Recycling of Industrial Waste Water, Feasible Technology and Economic Analysis

By

Syed Arsalan Akhtar

Baalaaj Waheed

M. Huzaifa Irfan

School of Chemical and Materials Engineering (SCME)

National University of Sciences and Technology (NUST)

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Recycling of Industrial Waste Water, Feasible Technology and Economic Analysis

Syed Arsalan Akhtar	Reg.No: 00000128668
Baalaaj Waheed	Reg.No: 00000131234
Muhammad Huzaifa Irfan	Reg.No: 00000120633

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Supervisor Name: Dr. Zaib Jahan

School of Chemical and Materials Engineering (SCME)
National University of Sciences and Technology (NUST)
H-12 Islamabad, Pakistan

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Certificate

This is to certify that work in this thesis has been carried out by **Mr. Syed Arsalan Akhtar, Mr. Baalaaj Waheed** and **Mr. Muhammad Huzaifa Irfan,** completed under my supervision in School of Chemical and Materials Engineering, National University of Sciences and Technology, H-12, Islamabad, Pakistan.

Supervisor: ______________________________________

Dr. Zaib Jahan

Assistant Professor
Chemical Engineering Department
School of Chemical and Materials Engineering (SCME)
National University of Sciences and Technology (NUST), Islamabad
.

Submitted through**:**

HoD:______________________	**Principal: __________________**
Dr. Muhammad Bilal Khan Niazi	**Dr. Arshad Hussain**
Chemical Engineering Department	Principal/Dean SCME

Dedication

To our parents, to our teachers, to our friends, and to SCME

Acknowledgements

We are forever grateful to the Almighty, for His countless blessings and rewards, Who gave us the strength and ability to complete this project successfully.

We would very much like to thank our supervisor, Dr. Zaib Jahan, for her support and guidance during our project. She has been very generous and supportive, and helped a lot to complete this project. Her instruction and counsel are the major reasons for our motivation throughout the project. We are also indebted to the faculty of SCME who have supported us in times of need.

We are also thankful to our parents, without their support and encouragement, it would not have been possible to complete this degree successfully.

Abstract

The wastewater that is contained in the equalization basin at Fatima fertilizers' plant has the ability to be reused. The water that is being discharged to the scarp has potential to be utilized as cooling water makeup. This water contains high amount of TDS which if used as it is, would result in scaling of the equipment and is likely to be detrimental to the process. Our aim is to make sure that this water can be reused by employing a method that is economical and proven. The method that we have proposed is in line with today's technology and provides water that has the required specifications required for reuse.

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Chapter 1: Introduction

Fatima Fertilizers produces almost 354 m^3/hr. of waste water that is being discharged to the nearest scrap. This is huge quantity of water that can be used if treated properly. The specifications of this water are as follows:

Component	Amount
TDS	820.02Kg
T.NH3	19.9Kg
SS	6.02Kg
FLOURIDE	0.212Kg
OIL	1.77Kg

Table 1 Composition of Feed Water

Waste Water Treatment Plants (WWTPs) are installed in industries to treat waste water before its disposal to water channels. When such plants are used to treat waste water to such extent so that it can be reused, they are essentially called Waste Water Recycling Plants. The main purpose of this project is to reduce the TDS levels of the water. We would like to reduce the TDS levels by almost 90%.

TDS,or the Total Dissolved Solids, are the salts or minerals that have been completely dissolved in water, and therefore cannot be removed by large solid-liquid separators such as screens, etc. Therefore, they required special membranes that have perforations in the nano-scale or even smaller so that the salts can retain while the even smaller water molecules pass from the membrane.

Chapter 2: Literature Review

There are a number of methods available for the removal of TDS from water. Comparison of few of the technologies is given below:

2.1 Comparison Of different technologies:

2.1.1 REVERSE OSMOSIS:

2.1.1.1 Osmosis:

To completely understand the process of reverse osmosis, first we need to understand the naturally occurring process of Osmosis.

Osmosis is a process where a weaker saline solution has a natural tendency of migrating towards a stronger saline solution. This occurs due to the concentration gradient present between both solutions.

For example:

If we have two containers, one container having water with low salt concentration and other container having water with high salt concentration. These two containers are separated by a semi permeable membrane. The water with low salt concentration will naturally move towards the high salt concentration due to concentration gradient.

It is important to note that natural osmosis occurs without need of any external forces.

2.1.1.2 Reverse Osmosis:

Reverse osmosis is in simple words process of osmosis occurring in reverse. Reverse osmosis requires application of some external force to the more saline solution. Reverse osmosis usually uses semi permeable membranes that allow water to pass through them but salt is retained. However, the water won't pass through the membrane if applied pressure is less than naturally occurring osmotic pressure.

2.1.1.3 Mechanism:

In a RO process the feed is usually passed through a high-pressure pump to increase the pressure above osmotic pressure. After the water is passed through the RO membrane usually 95 to 99% of salts are removed. The pressure required depends on the salt concentration in the feed.

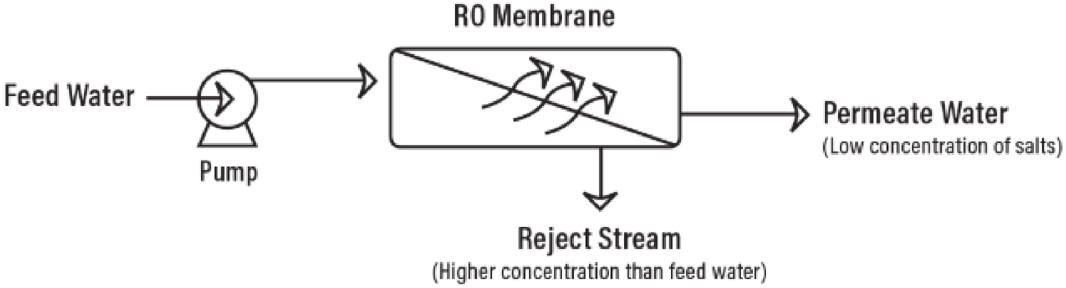


Figure 1 RO Process

It is important that RO employs a cross filtration process rather than the standard filtration. This is due to the fact that in standard filtration the contaminants are collected inside the filter which will cause massive fouling of our membrane. To avoid this buildup of impurities cross filtration is used.

2.1.1.4 What kind of impurities RO removes?

RO is capable of removing the following impurities:

- Particles
- Colloids

- Organics
- Bacteria
- Pyrogens

It must be noted that RO won’t remove 100% of the bacteria and viruses. A RO membrane separates on the basis of charge and size.

2.1.1.5 Performance Parameters Of RO:

The performance of RO membrane depends upon the following factors:

- Feed Pressure
- Permeate Pressure
- Concentrate Pressure
- Feed Conductivity
- Permeate Conductivity
- Feed Flow
- Permeate Flow
- Number of passes and stages in RO system
- Fouling
- Pre-treatment

2.1.1.6 Advantages of RO:

- As no phase change occurs during the process the energy requirements are low.
- RO systems are very compact so space requirements are small.
- RO systems require less labour to operate as system is mostly automated.
- RO provides highly pure and clean water, almost 99% of the salts are removed.

2.1.1.7 Disadvantages of RO:

- High water rejection rates.

2.1.2 MEMBRANE BIO REACTORS:

Membrane Bio Reactor process combines the biological activated sludge process with another membrane filtration process. The main advantage of using MBR instead of conventional activated sludge process is that a much high quality effluent is obtained using the MBR. MBR can be operated at much higher solid concentrations as compared to conventional methods.

2.1.2.1 Mechanism:

Usually before the feed enters the MBR system some pretreatment takes place. After the pretreatment the feed enters MBR system Different configurations are used such as:

- Membrane Immersed in Bioreactor
- External Membrane System

2.1.2.2 Impurities removed by MBR:

MBR efficiently removes the following impurities:

- Solid Particles
- Bacteria and viruses
- Organic materials

2.1.2.3 Factors influencing MBR:

- The Biomass concentration
- Membrane Configuration
- Fouling
- Transmembrane Pressure
- Feed Flux

2.1.2.4 **Advantages of MBR:**

- Almost complete solids and bacteria removal.
- High effluent quality; modular design with good expandability.
- Robustness in recovery resistant to upsets due to shock loadings or peak and fluctuating flows.
- Less odour.
- Sophisticated but yet simple controls.

2.1.2.5 Disadvantages of MBR:

- MBR requires high operating costs due to high fouling that occurs.
- Fine screening is required.
- Chemical cleaning is necessary.

