Waste Water Recycling

Akash Kumar	**NUST201434348BSCME99114F**
Shahzeen Akhtar	**NUST201433677BSCME99114F**
Hafiz M. Usama Saleem	**NUST201433511BSCME99114F**

School of Chemical and Materials Engineering (SCME)

National University of Sciences and Technology (NUST)

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Akash Kumar NUST201434348BSCME99114F

Shahzeen Akhtar NUST201433677BSCME99114F

Hafiz M. Usama Saleem NUST201433511BSCME99114F

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Supervisor Name: Dr. Erum Pervaiz

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 **Akash Kumar, Shahzeen Akhtar** and **Hafiz M. Usama Saleem** and completed under supervision of **Dr. Erum Pervaiz** in school of chemical and materials engineering (SCME), National University of Sciences and Technology, H-12, Islamabad, Pakistan.

Supervisor:

Dr. Erum Pervaiz
UG Coordinator Chemical Engineering Department

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

Submitted through:

Dr. Bilal Khan Niazi
HoD Chemical Engineering

Dr. Arshad Hussain
Dean/Principal SCME

Dedication

Our work is dedicated to our parents and families and to SCME where we learned some valuable lessons of life.

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We are indeed blessed by Allah Almighty, the Omniscient and Omnipresent, Who made us able to complete the project respectably and honestly.

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Abstract

The waste water from the Engro Foods Ltd. plant contains significantly high levels of TDS, BOD, COD and FOG which makes the water unsuitable for reuse. The presence of BOD and COD consumes the dissolved oxygen available in the water and promotes the growth of unwanted microorganism in the water. This results in contamination of the water. The Fats Oils and Grease present cause bad odor, and cause clogging wherever they get accumulated such as on the surface of the membranes. The TDS interferes with the taste of the food and causes scale formation in the equipment. Additionally, the inlet pH is in the range of 6 to 9 and needs to be maintained for proper operation of the plant. Therefore, the project requires us to minimize these contaminants and maintain a certain pH level by designing a treatment system so that the water can be recycled to be used in the manufacturing process instead of being disposed of. Our proposed model meets with all the requirements of the project making the water reusable.

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Chapter 1: Introduction

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 achieve the fresh water standards by reducing TDS, BOD, COD and FOG, and by maintaining pH so that the water can be used in manufacturing of products such as milk, ice cream, etc., to make the process economical.

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.

BOD, or Biological Oxygen Demand, represents the amount of Oxygen required by microorganisms present in water to decompose the organic matter present. When provided with sufficient Oxygen, the microorganisms become active and use that Oxygen to feed on the organic matter, thereby decomposing it. However, they are still present in the water; therefore, a solid separation system like a partially permeable membrane is required to filter them out.

COD, or Chemical Oxygen Demand, represents the amount of Oxygen required by the water for the decomposition of some chemical compounds. When provided with sufficient Oxygen, these compounds are oxidized, thereby reducing the amount of unwanted chemical compounds that may contaminate the process.

FOG, or Fats Oils and Grease, are the saturated and unsaturated hydrocarbons that exist as fats and oils. They add bad odor to the water and cause clogging when they are accumulated. In our process stream, the presence of FOG is brought about by the dairy compounds that are manufactured in the process plant, which is the source of our waste water. They are essentially separated based on the difference between the densities of FOG compounds and water. Once formed as separate layer, they are removed from the water.

pH, or the power of Hydrogen, is actually a numeric scale which denotes the acidity and alkalinity of the water. While pH=7 is termed as neutral, pH below 7 is said to be acidic and pH greater than 7 is said to be alkaline. Acidic streams can cause corrosion of the process equipment, while alkaline streams result in fouling. Hence to bring the pH to a neutral value, acidic streams are treated with bases, and alkaline streams are treated with acids.

The purpose of our project is to treat these 5 parameters and to have the following specifications:

Feed Water		**Desired Treated Water**
BOD	80 ppm	Nil
COD	150 ppm	Nil
pH	6-9	7.5-8
FOG	5 ppm	Not specified
TDS	3500 ppm	20

Table 1: Objectives of the project

Chapter 2: Literature Review

2.1 Process Selection for pH

Neutralization is the only suitable process used for pH control. Essentially in a neutralization process, a continuously stirred tank reactor (CSTR) is present in which the process stream flows into. There are acid and base tanks above the reactor from which acid or base enter the reactor and are mixed with the process stream. In general, the reactors are designed so that there is sufficient residence time for the reaction to take place. Since the water formation reaction (neutralization) is an extremely fast reaction, it eliminates the need for a vessel. On the other hand, since there is also a need to equalize the incoming flow rate to a steady value, the equipment can be designed in the manner of an equalization tank since a CSTR is essentially a tank with an agitator. So, the equalization tank with an agitator was selected so as to provide the point of acid/base dosing and so that the incoming variable volumetric flow rate can be stabilized.

2.2 Process Selection for FOG

Fat, Oil and Grease (FOG) compounds essentially separated from water by one of two methods. One is by the use of a decanter and the other is by the use of a grease trap (interceptor). In general, decanters are used when the amount of oil is significantly large in the water-oil mixture. Additionally, to use a decanter, it is also necessary that the oil is of constant density, i.e. only one component of oil is present. On the other hand, a grease trap is used to remove the oils from water when they are in a sufficiently smaller amount and when the oil compounds are allowed to be a mixture of variable density compounds where some may be lighter than water while others may be heavier than water. The basis of separation in both the equipment is density difference. However, their designs are significantly different, allowing the grease trap to remove variable density oil compounds from water. Hence, the grease trap was selected since the water stream had the possibility of containing heavier FOG compounds as well as lighter ones as compared to water.

2.3 Process Selection for BOD and COD

There are a number of techniques that can be used to remove BOD and COD from water. Some of the most common ones are highlighted below:

- Treatment with Chemicals: In this method, the wastewater containing BOD and COD are treated with chemicals such as H_2O_2 (most common), ozone, etc. The compounds responsible for BOD and COD are oxidized and a further filtration down the line is carried out to remove the microorganisms present in water.

- Advanced Oxidation: In this technique, UV radiation is used to oxidize the BOD and COD compounds similarly to chemical treatment method. Again, further filtration down the line is possibly required to remove the microorganisms present.

- Conventional Activated Sludge Treatment with Clarifier: In this method, aeration is essentially used to oxidize the BOD and COD compounds. The aeration is provided with the help of blowers that transfer oxygen to the water. The water stream then moves to the clarifier, which is essentially a settling tank. The sludge-water mixture is provided with sufficient time for the sludge to settle (i.e. sedimentation occurs). The clear water is them removed from the top and filtered out.

