DESIGN OF EFFLUENT WATER TREATMENT SYSTEM FOR REUSE IN REFINERY OPERATIONS AT ATTOCK REFINERY LIMITED

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2024

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A THESIS

Submitted to
National University of Sciences and Technology
in partial fulfillment of the requirements
for the degree of

B.E. CHEMICAL ENGINEERING

School of Chemical and Materials Engineering (SCME)

National University of Sciences and Technology (NUST)

June 2024

CERTIFICATE

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DEDICATION

This work is dedicated to our parents for always believing in us, our teachers, for broadening our perspective of the world and our tireless hard work.

ACKNOWLEDGEMENT

We would first like to express our heartfelt gratitude to Allah Almighty for being so merciful. Without His guidance and blessings, the successful completion of the project would not have been possible.

We would then like to extend our earnest appreciation to our faculty supervisor Dr. Iftikhar Ahmad for providing his invaluable support and guidance, and always being available to assist us.

We are also thankful to our parents for their constant prayers and for having faith in us. Their encouragement and motivation have played a key role in helping us overcome the challenges in achieving this milestone.

ABSTRACT

Effluent treatment plants are essential in industrial processes and environmental conservation, ensuring wastewater is safely discharged or reused. This project explores a multi-stage treatment process for industrial effluent to meet reuse standards set by the National Environmental Quality Standards.

The main goals of this project include achieving compliance in pH control, reducing Biological Oxygen Demand and Chemical Oxygen Demand, and separating oil and other metals. The treatment process involves coagulation, dissolved air flotation, clarification, and reverse osmosis membrane filtration. Coagulation will destabilize suspended solids and colloids for removal, while DAF and clarification will eliminate any remaining solids. Finally, the RO membrane will separate dissolved contaminants, producing high-quality treated effluent suitable for industrial reuse.

The findings will help develop a sustainable and cost-effective effluent treatment system for industrial applications.

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CHAPTER 01

INTRODUCTION

1.1 About the company

The Attock Refinery Limited is a Pakistani petroleum company which is a subsidiary of UK-domiciled Attock Oil Company. It is active in crude oil refining in the country. The company is based in Rawalpindi, Punjab, Pakistan. The project has been assigned to treat effluent water coming from different oil refinery operations, so that this treated water can be reused in industry.

Fresh water

Oil refineries rely heavily on clean, fresh water even though it is not directly involved in refining the oil itself. The biggest use of this water is for cooling. During the refining process, tremendous heat is generated. To prevent equipment damage and maintain optimal temperatures, a cooling system circulates water through heat exchangers.

This water gets hot and needs to be cooled down in towers before being recirculated. Refineries also use clean water to generate steam for various purposes like powering turbines or heating equipment. While the amount is smaller, some clean water is also used for washing certain oil streams, preparing solutions, and supplying restrooms, showers, and drinking water for workers. In essence, clean water is crucial for various refinery operations and worker well-being. However, with growing concerns about water scarcity, industry is constantly seeking ways to reduce its freshwater dependence.

Why is the treatment important?

High levels of nutrients like bicarbonate and Phosphate cause eutrophication which is one the most problematic kind of water pollution. 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.

Overall, water purification plays a vital role in safeguarding public health, improving water quality for consumption and various applications, and ensuring the smooth operation of industrial processes.

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

1.2 Essentials of Water Treatment

Total Dissolved Solids (TDS)

The salts and minerals that are completely dissolved in water and cannot 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.

Total Suspended Solids (TSS)

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

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 bioreactors.

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.

pH Balance

pH represents acidity or alkalinity of water. pH 7 is considered to be the neutral pH that is neither basic nor acidic. The 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.

1.3 Treatment guidelines

Here are some general guidelines for treating wastewater in an oil refinery for reuse in various operations:

Pre-treatment

- **Screening and Filtration**

  The first step often involves removing large solids, debris, and grease using screens and filters. This protects downstream equipment from clogging and improves the efficiency of subsequent treatment stages.

- **API Separation**

  If the wastewater contains oil and grease, an API separator is used to remove these lighter-than-water hydrocarbons through gravity separation.

- **Equalization**

  Wastewater flow rates and characteristics can fluctuate. Equalization tanks help even out these variations, ensuring a more consistent stream entering the subsequent treatment stages.

Primary Treatment

- **Sedimentation**

Gravity settling allows heavier solids to sink, while lighter materials like oil and scum float to the top. These settled solids and floating materials are then removed for further treatment or disposal.

Secondary Treatment

- **Biological Treatment**

This stage utilizes microorganisms (bacteria) to break down organic matter present in the wastewater. Two common biological treatment methods are:

- **Activated Sludge Process**

Microorganisms are suspended in a well-aerated tank where they biodegrade organic contaminants. Settled sludge is then separated for further processing.

- **Trickling Filters**

Wastewater is sprayed over a fixed bed of media containing microorganisms that consume the organic matter.

- **Chemical Clarification**

In some cases, chemical coagulants and flocculants might be added to enhance the removal of suspended solids and improve the efficiency of settling or filtration processes.

Tertiary Treatment (Optional)

- **Filtration**

After biological treatment, additional filtration processes like sand filters or membrane filtration (e.g., reverse osmosis) might be employed to remove any remaining suspended solids, bacteria, and other impurities. This can be particularly important if the treated water is intended for critical reuse applications.

- **Disinfection**

Disinfection with chlorine, ultraviolet light, or other methods might be used to eliminate any remaining pathogens in the treated wastewater, especially if it is intended for reuse in processes involving human contact.

1.4 Important Considerations

- **Treatment Levels**

  The level of treatment needed will vary based on the intended reuse application in the refinery. More rigorous treatment may be required for processes like boiler feedwater, makeup water for cooling towers, or any applications involving direct contact with humans.

- **Regulations**

  Refineries must adhere to local and national regulations set regarding wastewater treatment and its discharge or reuse. These regulations will usually dictate the minimum treatment standards that must be achieved.

- **Cost-Effectiveness**

  The selected treatment processes should offer a balance between achieving the required water quality for reuse and minimizing treatment costs.

Additional Considerations

- **Oil and Grease Removal**

  Additional oil and grease removal techniques like dissolved air flotation (DAF) might become a compulsion to meet reuse requirements, depending on the specific wastewater stream.

- **Nutrient Removal**

In some cases, processes for the removal of nitrogen and phosphorus might be required, particularly if the treated wastewater is to be discharged into a sensitive water body.

- **Monitoring and Maintenance**

  Conducting regular monitoring of the wastewater quality and treatment system performance is essential to ensure consistent and effective treatment for reuse purposes.

By following these guidelines while considering refinery's specific requirements, wastewater can be effectively treated and reused in various operations. Hence, the freshwater consumption can be reduced and sustainable water management practices can be promoted.

1.5 Our Goals and Objectives

- **Elimination of hazardous chemicals** enhances workplace safety, reduces environmental impact, and ensures compliance with regulations.

Reduced chemical usage in membrane technology conserves resources, minimizes waste, and leads to significant **long-term cost savings** through extended equipment life.

Table 1 Comparison of effluent parameters with desired parameters

Component	Unit	Influent	Desired
Water	L/hr	27250	-
TSS	mg/L	345	200
Oil	mg/L	20	10
TDS	mg/L	2500	250

BOD	mg/L	132.7	150
COD	mg/L	42.14	80
Bicarbonate	mg/L	318.6	-
Chloride	mg/L	42	-
Calcium	mg/L	44.4	< 2
Sodium Sulaphte	mg/L	296.6	-
Nitrates	mg/L	3.8	50-100

- The use of membrane technology promotes **water conservation** by efficiently treating high-quality water, preventing scaling, and ensuring a longer equipment life.
- Designing an efficient and economically viable water treatment process to reuse it in industry.

Treatment of waste water:

Our aim to is to achieve values less than the desired values in order to reuse to treated water in refinery operations.

Flow rate:

27250 liter/

CHAPTER 02

LITERATURE REVIEW

Oil refineries consume large volumes of freshwater for various processes, including cooling, boiler feedwater, and equipment washing. However, with growing concerns about water scarcity and stricter environmental regulations, the industry is increasingly focusing on reusing treated effluent water. This approach not only reduces freshwater consumption but also minimizes wastewater discharge and its associated environmental impact.

This report reviews the current literature on various techniques employed for treating effluent water in oil refineries to enable its reuse in different refinery operations.

2.1 Techniques for Effluent Water Treatment

Several techniques can be employed, either individually or in combination, to achieve the desired level of treatment for effluent water reuse in refineries. Here is a breakdown of some common methods:

2.1.1 Pre-treatment

- **Pen spark Screening and Filtration**

Large solids, debris, and grease are removed through screens and filters to protect downstream equipment and improve treatment efficiency.

Figure 1 Pen Spark Filter

- **API Separation**

Oil and grease are separated from the wastewater using gravity separation in API separators.

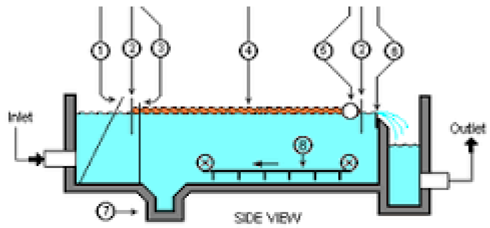


Figure 2 API Separator

- **Equalization**

Fluctuations in wastewater flow rate and characteristics are evened out in equalization tanks to ensure consistent treatment throughout the process.

Figure 3 Equalization Tank

2.1.2 Primary Treatment

- **Sedimentation**

Heavier solids settle at the bottom of settling tanks due to gravity, while lighter materials like oil and scum float to the top for removal.