Chapter 3: Process Description

3.1 PFD:

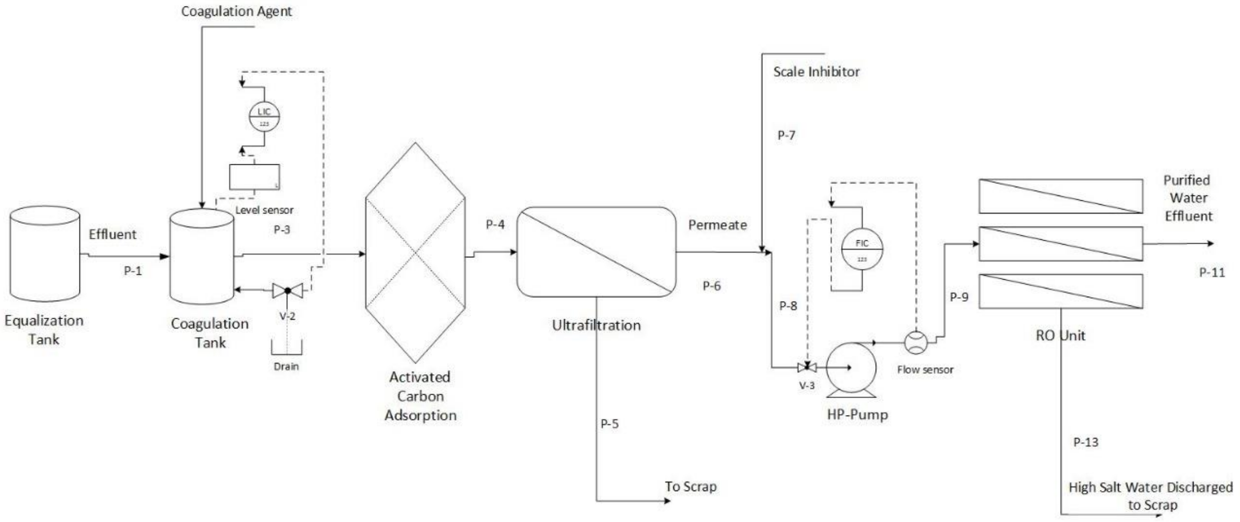


Figure 2 PFD

3.1.1 Equalization Tank:

The feed water coming as waste water first enters an equalization tank. The use of equalization tank serves the following purposes:

- The flow rate of feed entering the system is varying so equalization tank helps in stabilizing the flow rate. This is done to prevent upsizing of downstream equipment.
- Equalization tank also helps in reducing the amount of chemicals used in upcoming steps.
- Another advantage of using equalization tank is to maintain an appropriate level of ph.
- Equalization of flow rates helps in increased efficiency of the process.

3.1.2 Coagulation Tank:

After leaving the equalization tank the water enters a coagulation tank. Coagulation is used to remove color, turbidity, suspended solids and other such impurities. In our process we will be using Alum as the coagulant. The quantity of coagulant depends upon the feed rate and quality of incoming water. Coagulation has an advantage over sedimentation as it reduces the time required to remove the suspended solids. It must be kept in mind that for coagulation to be carried out efficiently the dosage amount of coagulant must be calculated accurately. The efficiency of coagulation depends upon the following factors:

- The coagulant used.
- The flow rate of feed water.
- The properties of feed water.
- The coagulant dose rates.

In the process of coagulation, the coagulant destabilizes the charge present on the particles. The coagulant added to the water has opposite charge as compared to that of suspended solids. This neutralizes the charge present on the particles due to which particles and stick to each other and form micro flocs. Mixing is than done to increase turbulence and particle collision due to which a large number of micro flocs are obtained. After which the particles settle down and can be easily removed.

3.1.3 Activated Carbon Adsorption:

The process of adsorption is used to remove soluble substances from water. We in our process will be using the process of carbon adsorption to remove the oil present in our feed water. If this oil is not removed it can cause fouling of membranes and decreasing their efficiency.

Water will enter a column containing the activated carbon bed, the area of the bed required depends upon the amount of impurities present in the water. The substances and impurities are accumulated in the carbon bed. This accumulation of impurities causes a decrease in efficiency of the process due to which the bed needs to be replaced periodically.

Following factors influence the efficiency of the process:

1) The type of impurities and substances that need to be removed.
2) The amount of impurities present in the feed water. If the amount of impurities is high the consumption of carbon will also increase.
3) The flow rate of incoming water.
4) Temperature and pressure also influence the performance of activated carbon adsorption.

3.1.4 Ultrafiltration:

Ultrafiltration is a separation process in which separation occurs on the basis of size difference. Ultrafiltration can separate particles between size range of 0.1 to 0.001 micron. In our process we are using Ultrafiltration to remove the remaining amounts of oil and suspended solids present in the water. This is important because if these impurities are not removed, they can cause fouling of the RO membrane in the next step. Which would significantly reduce the efficiency of the process. The type of membrane material used and its efficiency depends upon the following factors:

- Module used for membrane.
- Pore size of membrane used.
- Flow type meaning whether the process will occur in crossflow pattern or in Dead end.
- Feed flow rate.
- Temperature and pressure at which membrane is being operated.
- Concentration of impurities present.

3.1.5 High Pressure Pump:

The High Pressure (HP) Pump provides the water with such an amount of pressure so 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.

3.1.6 RO Unit:

The RO Membrane unit is used to rid the water off of the dissolved salts so as to achieve the fresh water standards. When the water containing high amounts of TDS flows into the RO unit, it passes through membrane elements which 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 amount 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 cross flow in the RO unit.

Chapter 4: Material Balance

Inlet:

Basis: 1 hr for the whole plant.

Component	**Flow Rate**
Water Flow	354,000 kg/hr.
TDS	820.218 kg/hr.
SS	6.018 kg/hr.
Fluoride	0.2124 kg/hr.
TNH_3	19.89448 kg/hr.
Oil	1.77 kg/hr.

Table 2 Inlet Flowrates

4.1Coagulation Tank:

- 90% SS will be removed.

$$In = Out + Removed\ SS$$

$$354{,}000\ kg = out + 5.4162\ kg$$

$$out = 353{,}994.58\ kg$$

Component	**IN**	**Out**
TDS	820.02Kg	820.02Kg
T.NH3	19.9Kg	19.9Kg
SS	6.02Kg	0.602Kg
FLOURIDE	0.212Kg	0.212Kg
OIL	1.77Kg	1.77Kg

Table 3 Material Balance on Coagulation Tank

4.2 Carbon Adsorption:

- Carbon adsorption removes 80% the oil.

$$In = Out + Removed\ Oil$$

$$353{,}994.58\ kg = out + 1.416\ kg$$

$$out = 353992.81\ kg$$

Component	**IN**	**OUT**
TDS	820.02Kg	820.02Kg
T.NH3	19.9Kg	19.9Kg
SS	0.602Kg	0.602Kg

FLOURIDE	0.212Kg	0.212Kg
OIL	1.77Kg	0.354Kg

Table 4 Material Balance on Carbon Adsorption Unit

4.3 UF Filtration:

- 99% of oil and TSS are removed.

$$In = Out + Removed\ Organics$$

$$353{,}992.81\ kg = out +\ 2.01366$$

$$out = 353{,}990.796\ kg$$

Component	IN	OUT
TDS	820.02Kg	820.02Kg
T.NH3	19.9Kg	19.9Kg
SS	0.602Kg	0.00602Kg
FLOURIDE	0.212Kg	0.212Kg
OIL	0.354Kg	0.00354Kg

Table 5 Material Balance on UF

4.4 RO:

- Around 90% of TDS is removed.
- 40% water is rejected during the process.

$$In = Out + Removed\ TDS + Rejected\ Water$$

$$353{,}974.81\ kg = out + 738.018\ kg + 141{,}589.92\ kg$$

$$out = 211{,}646.87\ kg$$

Component	**IN**	**OUT**
TDS	820.02Kg	82.02Kg
T.NH3	19.9Kg	19.9Kg
SS	0.602Kg	0.00602Kg
FLOURIDE	0.212Kg	0.212Kg
OIL	0.354Kg	0.00354Kg

Table 6 Material Balance on RO

Chapter 5: Energy Balance

General Equation:

$$\boldsymbol{\Delta H + \Delta K.E + \Delta P.E = Q + W}$$

Where:

ΔH: Change in Enthalpy

ΔK.E: Change in Kinetic Energy

ΔP.E: Change in Potential Energy

Q: Heat Input

W: Work done

5.1 Equalization Basin:

Water Flow in	354 m^3/hr.
Inlet Temperature	30 ℃
Specific Enthalpy	125.75 KJ/Kg
Outlet Temperature	30 ℃

Table 7 Equalization Basin Energy Balance Data

The energy balance equation is reduced to:

$$Q = \Delta H$$

As Q= 0

$$H_{in} = H_{out}$$

$$125.75 \times (\ 354 \times 1000) + 412 \times 990.48$$
$$= 125.75 \times (\ 354 \times 1000) + 412 \times 990.48$$

$$4.492\ \times 10^7 KJ = 4.492\ \times 10^7 KJ$$

5.2 Coagulation Tank:

Water Flow in	354 m^3/hr.
Inlet Temperature	30 ℃
Specific Enthalpy	125.75 KJ/Kg
Outlet Temperature	30 ℃
Inlet Temperature	4.492 ×10^7 KJ

Table 8 Coagulation Tank Energy Balance Data

The energy balance equation is reduced to:

$$Q = \Delta H$$

As Q= 0

$$H_{in} = H_{out}$$

$$125.75 \times (\ 354 \times 1000) + 412 \times 990.48$$
$$= 125.75 \times (\ 354 \times 1000) + 412 \times 990.48$$

$$4.492\ \times 10^7 KJ = 4.492\ \times 10^7 KJ$$

5.3 Ultra-Filtration:

Water Flow in	354 m^3/hr.
Inlet Temperature	30 ℃
Specific Enthalpy	125.75 KJ/Kg
Outlet Temperature	30 ℃
Inlet Temperature	4.492 ×10^7 KJ