- Membrane Bio-Reactor: This method is essentially a combination of activated sludge method and membrane filtration. For the activated sludge treatment part, the wastewater is supplied with oxygen using a blower to oxidize the BOD and COD compounds. However, this MBR technology eliminates the need of a clarifier by providing a membrane inside the aeration vessel to separate the sludge from the water and allowing it to move forward without the impurities present.

MBR was the technology that was chosen for this project as it was considered to be superior to the others. It could be used for large flow rates. It eliminates the need of clarifiers which are generally extremely large because of the high settling time needed for the liquid-solid separation. It is a technology that is being used more commonly in the world because of its high efficiency i.e. higher effluent quality. It also has a low sludge production rate and easy operation.

Once MBR technology was selected, there were various other parameters to be considered for this technology.

2.3.1 Selection of MBR System Configuration

There are two MBR system configurations namely Immersed (Submerged) MBR and Side-stream MBR.

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

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

The system selected was IMBR because:

- unlike the SMBR, the IMBR doesn't require an additional pressure vessel reducing the required capital.
- the IMBR doesn't require a high pressure pump before the membrane separation, unlike the SMBR (which increase the operational costs)
- the IMBR employs dead end flow where recovery (permeate flow as a percentage of feed flow) is essentially 100% unlike the lower recovery of the cross flow of SMBR.

2.3.2 Selection of Membrane Configuration

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

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

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

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

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

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

2.3.3 Selection of Membrane Material

There are a number of materials which can be used for the membranes. A table comparing common used membrane materials is provided below:

Material	Advantages	Disadvantages
Polypropylene (PP)	• Low cost • High pH range	• No chlorine tolerance • Expensive cleaning chemicals required
Polyvinylidene fluoride (PVDF)	• High chlorine tolerance • Reasonable cost • Simple cleaning chemicals	• Cannot sustain pH>10
Polyether Sulfone & Polysulfone (PES & PS)	• High chlorine tolerance • Reasonable cost	• Brittle material requires support
Polyacrylonitrile (PAN)	• Low Cost	• Less chemically resistant than PVDF
Cellulose Acetate	• Low Cost	• Narrow pH range • Biologically active

Table 2: Advantages and Disadvantages of Materials Used For Membranes

Hence, PVDF was selected because of its reasonable cost, requirement of simple cleaning chemicals, chemical resistance and biological inactivity.

2.4 Process Selection for TDS

There are also a number of methods available for the removal of TDS from water. Alum can be employed to remove TDS chemically but it very low efficiency. Sand filters and carbon filters can be used but they are used for systems which don't have such high flow rates and such high amounts of TDS. The best option available was the use of Reverse Osmosis (RO) membranes which physically separates the TDS from the water and is applicable for la;6rge flow rates, high amounts of TDS and provides high salt rejection rates.

Chapter 3: Process Description

3.1 Process Flow Diagram (PFD)

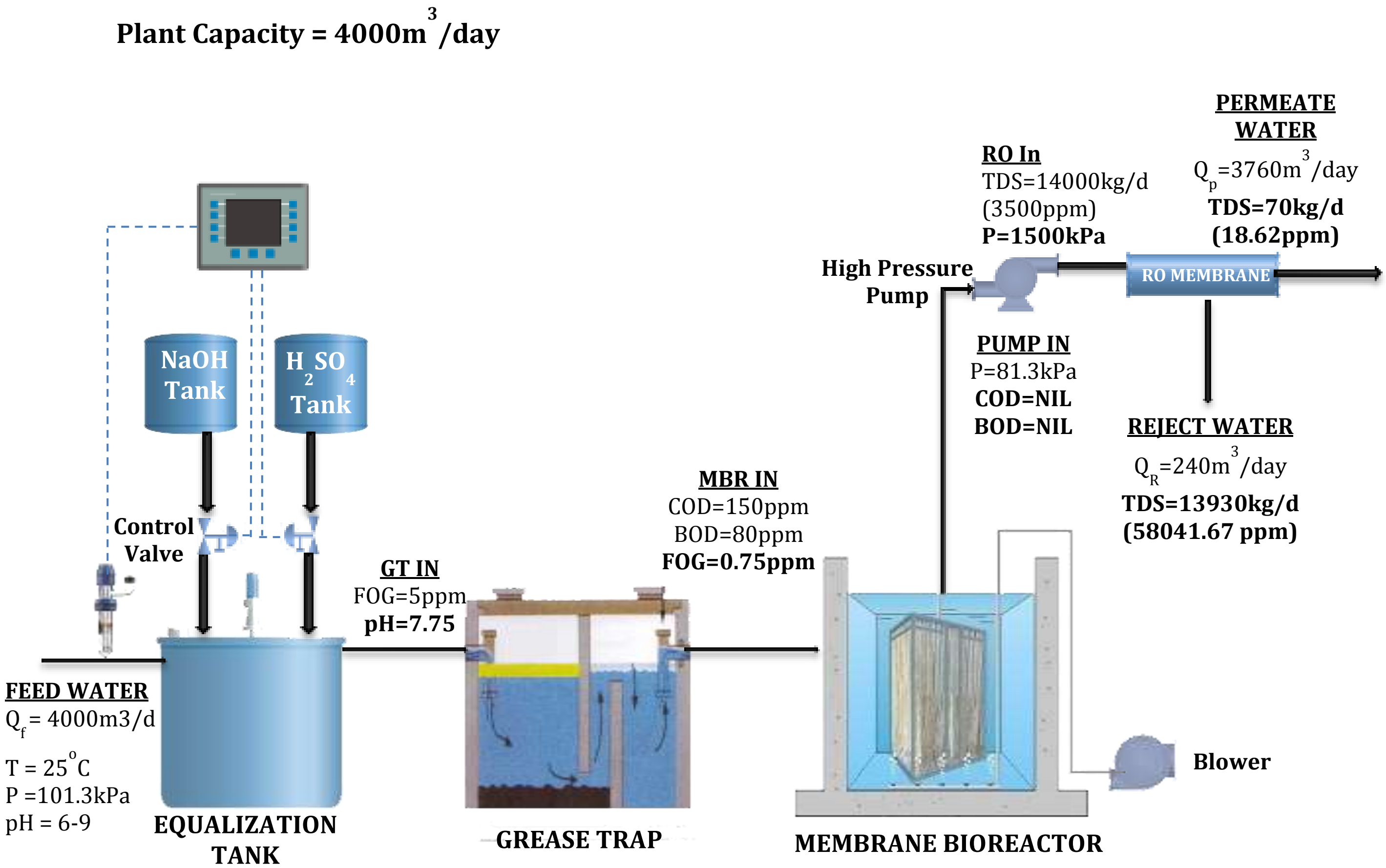


Figure 1: Process Flow Diagram

3.2 Process Description

3.2.1 Equalization Tank

The feed water initially flows into an equalization tank which serves 2 purposes:

- equalizing the variable feed flow rate to a steady flow rate value so as to prevent the oversizing of the downstream equipment
- act as a dosing point for the acid/base into the water stream to attain the desired pH level and to provide with sufficient mixing to ensure neutralization reaction completion

There is a pH sensor before the Equalization Tank which senses the inlet pH and sends that value to the controller. Additionally, a flow sensor record the inlet flow rate and sends that value to the controller as well. The controller, using the set value of pH=7.75, determines the difference in H^+ moles and decides the amount of acid or base that needs to be added to the water stream. Consequently, the controller sends signals to the control valves to open proportionally to add the required amount of acid or base.