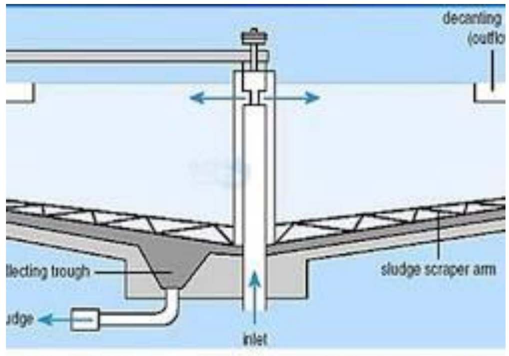


Figure 4 Sedimentation

2.1.3 Secondary Treatment

- **Biological Treatment**

Microorganisms (bacteria) break down organic matter present in the wastewater. Two common biological treatment methods are:

- **Activated Sludge Process**

Microorganisms are suspended in a well-aerated tank where they biodegrade organic contaminants. The settled sludge is then separated for further processing.

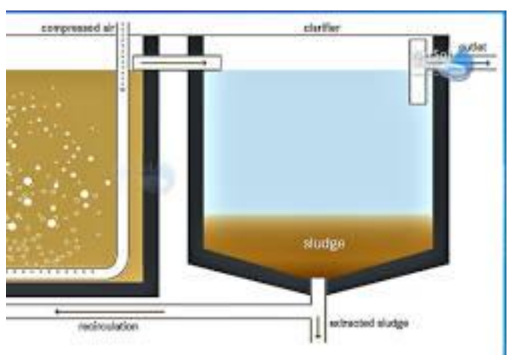


Figure 5 Activated Sludge Process

- **Trickling Filters**

Wastewater is sprayed over a fixed bed of media containing microorganisms that consume organic matter.

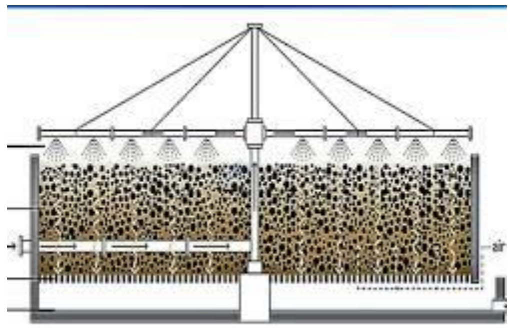


Figure 6 Trickling Filter

- **Chemical Clarification**

  Chemical coagulants and flocculants might be added to enhance the removal of suspended solids and improve the efficiency of settling or filtration processes.

2.1.4 Tertiary Treatment (Optional)

- **Filtration**

  Additional filtration processes like sand filters or membrane filtration (e.g., reverse osmosis) might be employed to remove any remaining suspended solids, bacteria, and other impurities, especially if the treated water is intended for critical reuse applications.

Figure 7 Filtration

- **Disinfection**

Disinfection with chlorine, ultraviolet light, or other methods might be used to eliminate any remaining pathogens in the treated wastewater, especially if it is intended for reuse in processes involving human contact.

Factors Affecting Treatment Choice

The specific treatment techniques chosen for an oil refinery's effluent water depend on several factors, including:

- **Desired reuse application**

The required level of water quality varies depending on the intended reuse purpose (e.g., boiler feedwater, cooling tower makeup water, etc.).

- **Regulations**

Local and national regulations regarding wastewater treatment and reuse must be adhered to.

- **Cost-effectiveness**

The chosen treatment processes should strike a balance between achieving the required water quality and minimizing treatment costs.

- **Characteristics of the effluent water**

The choice of treatment methods will be influenced by the specific composition and characteristics of the wastewater

2.2 Emerging Technologies:

- **Membrane bioreactors (MBRs)**

  These systems merge biological treatment with membrane filtration into one unit, providing a compact and productive treatment solution.

- **Advanced oxidation processes (AOPs)**

These methods utilize powerful oxidants e.g., ozone, and hydroxyl radicals, to breakdown organic pollutants and developing contaminants.

- **Microbial fuel cells (MFCs)**

  These innovative systems have the potential to generate electricity while treating wastewater, which offers a sustainable approach to wastewater treatment.

Conclusion

By making reuse of treated effluent, one gets significant benefits in oil refineries, including reduced freshwater consumption, minimized environmental impact, and potential cost savings. By implementing a combination of suitable treatment techniques, refineries can attain the desired water quality for various applications while adhering to environmental regulations. Ongoing development and research on advanced treatment technologies offer potential for further improving water treatment and improvising upcycling in the oil refining industry.

Future Considerations

- Through integrating advanced monitoring and control systems, treatment processes can be improved and consistent water quality can be ensured for reuse.
- The development of cost-effective and energy-efficient treatment technologies in an ongoing research focus. In addition, the cleaning challenges associated with units involving membranes also requires significant research.
- Minimizing wastewater generation at the source through process optimization is a key to sustainable water management in refineries.

CHAPTER 03

PROCESS DESCRIPTION

The finalization of the Process Flow Diagram (PFD) represents an important aspect in the design of the effluent water treatment system for reuse in refinery operations. It comprehensively and systematically represents the entire treatment process, beginning with the entry of effluent water into the coagulation tank in which the turbidity causing solids are removed by using alum as a coagulant. The Dissolved Air Flotation (DAF) unit, following coagulation, also plays a pivotal role in separating suspended solids through the introduction of air bubbles. The comparatively cleaner effluent then undergoes further purification in the clarifier, where residual solids settle, ensuring a clarified and cleaner water stream. Subsequently, the treated water passes through the Reverse Osmosis membrane, effectively removing dissolved impurities and achieving the desired water quality for reuse in the utilities for refinery processes. The finalized PFD serves as a visual representation of the interconnected processes, aiding in the clear communication of the system design and facilitating furtheranalysis and optimization.

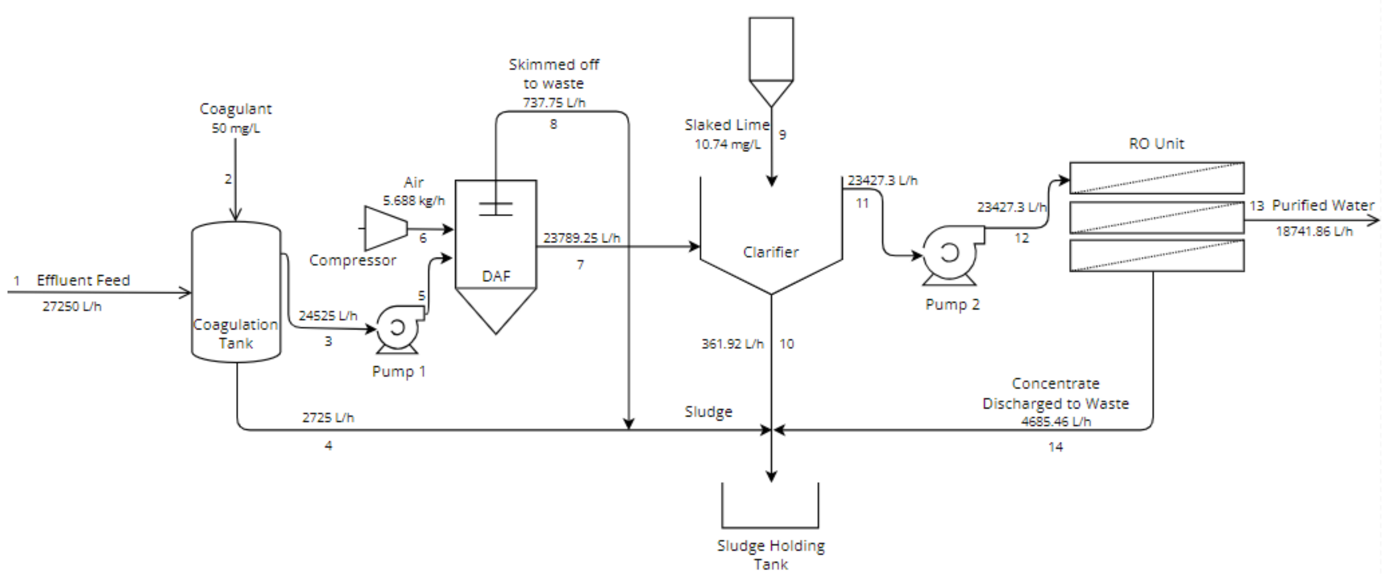


Figure 8 Process Flow Diagram

3.1 Coagulation tank

Coagulation tanks play a key role in wastewater treatment, including oil refineries, for removing total suspended solids (TSS) and oil with the help of aluminum sulfate (alum). Here is how it works:

Coagulant Addition

Aluminum sulfate ($Al_2(SO_4)_3$), a common coagulant, is added to the wastewater stream entering the coagulation tank. The optimal dosage depends on the characteristics of the wastewater, and jar testing might be necessary to determine the most effective amount.

Destabilization of Particles

Aluminum sulfate reacts with water to form positively charged aluminum hydroxide ($Al(OH)_3$) flocs. These flocs have a high affinity for the negatively charged surfaces of suspended solids and oil droplets present in the wastewater.

Colloidal Destabilization

Aluminum ions can also destabilize colloidal particles (very small, suspended particles) by neutralizing their electrical charges. This allows these colloids to clump together and become easier to remove.

Flocculation

The gentle mixing within the coagulation tank encourages collisions between the aluminum hydroxide flocs, suspended solids, and oil droplets. These collisions cause them to adhere to each other, forming larger and heavier flocs.

Sedimentation

Due to their increased size and weight, the formed flocs settle down towards the bottom of the coagulation tank. This allows for separation of the solids and oil from the treated wastewater.

Effectiveness of Aluminum Sulfate Aluminum sulfate is effective for removing various types of TSS, including:

- Sand
- Silt
- Clay
- Organic matter

It also helps to capture oil droplets by enmeshing them within the flocs.