Table 9 UF Energy Balance Data

The energy balance equation is reduced to:

$$Q = \Delta H$$

As Q= 0

$$H_{in} = H_{out}$$

$$125.75 \times (354 \times 1000) + 412 \times 990.48$$
$$= 125.75 \times (354 \times 1000) + 412 \times 990.48$$

$$4.492 \ \times 10^7 KJ = 4.492 \ \times 10^7 KJ$$

5.4 Pump:

The Equation for Energy Balance of Pump is as follows:

$$W = \frac{V \, \Delta P \, (1 - \beta T)}{\varepsilon}$$

Inlet pressure(kpa)	500
Outlet pressure(kpa)	2000
Inlet temperature(°C)	30
Water flowrate(m^3/hr.)	352
Efficiency of pump	0.75
Expansivity co-efficient(1/K)	0.00028
Energy provided by pump(kW)	93
Energy at inlet(kJ)x10^7	4.492
Energy at outlet(kJ)x10^7	4.530

Table 10 Pump Energy Balance Data

5.5 RO:

Water Flow in	354 m^3/hr.
Inlet Temperature	30 ℃
Specific Enthalpy	125.75 KJ/Kg
Outlet Temperature	30 ℃
Inlet Temperature	4.453 $\times 10^7$ KJ

Table 11 RO Energy Balance Data

The energy balance equation is reduced to:

$$Q = \Delta H$$

As Q= 0

$$H_{in} = H_{permeate} + H_{concentrate}$$

$$4.453 \times 10^7 KJ = 211 \times 10^7 KJ + 141 \times 10^7 KJ$$

Chapter 6: Equipment Design

6.1 COAGULATION TANK

6.1.1 Volume of Tank:

The volume of the coagulation tank is found by the following formula:

$$V = L \times W \times H$$

Flow rate of water=$8496m^3/hr$

Retention time within tank= 2 hours

Capacity of tank= $\frac{8496\times2}{24} = 708m^3$

$$708m^3 = L \times W \times H$$

Assuming that the depth= 3m

This is an accurate assumption based on rectangular coagulation tanks.

Length = 3W

$$708 = 3W \times W \times 3$$

$$708 = 9W^2$$

$$W = 8.9m$$

$$L = 3W = 26.7m$$

Allowing 3 meters additional length for the inlet and outlet sections:

Total length comes out to be 29.7m ≈30m

To allow for the settling of sediment, 1 meter additional depth is provided.

6.1.2 Final Specifications:

The final dimensions of the coagulation tank come out to be:

L=30m

W=9m

D=4m

Actual Volume= $1080m^3$

6.2 ACTIVATED CARBON ADSORPTION COLUMN

6.2.1 Pilot Column Specifications:

The activated carbon adsorption column has been designed on the model of a pilot scale plant. The pilot scale plant has been scaled up in order to achieve the specifications that our activated carbon adsorption column demands.

The pilot scale plant has the following specifications:

Q=200 L/hr

Diameter=10cm

Depth=600cm

Packed bed density=$400kg/m^3$

Breakthrough volume= 15000L

Exhaustion volume= 16500L

6.2.2 Filtration Rate:

Filtration Rate= $\frac{2550cm^3}{hr.cm^2}$

The packed column has the same filtration rate as that of the pilot plant.

$$FR = \frac{Q}{A}$$

Where:

FR= filtration rate

Q= volumetric flow rate

A= cross sectional area

6.2.3 Area of Packed Column:

$$2550 = \frac{354 \times 10^6}{A}$$

$$A = 138\,800cm^2$$

$$A = \frac{\pi d^2}{4}$$

$$d = 4.24m$$

The diameter of the packed bed column is 4.24 m.

6.2.4 Empty Bed Contact Time:

Empty bed contact time of the pilot is:

$$\tau = \frac{\forall}{Q}$$

Where:

$$\tau = emptybedcontacttime$$

$$Q = volumetric\ flow\ rate$$

$$\forall = volume\ of\ pilot\ column$$

Volume of pilot column= Area x Height

Volume= 47L

$$\tau = \frac{47}{200}$$

$$\tau = 14.1\ min$$

The empty bed contact time for the packed column is the same as that of the pilot column. As the EBCT is the same, the height of the column is also the same.

The height of the packed column= 6m

6.2.5 Mass of Carbon in Packed Column:

Mass of carbon required in the packed column:

$$mass\ of\ carbon = volume\ of\ column \times packing\ density$$

$$mass\ of\ carbon = 84 \times 400$$

$$mass\ of\ carbon = 34\ tonnes$$

$$TOC\ removed\ by\ pilot\ column = TOC \times volume\ of\ exhaustion$$

$$TOC\ removed = 20 \times 16500 = 330\ 000 mg$$

TOC removed per gram of carbon= $\frac{330\ 000}{9500} = \frac{34 mg}{g} C$

6.2.6 Organic Loading:

Organic loading of packed column:

$$organic\ loading = 20\ \times 8496\ \times 1000 = 16.99 \times 10^7\ mg/d$$

$$carbon\ consumption = 4471\ kilograms\ per\ day$$

Carbon consumed total before breakthrough:

$$34\ 000\ \times\ 0.91 = 30\ 940\ kg$$

Breakthrough time:

$$\frac{34\ 700}{4471} = 7\ days$$

Volume treated before breakthrough= 60 000 cubic meters.

6.2.7 Final Specifications of the Column:

Final specifications of column:

Height= 6m

Diameter= 4.24m

Carbon amount= 34 tonnes

Volume of column=$84m^3$

6.3 ULTRA-FILTRATION

6.3.1 Flux Calculation:

Formula for flux calculation:

$$J = \frac{Qp}{Am}$$

J= flux through membrane

Qp= permeate flow

Am= area of membrane

For an operating flux of 80 Lmh (common for ultra-filtration units)

Recovery of 99.4%

Qp= 0.994 x 354= 352 cubic meters per hour

6.3.2 Area of Membrane:

Area of membrane required:

$$Am = \frac{354\ 000}{80} = 4425m^2$$

Each element has an area of 54 square meters.

The number of elements thus required is:

$$\frac{4425}{54} = 82$$

6.3.3 Final Membrane Specs:

Final UF membrane specs:

Spiral wound membrane composed of poly-sulfone

Area of membrane=$4425m^2$

Number of membrane elements required=82

6.4 PUMP

6.4.1 Differential Head:

Suction Head = 500 Kpa

Discharge Pressure = 2000 Kpa

Differential Head, H, is given by

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

$$= (2000 - 500) * \frac{1000}{1000 * 9.8}$$

$$= \mathbf{153.06}\ \boldsymbol{m}$$

6.4.2 NPSH Available

$$NPSH\ available = (Psuc - Pvap) * \frac{1000}{\rho g}$$

$$= 500 - 3.17\ \frac{1000}{1000 * 9.8}$$

$$= \mathbf{50.69}\boldsymbol{m}$$

6.4.3 Impeller Diameter and Efficiency

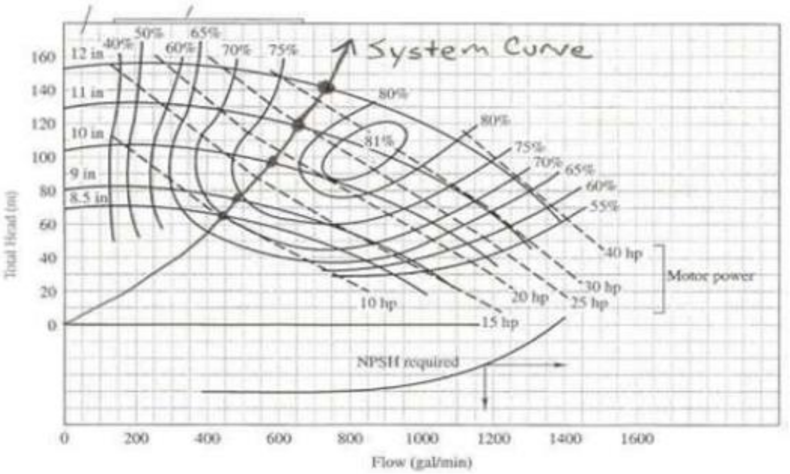


Figure 3 Pump Performance Curve

$$Volumetric\ Flow\ Rate = 8496\frac{m^3}{hr.}\ x\ 0.18\ \frac{gpm}{1\ \frac{m^3}{day}}$$

$$= 1529\ gpm$$

Given the flow rate of 1529gpm and 153.06m of differential pressure head, the suitable impeller diameter would be 13in and efficiency would be around 75%

6.5 REVERSE OSMOSIS MEMBRANE

6.5.1 Feed Specification and Target:

The reverse osmosis unit is where the process of reduction of TDS is taking place. The TDS is reduced from 2300ppm to around 200ppm. This is a reduction of almost 90%.

Amount of water is 352 cubic meters per hour.

We are targeting 60% recovery.

6.5.2 Flow Arrangement:

The flow arrangement is as follows:

Plug flow with single pass.

The element that is being used has a diameter of 8 inches.

Flux of brackish water that has been found from literature is usually 20Gfd.

The membrane element widely used in desalination plants today is BW 30-445

This element has an active area of 440 square meters.

6.5.3 Number of Elements Required:

To calculate the number of elements:

$$Ne = \frac{permeate\ flow}{flux * area}$$

Permeate flow with 60% recovery = 780 gpm

So Ne:

$$\frac{780\ \times 1440\,\frac{gpd}{gpm}}{20gfd\ \times 440\ ft^2} = 128$$

The number of elements comes out to be 128.

6.5.4 Number of pressure vessels required:

The number of pressure vessels required to house this number of elements is:

Each vessel can hold up to 6 elements.

$$\frac{128}{8} = 16$$

16 vessels are needed to house the required number of elements.

