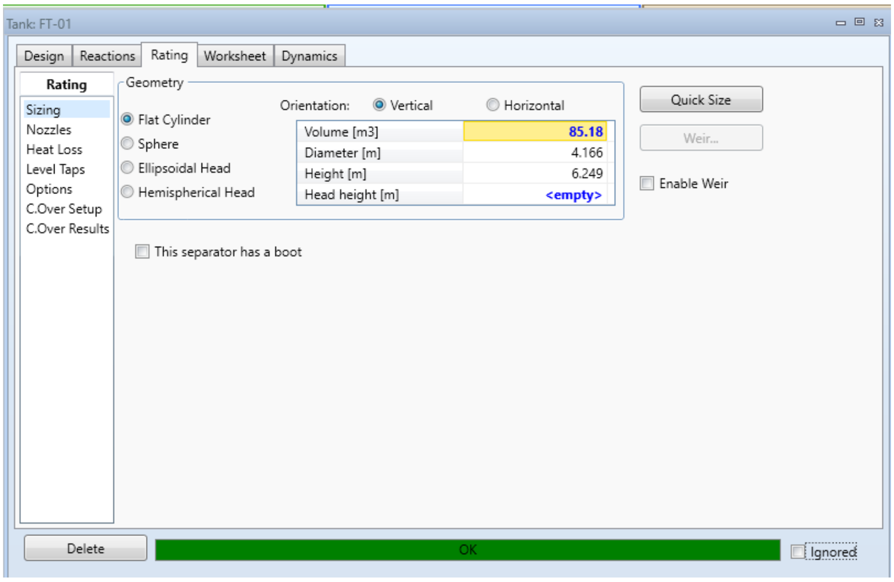


Figure 17. Storage Tank Specifications

5.5 Bio Reactor

In the Bio reactor conversion reactor is used for the since the type of reaction used is conversion type. After connecting the feed stream and adding the reaction set the reactor converges and by giving the designed volume of 10.1 m^3 reactor was simulated.

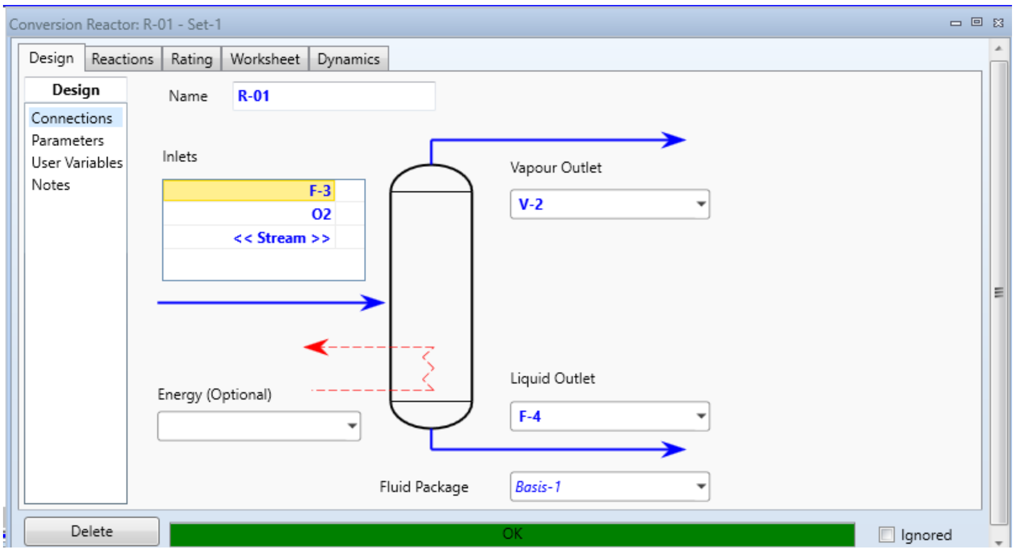
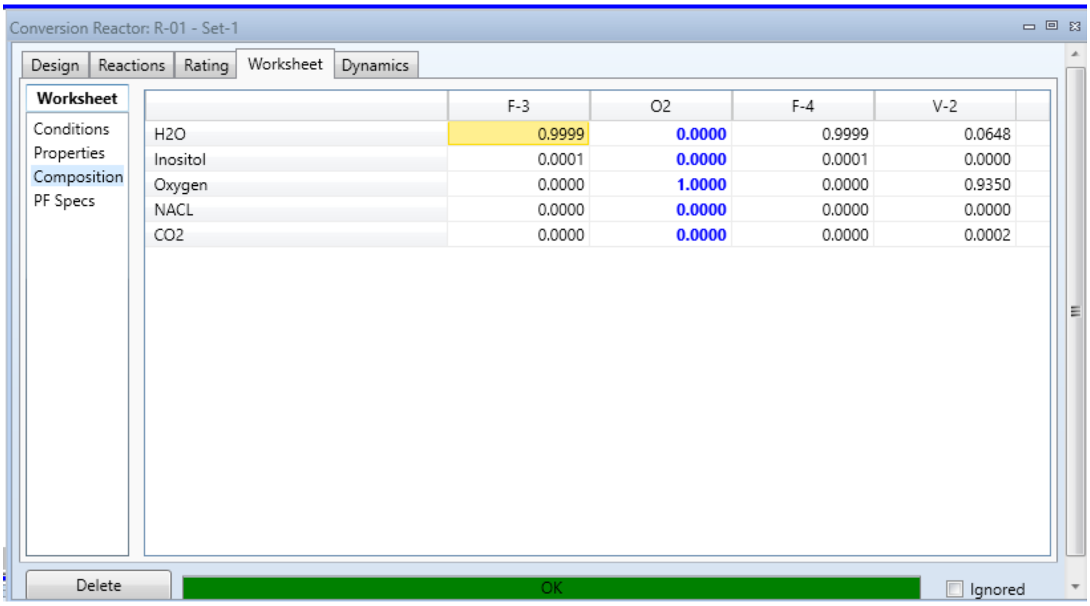