3.2.2 Grease Trap

The Grease Trap is used for the removal of Fats, Oils and Grease from the water stream. It does so by providing sufficient residence time to the water to allow the heavier FOG components such as skimmed milk to settle down and for the lighter FOG components such as whipped cream to form a layer on the top. Consequently, water comes out of the Grease Trap with significantly lower amount of FOG present in it. The FOG that is accumulated in the Grease Trap is in very low amounts. Hence, the Grease Trap is cleaned after 3 months to remove the FOG.

3.2.3 Membrane Bio-Reactor (MBR)

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

3.2.4 **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.

3.2.5 **RO Membrane**

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

4.1 Equalization Tank

4.1.1 Formulae Used

- $\boldsymbol{In + Generated = Out + Consumed}$
- $[\boldsymbol{H}+]\ \boldsymbol{conc.}\,(\boldsymbol{mol/L})\ =\ \mathbf{10}\text{^}(-\,\boldsymbol{pH})$
- $\boldsymbol{mass = density\ x\ volume}$
- $\boldsymbol{moles = molar\ concentration\ x\ volume}$
- $\boldsymbol{NaOH\ Required}\ \left(\frac{g}{d}\right) =\ \boldsymbol{NaOH\ Required}\ \left(\frac{mol}{d}\right) * \mathbf{40}$
- $\boldsymbol{H_2SO_4\ Required}\ \left(\frac{g}{d}\right) =\ \boldsymbol{H2SO4\ Required}\ \left(\frac{mol}{d}\right) * \mathbf{98}$

4.1.2 Balance Data

When pH < 7.75	
Water Inflow (m^3/d)	4000
Inlet pH	6
Inlet [H^+] conc. (mol/L) ($x10^{-7}$)	10.00
Inlet H^+ Flow Rate (mol/d)	4.000
Desired Outlet pH	7.75
Desired Outlet [H^+] conc. (mol/L) ($x10^{-7}$)	0.178
Desired H^+ Outflow (mol/d)	0.071
H^+ Consumption (mol/d)	3.929
NaOH Required (mol/d)	3.929
NaOH Required (g/d)	157.2

Table 3 : Equalization Tank Material Balance when pH<7.75

When pH > 7.75	
Water Inflow (m^3/d)	4000
Inlet pH	9
Inlet [H^+] conc. (mol/L) (x10^{-9})	1.000
Inlet H^+ Flow Rate (mol/d)	0.004
Desired Outlet pH	7.75
Desired Outlet [H^+] conc. (mol/L) (x10^{-9})	17.78
Desired H^+ Outflow (mol/d)	0.071
H^+ Generation (mol/d)	0.067
H_2SO_4 Required (mol/d)	0.034
H_2SO_4 Required (g/d)	3.289

Table 4: Equalization Tank Material Balance when pH>7.75

The target pH is 7.75. When the pH is below that value, we need to add a strong base to increase it, whereas when the pH is above that value, we need to add a strong acid to reach the target value. Since inlet pH varies between 6 and 9, the amount of acid or base used would also vary. These variations in required acid and base with variation in inlet pH are shown ahead.

4.1.3 Variations in NaOH Addition With Inlet pH

Inlet pH	Desired Outlet pH	H+ Consumption (mol/d)	NaOH Required (mol/d)	NaOH Required (g/d)
6	7.75	3.929	3.929	157.2
6.1	7.75	3.106	3.106	124.2
6.2	7.75	2.453	2.453	98.11
6.3	7.75	1.934	1.934	77.34
6.4	7.75	1.521	1.521	60.85
6.5	7.75	1.194	1.194	47.75
6.6	7.75	0.934	0.934	37.34
6.7	7.75	0.727	0.727	29.08
6.8	7.75	0.563	0.563	22.51
6.9	7.75	0.432	0.432	17.30
7	7.75	0.329	0.329	13.15
7.1	7.75	0.247	0.247	9.864
7.2	7.75	0.181	0.181	7.250
7.3	7.75	0.129	0.129	5.174
7.4	7.75	0.088	0.088	3.524
7.5	7.75	0.055	0.055	2.214
7.6	7.75	0.029	0.029	1.174
7.7	7.75	0.009	0.009	0.347
7.74	7.75	0.002	0.002	0.066

Table 5: Variation in NaOH dosage according to inlet pH

4.1.4 Variations in H_2SO_4 Addition With Inlet pH

Inlet pH	Desired Outlet pH	H+ Generation (mol/d)	H_2SO_4 Required (mol/d)	H_2SO_4 Required (g/d)
9	7.75	0.067	0.034	3.289
8.9	7.75	0.066	0.033	3.239
8.8	7.75	0.065	0.032	3.175
8.7	7.75	0.063	0.032	3.094
8.6	7.75	0.061	0.031	2.993
8.5	7.75	0.058	0.029	2.866
8.4	7.75	0.055	0.028	2.705
8.3	7.75	0.051	0.026	2.503
8.2	7.75	0.046	0.023	2.249
8.1	7.75	0.039	0.020	1.929
8	7.75	0.031	0.016	1.525
7.9	7.75	0.021	0.010	1.018
7.8	7.75	0.008	0.004	0.379
7.76	7.75	0.002	0.001	0.079

Table 6: Variation in H_2SO_4 dosage according to inlet pH

4.2 Grease Trap

4.2.1 Formulae Used

- $\boldsymbol{FOG\ Mass\ Inflow/Outlflow\left(\frac{kg}{d}\right) = volumetric\ flowrate * concentration}$
- $\boldsymbol{FOG\ Removed\ \left(\frac{kg}{d}\right) = \ FOG\ Mass\ Inflow * \ Grease\ Trap\ Efficiency}$
- $\boldsymbol{In = Out + Accumulated}$