As the amount of water is very high so the number of stages in our RO system with 60% recovery is 1. All the pressure vessels are in the same stage.

6.5.5 Volume of a single pressure vessel:

Diameter of each element= 8 inches

Vessel dia= 8+1= 9 inches

1 inch is the allowance

Each element is 40 inches long.

Total length of vessel (elements connected in series):

$$length = (6\ \times 40) + 1 = 241\ inches$$

1 inch is the allowance. 0.5 inch at each end.

Volume of one vessel is:

$$volume = \frac{\pi d^2}{4} L$$

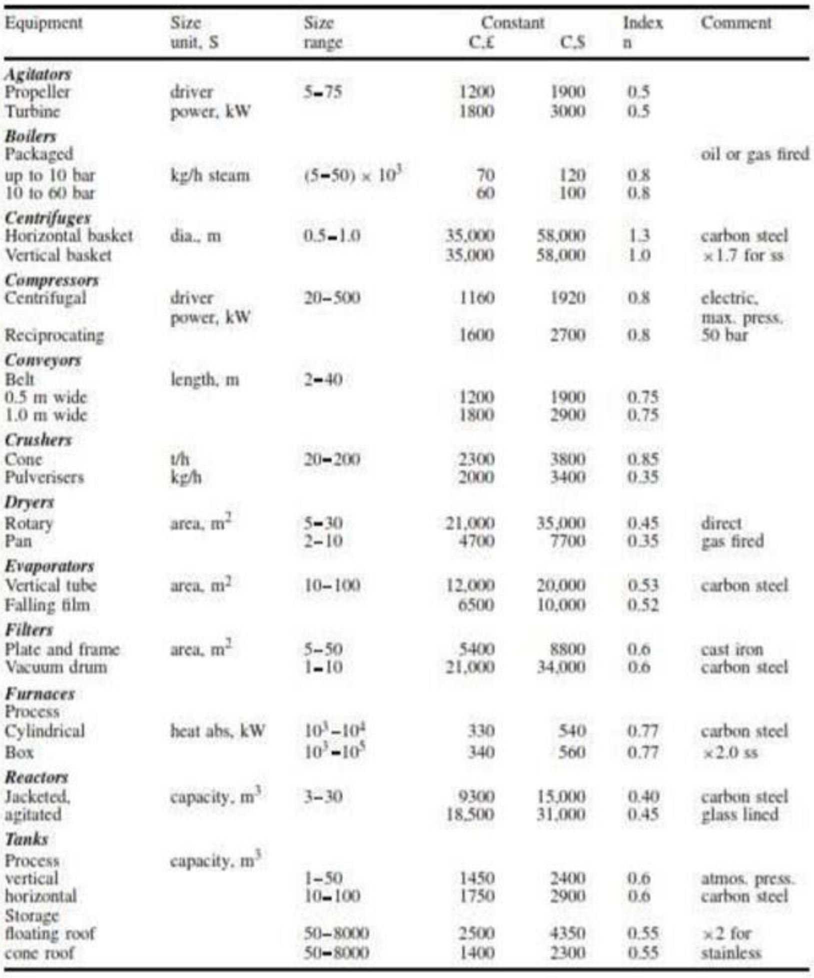
$$\frac{\pi}{4} \times 8.9^2 \times 241 = 14\,993\ in^3$$

14 993 square inches when converted to meters=$0.246m^3$

So, the volume of one pressure vessel is $0.246m^3$

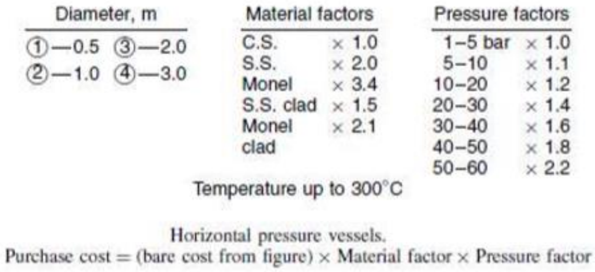
Chapter 7: Costing

Following charts and graphs have been used to perform the costing of the equipment individually and the economic analysis of the plant as a whole.



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

Table 12 Base costs, size units and cost indices for different equipment



Diameter, m

①—0.5 ③—2.0
②—1.0 ④—3.0

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

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

Temperature up to 300°C

Horizontal pressure vessels.
Purchase cost = (bare cost from figure) × Material factor × Pressure factor

7.1 Individual Equipment Costing

7.1.2 Equalization Tank:

Although our process flow diagram shows Equalization basin as a part of our design process, it is already in place working and there is no for the re-installation of this component considering the economic restraints.

7.1.3 Coagulation Tank:

One of the main objectives of the project is to design a proven system with economic efficiency and feasibility. To achieve that objective, we have performed such calculations where desired concentration would be achieved without the installation of the impeller. Hence the cost calculation will only be limited to the tank.

Capacity of the Tank = **1080 m^3**

$$Cost = \boldsymbol{CS^n}$$

$$= 2400 * (1080)^{0.6}$$

= **610,000 USD**

7.1.4 Activated Carbon Adsorption:

The costing of this component includes the costing of the column as well as the packed carbon bed. After design of this adsorption column following data has been calculated which will be used to calculate the cost.

Volume of the column = 84 m^3

Packing Density = 400 kg/m^3

Amount of Carbon = 34 tonnes

$$COST_{(column)} = CS^n$$

$$= 2400 * (84)^{0.6}$$

$$\text{Total Cost} = COST_{(column)} + COST_{(carbon)}$$

= **400,000 USD**

7.1.5 Ultra-Filtration Membrane:

In the design phase it was decided that according to our need, maintenance, plasticization pressure and economic allowance POLY-SULFONE material hollowfiber membranes will be installed for the removal of total suspended solids by ultra-filtration.

Membrane Area = **4425 m^2**

*COST = Cost per unit area * area*

= 225.9 * 4425

=**1,000,000 USD**

7.1.6 High Pressure Pump:

For the costing of the HP pump following table was used. Capacity/ flow rate has been plotted on the x-axis of the graph while the purchase cost in USD is plotted on the Y-axis.

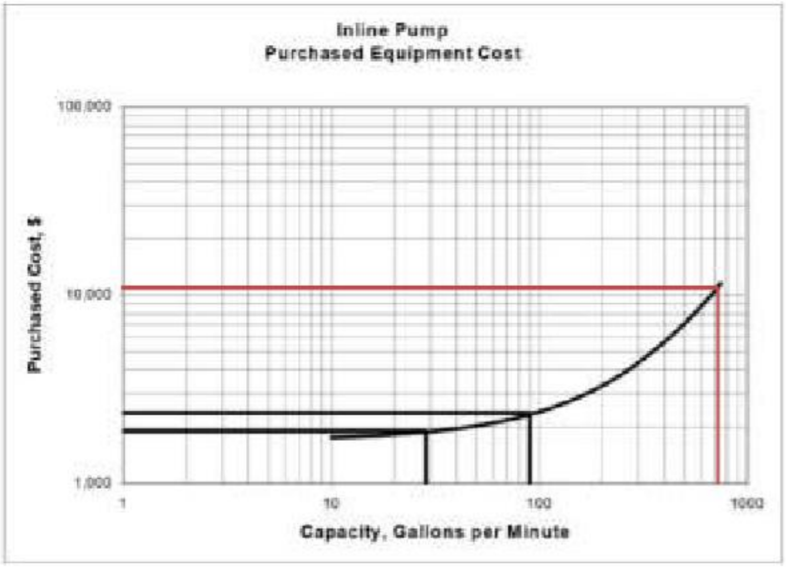


Figure 4 Pump Capacity vs Purchased Cost

Volumetric Flow Rate = **1529.2 GPM**

Cost from Graph = **64500 USD**

7.1.7 RO Membrane:

Total cost of the Reverse osmosis which is the most important part of the process depends upon the cost of pressure vessels and the membrane elements.

a. **Pressure Vessels:**

x = # of vessels = 16

Capacity of Vessels = **0.331 m^3**

COST **= *xCS^n***

$= 16 * 290000 * (0.331)^{0.6}$

= **2,390,000.9 USD**

Accounting for the pressure factor, the cost of RO vessels will be as follows

*Purchase Cost = Cost * Pressure Factor*

= 23900.9 * 1.2

= **2,868,100.12 USD**

b. **Membrane Elements**

*No. of elements = no. of elements per vessel * no. of vessels*

= 8 * 16 = 128 membrane elements

*Cost = Cost per element * no. of elements*

= 54500 * 128

= **6,976,000 USD**

c. **Total RO cost**

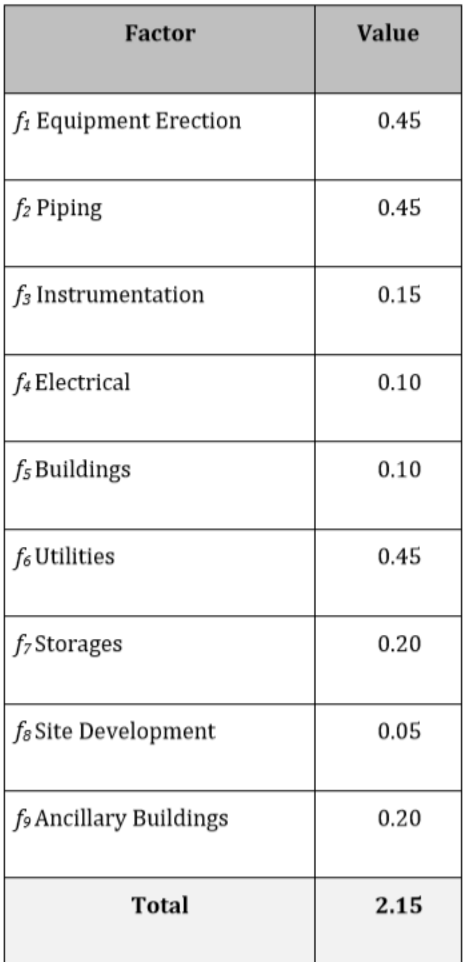
$$COST_{(RO\ total)} = COST_{(Vessels)} + COST_{(Elements)}$$

$$= 2{,}868{,}100 + 6{,}976{,}000$$

$$\mathbf{= 9{,}844{,}100.17\ USD}$$

7.1.8 Plant Physical Cost:

Following Lang's factors are multiplied with the total equipment cost for the calculation of plant physical cost