Figure 18. Design Specifications of Bio Reactor

The worksheet tab shows that the formation of water and carbon dioxide in the product stream implementing the reaction is completed.



Conversion Reactor: R-01 - Set-1

Design | Reactions | Rating | Worksheet | Dynamics

Worksheet: Conditions, Properties, Composition, PF Specs

	F-3	O2	F-4	V-2
H2O	0.9999	0.0000	0.9999	0.0648
Inositol	0.0001	0.0000	0.0001	0.0000
Oxygen	0.0000	1.0000	0.0000	0.9350
NACL	0.0000	0.0000	0.0000	0.0000
CO2	0.0000	0.0000	0.0000	0.0002

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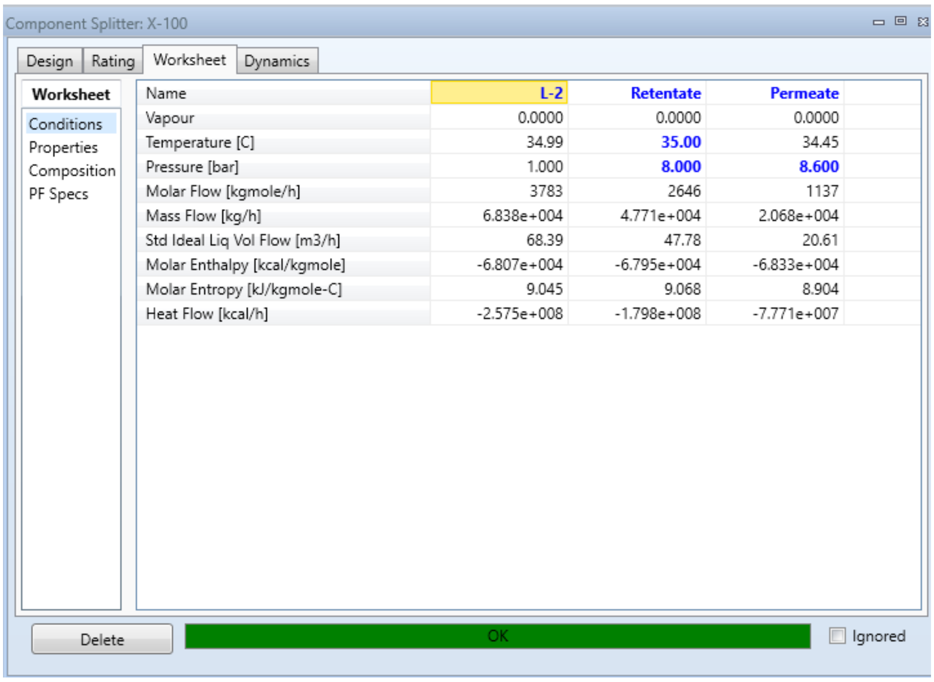
Figure 19. Bio Reactor Worksheet

5.6 Component Splitter

The component splitter is just to show the behavior of membrane. After adding a designed split and pressure it is converged with the following results.