4.2.2 Balance Data

Water Inflow (m^3/d)	4000
FOG conc. (ppm or mg/L)	5
FOG Mass Inflow (kg/d)	20
Grease Trap Efficiency	0.85
FOG Removed (kg/d)	17
FOG Outflow (kg/d)	3
FOG Outflow (ppm or mg/L)	0.75

Table 7: Grease Trap Material Balance

4.3 Membrane Bio-Reactor

4.3.1 Formulae Used

- $\boldsymbol{BOD\ In\ \left(\frac{kg}{d}\right) = Water\ Inflow\ *\ BOD\ In\ (concentration)}$
- $\boldsymbol{COD\ In\ \left(\frac{kg}{d}\right) = Water\ Inflow\ *\ COD\ In\ (concentration)}$
- $\boldsymbol{Oxygen\ To\ Be\ Supplied\ (kg/d) = BOD\ In + COD\ In}$
- $\boldsymbol{Air\ To\ Be\ Supplied\ (kg/d) = Oxygen\ To\ Be\ Supplied\ /0.23}$
- $\boldsymbol{Volume\ of\ Air\ Required\ \left(\frac{m3}{d}\right) = \frac{Air\ To\ Be\ Supplied\ (kg/d)}{Density\ of\ Air\ (kg/m3)}}$
- $\boldsymbol{In = Out\ + Consumed}$

4.3.2 Balance Data

Water Inflow (m^3/d)	4000
BOD In (ppm or mg/L)	80
BOD In (kg/d)	320
COD In (ppm or mg/L)	150
COD In (kg/d)	600
Oxygen To Be Supplied (kg/d)	920
Air To Be Supplied (kg/d)	4000
Density of Air (kg/m3)	1.184
Volume of Air Required (m^3/d)	3378

Table 8: MBR Material Balance

4.4 RO Membrane

4.4.1 Formulae Used

- $\boldsymbol{TDS\ Inflow\ (kg/d) = Water\ Inflow * TDS\ In\ (concentration)}$
- $\boldsymbol{TDS\ in\ Rejects\ \left(\frac{kg}{d}\right) = TDS\ Inflow * Salt\ Rejection}\ (\%)$
- $\boldsymbol{TDS\ in\ Permeate\ (kg/d) = TDS\ Inflow - TDS\ in\ Rejects}$
- $\boldsymbol{Recovery = \frac{Permeate\ Water\ Flow}{Feed\ Water\ Inflow}}$
- $\boldsymbol{RO\ Reject\ Water\ \left(\frac{m3}{d}\right) = Water\ Inflow - Permeate\ Water\ Flow}$

4.4.2 Balance Data

Water Inflow (m^3/d)	4000
TDS In (ppm or mg/L)	3500
TDS Inflow (kg/d)	14000
Salt Rejection (%)	99.5
TDS in Permeate (kg/d)	70
TDS in Rejects (kg/d)	13930
RO Permeate Water (m^3/d)	3760
RO Reject Water (m^3/d)	240
TDS in Permeate (ppm)	18.62
TDS in Reject (ppm)	58041.66

Table 9: RO Material Balance

4.5 Summarized Material Balance

Equipment	Parameter	In	Out	Removed	Added
Equalization Tank	H^+ moles (when ph=6) (mol/d)	4.000	0.071	3.929	-
	H^+ moles (when ph=9) (mol/d)	0.004	0.071	-	0.067
Grease Trap	FOG (kg/d)	20	3	17	-
MBR	BOD (kg/d)	320	0	320	-
	COD (kg/d)	600	0	600	-
RO Unit	TDS (kg/d)	14000	70	13930	-

Table 10: Summary of Material Balance

Chapter 5: Energy Balance

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

5.1 Equalization Tank

5.1.1 Formulae Used

- $\boldsymbol{Mass = Density * Volume}$
- $\boldsymbol{Energy\ In = Mass\ Inflow * Enthalpy}$
- $\boldsymbol{Energy\ of\ Reaction = Moles\ Required * Enthalpy\ of\ reaction}$
- $\boldsymbol{Shaft\ Work\ (kW) = Power\ ratio\ \left(converted\ to\ \frac{kJ}{m^3}\right) * Volumetric\ Flow\ Rate}$

5.1.2 Balance Data

Water Density (kg/m3)	999.71
Water Inflow (m^3/d)	4000
Mass Inflow (kg/d) ($x10^4$)	399.9
Inlet Temperature (°C)	25
Enthalpy (J/kg)	104.92
Energy In (kW)	4.856
Mass Outflow (kg/d) ($x10^4$)	399.9
Enthalpy of Reaction (kJ/mol)	57.62
Energy of Reaction (kW)	0.002620
Power Ratio (hp/1000gal)	0.75
Shaft Work (kW)	0.006841
Energy Outflow (kW)	4.865
Enthalpy Out (J/kg)	105.12
Temperature Out (°C)	~25

Table 11: Equalization Tank Energy Balance

5.2 Grease Trap

5.2.1 Balance Data

Energy In (kW)	4.865
Energy Outflow (kW)	4.865

Table 12: Grease Trap Energy Balance

5.3 Membrane Bio-Reactor

5.3.1 Balance Data

Energy In From GT (kW)	4.865
Energy Out (kW)	4.865

Table 13: MBR Energy Balance

5.4 High Pressure Pump

5.4.1 Formula Used

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

5.4.2 Balance Data

Pressure In (kPa)	81.30
Pressure Out (kPa)	1500
Water Inflow (m^3/d)	4000
Pump Efficiency	0.7
Expansivity Coefficient (1/K)	0.000248
Temperature (°C)	25
Energy Required (kW)	86.89
Energy Inflow From MBR (kW)	4.865
Energy Outflow (kW)	91.76

Table 14: HP Pump Energy Balance

5.5 RO Membrane

5.5.1 Formula Used

- $\boldsymbol{Energy\ In\ Permeate = \frac{Permeate\ Flow}{Feed\ Flow}\ x\ Energy\ In\ Feed}$
- $\boldsymbol{Energy\ In\ Rejects =\ Energy\ In\ Feed - Energy\ In\ Permeate}$

5.5.2 Balance Data

Energy In From HP Pump (kW)	91.76
Water Flow of Permeate (m^3/d)	3760
Water Flow of Reject (m^3/d)	240
Energy Out In Permeate (kW)	86.25
Energy Out In Reject (kW)	5.506

Table 15: RO Energy Balance

5.6 Summarized Energy Balance

Equipment	Inflow (kW)	Added (kW)	Generated (kW)	Outflow (kW)
Equalization Tank	4.856	6.84E-03	2.620E-03	4.865
Grease Trap	4.865	-	-	4.865
MBR	4.865	-	-	4.865
HP Pump	4.865	86.89	-	91.76
RO Unit	91.76	-5.506		86.25