Factor	Value
f_1 Equipment Erection	0.45
f_2 Piping	0.45
f_3 Instrumentation	0.15
f_4 Electrical	0.10
f_5 Buildings	0.10
f_6 Utilities	0.45
f_7 Storages	0.20
f_8 Site Development	0.05
f_9 Ancillary Buildings	0.20
Total	**2.15**

Table 13Lang's factors to calculate PPC for system containing solids and liquids

7.2 Fixed Capital Costing:

After the calculation of purchase cost of each equipment individually, we can now perform an economic analysis on the plant under the heading of Fixed Capital cost which will cover the equipment purchase and installation cost.

The following table shows the calculation of fixed capital cost.

Equipment name	Cost ($)
Coagulation Tank	**0.21 million**
Carbon Adsorption Column	**0.4 million**
Ultra-Filtration Membrane	**1 million**
HP Pump	**0.0645 million**
Reverse Osmosis Membrane	**10 million**
Total Fixed Capital	**11.7 million**

Table 14 Fixed Capital Cost

7.2.1 Working Capital and Initial Investment:

Working Capital is taken to be 2% of the fixed capital

= 0.02 * 11.7 million USD

= **230,000 USD**

7.2.2 Total Initial Investment:

Initial investment = fixed capital + working capital

= 11,700,000 + 230,000

= **11.93 million USD**

7.2.3 Annual Operating Costs:

Operating time (allowing for plant attainment) = 95% * 365

= 347 days/year

= 8328 h/year

Kind of cost	Assumption made	Cost($)
Maintenance	1% of fixed capital	117000
Operating labor	Labor required	100000
supervision	20% of labor	20000
Plant overheads	50% of labor	50000
Capital charges	5% of fixed capital	600000
Taxes	1% of fixed capital	117000
Operating cost	Sum of all costs	1.004 million

Table 15 Annual Operating Costs

$$\text{Annual Operating Cost} = \text{Fixed operating cost} + \text{variable operating cost}$$

$$= \mathbf{1{,}004{,}000\ USD}$$

Chapter 8: HAZOP Analysis

Hazard and operability (HAZOP) analysis is done on a plant to predict possible deviations from the design parameters. This analysis is the modern day safety measure which is divided into many stages which include the identification of possible hazard, the causes due to which that problem might occur, the consequences of that problem from the minimum damage possible to the worst case scenario and recommendations (actions) that must be taken in order to avoid any incident.

HAZOP study is done on the entire plant including the individual equipment, piping, utilities and valves etc. Main purpose of HAZOP is the identification of threat, any actions that are taken to prevent should be economic and realistic. For example, the installation of temperature control system in an equipment where temperature rise is not a hazard is both a waste of time and resources. Care must be taken to avoid finding solutions that are not apparent.

8.1 Terminology:

Following is the table of terminologies that will be used while performing HAZOP study along with their meanings/definitions.

Term	**Meaning**
- Study Nodes	The area that is limited by the parameters in consideration
- Operating Steps	The procedure being analyzed by the team performing HAZOP
- Intention	The routine operations that are expected of the study node
- Process Parameters	Characteristics used to define the process and which may be chemical or physical
- Deviation	Difference in operations from the desired intention
- Cause	The possible reasons behind the deviations
- Consequences	The results of the changes in the system
- Safeguards	Engineered systems to ensure that the system follows the intention
- Actions	Requirements rising from the deviations.

Table 16 HAZOP Terminologies

8.2 High Pressure Pump:

Deviation	**Causes**	**Consequences**	**Recommendations**
Pressure	• Overflow to cause increased Pressure • Restricted flow to cause decrease in Pressure	• Cavitation • Damage to pump • Recirculation • Increased power consumption	• Application of control loop. Regulation and control of flow
Temperature	• Increased or decreased temperature	• Increased risk of cavitation	• Temperatures control and regulation columns
Flow	• More or less flow	• Recirculation • Reduced Efficiency • Cavitation	• Flow regulation and transmittance

Table 17 HAZOP of PUMP

8.3 Carbon Adsorption Column:

Deviation	Causes	Consequences	Recommendations
No Flow	• Valves from equalization basin closed • The pump has shut down	• No removal of organic impurities	• Manual Operation of closed valves • Non stop working of pump
Less Flow	• Tubing is pinched • Less flow of water to column	• Insufficient flow to decrease impurity removal	• Tube cleaning • Change of pinched tubes/pipes
More Flow	• Power surge to increase the flow from pump • Increased pump speed error by operator	• Overflow of water to fill the absorber and cause drainage	• Power surging prevention system with all the pumps • Flow limiting automatic valve installation

Table 18 HAZOP of Carbon Adsorption Unit

8.4 RO Membrane:

Deviation	Causes	Consequences	Recommendations
No Pressure	• Blockage at inlet or outlet • Pump Failure • Fouling • Manual Valve Failure	• Line trip • No permeate production	• Installation of auto vent on line • Install safety lock switches
Low Pressure	• Decrease in water level • Strainer Blockage • Pump Corrosion	• Line trip • No permeate production	• Controlling of manual valves • Installing moisture sensor near sand filter pump
Low Flow	• Failure in pump suction • Check valve blockage • No manual valve at raw water pump outlet	• Line trip • No permeate production	• Controlling manual valves • Regular Backwash of sand filters • Periodic Inspection and Maintenance
High Flow	• Start accidental pump • No manual valve • Mechanical failure in flange	• Line trip • Pipe cracking • No production of permeate	• Programming on PLC that no start additional pump when one pump is running
Service Failures	• Acid Pump Corrosion • Mechanical failure in acid instrument	• No unloading of Acid,	• Maintenance and periodical repairing

		diffusion of Acid on place	

Table 19 HAZOP of RO

8.5 Equalization Tank:

Deviation	**Causes**	**Consequences**	**Safeguards**	**Recommendations**
High Flow Rate	Tanker man sets the flowrate too high or might be failure of control system	Potential to over pressurize the tank during filling. It could cause injury to operator in area	Tanker man to detect the problem There is a reductant level control system	Verify that the relief valves on the tank are sized.
Low Flow Rate	Pump operator closes a valve at wrong time Valve fails closed	Leads to pump impeller, leak aging and vibration	Level control valves and level control system must be inspected regularly	Consider installing flow rate indicators in the filling lines

Table 20 HAZOP of Equalization Tank

Chapter 9: Simulation

We have used DOW WAVE software for the simulation of the process. This software is specially designed for water treatment simulation applications as the name suggests, Water Application Value Engine. This software is a product of DOW chemicals which is the largest chemical company in the world by sales

Although it is mentioned in the results of the software that the simulation results may not adhere to the real-life situations, but after test runs and comparisons with our manual calculations, we have concluded that this software is useful for the calculation of water treatment systems involving membrane processes.

A series of screenshots from the software shows the simulation of Ultra-filtration and Reverse Osmosis membrane operation with our specified flow rate. Other parameters like percentage recovery, pressure drop and removal of total dissolved solids are calculated by the software. In addition to the calculation of the above-mentioned parameters, the software also decides if the RO process with single pass or double pass is economically feasible or not.