Component Splitter: X-100

Design | Rating | Worksheet | Dynamics

Worksheet: Conditions, Properties, Composition, PF Specs

Name	L-2	Retentate	Permeate
Vapour	0.0000	0.0000	0.0000
Temperature [C]	34.99	35.00	34.45
Pressure [bar]	1.000	8.000	8.600
Molar Flow [kgmole/h]	3783	2646	1137
Mass Flow [kg/h]	6.838e+004	4.771e+004	2.068e+004
Std Ideal Liq Vol Flow [m3/h]	68.39	47.78	20.61
Molar Enthalpy [kcal/kgmole]	-6.807e+004	-6.795e+004	-6.833e+004
Molar Entropy [kJ/kgmole-C]	9.045	9.068	8.904
Heat Flow [kcal/h]	-2.575e+008	-1.798e+008	-7.771e+007

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Figure 20. Component Splitter Worksheet

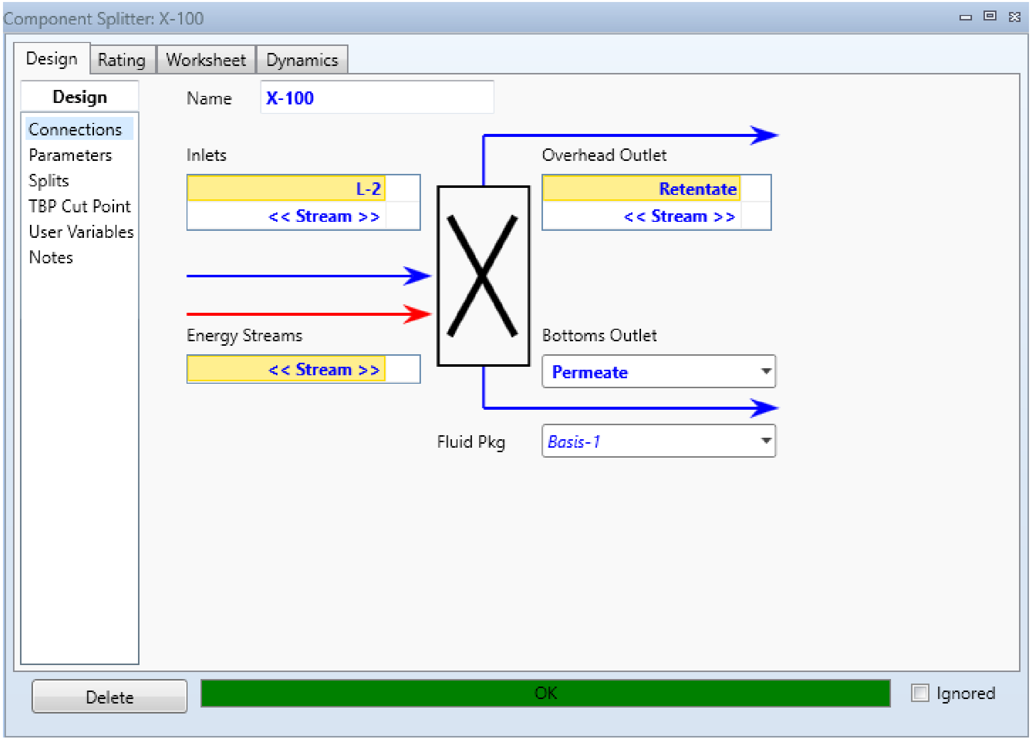


Figure 21. Design Specifications of Component Splitter

5.7 Heat Exchanger

The heat exchanger used is shell and tube type in which the steam with an inlet temperature of 180^{0}C and pressure of 3 bar is placed on the shell side and effluent stream on the tube side of the exchanger got converged.