Table 16: Summary of Energy Balance

Chapter 6: EQUIPMENT DESIGN

6.1 Equalization Tank

6.1.1 Volume

Time (hours)	Flow Rate (m^3/h)	Total Volume (m^3)	Cumulative Flow (m^3)
1	167	167	167
2	130	130	297
3	100	100	397
4	135	135	532
5	160	160	692
6	175	175	867
7	180	180	1047
8	190	190	1237
9	200	200	1437
10	200	200	1637
11	200	200	1837
12	195	195	2032
13	190	190	2222
14	185	185	2407
15	180	180	2587
16	170	170	2757
17	155	155	2912
18	145	145	3057
19	140	140	3197
20	150	150	3347
21	160	160	3507
22	160	160	3667
23	167	167	3834
24	166	166	4000

Table 17: Hourly flow data of feed

From the hydrograph below, we can determine that the capacity of the equalization tank. The total capacity of the equalization tank is the sum of the vertical distances from the average flow rate line to the parallel tangents which cut the curve above and below the average flow rate line. Hence,

$$\text{Capacity} = A + B \simeq \underline{\mathbf{200\ m^3}}$$

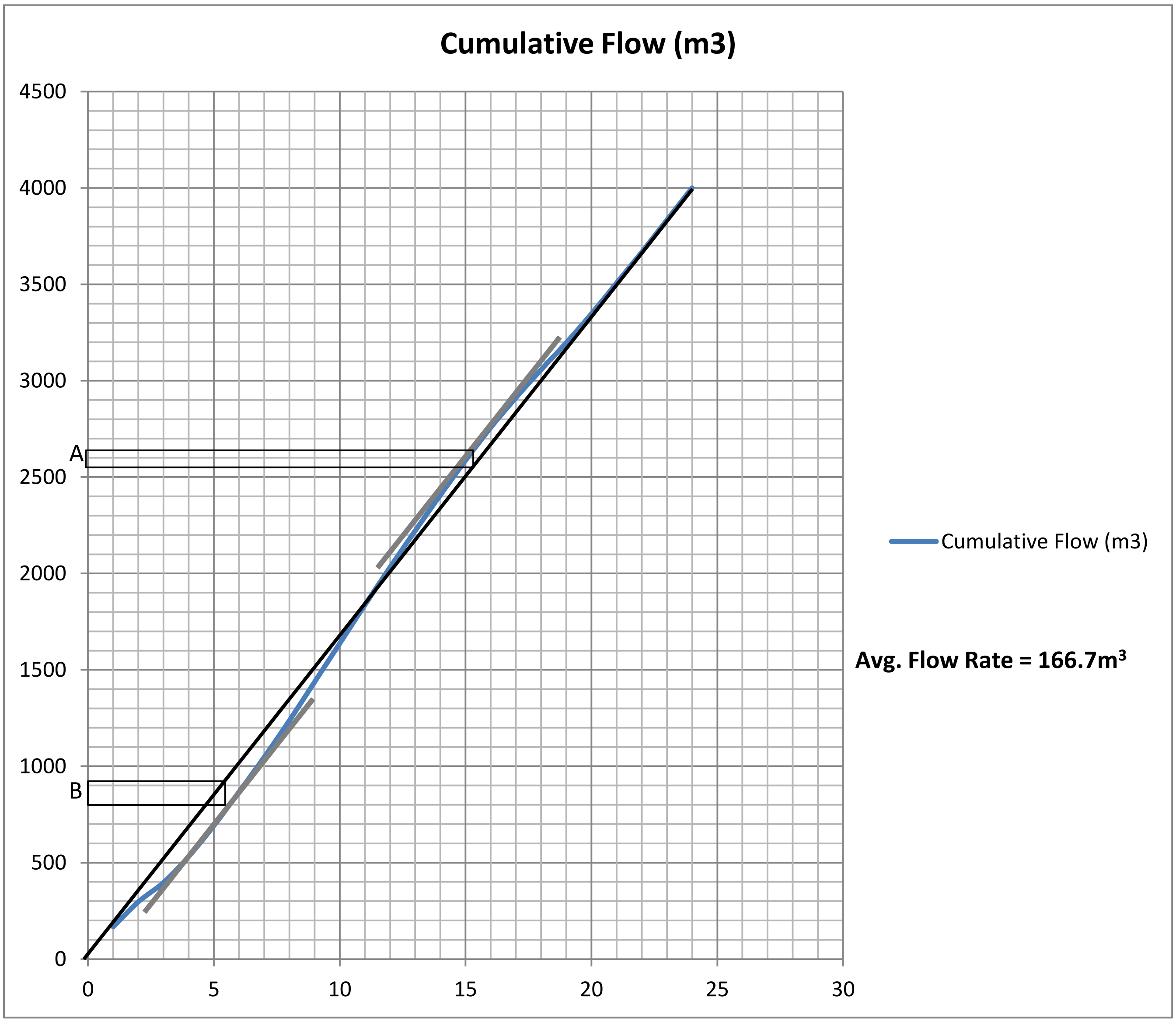


Figure 2: Hydrograph of Equalization Tank

6.1.2 Diameter and Height

$D_t : H_t = 1 : 2 \longrightarrow H_t = 2D_t$

$V = \frac{\pi}{4} D_t^2 H_t \longrightarrow V = \frac{\pi}{2} D_t^3$

$$200 = \frac{\pi}{2} D_t^3$$

$$D_t = \underline{\mathbf{5.03m}}$$

$$H_t = \underline{\mathbf{10.06m}}$$

6.1.3 Impellers

$D_i = 0.3D_t = 0.3 \times 5.03 = \underline{1.51\text{m}}$

Impeller Spacing = D_i = $\underline{1.51\text{m}}$

Height of bottom-most impeller = D_i = $\underline{1.51\text{m}}$

Average height of liquid in the tank,

$$H_L = \frac{166.7}{200} x\ 10.06 = \underline{8.385\text{m}}$$

Minimum no. of impellers,

$$n_{min} = \frac{H_L - 2D_i}{2D_i} = \frac{8.385 - 2(1.51)}{2(1.51)} = \underline{1.78}$$

Maximum no. of impellers,

$$n_{max} = \frac{H_L - D_i}{D_i} = \frac{8.385 - 1.51}{1.51} = \underline{4.55}$$

Number of impellers = **<u>3</u>**

Number of impeller blades = **<u>6</u>** (standard turbine blades)