9.1 Home:

UF and RO systems were selected for simulation runs and following specifications were fed to the software

$$\textit{Flow rate of water} = \mathbf{353\ m^3/h}$$

$$\textit{Product Permeate Flow rate} = \mathbf{210.65\ m^3/h}$$

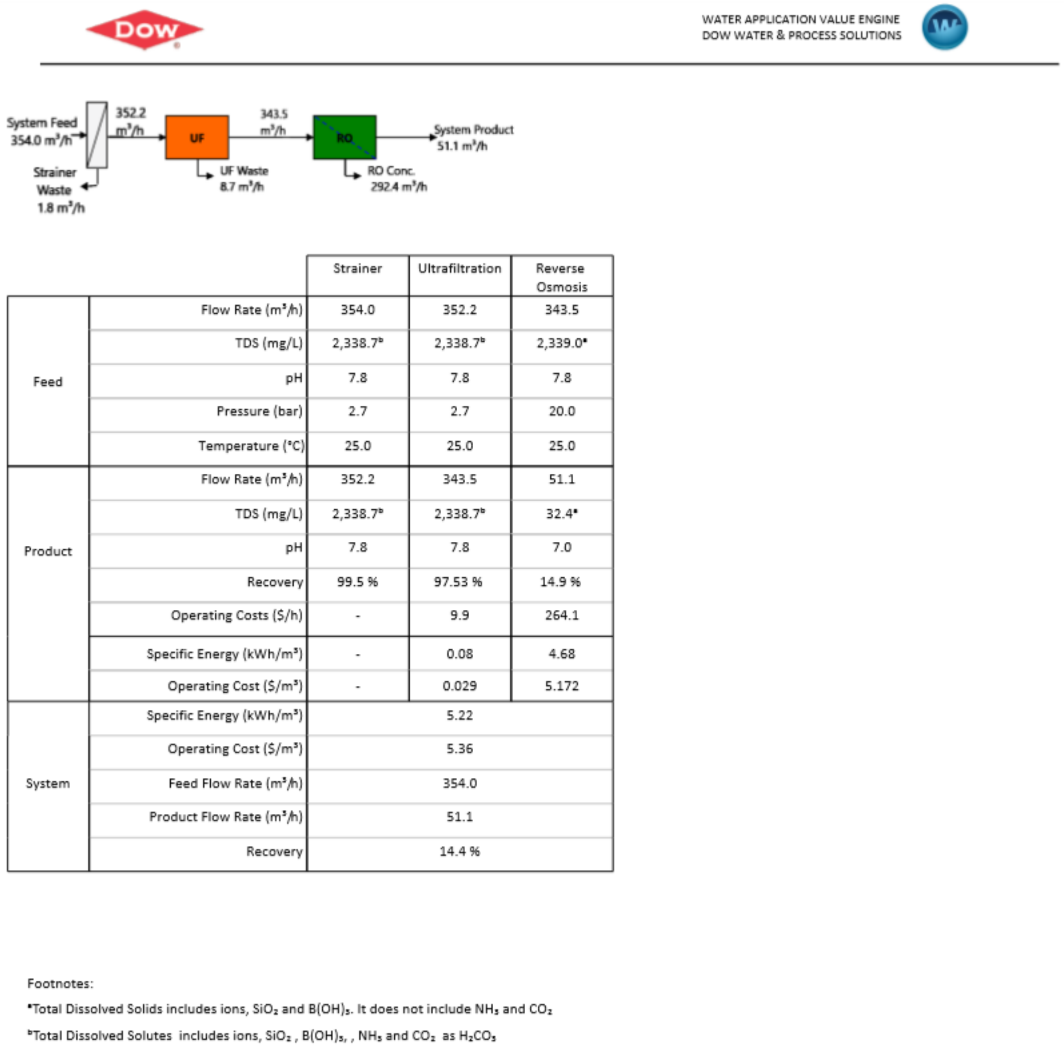
This shows a percentage recovery of about 62% which confirms our design calculations done in previous chapters.

Feed Water 354 m^3/h

Product Water 210.65 m^3/h

Figure 5 Simulation

9.2 Summary:



		Strainer	Ultrafiltration	Reverse Osmosis
Feed	Flow Rate (m^3/h)	354.0	352.2	343.5
	TDS (mg/L)	2,338.7^b	2,338.7^b	2,339.0^a
	pH	7.8	7.8	7.8
	Pressure (bar)	2.7	2.7	20.0
	Temperature (°C)	25.0	25.0	25.0
Product	Flow Rate (m^3/h)	352.2	343.5	51.1
	TDS (mg/L)	2,338.7^b	2,338.7^b	32.4^a
	pH	7.8	7.8	7.0
	Recovery	99.5 %	97.53 %	14.9 %
	Operating Costs ($/h)	-	9.9	264.1
	Specific Energy (kWh/m^3)	-	0.08	4.68
	Operating Cost ($\$/m^3$)	-	0.029	5.172
System	Specific Energy (kWh/m^3)	5.22		
	Operating Cost ($\$/m^3$)	5.36		
	Feed Flow Rate (m^3/h)	354.0		
	Product Flow Rate (m^3/h)	51.1		
	Recovery	14.4 %		

Footnotes:

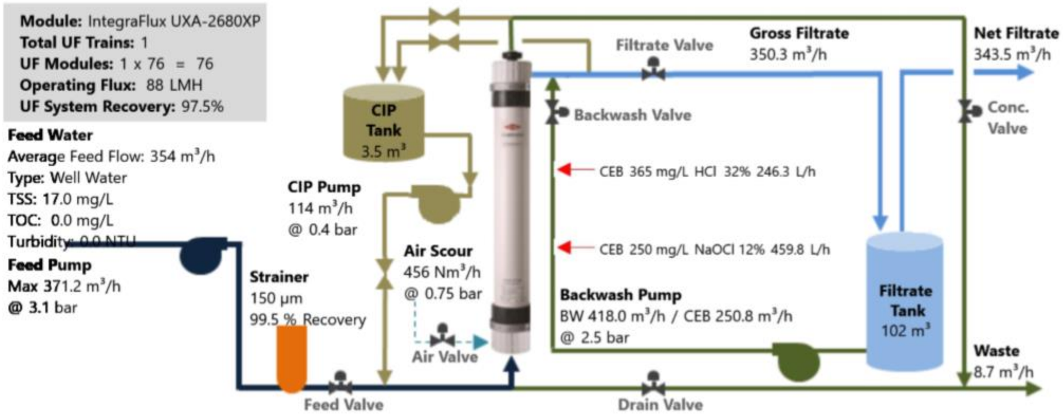
^{a}Total Dissolved Solids includes ions, SiO_2 and $B(OH)_3$. It does not include NH_3 and CO_2

^{b}Total Dissolved Solutes includes ions, SiO_2 , $B(OH)_3$, , NH_3 and CO_2 as H_2CO_3

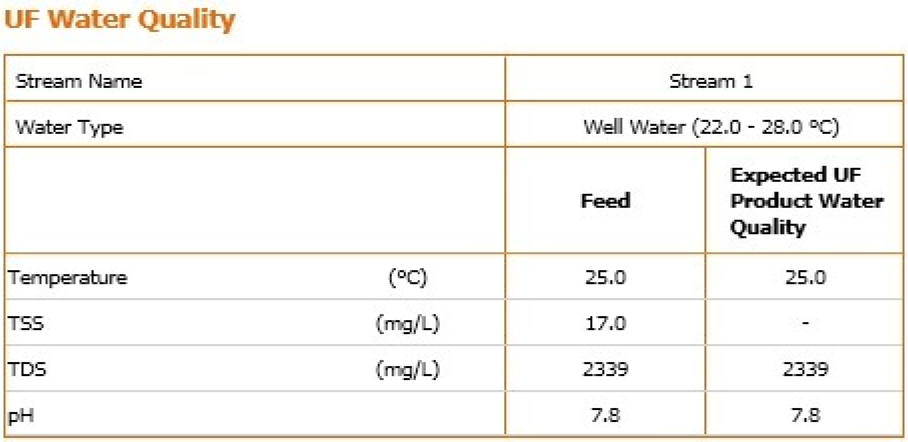
Table 21 Simulation Summary

9.3 Ultra-Filtration:

UF Detailed Report



We have installed Ultra filtration membrane as a support to our RO unit, UF acts as a preliminary membrane which removes all of suspended solids which might choke the RO membrane, software shows following results on UF

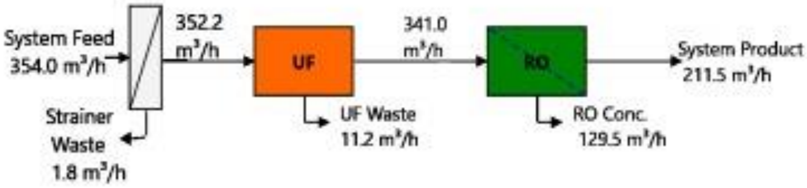


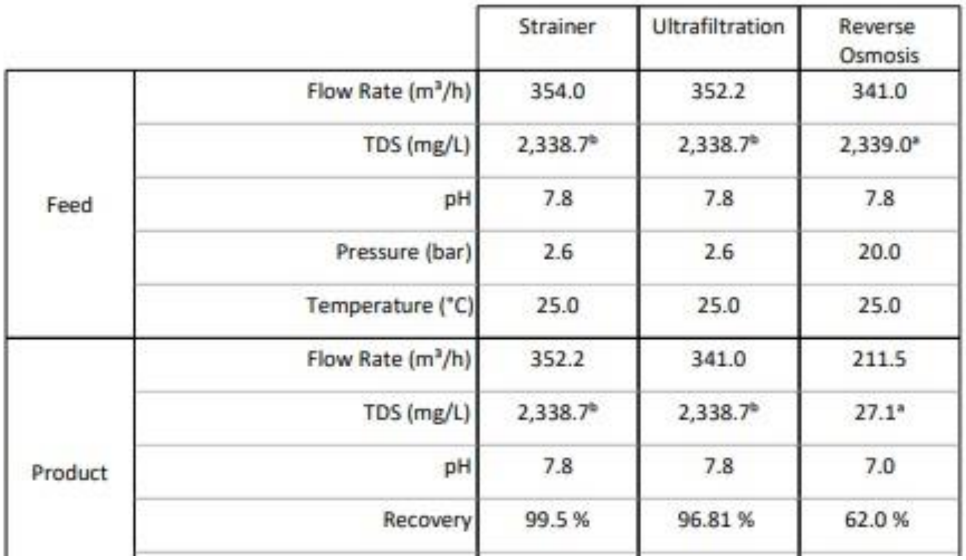
UF Water Quality

Stream Name		Stream 1	
Water Type		Well Water (22.0 - 28.0 °C)	
		Feed	**Expected UF Product Water Quality**
Temperature	(°C)	25.0	25.0
TSS	(mg/L)	17.0	-
TDS	(mg/L)	2339	2339
pH		7.8	7.8