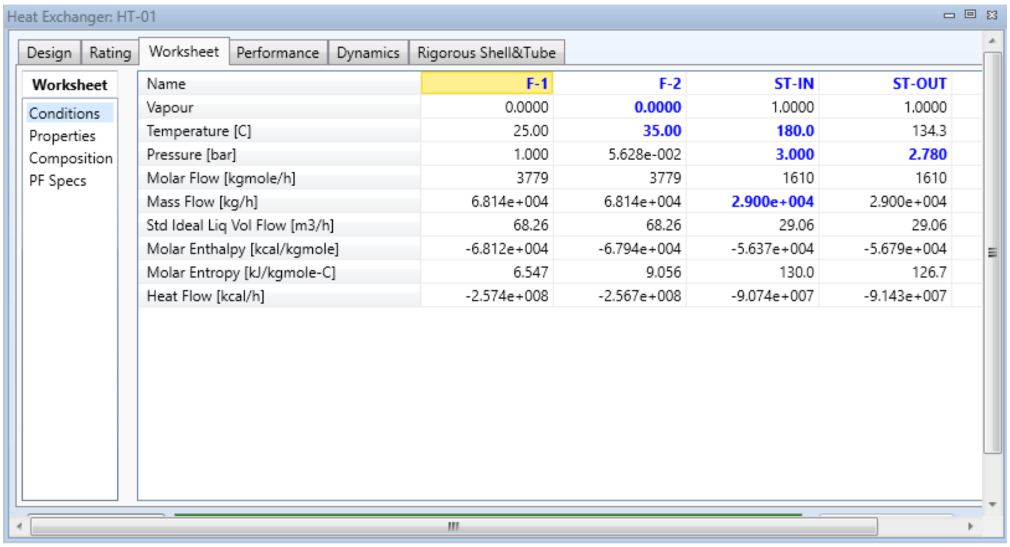


Figure 22. Heat Exchanger Worksheet

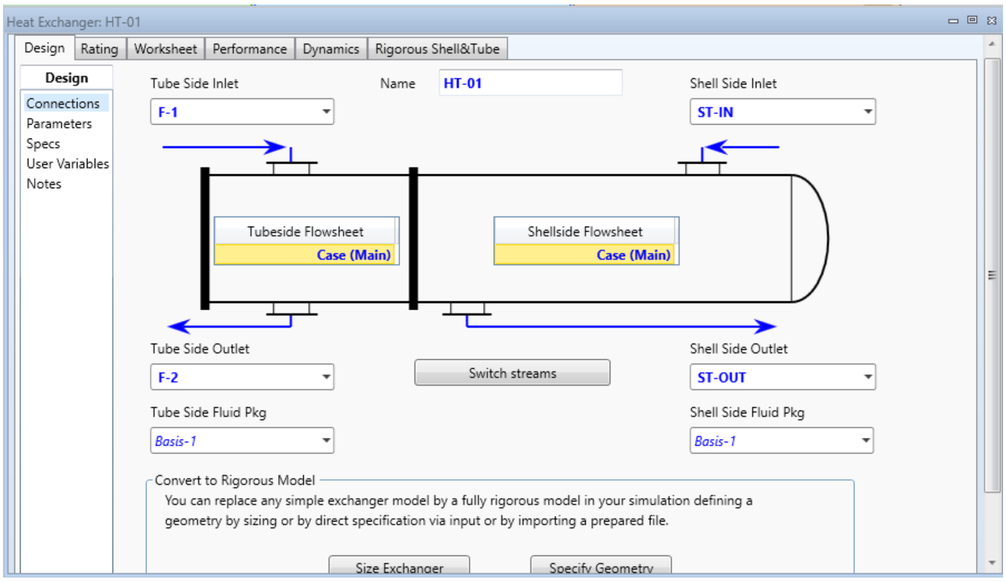


Figure 23. Design Specifications of Heat Exchanger

5.8 RO Membrane

The best behavioral study of the membrane is possible by using specific software of the membrane such as IMS design.

Integrated Membrane Solution (IMS) design software is a specialized software tool used for designing and optimizing membrane-based separation processes. IMS design software assists engineers and researchers in developing efficient and cost-effective separation systems that utilize various types of membranes, such as reverse osmosis (RO), nanofiltration (NF), ultrafiltration (UF), and microfiltration (MF).

The primary objective of IMS design software is to aid in the design and analysis of membrane processes, allowing users to simulate, optimize, and evaluate different system configurations, operating conditions, and membrane properties. By utilizing IMS design software, engineers can streamline the design process, reduce experimental trial and error, and achieve optimal performance for their membrane-based separation applications.

Key features and functionalities of IMS design software may include:

1. Membrane Selection and Property Input
2. Process Modeling and Simulation
3. Fouling and Cleaning Analysis
4. Visualization and Reporting

By leveraging IMS design software, engineers and researchers can expedite the development and optimization of membrane-based separation processes. This leads to improved efficiency, reduced costs, and an enhanced understanding of membrane system behavior, enabling the implementation of membrane technology in diverse applications such as water treatment, pharmaceutical manufacturing, food and beverage processing, and more.

The following specification is added:

1. Water Type: Brackish water
2. TDS: 2500 ppm
3. Recovery: 70%
4. Permeate Flow Rate: 46.7 m^3/h

After this, the software selected the most suitable membrane module was selected, and the system converged.