3.2 Dissolved air flotation

Dissolved Air Flotation (DAF) is another effective method used in wastewater treatment, including oil refineries, to remove oil and total suspended solids (TSS). The steps involved are as follow:

Saturation with Microscopic Air Bubbles

- A portion of the wastewater stream is recirculated and pressurized in a saturation tank.
- Under pressure, air dissolves into the water to a much greater extent than at atmospheric pressure.

Release of Micro Bubbles

- The pressurized, air-saturated water is then mixed with the main wastewater stream entering the DAF tank.
- As the pressure is released, the dissolved air comes out of solution and forms millions of tiny air bubbles (typically 30-50 microns in size). These bubbles readily attach to the surfaces of oil droplets and suspended solids present in the wastewater.

Buoyancy and Flotation

Air has a much lower density than water. The microscopic air bubbles attached to the oil and TSS particles significantly reduce their overall density, causing them to become buoyant and rise to the surface of the DAF tank.

Scum Layer Formation

As the oil and TSS particles rise, they accumulate at the surface, forming a thick scum layer.

Skimming and Removal

A mechanical scraper system continuously skims the surface of the DAF tank, removing the accumulated oil and TSS layer. This layer can then be further processed or disposed of.

3.3 Clarifiers

While clarifiers themselves do not directly remove hardness-causing minerals, slaked lime (calcium hydroxide, $Ca(OH)_2$) can be used in conjunction with a clarifier system to soften hard water. The steps followed are enlisted as follow:

Lime Addition

As the effluent enters the clarifier, slaked lime is added to it.

Chemical Reaction

The calcium hydroxide reacts with the dissolved hardness-causing minerals, primarily calcium and magnesium ions, in the water. A reaction then takes place which forms insoluble calcium carbonate ($CaCO_3$) and magnesium hydroxide ($Mg(OH)_2$) precipitates, which are basically in solid form.

The pH of water leaving a clarifier after lime softening depends on the chemical reactions that occur during the softening process. In lime softening, calcium hydroxide, the slaked lime, is added to water to raise the pH and precipitate calcium carbonate and magnesium hydroxide, which are then removed as solids.

The lime softening step involves the following primary reactions:

1. Formation of calcium hydroxide:

$$Ca(OH)^2 \rightarrow Ca^2 + +2OH^-$$

2. Precipitation of calcium carbonate:

$$Ca^{2+} + 2HCO_3^- \rightarrow CaCO_3 + H_2O$$

3. Precipitation of magnesium hydroxide:

$$Mg^{2+} + 2OH^- = \mathrm{Mg(OH)_2}$$

The increased pH is because of the precipitation of calcium carbonate and magnesium hydroxide, which helps in the removal of hardness-causing ions and reduces the potential for scaling in downstream processes. It is important to monitor and adjust the pH as needed to ensure that the treated water meets the desired quality standards and is suitable for its intended use.

Clarification

As the solid precipitates are obtained, they settle at the bottom of the clarifier due to gravity. These heavier flocs containing the hardness-causing precipitates are then removed as sludge.

Softened Water Collection

The clarified water at the top of the clarifier has a lower concentration of dissolved hardness minerals. This softened water can then undergo further treatment stages depending on the specific application.

Sludge Removal

The accumulated sludge from the bottom of the clarifier, rich in calcium carbonate and magnesium hydroxide, needs to be removed periodically for proper disposal.

Important Points

The clarifier itself primarily functions as a physical separation unit. It allows the lime-induced precipitates (solids) to settle out due to gravity.

The addition of slaked lime increases the total dissolved solids (TDS) in the water slightly due to the formation of calcium carbonate and magnesium hydroxide precipitates. However, these precipitates are removed in the clarifier, resulting in softened water with lower hardness.

This process is often referred to as lime softening or milk of lime treatment.

3.4 Reverse Osmosis Unit

Reverse osmosis (RO) is a powerful membrane filtration technology that can effectively remove a wide range of contaminants from water, including total suspended solids (TSS). Its working and the role of the polyamide composite membrane is as follow:

Pre-treatment

Before introducing the wastewater to the RO membrane, it is typically made to undergo pre-treatment steps to remove large particles, grease, and chlorine that could damage the membrane used in the RO unit.

Pressure Application

The pre-treated wastewater is pressurized by a pump before it enters into the RO membrane. This forms the driving force that allows the purification to take place.

Semi-permeable Membrane

The key component of an RO system is a semi-permeable membrane. This membrane is typically made of a polyamide composite material. It is formed of microscopic pores that allow water molecules to pass through but restrict the passage of most dissolved ions and larger molecules that tend to contribute to an increased level of TSS.

Permeate Stream

When the pressurized water comes into contact with the RO membrane, the water molecules pass through the membrane pores due to their small size. This filtered water stream is called permeate. The permeate is essentially desalinated water with significantly lower TDS and TSS than the water at the membrane inlet.

Reject Stream

The RO membrane also rejects dissolved ions, larger molecules, and suspended solids that cannot pass through the pores. These rejected contaminants become concentrated in a stream called the reject stream. This reject stream requires further treatment or disposal.

Polyamide Composite Membrane

The polyamide composite membrane is the heart of the RO system. It is typically a thin film composed of two layers:

- **Polyamide Selective Layer**

  This dense layer is responsible for selective permeation. It allows water molecules to pass through due to their size and polarity, while rejecting most dissolved ions and larger molecules.

- **Support Layer**

  This porous layer provides mechanical support for the selective layer and facilitates water flow towards the permeated collection channel.

How Reverse Osmosis Membrane Removes TSS ?

While RO primarily targets dissolved contaminants, it also effectively removes TSS because these suspended solids are physically larger than water molecules. The tight pores of the polyamide membrane act as a barrier, preventing most TSS from passing through to the permeate stream.

It is important to note that the efficiency of TSS removal by RO depends on the size and characteristics of the suspended solids. Very small particles or those that can deform might have a slightly higher chance of passing through the membrane.

3.5 Mechanical and piping

It is imperative that the whole wastewater treatment plant has been physically checked and if and where necessary corrected and/or rectified. All liquid lines should have been tested for their absence of leaks, internal obstructions, dirt, and other types of debris into the line. Specifically, the HDPE, PVC and other thermoplastic transfer lines must be cleaned thoroughly to remove cuttings and other machining waste left after the cutting and welding of sections.

The rather light cuttings travel easily with a flow of water and are likely to cause problems amongst e.g. check valves, dosing pumps etc. If dirt is found in the pipes, it should be removed first, so that it cannot cause consequential damage etc. Mechanical components such as aerators and pumps are checked for their smooth running and proper alignment with their drivers, once their foundation blocks have been cast and set. A proper alignment and balance re-check will result in a prolonged life expectancy of the equipment and minimum noise and heat generation. Protective temporary strainers are placed in pump suction lines (and removed after successful start-up).

The sealing/cooling/lubricating oils of the pumps, aerators etc. must be checked and topped up as per the manufacturers' instructions. The utility supplies must be inspected as well. Compressed air and freshwater lines 19 are blown/flushed out to prevent impurities from entering control and e.g. chemical solution make-up equipment. Air filters must be checked. Concerning the chemical dosing, some general advice are given here. Special care should be given to the cleanliness of chemical dosing systems. Tanks, piping, pipe strainers, temporary strainers (where applicable) and other components must be inspected for the presence of fibers, pipe-cutting waste, sealing material fragments. Such impurities will invariably lead to a malfunctioning of the dosing pumps, pressure safety valves, and backpressure valves, injection nozzles and other associated elements. Cleaning all with tap water while there is still no chemical in them is the easiest and the most effective.

Special attention must be paid to the correct setting of the dosing equipment and its accessories like back-pressure valves etc. Inaccurate pressure settings may result in too high delivery pressures (with its inherent risk of bodily harm when a chemical dosing line breaks) or in an erratic flow of chemicals to the Coiled Pipe Flocculator. Latter may ultimately result in severe corrosion damage to the TPF basin and its ancillaries.

CHAPTER 04

MATERIAL BALANCE

4.1 Coagulation Tank

Assuming that all coagulant is removed with TSS in the form of sludge

Efficiency = 54%

10% water in sludge

Table 2 Material Balance on Coagulation Tank

Components	Units	Inlet	Outlet
Water	L/hr	27250	24525
TSS	mg/L	345	176.14
Oil	mg/L	20	10.19
Aluminum Sulfate	mg/L	50	0

4.2 Dissolved Air Flotation

Efficiency = 93%

3% water via skimmer

Table 3 Material Balance on DAF

Components	Units	Inlet	Outlet
Water	L/hr	24525	23789.25
TSS	mg/L	176.14	12.74
oil	mg/L	10.19	0.8659

BOD	mg/L	132.7	33.75
COD	mg/L	42.14	15.21

4.3 Clarifier

$$Ca(HCO_3)_2 + Ca(OH)_2 \longrightarrow 2CaCO_3 + 2H_2O$$

$$Mg(HCO_3)_2 + Ca(OH)_2 \longrightarrow CaCO_3 + MgCO_3 + 2H_2O$$

Conversion = 85%

Total inflow water = 23789.25 kg/h

Lime required per hour = (1108.78 moles/h+1438.64 moles/h) ×74.09 g/mol

=255,366.22 g/h or 10.74 mg/L

Table 4 Material Balance on Clarifier

Components	**Units**	**Inlet**	**Outlet**
Effluent	L/hr	23789.25	23427.33
TSS	mg/L	12.74	4.38
Bicarbonate	mg/L	493	329
Calcium	mg/L	51.8	43.4
Magnesium	mg/L	42	35

4.4 Rever Osmosis Unit

With 80% recovery; Salt rejection = 95%

TDS rejected = TDS feed/(1- % recovery) = 145 ppm = 2.72 kg/hr

TDS passed = TDS feed * (1- %salt rejection) = 11 kg/hr

Table 5 Material Balance on RO

Components	Units	Inlet	Outlet
Effluent	L/hr	23427.33	18741.86
TDS	mg/L	2900	145
	Kg/hr	68	2.72

4.5 Over Mass Balance

The plant's overall mass balance tracks the flow of water and contaminants throughout the process. Thisincludes influent and effluent flow rates, chemical consumption, sludge production, and permeate and concentrate streams from the RO unit. A detailed mass balance ensures efficient resource utilization andidentifies potential waste streams for proper disposal or treatment.