Table 22 UF Summary

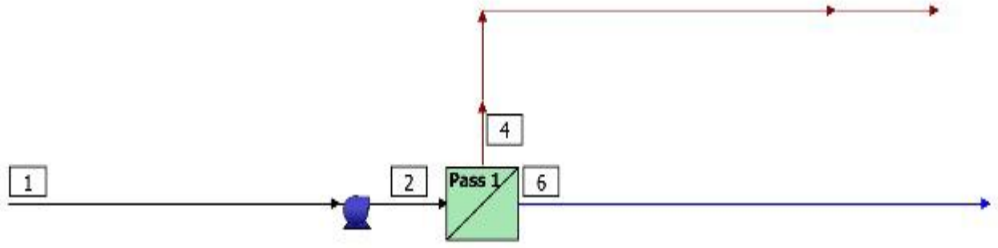
9.4 Reverse Osmosis Unit:





		Strainer	Ultrafiltration	Reverse Osmosis
Feed	Flow Rate (m³/h)	354.0	352.2	341.0
	TDS (mg/L)	2,338.7[b]	2,338.7[b]	2,339.0[a]
	pH	7.8	7.8	7.8
	Pressure (bar)	2.6	2.6	20.0
	Temperature (°C)	25.0	25.0	25.0
Product	Flow Rate (m³/h)	352.2	341.0	211.5
	TDS (mg/L)	2,338.7[b]	2,338.7[b]	27.1[a]
	pH	7.8	7.8	7.0
	Recovery	99.5 %	96.81 %	62.0 %

Table 23 RO Summary



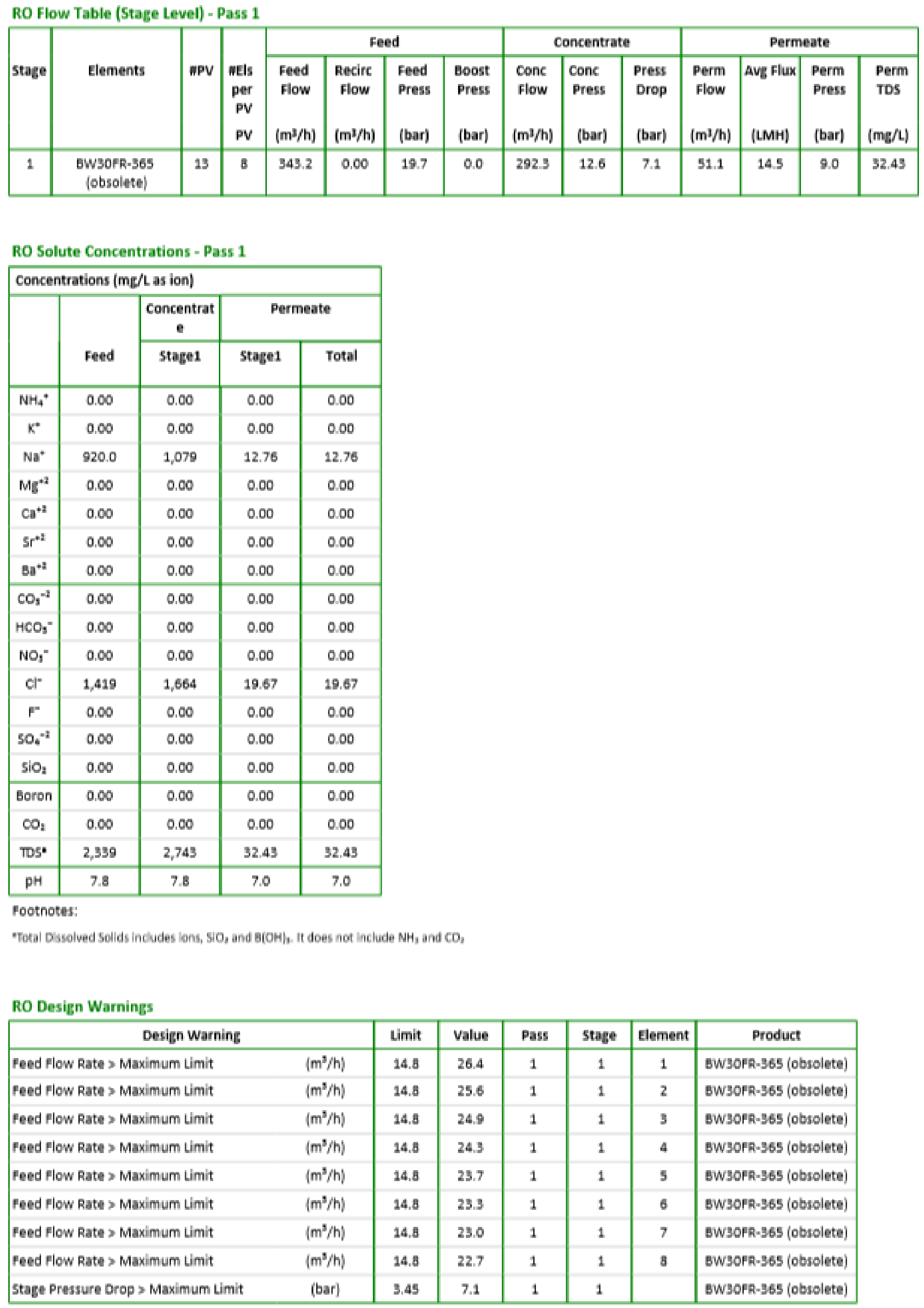
#	Description	Flow (m³/h)	TDS (mg/L)	Pressure (bar)
1	Raw Feed to RO System	341.0	2,339	5.0
2	Net Feed to Pass 1	340.7	2,341	20.0
4	Total Concentrate from Pass 1	129.4	6,118	14.1
6	Net Product from RO System	211.5	27.13	18.0

Table 24 RO Summary

Feed Entering the RO = ***20bar***

Permeate Pressure = ***18bar***

9.5 Simulation Results:



RO Flow Table (Stage Level) - Pass 1

Stage	Elements	#PV	#Els per PV PV	Feed Feed Flow (m³/h)	Feed Recirc Flow (m³/h)	Feed Feed Press (bar)	Feed Boost Press (bar)	Concentrate Conc Flow (m³/h)	Concentrate Conc Press (bar)	Concentrate Press Drop (bar)	Permeate Perm Flow (m³/h)	Permeate Avg Flux (LMH)	Permeate Perm Press (bar)	Permeate Perm TDS (mg/L)
1	BW30FR-365 (obsolete)	13	8	343.2	0.00	19.7	0.0	292.3	12.6	7.1	51.1	14.5	9.0	32.43

RO Solute Concentrations - Pass 1

Concentrations (mg/L as ion)

	Feed	Concentrate Stage1	Permeate Stage1	Permeate Total
NH_4^+	0.00	0.00	0.00	0.00
K^+	0.00	0.00	0.00	0.00
Na^+	920.0	1,079	12.76	12.76
Mg^{+2}	0.00	0.00	0.00	0.00
Ca^{+2}	0.00	0.00	0.00	0.00
Sr^{+2}	0.00	0.00	0.00	0.00
Ba^{+2}	0.00	0.00	0.00	0.00
CO_3^{-2}	0.00	0.00	0.00	0.00
HCO_3^-	0.00	0.00	0.00	0.00
NO_3^-	0.00	0.00	0.00	0.00
Cl^-	1,419	1,664	19.67	19.67
F^-	0.00	0.00	0.00	0.00
SO_4^{-2}	0.00	0.00	0.00	0.00
SiO_2	0.00	0.00	0.00	0.00
Boron	0.00	0.00	0.00	0.00
CO_2	0.00	0.00	0.00	0.00
TDS*	2,339	2,743	32.43	32.43
pH	7.8	7.8	7.0	7.0

Footnotes:

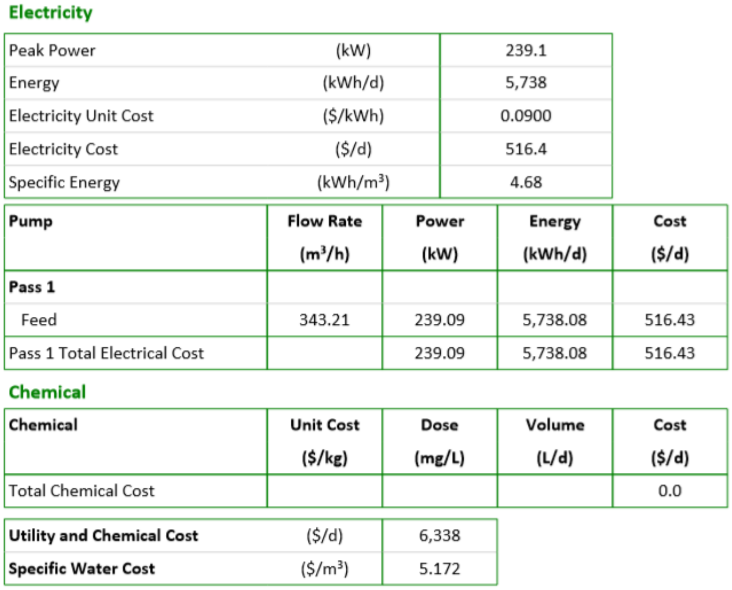
*Total Dissolved Solids includes ions, SiO_2 and $B(OH)_3$. It does not include NH_3 and CO_2