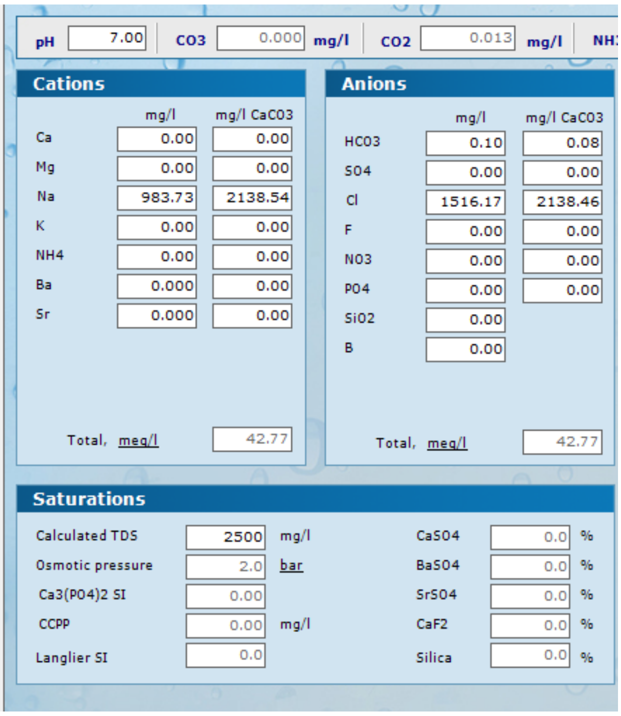


Figure 24 Specifications for RO Membrane

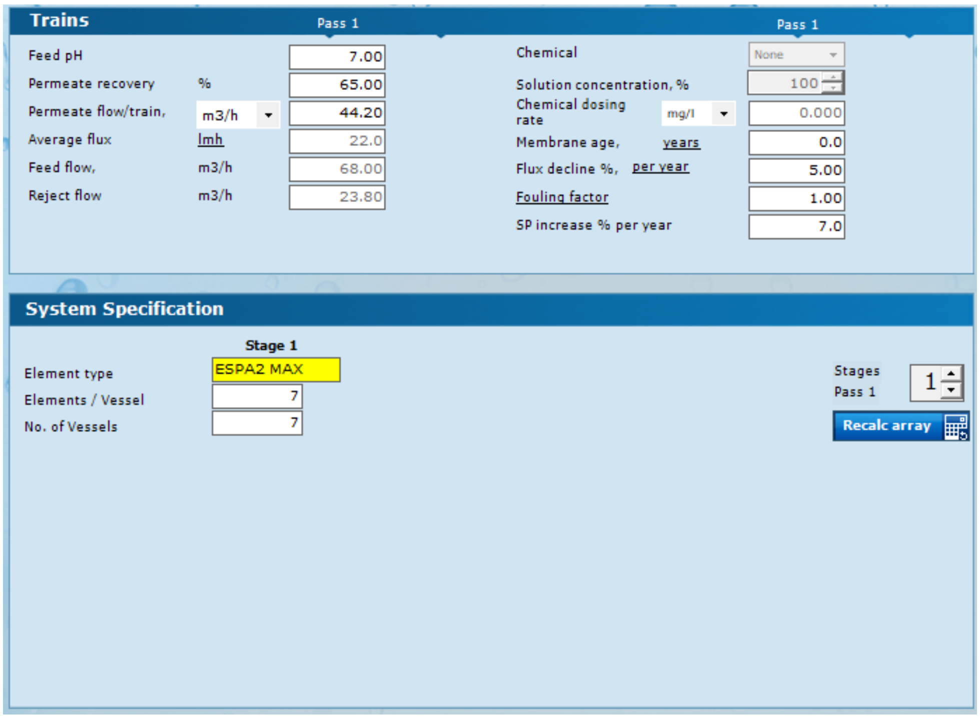


Figure 25. System Specifications for RO Membrane

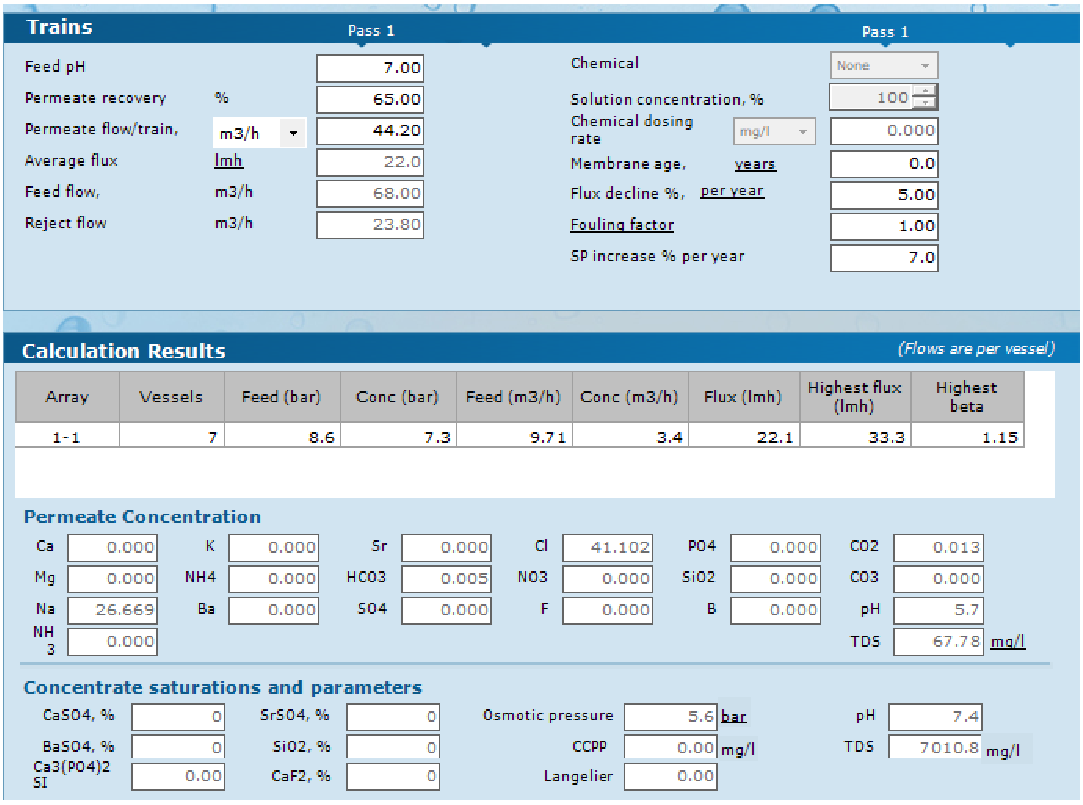


Figure 26. Calculation Results for RO Membrane

CHAPTER 6

ECONOMIC ANALYSIS

6.1 Purchase Cost of Equipment (PCE)

The purchase of equipment in the year 2004 was calculated using graphs given and relevant tables from Richardson and Coulson Vol 6. The values obtained were inflation-adjusted using the following formula:

$$Cost\ in\ year\ 2023 = Cost\ in\ year\ 2004 \times \frac{Cost\ in\ year\ 2023}{Cost\ in\ year\ 2004}$$

6.1.1 Storage Tank

The cost of the storage tank was calculated using the following formula, which depends on the design parameter raised to the respective index value obtained from the table.

$$C_e = CS^n$$

where,

C_e = Purchased Equipment Cost

S = Characteristic Size Parameter

C = Cost Constant

n = Index for that type of Equipment

Table 6.2. Purchase cost of miscellaneous equipment, cost factors for use in equation 6.7. Cost basis mid 2004

Equipment	Size unit, S	Size range	Constant C,£	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

Figure 27. Purchase Cost of Miscellaneous Equipment

Index used

$$Marshall\ and\ Swift\ Index = \frac{1754}{1282} = 1.36$$

$$C = \$\ 4350,\ n = 0.55,\ S = 85.17$$