		COAGULATION		DAF		CLARIFIERS		RO Unit	
Components	Units	In	Out	In	Out	In	Out	In	Permeate
Effuent	L/hr	27250	24525	24525	23789.25	23789.25	23427.33	23427.33	18741.86
TSS	ppm	345	176.14	176.14	12.74	12.74	4.38	4.38	4.38
TDS	ppm	2900	2900	2900	2900	2900	2900	2900	145
Oil	ppm	20	10.19	10.19	0.8659	0.8659	0.8659	0.8659	0.8659
COD	ppm	42.14	42.14	42.14	15.21	15.21	15.21	15.21	15.21
BOD	ppm	132.7	132.7	132.7	33.75	33.75	16.875	16.875	16.875
Bicarbonate	ppm	493	493	493	493	493	329	329	3.229
Chloride	ppm	79.6	79.6	79.6	79.6	79.6	79.6	79.6	0.435
Calcium	ppm	51.8	51.8	51.8	51.8	51.8	43.4	43.4	0.021
Magnesium	ppm	42	42	42	42	42	35	35	0.017
nitrates	ppm	4.2	4.2	4.2	4.2	4.2	4.2	4.2	0.169
Sodium	ppm	61	61	61	61	61	61	61	1.508

CHAPTER 05

ENERGY BALANCE

5.1 Energy Balance on Pump 1

Using formula: Δ**H = Q + W**

$$W = \frac{\Delta P . \dot{V}}{\text{Efficiency}}$$

Table 6 Energy Balance on Pump 1

Series no:	ΔP (kPa)	Volumetric Flow Rate (Cubic meter/ s)	Efficiency	Duty (kW)
1	709.275-200 = 509.275	0.007569	75%	5.13

5.2 Energy Balance on Pump 2

Table 7 Energy Balance on Pump 2

Series no:	ΔP (kPa)	Volumetric Flow Rate (Cubic meter/ s)	Efficiency	Duty (kW)
1	400-101.3 = 298.7	0.006607	75%	2.63

5.3 Energy Balance on Compressor

Using formula: $w_c = C_p\, T_1 \left[(p_2/p_1)^{(k-1)/k} - 1\right]$

Table 8 Energy Balance on Compressor

mass of air (kg/s)	specific heat of air (cp) (KJ/KgK)	ΔT (k)	ΔP (KPa)	H (inlet) KJ/Kg	H(outlet) KJ/Kg	Win (KJ)
1.3625	at 298K = 1.005 at 543.8K = 1.1	-298= 245.8	800-101.3 = 698.7	35.18	129.06	328.4

The energy balance accounts for the power consumption of all equipment involved in the treatment process. This includes mixers, pumps, air blowers, compressor and RO systems. Optimizing energy consumption is crucial for cost-effectiveness and minimizing the environmental footprint of the plant.

CHAPTER 06

EQUIPMENT DESIGN

6.1 Coagulation tank

Flow rate = 27250 kg/hr = 27.25 m^3/hr

Retention time = 1 hr

Volume = 27.25 m^3/hr * 1 hr

= 27.25 + (10/100 * 27.25)

= 27.25 + 2.725 = 30 m^3

hence,

H = 2D

Our coagulation tank is of cylinder shape

$V = \pi d^2 h/4$

$= \pi d^3/2$

D = 2.67 m

H = 5.34 m

Table 9 Design Specification on Coagulation Tank

Volume	30 m^3
Diameter	2.67 m
Height	5.34 m

6.2 Dissolved air flotation

Flow rate (Q_{in}) = 24525 kg/hr = 24.525 m^3/hr

Retention time = 45 min = 0.75 hr

Allowance Volume = 20%

Volume = 24.525 m^3/hr * 0.75 hr

= 18.39375 + (20/100 * 18.393)

= 18.39375 + 3.678 = 22.0725 m^3

surface area= Flow Rate (Q_{in}) /Surface Loading Rate (SLR)

S.A = 22.0725 m^3/7 m^3/m^2, **S.A = 3.153 m^2**

As, H = 2D

Our DAF tank is of cylinder shape

$V = \pi d^2 h/4$

$= \pi d^3/2$

D = 2.413 m

H = 4.826 m

Skimmer Design:

Blade Height: Adjustable from just above the water surface to 2-4 inches (5-10 cm) above. Lower for thin scum layers, higher for thick layers.

Skimmer Blade Angle: Adjustable from 0 to 45 degrees. Horizontal for thin layers, steeper for thick layers. So, an angle of 30 degrees has been used.

Rotary Skimmer Speed: For refinery wastewater treatment in DAF systems, the optimal speed is 1-5 RPM

- **1-2 RPM:** Gentle skimming, preventing re-mixing and minimizing water entrainment.
- **3-5 RPM:** For higher loads, ensuring quick removal but avoiding excessive turbulence.

So, a skimmer speed of 3 RPM has been used.

Table 10 Design Specifications of DAF

Volume	22.075 m^3
Diameter	2.413 m
Height	4.862 m

6.3 Clarifier

Flow rate = 23789.25 kg/hr = 23.8 m^3/hr

Detention time = 1.5 hr

Settling velocity= 1 m/h

Volume = 23.8 m^3/hr * 1.5 hr

= 35.7 + (10/100 * 35.7)

= 39.27 m^3

D = 3D (solid contact clarifier, circular)

$V = \pi d^2 h/4 = \pi d^3/12$

D = 5.3 m

H = 1.77 m

Feed well Diameter = 3% of D = 1.59m

S.A = $\pi r^2 + 2\pi rh$ = 51.5 m^3

S.A/ inflow rate = 2.15 (acceptable)

SOR = 0.462 (adequate)

Table 11 Design Specification of Clarifier

Volume	39.27 m^3
Diameter	5.3 m
Height	1.77 m

6.4 RO

Flow configuration: spiral wound, single flow

Type of element: BW30-400/34i

Reasons to choose the BW-30-400/34i:

- **High Salt Rejection:** Stabilized Salt Rejection: 99.6%
- **Wide Operating Range:** Performs well with varying water compositions
- **Versatile Applications:** Suitable for brackish water and desalination plants

Key Features:

- **Enhanced Fouling Protection:** 34 mil feed spacer creates channels for feedwater flow, minimizing pressure drop and reducing fouling
- **Innovative End Caps:** iLEC™ interlocking end caps provide a fixed mechanical connection, reducing operating costs and the risk of O-ring leaks, thus ensuring

better water quality

No. of element = $\frac{\text{permeate flow}}{\text{design flux} \times \text{active area of membrane}}$

= (18740L/hr)/23.7lmh * 40.2 m^2 = **18 elements**

No. of pressure vessels = $\frac{\text{total no. of elemens}}{\text{no. of elements per vessel}}$

= 18/6 = **3 vessels**

Volume of single pressure vessel:

Dia of each element = 8 inches

Vessel Dia = 8+1 = **9 inches** (0.5 in allowance)

Length of each element = 40 inches

Vessel Length = (6 * 40) + 1 = **241 inches** (0.5 in allowance at each end)

Vol of one vessel = $\frac{\pi d^2 L}{4}$ = (3.14 * 9^2 * 241) / 4 = 1702.3 in^3 = **0.251 m^3**

Table 12 Design Specifications of RO

Volume	0.754 m^3
Diameter	0.2286 m
Height	6.1214 m
Membrane element	BW30-400/34i
Material	Polyamide composite
Flux	23.7 LMH
Stage	1
Recovery	80%

CHAPTER 07

SIMULATION

Aspen HYSYS simulation software having Electrolyte environment was used as the simulation software to simulate the whole process because of the involvement of ions and their reactions.

As the world is shifting towards Artificial Intelligence, so the need for simulation software has become significantly important. Aspen PLUS simulation software is one of the best software for the modelling and simulation of process industries because of the following reasons:

1. Prediction and Analysis: It allows for the creation of virtual models that mimic real world systems or processes. By running simulations, the behavior of these systems is predicted and analyzed before they are implemented in actual.

2. Cost and Time Savings: Carrying out simulations on complex processes can save considerable costs and time compared to physical experimentation and testing.

3. Design Optimization: It enables engineers and designers to create virtual prototypes and iterate several designs. This iterative process helps in improving product quality.

4. Performance Evaluation: It allows to make comparisons among the performance of different systems under varying conditions, which can optimize the overall manufacturing processes.

5. Visualization and Communication: It often provides visual representations of complex data and models, making it easier for the user to understand findings.

7.1 Property Package

In Aspen Hysys, a **property package** is basically a set of thermodynamic models that calculate the physical and chemical properties of fluids during simulation. These properties are required for various calculations, including:

- Phase equilibria (vapor-liquid, liquid-liquid, etc.)
- Enthalpy (heat content)
- Entropy (measure of disorder)
- Density
- Viscosity
- Vapor pressure

It is necessary to choose the right property package for obtaining accurate results of simulation. Also, the Peng-Robinson (PR) equation of state is a common choice for wastewater treatment simulations for following reasons:

Peng-Robinson Equation of State (PR)

- The PR package is a widely used and well-established thermodynamic model for representing the behavior of fluids as it offers a good balance between accuracy and computational efficiency.