Typical tip speed of impeller, v = 5m/s

$$v = \pi N D_i$$

$$5 = \pi N(1.51)$$

$$N = 1.054 \text{ rps} = \underline{\mathbf{63.2\ rpm}}$$

6.1.4 <u>Baffles</u>

Number of baffles = **<u>4</u>**

Baffle width, $J = \frac{D_t}{12}$

$$J = \frac{5.03}{12} = \underline{\mathbf{0.42m}}$$

6.2 Grease Trap

6.2.1 Volume

Residence time= 30 min

$$Volume = \ volumetric\ flow\ rate * time$$

$$= 4000m3/day * \ 1day/24h * \ 1h/60min * \ 30min$$

= **$83.3m^3$**

Nominal Size is given by

$$NS = QS * ft * fd * fr$$

Where,

Q_s= flow rate in litre/sec

f_t= temperature co-efficient

f_d= density co-efficient

f_r= detergent and soap co-efficient

Temp	f_t	Density	f_d	Detergent use	f_r
<60°C	1.0	≤0.94 g/cm³	1.0	Never	1.0
≥60°C	1.3	>0.94 g/cm³	1.5	always	1.3
				In special case	≥1.5

Table 18: Factors affecting Grease Trap size

Hence,

$$NS = 4000m3/day * 1000L/m3 * 1day/24hrs * 1hr/3600s * 1.0 * 1.5 * 1.0$$

= **69.44 L/s**

6.2.2 Surface Area

Minimum Grease Trap Surface Area, A_{min}= 0.25xNS

where 0.25 also accounts for conversion of units

$$A_{min} = 0.25*69.44$$

A_{min} = **17.36 m²**

6.3 Membrane Bio-Reactor

6.3.1 Volume

Hydraulic Residence Time (HRT) = 8h

$$Volume = \ Volumetric\ Flow\ rate * Hydraullic\ Residence\ Time\ (HRT)$$

$$= 4000 m3/day * \ 1 day/24h * \ 8h$$

$$= \mathbf{\underline{1333.3m^3}}$$

6.3.2 Diameter and Height

$D_t : H_t = 1 : 2 \longrightarrow H_t = 2D_t$

$V = \frac{\pi}{4} D_t^2 H_t \longrightarrow V = \frac{\pi}{2} D_t^3$

$$1333.3 = \frac{\pi}{2} D_t^3$$

$$D_t = \mathbf{\underline{9.47m}}$$

$$H_t = \mathbf{\underline{18.94m}}$$

6.3.3 Membrane Specifications

Pore size = 0.03μm

Configuration = Hollow Fiber

Material = PVDF (Polyvinylidene Flouride)

Element Type = DOW IntegraFlux™ Module SFP-2880XP

Permeability of Hollow Fiber PVDF = 233L/m²hbar

Trans-membrane Pressure (TMP) = 0.2bar

$$Flux = Permeability\ x\ TMP$$

$$= 233\ L/m^2hbar\ x\ 0.2bar$$

$$= \underline{\mathbf{46.6L/m^2h}}$$

Total Required Membrane Area of All Membrane Modules

$$Area = \frac{Volumetric\ Flow\ Rate}{Flux}$$

$$= \frac{\frac{4000m^3}{d} x \frac{1000L}{m^3} x \frac{1d}{24h}}{46.6L/m^2h}$$

$$= \underline{\mathbf{3576.5m^2}}$$

Number of membrane modules for the selected membrane module is as follows

$$Number\ of\ modules = \frac{Total\ Required\ Area}{Area\ of\ one\ module}$$

$$= \frac{3576.5}{77} = 46.44$$

$$= \underline{\mathbf{47}}$$

6.4 High Pressure Pump

6.4.1 Differential Head

Suction Pressure = 81.30 kPa

Discharge Pressure = 1500 kPa (to overcome the osmotic pressure of the RO membrane)

Differential Head, H, is given by

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

$$= (1500 - 81.30) * \frac{1000}{1000*9.8}$$

=**144.8m**

6.4.2 NPSH available

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

$$= (81.30 - 3.17) * \frac{1000}{1000 * 9.8}$$

= **7.97m**

6.4.3 <u>Impeller Diameter and Efficiency</u>

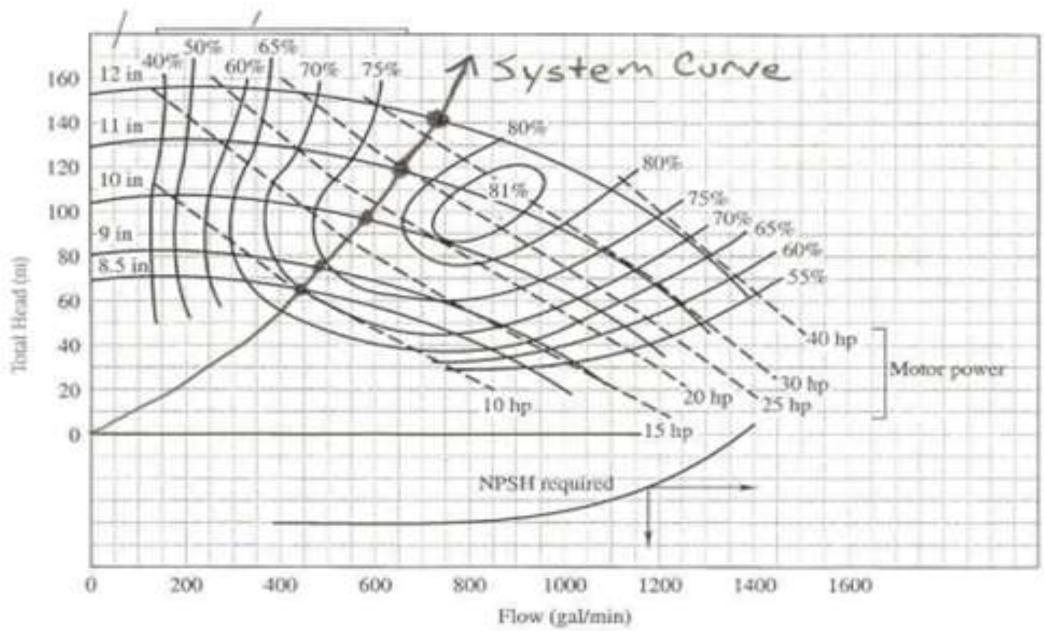


Figure 3: Performance curve of pump

$$Volumetric\ Flow\ Rate = 4000\ \frac{m^3}{day}\ x\ 0.18\ \frac{gpm}{1\ m^3/day}$$

= 733.8 gpm

Given the flow rate of 733.8 gpm and 144.8m of differential pressure head, the suitable impeller diameter would be **<u>12in</u>** and efficiency would be around **<u>77%</u>**.