$$C_e = CS^n$$

$$C_e = (4350)(85.17)^{0.55}$$

$$C_e = \$\ 68{,}593$$

Similarly, for the feed tank same calculation was carried out.

$$C = \$\ 4350,\ n = 0.55,\ S = 85.17$$

$$C_e = CS^n$$

$$C_e = (4350)\ (85.17)^{0.55}$$

$$C_e = \$\ 68{,}593$$

Therefore, the total Purchase Cost of Equipment was found to be $ 137,188.

6.1.2 pH Tank

Index used

$$\textit{Marshall and Swift Index} = \frac{1754}{1282} = 1.36$$

$$C = \$\ 4350,\ n = 0.55,\ S = 85.17$$

$$C_e = CS^n$$

$$C_e = (4350)(85.17)^{0.55}$$

$$C_e = \$\ 68{,}593$$

6.1.3 Bio Reactor

Index used:

$$\textit{Marshall and Swift Index} = \frac{1754}{1282} = 1.36$$

$$C = \$\ 31{,}000,\ n = 0.4,\ S = 10.1$$

$$C_e = CS^n$$

$$C_e = (31000)(10.1)^{0.4}$$

$$C_e = \$\ 106{,}324$$

6.1.4 RO Membrane

Index used:

$$\textit{Marshall and Swift Index} = \frac{1754}{1282} = 1.36$$

$$C = \$\ 2900,\ n = 0.6,\ S = 9.71$$

$$C_e = CS^n$$

No. of Pressure Vessels = 7

Capacity of a single Pressure Vessel (S) = $\frac{68}{7}$ = 9.71 m^3

$$C_e = (2900)\ (9.71)^{0.6}$$

$$C_e = \$\ 11{,}343 \text{ per vessel}$$

$$\text{Total Cost of Pressure Vessel} = 11343 \times 7 \times 1.36 = \$\ 107{,}985$$

No. of elements needed = 49

Cost of elements = 49 × 800 = $ 39,200

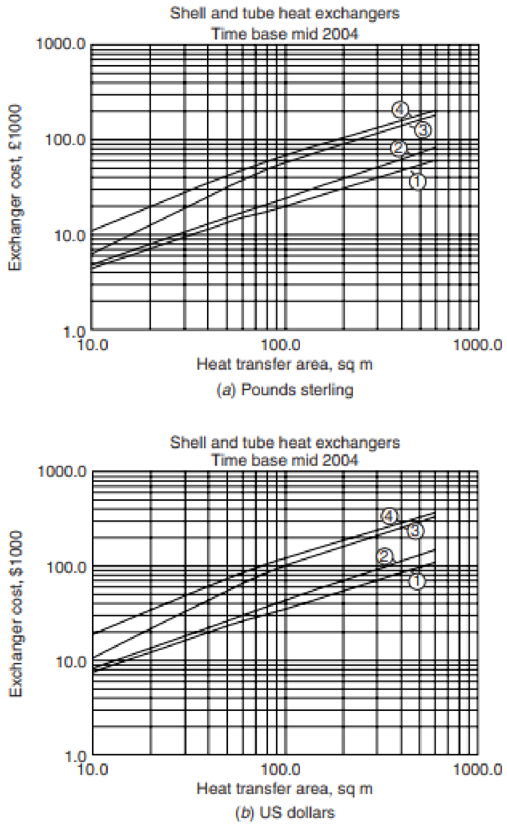
Total Calculated Cost of RO Membrane = $ 107,985 + $ 39,200 = $ 147,185