- Compared to simpler models like ideal gas law, PR works on real fluids as well, accounting for the non-ideality. This characteristic makes it well-known for wastewater treatment simulations as wastewater is typically composed of several components with varying properties, and PR can handle these complexities quite well.

- In addition, Aspen Hysys offers various enhancements to the PR model, making it particularly suitable for hydrocarbon systems. These enhancements further improve the model's accuracy when it comes to predicting properties like vapor pressure and fugacity coefficients.

Why PR might be suitable for wastewater treatment ?

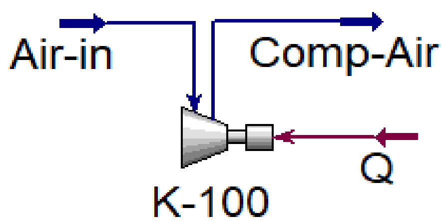
- **Wastewater Composition:** Wastewater can contain a mixture of organic and inorganic compounds. It varies the degree of polarity in the effluent. PR can handle these varying properties effectively.

- **Temperature and Pressure Range:** Wastewater treatment processes typically operate at moderate temperatures and pressures. PR has a good applicability range that covers these conditions.

- **Computational Efficiency:** While there are more complex thermodynamic models available in Aspen Hysys, PR offers a good balance between accuracy and computational cost.

7.2 Simulating Compressor using Aspen HYSYS

Fluid Package: **Peng-Robinson**



Worksheet | Performance | Dynamics

Name	Air-in	Comp-Air
Vapour	1.0000	1.0000
Temperature [C]	25.00	339.9
Pressure [kPa]	101.3	800.0
Molar Flow [kgmole/h]	0.1965	0.1965
Mass Flow [kg/h]	5.688	5.688
LiqVol Flow [m3/h]	6.467e-003	6.467e-003
Molar Enthalpy [kJ/kgmole]	-8.138	9311
Molar Entropy [kJ/kgmole-C]	118.2	122.2
Heat Flow [kJ/h]	-1.599	1829

Figure 9 Specifications for Compressor

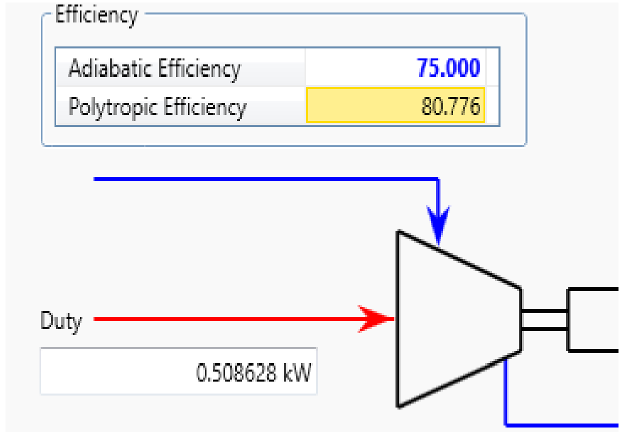
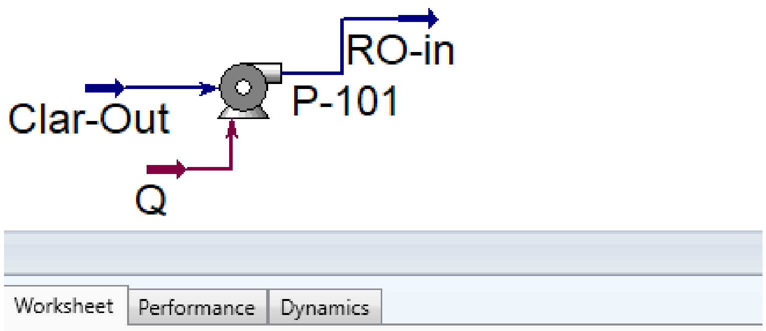


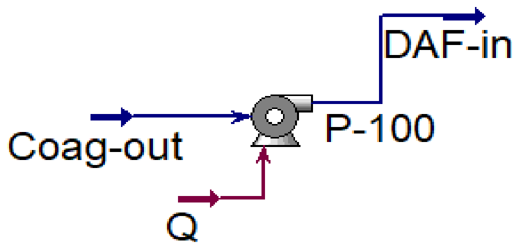
Figure 10 Calculated Duty for Compressor

7.3 Simulating Pumps using Aspen HYSYS



Name	Clar-Out	RO-in
Vapour	0.0000	0.0000
Temperature [C]	25.00	25.03
Pressure [kPa]	101.3	400.0
Molar Flow [kgmole/h]	1318	1318
Mass Flow [kg/h]	2.374e+004	2.374e+004
Std Ideal Liq Vol Flow [m3/h]	23.79	23.79
Molar Enthalpy [kJ/kgmole]	-2.850e+005	-2.850e+005
Molar Entropy [kJ/kgmole-C]	6.610	6.616
Heat Flow [kJ/h]	-3.755e+008	-3.755e+008

Figure 11 Specifications for RO Pump



Worksheet | Performance | Dynamics

Name	Coag-out	DAF-in
Vapour	0.0000	0.0000
Temperature [C]	25.00	25.05
Pressure [kPa]	200.0	709.3
Molar Flow [kgmole/h]	1509	1509
Mass Flow [kg/h]	2.719e+004	2.719e+004
Std Ideal Liq Vol Flow [m3/h]	27.25	27.25
Molar Enthalpy [kJ/kgmole]	-2.850e+005	-2.850e+005
Molar Entropy [kJ/kgmole-C]	6.610	6.620
Heat Flow [kJ/h]	-4.302e+008	-4.302e+008

Figure 12 Specifications for DAF Pump

IMS DESIGN

IMS design software, also known as **Integrated Membrane Solutions Design**, is a software specifically designed for simulating and optimizing various membrane systems. Its application ranges from Ultrafiltration membranes to Reverse Osmosis membranes. It is developed by Hydranautics, which is a leading manufacturer of RO membranes.

The working of IMS design software design and the reason behind its value is as follow:

Functionality of IMS Design Software

- **Membrane Selection:** There is a database of various Hydranautics RO membranes provided in the software, with their performance characteristics. The user can select the most suitable membrane based on the specific feed water quality, desired permeate (treated water) flow rate, and target rejection rate (percentage of contaminants removed).

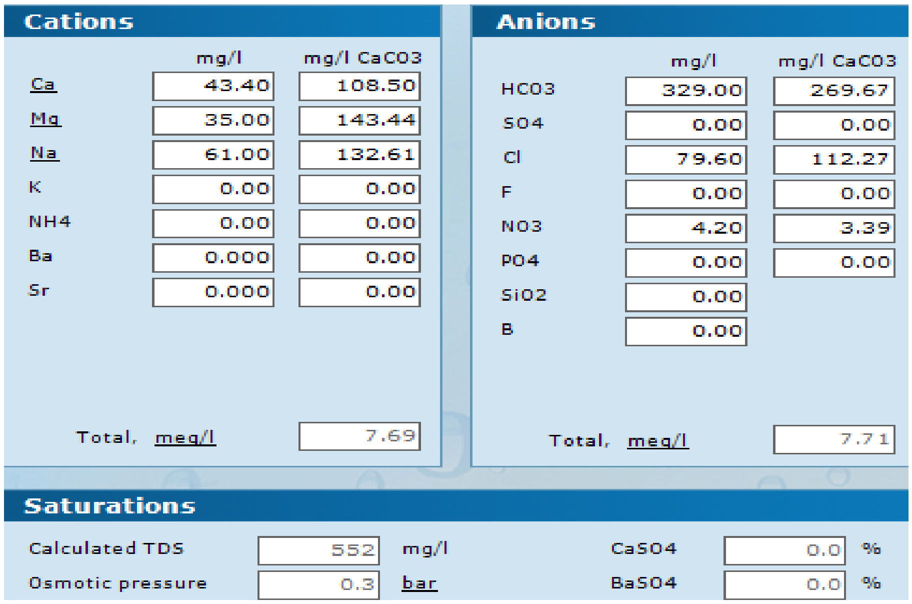
- **System Design and Simulation:** Using IMS, the user can design his own RO system by specifying components like the number of membrane elements, pressure vessels, feed flow rate, and operating pressure. It is then followed by the simulation carried out on the system by the software, predicting key parameters such as:
    - Permeate flow rate
    - Permeate quality (conductivity, salinity)
    - Pressure drop across the system
    - Energy consumption
- **Optimization Tools:** IMS also offers tools to help the user optimize the RO system design. One can analyze the impact of different operating conditions, like pressure, and flow rate, on the RO unit's performance and energy efficiency. This allows one to create a balance between the level of treatment required and operational costs associated with it.

Benefits of Using IMS Design Software for RO Membrane Simulation

- **Improved Design Decisions:** By simulating different values, IMS helps one select the most appropriate RO membrane and thus, create a design that efficiently meets the specific water treatment requirements.
- **Reduced Costs:** As the software helps one optimize the system design, it leads to potential reduction in energy consumption, while maximizing water recovery. This can result in significant cost savings over the long term.
- **Reduced Risk:** By simulating the system's performance beforehand, one can identify potential bottlenecks or limitations in the design. This helps avoid costly mistakes during the construction and operation phases.

- **Faster Design Process:** IMS streamlines the design process by providing a user-friendly interface and pre-defined models for RO membranes and system components.