6.4.4 <u>Hydraulic Power</u>

$$Power = \frac{Head\ x\ Vol.Flowrate\ x\ Density\ x\ gravitational\ acceleration}{efficiency}$$

$$Power = \frac{144.8m\ x\ 4000\frac{m^3}{day}x\frac{1\ day}{86400s}x1000\frac{kg}{m^3}x\ 9.8\frac{m}{s^2}}{0.77}$$

$$Power = 85319.86W$$

$$Power = \underline{\mathbf{85.32\ kW}}$$

6.5 Reverse Osmosis Membrane

6.5.1 Feed and Permeate Specification

Feed Source= Brackish water

Feed flow rate= 4000m^3/day= 734 gal/min

Feed TDS concentration = 3500ppm

Permeate flow rate = 3760m^3/day

Permeate TDS = 18.62 ppm

$$Recovery = \frac{Permeate\ Flow\ Rate}{Feed\ Flow\ Rate}\ x\ 100$$

$$= \frac{3760}{4000}\ x\ 100$$

= **94%**

6.5.2 Selecting Flow Configurations and No. of Passes

Flow configuration = plug flow (standard - with spiral wound membrane)

No. of passes = 1 (standard)

6.5.3 Selecting Membrane Element Type

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

Table 19: Different types of membrane module elements

Membrane element= BW30-400/34i (used for brackish water with less than 5000 ppm in feed) with an active area of 34m^2.

6.5.4 Selecting Average Membrane Flux

Flux=37L/m^{2}h (According to feed source)

6.5.5 Number of Elements Needed

$$Ne = \frac{Qp}{F\ x\ A}$$

$$= \frac{\frac{3760m^3}{day} x 1000 \frac{L}{m^3} x \frac{1\ day}{24h}}{37 \frac{L}{m^2h} x\ 34\ m^2}$$

= **125**

6.5.6 Number of Pressure Vessels Needed

$$Nv = \frac{Ne}{number\ of\ elements\ per\ vessel}$$

=125/8

=**16**

A vessel can contain up to 8 elements.

6.5.7 Number of Stages

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

Table 20: Data showing relation between system recovery and number of stages

Since our system has 94% recovery and 8 elements in a vessel, we can reasonably assume that we can select the number of stages as 3.

6.5.8 Staging Ratio

$$\mathrm{R} = \left[\frac{1}{1-\mathrm{Y}}\right]^{1/n}$$

Where

R= staging ratio

Y=recovery in fractions

N= no. of stages

$$R = \left[\frac{1}{1-0.94}\right]^{1/3} = \underline{\mathbf{2.55}}$$

Nv(1)= no. of vessels in first stage

Nv(2)= no. of vessesls in second stage

Nv(3)=no. of vessels in third stage

$$Nv(1) = \frac{Nv}{1 + R^{-1} + R^{-2}} = \mathbf{10}$$

$$Nv(2) = \frac{Nv(1)}{R} = \mathbf{4}$$

$$Nv(3) = Nv - Nv(1) - Nv(2) = 16 - 10 - 4 = \mathbf{2}$$

Ratio of Nv(1) : Nv(2) : Nv(3) = 5 : 2 : 1

6.5.9 <u>Pressure Vessels</u>

Diameter of each element, D_e = 7.9 inches

Diameter of vessel = D_e + allowance = 7.9 + 1 = 8.9 inches

Length of each element, L_e = 40.5 inches

Length of vessel = No. of elements x L_e + allowance = 8 x 40.5 + 1 = 325 inches

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

$$= \frac{\pi}{4} 8.9^2 \; x \; 325$$

= 20218.70 in^3

= **$0.331m^3$**

6.6 Storage Tanks

6.6.1 NaOH Tank

Maximum moles of NaOH that can be used = 3.929 moles/day

Concentration of NaOH = 0.5 M (considering the hazards of using higher concentration, 0.5M is suitable value to be used industrially)

Storage Time = 2 weeks

Hence,

$$Capacity = \frac{3.929 \; \frac{mol}{day} \; x \; 2 \; weeks \; x \; \frac{7 \; days}{1 \; week}}{0.5 \; \frac{mol}{L}}$$

= 110 L

= **$0.11 \; m^3$**

6.6.2 H_2SO_4 Tank

Maximum moles of H_2SO_4 that can be used = 0.034 moles/day

Concentration of H_2SO_4 = 0.01 M (as H_2SO_4 is significantly more hazardous, 0.01M is a more suitable value to be used industrially)

Storage Time = 2 weeks

Hence,

$$Capacity = \frac{0.034\ \frac{mol}{day}\ x\ 2\ weeks\ x\ \frac{7\ days}{1\ week}}{0.01\ \frac{mol}{L}}$$