6.1.5 Heat Exchanger

Pressure Factor = 1

Type Factor = 0.85

Heat Transfer Area = 49.8 m^2



Materials		Pressure factors		Type factors	
Shell	Tubes				
1 Carbon steel	Carbon steel	1–10 bar	× 1.0	Floating head	× 1.0
2 C.S.	Brass	10–20	× 1.1	Fixed tube sheet	× 0.8
3 C.S.	Stainless steel	20–30	× 1.25	U tube	× 0.85
4 S.S.	S.S.	30–50	× 1.3	Kettle	× 1.3
		50–70	× 1.5		

Figure 28. Cost of Shell and Tube Heat Exchangers

From above graph

Cost in 2004 = 48000 × 1 × 0.85 = £ 40.800

Converting to a dollar exchange rate

£ 1 = $ 1.83

$$\text{Cost in 2023} = 40800 \times 1.83 \times 1.36 = \$101{,}543$$

6.1.6 Pumps

The total cost of the pump was found with the help of Aspen HYSYS.

Total No. of Units = 2

Total Cost = $ 60,240

6.1.7 Total Purchase Cost of Equipment (PCE)

$$PCE = 137188 + 68593 + 106324 + 147185 + 101543 + 60240$$

$$PCE = \$\ 621{,}073$$

6.2 Physical Plant Cost (PPC)

Table 6.1. Typical factors for estimation of project 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

*Omitted for minor extensions or additions to existing sites.

Figure 29. Typical Factors for Physical Plant Cost

Typical factors for the estimation of project fixed capital cost are given in the above table.

$$\text{Total Physical Plant Cost (PPC)} = PCE\ (1 + f_1 + f_2 + \ldots + f_9)$$

$$PPC = PCE\ (1 + 0.4 + 0.7 + 0.2 + 0.1 + 0.5)$$

$$PPC = \$\ 1{,}801{,}112$$

6.3 Fixed Capital Cost

Fixed Capital Cost is calculated as follows.

$$\text{Fixed Capital (FC)} = \text{PPC}\ (1 + f_{10} + f_{11} + f_{12})$$

$$\text{FC} = \text{PPC}\ (1 + 0.3 + 0.05 + 0.1)$$

$$\text{FC} = \$\ 1{,}981{,}224$$

6.4 Working Capital Cost

Working Capital Cost is calculated as follows.

$$\text{Working Capital (WC)} = 15\ \%\ \text{of FC} = \$\ 297{,}183$$

6.5 Total Investment

Total Investment is calculated as follows.

$$\text{Total Investment Required} = \text{FC} + \text{WC}$$

$$\text{Total Investment Required} = \$\ 2{,}278{,}407$$

CHAPTER 7

HAZOP ANALYSIS

Process safety is of paramount importance in all chemical plants. One mistake or oversight can lead to a disaster. Hence, it's essential to carry out risk assessments to avoid loss of personnel or equipment. Hazard and Operability study is a systematic risk assessment to review, identify and evaluate problems in the process design, facilities, equipment, and operation that may qualify as a risk or hazard to personnel or equipment. Problems are assumed to occur when the process deviates from set operational parameters.

In order to carry out this study, the complex process is broken down into smaller processes called "nodes," which are then individually evaluated. It is carried out by experienced professionals who are expected to use good intuition and judgment to come up with all possible hazards, emergencies, and risks at each individual node. Guide-word prompts are used to mark each node. The following table explains the guide words.

Table 16. Guide words for HAZOP

Guide Word	Meaning
NO OR NOT	Complete negation of the design intent
MORE	Quantitative increase
LESS	Quantitative decrease
AS WELL AS	Qualitative modification/increase
PART OF	Qualitative modification/decrease
REVERSE	Logical opposite of the design intent

OTHER THAN / INSTEAD	Complete substitution
EARLY	Relative to the clock time
LATE	Relative to the clock time
BEFORE	Relating to order or sequence
AFTER	Relating to order or sequence

The deviation from design intent is identified for each node, along with its consequences and troubleshooting mechanism. It is further decided whether an additional safeguard measure needs to be installed or not. Before moving on to the next node, the team will suggest measures to minimize the chances of deviation from the design intent.