RO Design Warnings

Design Warning		Limit	Value	Pass	Stage	Element	Product
Feed Flow Rate > Maximum Limit	(m³/h)	14.8	26.4	1	1	1	BW30FR-365 (obsolete)
Feed Flow Rate > Maximum Limit	(m³/h)	14.8	25.6	1	1	2	BW30FR-365 (obsolete)
Feed Flow Rate > Maximum Limit	(m³/h)	14.8	24.9	1	1	3	BW30FR-365 (obsolete)
Feed Flow Rate > Maximum Limit	(m³/h)	14.8	24.3	1	1	4	BW30FR-365 (obsolete)
Feed Flow Rate > Maximum Limit	(m³/h)	14.8	23.7	1	1	5	BW30FR-365 (obsolete)
Feed Flow Rate > Maximum Limit	(m³/h)	14.8	23.3	1	1	6	BW30FR-365 (obsolete)
Feed Flow Rate > Maximum Limit	(m³/h)	14.8	23.0	1	1	7	BW30FR-365 (obsolete)
Feed Flow Rate > Maximum Limit	(m³/h)	14.8	22.7	1	1	8	BW30FR-365 (obsolete)
Stage Pressure Drop > Maximum Limit	(bar)	3.45	7.1	1	1		BW30FR-365 (obsolete)

Table 25 Simulation Results

9.6 Cost Analysis by Software:



Electricity

Peak Power	(kW)	239.1
Energy	(kWh/d)	5,738
Electricity Unit Cost	($/kWh)	0.0900
Electricity Cost	($/d)	516.4
Specific Energy	(kWh/m³)	4.68

Pump	**Flow Rate (m³/h)**	**Power (kW)**	**Energy (kWh/d)**	**Cost ($/d)**
Pass 1				
Feed	343.21	239.09	5,738.08	516.43
Pass 1 Total Electrical Cost		239.09	5,738.08	516.43

Chemical

Chemical	**Unit Cost ($/kg)**	**Dose (mg/L)**	**Volume (L/d)**	**Cost ($/d)**
Total Chemical Cost				0.0

Utility and Chemical Cost	($/d)	6,338
Specific Water Cost	($/m³)	5.172

Table 26 Simulation Cost Analysis

Chapter 10 Instrumentation

As discussed in the chapter of HAZOP analysis, in case of all the parameters i.e. pressure, temperature and flow, the recommendations and actions suggested the use of control systems and instrumentation. Instrumentation is done on all the components of the design process. Costing of the plant includes the cost of instrumentation.

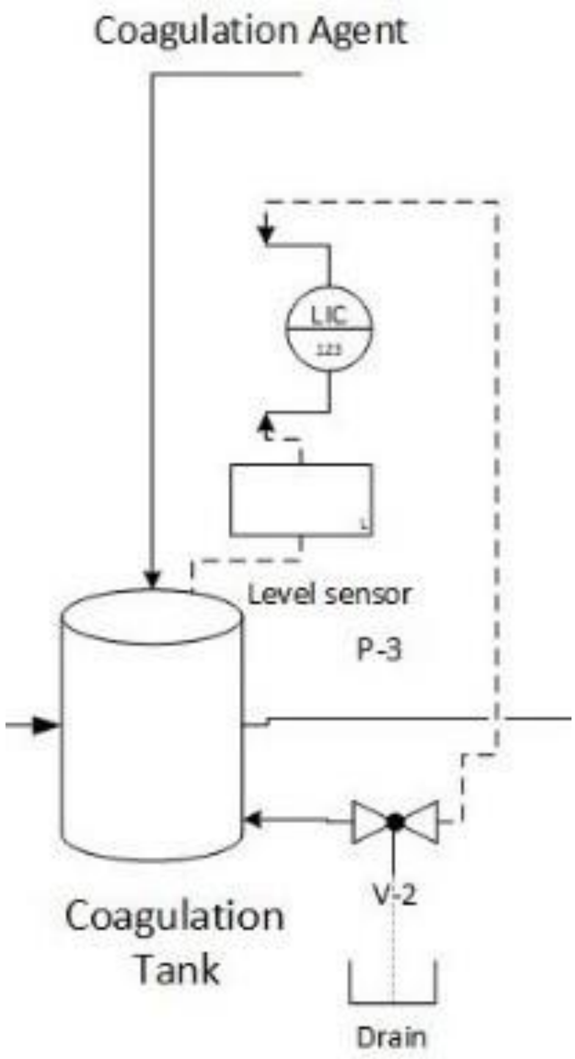
Different controllers such as level controllers, flow controllers etc. have been installed on tanks and columns in the process along with pneumatically controlled valves.

A controller normally consists of a sensor or sensing element which generates an electric signal which is sent to the controller (proportional integral PI). This controller converts this electric signal into pneumatic command using IP converter which opens or closes the valve according to the need.

In this chapter we will be displaying the control system of one level controller on the coagulation tank and flow controller on the High-pressure pump.

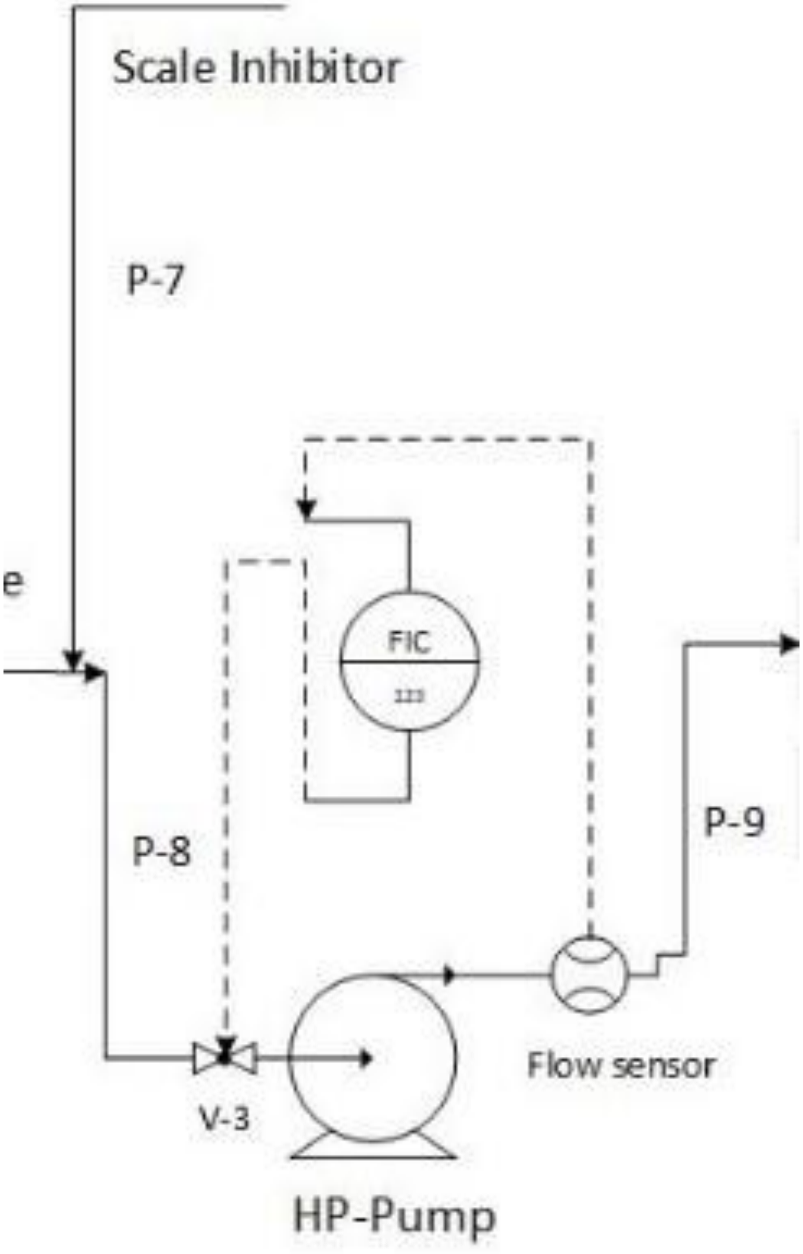
10.1 Coagulation Tank:

Following is a demonstration of level controller installed on the Coagulation Tank



the level controller basically serves the purpose of ensuring that the level of water within the coagulation tank does not rise up or fall down below a certain level. Is there is a change in the level of water, the controller will make sure that the control valve of the drain is opened or closed accordingly in order to avoid any fluctuations in the process.

10.2 HP-Pump:



The flow sensor at the outlet of the pump monitors the flow at the discharge and sends a signal to the controller in the case of a deviation. The controller then decides whether to open or close the control valve inlet accordingly. In order to avoid cavitation within the pump, a certain amount of flow must always be ensured inside the pump.

Chapter 11 Conclusion

In conclusion, we have designed a process that allows us to achieve the purification that was required. Furthermore, the process is economically feasible and is already proven. It is extensively used in seawater desalination plants. With the purification of this water that is currently being discharged, Fatima fertilizers would be able to enhance the amount of cooling water that is available to them significantly. Implementation of this process would result in them achieving financial and environmental benefits likewise.

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