7.4 Simulation on Reverse Osmosis Unit using IMS DESIGN



Cations

	mg/l	mg/l CaCO3
Ca	43.40	108.50
Mg	35.00	143.44
Na	61.00	132.61
K	0.00	0.00
NH4	0.00	0.00
Ba	0.000	0.00
Sr	0.000	0.00
Total, meq/l		7.69

Anions

	mg/l	mg/l CaCO3
HCO3	329.00	269.67
SO4	0.00	0.00
Cl	79.60	112.27
F	0.00	0.00
NO3	4.20	3.39
PO4	0.00	0.00
SiO2	0.00	
B	0.00	
Total, meq/l		7.71

Saturations

Calculated TDS	552	mg/l	CaSO4	0.0	%
Osmotic pressure	0.3	bar	BaSO4	0.0	%

Figure 13 Specifications at RO Inlet

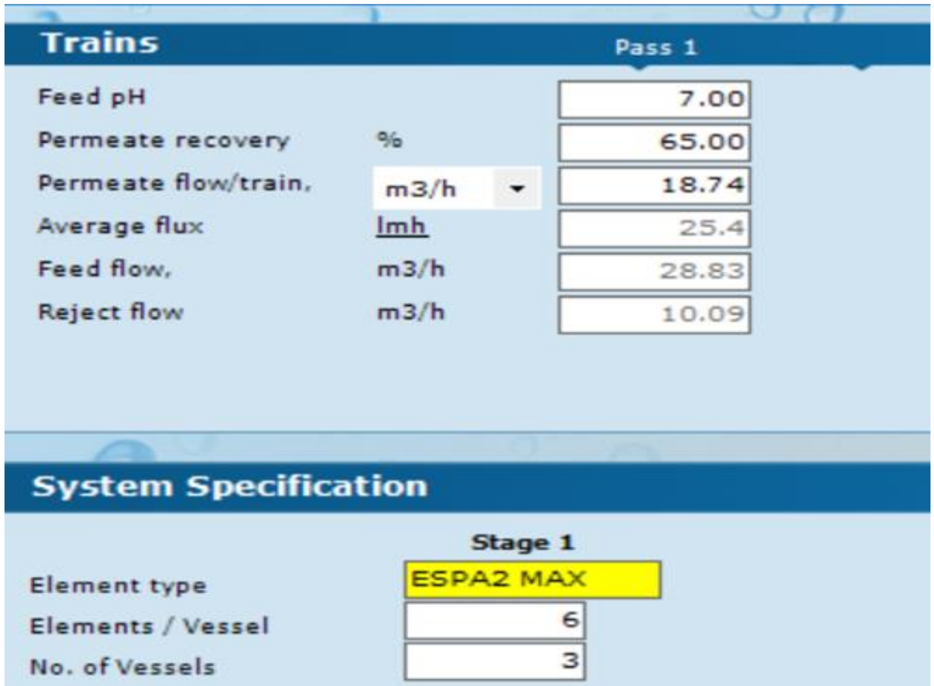


Figure 14 Conditions for RO

Results showing Permeate Concentration

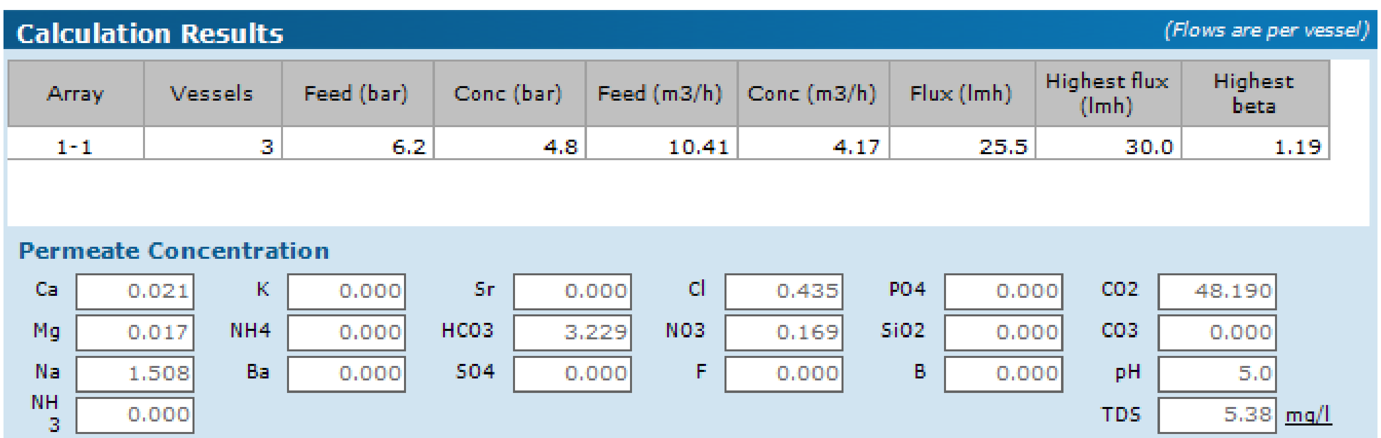


Figure 15 Results at RO Outlet

CHAPTER 08

COST ANALYSIS

The goal of any chemical processing plant is to generate profits or revenue. The chemical manufacturers try to reduce the cost per unit of the product produced while also making sure that the quality and the production capacity are not compromised. Before starting any business or the production of any product on an industrial scale, the economic analysis for the production is carried out.

The purpose of doing so is to ensure that the business will be economically feasible. Economic analysis is done for either the whole plant or some of those components that need to be replaced or optimized with the better ones. Cost analysis is one of the crucial parameters that helps investors in making informed decisions by giving an idea about the financial figures for various alternatives.

Economic analysis has been performed for the whole plant to check the ability of our plant to run successfully. To carry out this, the method proposed by Coulson and Richardson is used.

8.1 Equipment Purchase Cost

Table 11.1. Electrocatalytic reactors for Hydrogen, Ammonia and Compressor cost table.

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

Figure 16 Vessel Cost Table

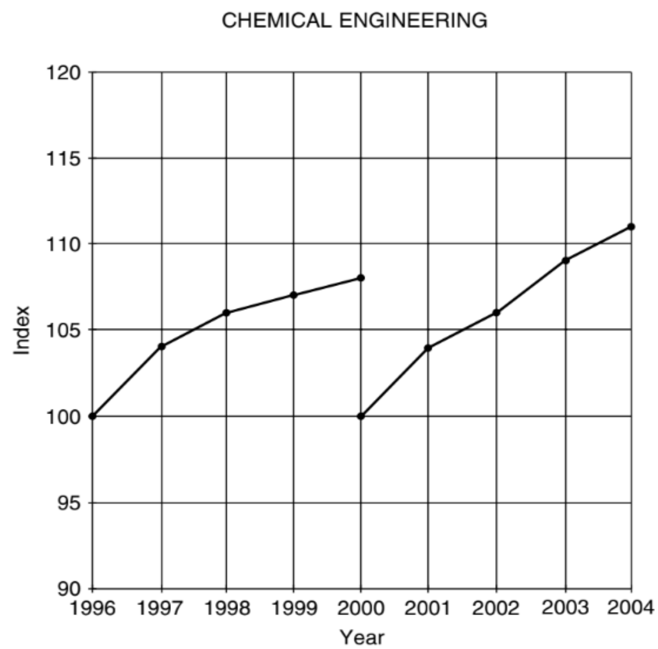


Figure 17 Process Engineering Index

Coagulation tank

Process Engineering Index = 182/111= 1.63

Cost in year A = Cost in year B x (Cost index in year A / Cost index in year B)

Capacity of Tank = 30 m^3

Cost = CS^n

= 2400 x $(30)^{0.6}$

= $18470

= $30284

DAF Costing

Process Engineering Index = 182/111= 1.63

Cost in year A = Cost in year B x (Cost index in year A / Cost index in year B)

Capacity of Tank = 20.23 m^3

Cost = CS^n

= 2400 x $(20.23)^{0.6}$

= $14581

= $23767

Avg. skimmer cost for DAF = $5,000

Clarifier Costing

Process Engineering Index = 182/111= 1.63

Cost in year A = Cost in year B x (Cost index in year A / Cost index in year B)

Capacity of Tank = 39 m^3

Cost = CS^n

= 2400 x $(39)^{0.6}$

= $ 21620

= $ 35240

For a scraper blades, rake arm, walk-way and feed-well assembly, a minimum cost of $7,000 is required.

Reverse Osmosis Unit Costing

Purchase $Cost_{(RO\ total)} = Cost_{(Vessels)} + Cost_{(Elements)}$

Capacity of single vessel S = 7.8 m^3

$Cost_{(vessels)} = 3 * CS^n = 2 * 2900 * (7.8)^{0.6}$ = $ 29,838

Accounting for the pressure factor and cost index:

Cost * Pressure Factor = 29,838 * 1.2 * 182/111 = $ 58,709

$\text{Cost}_{(\text{elements})}$ = Cost per element * no. of elements = 800 * 18