Once a detailed study of HAZOP is performed, and a worksheet result containing lists of identified deviations, recommendations, and suggestions is created, a safety analysis is done. Guidewords such as NO, LESS, HIGH, LOW, AS WELL AS, OTHER THAN, INCREASED, and DECREASED are mostly used on a number of operational parameters such as flow, pressure, and temperature. Unfortunately, unexpected events are not included in the detailed HAZOP. In this hazard and operability analysis study, we will cover the important process vessels by taking one process line to find all possible deviations and their potential consequences. We will be proposing a solution regarding how to mitigate that specific deviation.

Apart from guide-word prompts mentioned above, guide words can also be used for process parameters.

Paramete r / Guide Word	More	Less	None	More	As well as	Part of	Other than
Flow	High flow	Low flow	No flow	High flow	Deviating concentra tion		Deviati ng materi al
Pressure	High pressure	Low pressure	Vacuum	High pressure	Delta P		Explosi on
Temperat ure	High tempera ture	Low temperat ure		High temperatur e			
Level	High level	Low level	No level	High level	Different level		
Time	Too long / Too late	Too short / Too soon	Sequenc e step skipped	Too long / Too late	Missing actions	Extra actio ns	Wrong time
Agitation	Fast mixing	Slow mixing	No mixing	Fast mixing			
Reaction	Fast reaction	Slow reaction	No reaction	Fast reaction/ru naway			Unwan ted reactio n
Start-up / Shutdown	Too fast	Too slow		Too fast	Actions missed		Wrong recipe

Draining / Venting	Too long	Too short	None	Too long	Deviating pressure	Wrong timing	
Inertising	High pressure	Low pressure	None	High pressure			Wrong material
Utility Failure			Failure				
DCS Failure			Failure				
Maintenance			None				
Vibrations	Too low	Too high	None	Too low			Wrong frequency

Table 17. HAZOP Study

We performed HAZOP analysis of the pH Controller, Bio Reactor CSTR, and RO Membrane networks. It has been summarized in the tables below.

7.1 HAZOP Analysis on pH Tank

Table 18. HAZOP Analysis on pH Tank

Process Parameters	**Deviation**	**Possible Causes**	**Possible Consequences**	**Action Required**
pH Level	Low	Low H_2SO_4	Yeast Growth Abnormal Sludge Growth	Install pH meter Sterilization of Reactor Tank
	High	Too much Lime	Bacterial Contamination Low Sludge Growth	Install pH meter Sterilization of Reactor Tank

7.2 HAZOP Analysis on Bio Reactor

Table 19. HAZOP Analysis on Bio Reactor

Process Parameters	Deviation	Causes	Consequences	Recommendations
Water Flow	No	Pump Failure Manual val ve closed Closed blo ck valve	Potential pipe fail ure Potential slip haza rd	Consider Modif- ying the Stand- rd Operating Proce dure Install flow meters
	Low	Line Blockage Failure of a flexible co upling	Prolonged treatment process	Install flow meters Consider relocating tank isolation valves
Temperature	Low	Low Ambient Temperatu re Low water Supply Temperatu re	Reactor Cools Reactant concentration builds up	Install Heat Exchanger

	High	High Ambient Temperature High water Supply Temperature Hot water temperature transmitter fails LOW	Potential overheating of sludge with potential to kill microorganisms Changes the reaction Kinematics Potential decrease in digester efficiency	Injection of cooling water Install Heat Exchanger

7.3 HAZOP Analysis on Membrane

Table 20. HAZOP Analysis on RO Membrane

Process Parameters	Deviation	Causes	Consequences	Recommendations
Pump Maintenance	Pump Maintenance	Pipe is not depressurized	Potential personnel exposure	Consider adding bleeder valves
Water Flux	No	Pump Failure Manual valve closed Closed block valve	Potential pipe failure Potential slip hazard	Consider modifying the Standard Operating Procedure Install flow meters
	Low	Line Blockage Failure of a flexible coupling	Prolonged treatment process	Install flow meters Consider relocating tank isolation valves

CONCLUSION

Groundwater recharge is an effective and sustainable solution to address water challenges faced by refineries. This project focuses on developing a practical groundwater recharge facility for Attock Oil Refinery, incorporating appropriate water treatment methods to meet the Punjab Environmental Quality Standards (PEQS) for organic content, dissolved solids, and suspended solids. The chosen approach utilizes Bio Reactor and RO Membrane technologies, which are not only practical but also economically viable for this specific project. By implementing this facility, a significant portion of the refinery's effluent stream can be recovered and reused. This recovery plays a crucial role in resolving issues like the high steam demand during summer days by supplying the reclaimed water to the boilers. However, it is important to monitor the concentration of dissolved solids to ensure they remain within acceptable limits. Moreover, the reclaimed water can be utilized in various applications such as gardening and washing. To fully leverage the benefits of this reclaimed water, it is advisable to implement Zero Liquid Discharge (ZLD), which involves making slight modifications such as incorporating an evaporator that can directly supply water to the boilers. This ZLD approach ensures no liquid discharge from the refinery, promoting a more sustainable and environmentally friendly operation.

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