= $ 15,200

Total calculated cost for RO membrane = 58,709 + 15,200

= $ 73,908

Pumps Costing

DAF Pump Duty = 5.13kW

Cost = $8400

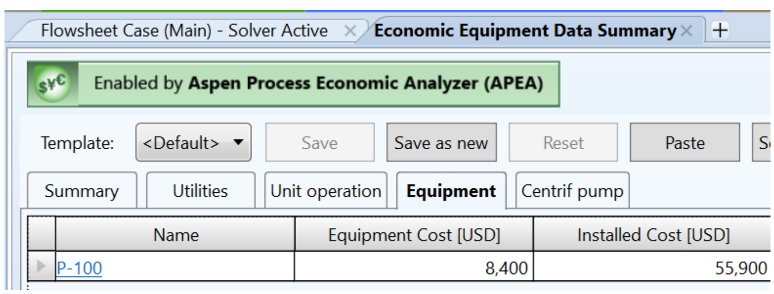


Figure 18 Pump Costing

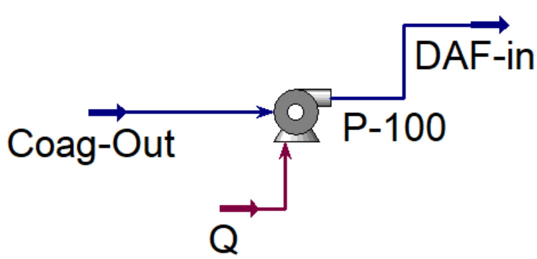


Figure 19 Pump Costing

RO Pump duty = 2.63kW

Cost = $7100

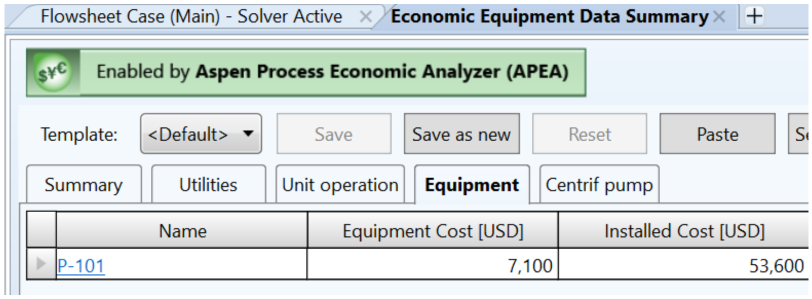


Figure 20 Pump 2 Costing

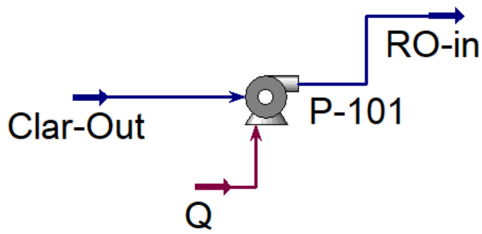


Figure 21 Pump 2 Costing

Compressor Costing

Compressor duty = 0.3831 kW

Cost = $ 914200

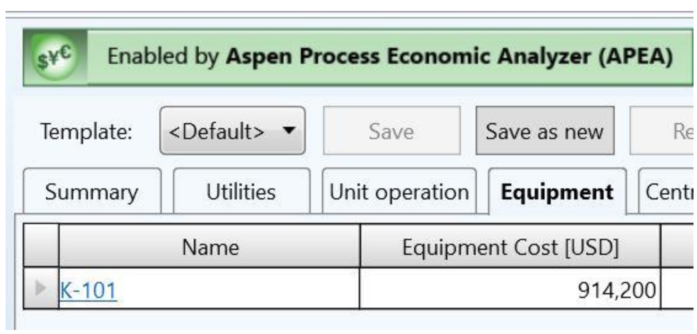


Figure 22 Compressor Costing

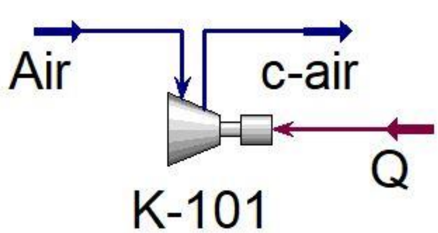


Figure 23 Compressor Costing

8.2 Summary of the Purchased Cost of Equipment

Table 13 Summarized Purchased Cost of Equipment

Equipment	PCE (USD)
Coagulation Tank	30284
Dissolved Air Flotation Tank	23767
Clarifier	35240
RO system	73908
Compressor	914200
DAF pump	8400
RO pump	7100

8.3 Physical Plant Cost

Physical Plant Cost =Purchased Cost of Equipment x (1 + f1 + .. +f9)

= 1,092,899 x 3.4

= $ 3715856.6

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) $PPC = PCE\,(1 + f_1 + \cdots + f_9)$			
$= PCE \times$	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 $= PPC\,(1 + f_{10} + f_{11} + f_{12})$			
$= PPC \times$	1.45	1.40	1.35

*Omitted for minor extensions or additions to existing sites.

Figure 24 Typical Factors for Fixed Capital Cost

8.4 Fixed Capital Cost

Fixed Capital Cost = Physical Plant Cost x (1+f10 + f11 + f12)

= $ 3.7M x 1.45

= $ 5387992.07

= $ 5.4M

8.5 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

= 0.05x5,387,992.07

= 269,399.604

= 0.27M

8.6 Total Investment

The Total Investment required is:

Total Investment = Fixed Capital + Working Capital

= $ 5387992.07 + $ 269,399.604

= $ 5,657,391.67

8.7 Variable cost

Table 6.5. Cost of utilities, typical figures mid-2004

Utility	UK	USA
Mains water (process water)	60 p/t	50 c/t
Natural gas	0.4 p/MJ	0.7 c/MJ
Electricity	1.0 p/MJ	1.5 c/MJ
Fuel oil	65 £/t	100 $/t
Cooling water (cooling towers)	1.5 p/t	1 c/t
Chilled water	5 p/t	8 c/t
Demineralised water	90 p/t	90 c/t
Steam (from direct fired boilers)	7 £/t	12 $/t
Compressed air (9 bar)	0.4 p/m^3 (Stp)	0.6 c/m^3
Instrument air (9 bar) (dry)	0.6 p/m^3 (Stp)	1 c/m^3
Refrigeration	1.0 p/MJ	1.5 c/MJ
Nitrogen	6 p/m^3 (Stp)	8 c/m^3

Note: £1 = 100p, 1$ = 100c, 1 t = 1000 kg = 2200 ib, stp = 1 atm, $0^{\circ}C$

Figure 25 Cost of Utilities

Typical prices for bulk purchases, mid-1998. All deliveries by rail or road tanker, and all materials technical/industrial grade; unless otherwise stated			
Chemical, and state	Cost unit	Cost £/unit	Cost $/unit
Acetaldehyde, 99%	kg	0.53	0.48
Acetic acid	kg	0.60	1.10
Acetic anhydride	kg	0.70	1.15
Acetone	kg	0.63	1.03
Acrylonitrile	kg	1.20	1.90
Ally alcohol	kg	1.40	2.30
Ammonia, anhydrous	t	180	280
Ammonium nitrate, bulk	t	100	170
Ammonium sulphate, bulk	t	90	150
Amyl alcohol, mixed isomers	kg	0.67	1.20
Aniline	kg	0.52	0.84
Benzaldehyde, drums	kg	1.95	3.21
Benzene	kg	0.20	0.33
Benzoic acid, drums	kg	2.20	3.60
Butene-1	kg	0.30	0.40
n-Butyl alcohol	kg	0.75	1.30
n-Butyl ether, drums	kg	1.95	3.20
Calcium carbide, bulk	t	320	530
Calcium carbonate, bulk, coarse	t	105	145
Calcium chloride, bulk	t	200	275
Calcium hydroxide (lime), bulk	t	55	90
Carbon disulphide	t	370	500
Carbon tetrachloride, drums	kg	0.50	0.83
Chlorine	t	140	200
Chloroform	kg	0.45	0.70
Cupric chloride, anhydrous	kg	3.30	5.5
Dichlorobenzene	kg	0.95	1.54
Diethanolamine	kg	1.20	1.70
Ethanol, 90%	kg	4.20	6.50
Ethyl ether	kg	0.80	1.35
Ethylene, contract	kg	0.46	0.70
Ethylene glycol	kg	0.56	0.83
Ethylene oxide	kg	0.60	0.90
Formaldehyde, 37% w/w	kg	0.31	0.46
Formic acid, 94% w/w, drums	kg	0.63	1.05

Figure 26 Raw Material and Product Cost

raw material= aluminum sulfate + lime

= $ 1193 + $ 224666.3

= $ 225859.3

Miscellaneous materials = 0.1 * 538799.207 = $53879.9207

utilities = $ 9652.04

Fixed cost

Maintenance = 0.1 * $ 5387992.07 = 538799.207

Operating labour = $ 1730

Laboratory costs 0.2 * 1730 = $346

Supervision = 0.2 * 1730= $346

Plant overheads = 0.5 * 1730 = $875

Capital charges = 0.1 * $ 5387992.07 = $538799.207

Insurance = 0.01 * $ 5387992.07= $53879.9207

Local taxes =0.02 * $ 5387992.07= $107759.841

Royalties= 0.01 * $ 5387992.07 = $53879.9207

8.8 Annual Production Cost

Annual production cost = variable cost + fixed cost

= 289391.261 +1296415.1

= $ 1585806.36

= $1.58M

Variable costs	*Typical values*
1. Raw materials	from flow-sheets
2. Miscellaneous materials	10 per cent of item (5)
3. Utilities	from flow-sheet
4. Shipping and packaging	usually negligible
Sub-total A	....
Fixed costs	
5. Maintenance	5–10 per cent of fixed capital
6. Operating labour	from manning estimates
7. Laboratory costs	20–23 per cent of 6
8. Supervision	20 per cent of item (6)
9. Plant overheads	50 per cent of item (6)
10. Capital charges	10 per cent of the fixed capital
11. Insurance	1 per cent of the fixed capital
12. Local taxes	2 per cent of the fixed capital
13. Royalties	1 per cent of the fixed capital
Sub-total B	....
Direct production costs A + B	....
13. Sales expense	20–30 per cent of the direct production cost
14. General overheads	
15. Research and development	
Sub-total C	....
Annual production cost = A + B + C =	....

$$\text{Production cost £/kg} = \frac{\text{Annual production cost}}{\text{Annual production rate}}$$

Figure 27 Production Cost

8.9 Payback Period

Payback period is calculated on the basis of savings as the clean water is utilized for reuse and it is not for sale.

Payback period = Total investment / Savings (for $0.009/L)

= $ 5,721,326.625 / $ 716620.5

= 2.6 years

CHAPTER 09

HAZOP ANALYSIS

HAZOP, short for Hazard and Operability study, is a systematic technique used in the process industry to identify potential hazards and operability problems in a process design or operation. It is a proactive approach that helps ensure safety, environmental protection, and efficient operation of the process. The following terms are considered during performing the HAZOP analysis.

Common HAZOP Guidewords:

- **No Flow / Low Flow / High Flow:** Deviations related to flow rate
- **No Pressure / Low Pressure / High Pressure:** Deviations related to pressure
- **High Temperature / Low Temperature:** Deviations related to temperature
- **Out of Specification:** Deviations in composition or other process parameters
- **Loss of Containment:** Potential leaks, spills, or breaches in equipment
- **Reverse Flow:** Flow in the unintended direction

9.1 HAZOP on Coagulation Tank

Table 14 The HAZOP for Coagulation Tank

Guideword	Deviation	Possible Causes	Consequences	Existing Safeguards
No Flow	No incoming wastewater flow to the tank.	Pump failure, Blockage in piping, Valve closure	Overflow from the tank, Ineffective coagulation, poorly treated effluent	Level alarms in the tank, High-level shutdown of upstream

				equipment, Standby pump
Low Flow	Insufficient wastewater flow rate entering the tank.	Partial pump failure, Control valve malfunction, Upstream process upset	Increased residence time may improve coagulation but can also lead to settling problems, Potential for short circuiting	Flow meter and alarms
High Flow	Excessive wastewater flow rate entering the tank.	Pump overcapacity, Control valve malfunction, Upstream process upset	Reduced residence time may hinder coagulation, Potential for overflowing the tank, Carryover of solids to downstream treatment	High-level alarms and shutdown, Flow rate monitoring and control system
No Agitation	Mixing mechanism malfunction in the tank.	Mechanical failure of mixer, Power outage, Control system malfunction	Poor mixing can lead to ineffective flocculation and settling, Carryover of flocs to downstream	Agitator motor alarms, Standby mixer (if available)
High/Low Temperature	Deviations from optimal temperature range for coagulation.	Ambient temperature fluctuations, Heating/cooling system issues	Can impact coagulant performance and floc formation, Reduced treatment efficiency	Temperature monitoring system
Out of Specification	Incorrect dosage of coagulant added.	Human error during preparation or addition, Equipment malfunction (e.g., metering pump)	Poor floc formation, Ineffective solids removal, Carryover of solids to downstream treatment	Coagulant dosage monitoring system, Alarms for high/low dosage levels

Loss of Containment	Leakage from the coagulation tank.	Tank wall or piping breach, Valve leaks, Overflow due to excessive flow	Environmental contamination, Safety hazards for personnel, Disruption of treatment	Leak detection systems, Containment around tank

9.2 HAZOP on DAF

Table 15 The HAZOP for DAF

Guide Word	Deviation	Consequences	Safeguard/Actions
No Flow	No flow of air or water in the DAF system	Accumulation of solids in the flotation tank, reduced separation efficiency	Check air compressor, water supply and valves,
High Flow	Excessive flow of air or water	Overloading in the DAF unit, equipment damage	Adjust flow rate, monitor system performance
Low Pressure	Insufficient air pressure	Poor flotation efficiency, inadequate removal of solids	Check air compressor, adjust pressure settings
High Pressure	Excessive air pressure	Risk of equipment failure, increased wear and tear	Adjust pressure settings, monitor system perfomance
Low pH	Acidic conditions	Corrosion of equipment	Add alkaline chemicals
High pH	Alkalinity	Precipitation of metal ions	Add acidic chemicals
High Temperature	Elevated water temperature	Reduced gas solubility	Monitor temperature

Low Temperature	Cold water conditions	Reduced gas solubility	Monitor temperature
Equipment Malfunction	Mechanical or electrical issues	System shutdown	Regular Maintenance, emergency shutdown

9.3 HAZOP on clarifier

Table 16 The HAZOP for Clarifier

Guide Word	**Deviation**	**Consequence**	**Safeguards/ Control**	**Recommend Actions**
More Influent Flow Rate	Increased	Overloading of clarifier, reduced settling efficiency	High-level alarm, overflow bypass	Install flow control valve to limit flow rate
Less Clarifier Level	Decreased	Risk of pump cavitation, loss of clarifier function	Low-level alarm, automatic shutdown	Verify pump operation, inspect for leaks or blockages
NO pH of Effluent	No Change	Potential of pH drift outside acceptable range	pH monitoring, chemical dosing control	Calibrate sensors, adjust chemical dosing rates as needed
Less Sludge Removal Rate	Decreased	Accumulation of sludge, reduced clarifier efficiency	Sludge blanket level monitoring	Adjust rake speed or inspect rake mechanism
More Chemical Dosing rate	Increased	Overdosing chemical spill, environmental impact	Automated dosing control, spill containment	Review dosing rates, calibrate dosing equipment

9.4 HAZOP on RO

Table 17 The HAZOP for RO

Guideword	Deviation	Possible Causes	Consequences	Existing Safeguards
No Flow	No permeate flow from the RO system.	Feed pump failure, Membrane fouling, blocked permeate line, Control valve closure	Loss of product water, Increased concentrate concentration, Potential for system shutdown	Pressure gauges on feed and permeate lines, Flow meters and alarms, Differential pressure switch across membrane
Low Flow	Reduced permeate flow compared to normal operating conditions.	Partial pump failure, Membrane degradation, Feed pressure or salinity exceeding limits, Anti-scaling dosing issues	Reduced water production, Increased concentrate salinity, Potential for membrane fouling	Flow monitoring and alarms, Conductivity meters for feed and permeate, Pressure and temperature monitoring
High Flow	Excessive permeate flow exceeding design capacity.	Control valve malfunction, Damaged RO membrane, Incorrect permeate pressure setting	Potential for exceeding downstream treatment capacity * Poor quality permeate due to inadequate treatment	Permeate flow control system and alarms, High-pressure shutdown
High Pressure Feed	Feed pressure exceeding the maximum design limit of the RO membrane.	Pump overcapacity, Control valve malfunction, Blocked concentrate line	Potential for membrane damage Increased energy consumption System leaks	Pressure relief valves, Pressure monitoring and alarms Automatic pump shut-off
Low Pressure Feed	Feed pressure falling below the minimum requirement for RO operation.	Pump failure, Feed line leaks, Insufficient feed flow	* Reduced permeate production, Poor desalination performance, Membrane fouling	Low-pressure alarms Feed pressure monitoring * Standby pump (if available)

High/Low Temperature	Feed water temperature deviating from the optimal operating range for the RO membrane.	Ambient temperature fluctuations, Heat exchanger issues, Excessive pressure drop	Can impact membrane performance and lifespan, reduced permeate quality, Increased energy consumption	Temperature monitoring system, Alarms for high/low temperature excursions
Loss of Containment	Leak from the RO membrane pressure vessel or associated piping.	Pressure vessel breach, Faulty connections, Corrosion of piping	Environmental contamination, Safety hazards for personnel, Loss of product water	Leak detection systems, Pressure switches for leak down line, Automatic shutdown on pressure loss

9.5 HAZOP on pump

Table 18 The HAZOP for Pumps

Guideword	Deviation	Possible Causes	Consequences	Existing Safeguards
No Flow	No permeate flow from the RO system.	Feed pump failure, Membrane fouling, blocked permeate line, Control valve closure	Loss of product water, Increased concentrate concentration, Potential for system shutdown	Pressure gauges on feed and permeate lines, Flow meters and alarms, Differential pressure switch across membrane
Low Flow	Reduced permeate flow compared to normal operating conditions.	Partial pump failure, Membrane degradation, Feed pressure or salinity exceeding limits, Anti-scaling dosing issues	Reduced water production, Increased concentrate salinity, Potential for membrane fouling	Flow monitoring and alarms, Conductivity meters for feed and permeate Pressure and temperature monitoring
High Flow	Excessive permeate flow exceeding	Control valve malfunction, Damaged	Potential for exceeding downstream treatment	Permeate flow control system and alarms,

	design capacity.	RO membrane, Incorrect permeate pressure setting	capacity, Poor quality permeate due to inadequate treatment	High-pressure shutdown
High Pressure Feed	Feed pressure exceeding the maximum design limit of the RO membrane.	Pump overcapacity, Control valve malfunction, Blocked concentrate line	Potential for membrane damage, Increased energy consumption, System leaks	Pressure relief valves Pressure monitoring and alarms, Automatic pump shut-off
Low Pressure Feed	Feed pressure falling below the minimum requirement for RO operation.	Pump failure, Feed line leaks, Insufficient feed flow	Reduced permeate production, Poor desalination performance, Membrane fouling	Low-pressure alarms Feed pressure monitoring, Standby pump (if available)
High/Low Temperature	Feed water temperature deviating from the optimal operating range for the RO membrane.	Ambient temperature fluctuations, Heat exchanger issues, Excessive pressure drop	Can impact membrane performance and lifespan, reduced permeate quality, Increased energy consumption	Temperature monitoring system, Alarms for high/low temperature excursions
Loss of Containment	Leak from the RO membrane pressure vessel or associated piping.	Pressure vessel breach, Faulty connections, Corrosion of piping	Environmental contamination, Safety hazards for personnel, Loss of product water	Leak detection systems, Pressure switches for leak down line, Automatic shutdown on pressure loss

CONCLUSION

Our project has successfully addressed the pressing need for efficient effluent management at refineries, focusing on pivotal processes such as BOD and COD removal, and oil and metal separation by using coagulation tank, dissolved air flotation tank, clarifier and reverse osmosis membrane while strictly adhering to environmental guidelines. With a remarkable purity level of 92.7% achieved in our treatment process, a substantial decrease in industrial reliance on freshwater resources is anticipated, as the reclaimed water can now be effectively utilized across various refinery processes. This process helps us to achieve our primary objectives of a compact, time-saving, and cost-effective water treatment process.

While it addresses the need for efficient and economical water treatment solutions, it also fulfills the present sustainability requirements aimed at reducing effluent waste, protecting water bodies and the environment from hazardous contaminants like nitrates and chlorides.

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