= 47.6 L

= **0.0476 m^3**

Chapter 7: Costing

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

Table 21: Base costs, size units and cost indices for different equipments

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 Equalization Tank

7.1.1 Tank

Capacity of tank = 200 m^3

$$Cost = CS^n$$

$$= 2400 \times (200)^{0.6}$$

$$= \$\ \mathbf{57653.97}$$

7.1.2 Agitator

Agitator Power = 0.006841 kW

$$Cost = CS^n$$

$$= 3000 \times (0.006841)^{0.5}$$

$$= \$\ \mathbf{248.13}$$

7.1.3 Total Cost

Total Cost = Cost of Tank + Cost of Agitator

= $ 57653.97 + $ 248.13

= **$ 57902.10**

7.2 Grease Trap

Capacity of tank = 83.3 m^3 = 22005.5 gal

$$Cost = C_1(S_2/S_1)^n$$

$$= 2000\ x\ (\frac{22005.5}{1000})^{0.6}$$

= $ 12780.53

7.3 Membrane Bio-Reactor

7.3.1 Vessel

Capacity of tank = 1333.3 m^3

$$Cost = CS^n$$

$$= 2400 \times (1333.3)^{0.6}$$

$$= \$\ \mathbf{179956.68}$$

7.3.2 Membrane

Area = 3576.5 m^2

$$Cost = Cost\ per\ unit\ area\ x\ Area$$

$$= 25 \times 3576.5$$

$$= \$\mathbf{89412.5}$$

7.3.3 Total Cost

Total Cost = Cost of Vessel + Cost of Membrane

= $ 179956.68 + $ 89412.5

= **$ 269369.18**

7.4 High Pressure Pump

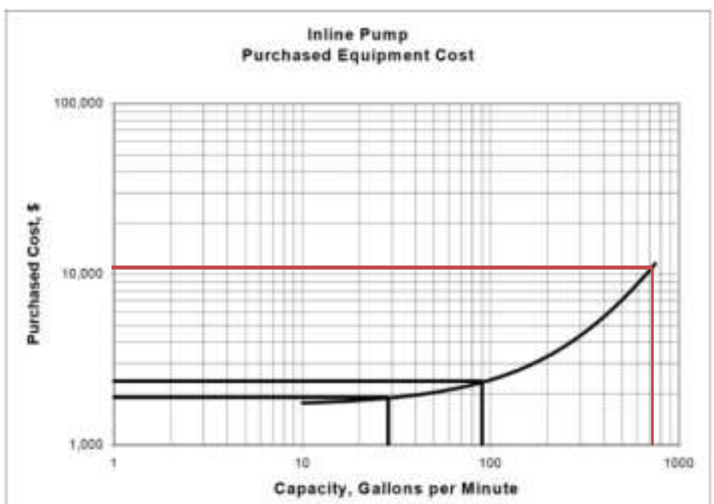


Figure 4: Pump capacity vs. purchased cost

Volumetric Flow Rate = 734 gpm

Cost from the Graph = **$ 12000**

7.5 RO Membrane

7.5.1 Pressure Vessels

$$Capacity\ of\ Vessel = 0.331\ m^3$$

where x = no. of vessels

$$Cost = xCS^n$$

$$= 16 \times 2900 \times (0.331)^{0.6}$$

$$= \$\ 16\ \times 1493.81$$

= **$23900.93**

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

$$Purchase\ Cost = Bare\ cost\ x\ Pressure\ factor$$

$$= \$23900.93\ x\ 1.2$$

= **28681.12**

7.5.2 Membrane Elements

$$No.of\ elements = 16\ x\ 8 = 128$$

$$Cost = Cost\ per\ unit\ element\ x\ No.of\ elements$$

$$= 545\ x\ 128$$

= $ **69760**

7.5.3 Total Cost

Total Cost = Cost of Pressure Vessels + Cost of Membrane Elements

= $ 28681.17 + $ 69760

= **$ 98441.17**

7.6 Storage Tanks

7.6.1 NaOH Tank

Capacity of tank = 0.11 m^3

$$Cost = CS^n$$

$$= 2400 \times (0.11)^{0.6}$$

$$= \$\ \mathbf{638.33}$$

7.6.2 H_2SO_4 Tank

Capacity of tank = 0.0476 m^3

$$Cost = CS^n$$

$$= 2400 \times (0.0476)^{0.6}$$

$$= \$\ \mathbf{386.17}$$

7.6.3 Total Cost

Total Cost = Cost of Tank + Cost of Agitator

= $ 638.33 + $ 386.17

= **$ 1024.50**

7.7 Purchased Cost of Equipment (PCE)

Total purchase cost of major equipment items is as follows:

Equipment	Cost ($)
Equalization Tank	57902.10
Grease Trap	12780.53
Membrane Bio-Reactor	269369.18
High Pressure Pump	12000
RO Unit	98441.17
Storage Tanks	1024.50
Total PCE	**451517.48**

Table 22: Summary & total of purchased equipment cost

7.8 Physical Plant Cost (PPC)

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

$$PPC = PCE\ x\ (1 + f_1 + \cdots + f_9)$$

$$= \$\ 451517.48\ x\ (1 + 2.15)$$

= **$ 1422280.06**

7.9 Fixed Capital

For systems with both liquid and solids, the following factors are used to determine the fixed capital.

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

Table 24: Lang's factors to calculate Fixed Capital for system containing solids and liquids

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

$$= \$\ 1422280.06\ x\ (1 + 0.4)$$

= **$ 1991192.08**

7.10 Working Capital

Working capital will be taken as 5% of Fixed Capital as our plant has a single product and a rather simple process.

$$Working\ Capital = 5\%\ x\ Fixed\ Capital$$

$$= 5\%\ x\ \$\ 1991192.08$$

= **$ 99559.60**

7.11 Total Investment

$$Total\ Investment = Fixed\ Capital + Working\ Capital$$

$$= \$\ 1991192.08 + \$\ 99559.60$$

= **$ 2090751.68**

7.12 Operating Costs

$$Operating\ Time\ (Allowing\ for\ plant\ attainment) = 95\%\ x\ 365$$

= 347 days/y

=8328 h/y

7.12.1 Fixed Costs

Type of Cost	Method of Calculation	Cost ($)
Maintenance	5% of Fixed Capital	99559.60
Operating Labor	Manning Estimate	100000
Laboratory Costs	20% of Operating Labor	20000
Supervision	20% of Operating Labor	20000
Plant Overheads	50% of Operating Labor	50000
Capital Charges	10% of Fixed Capital	199119.21

Insurance	1% of Fixed Capital	19911.92
Local Taxes	2% of Fixed Capital	39823.84
Royalties	1% of Fixed Capital	19911.92
Total		**568326.49**

Table 25: Fixed Operating Costs

7.12.2 Variable Costs

Type of Cost	Method of Calculation	Cost ($)
Raw Materials	NaOH = 0.1572kg/d x $2.6/kg x347d/y	141.83
	H_2SO_4 = 0.003289kg/d x $0.065/kg x 347d/y	
Miscellaneous Materials	10% of Maintenance Costs	9955.96
Utilities	$0.015/MJ x Energy/year	38372.50
Total		**48470.29**

Table 26: Variable Operating Costs

7.12.3 Annual Operating Cost

$$Annual\ Operating\ Cost = Fixed\ Costs + Variable\ Costs$$

$$= \$\ 568326.49 + \$\ 48470.29$$

= **$ 616796.78**

Chapter 8: HAZOP Analysis

A HAZOP study identifies hazards and operability problems. The concept involves investigating how the plant might deviate from the design intent. If in the process of identifying problems during a HAZOP study, a solution becomes apparent, it is recorded as part of the HAZOP result; however, care must be taken to avoid trying to find solutions which are not so apparent, because the prime objective for the HAZOP is problem identification.

Although the HAZOP study was developed to supplement experience based practices when a new design or technology is involved, its use has expanded to almost all phases of a plant's life. HAZOP is based on the principle that several experts with different backgrounds can interact and identify more problems when working together than when working separately and combining their results.

8.1 Terminology

The following terminology is considered when performing a HAZOP analysis.

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 27: Meanings of different terminologies used in HAZOP Analysis

8.2 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 monitoring 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 28: Factors involved in HAZOP Analysis of Equalization Tank

8.3 Grease Trap

Deviation	Causes	Consequences	Recommendations
Less flow	• Leaking flange of valved stub not blanked and leaking.	• Material loss	• Install high level of alarm on LIC and check sizing of relief opposite liquid overfilling.
Less temperature	• Winter conditions	• Water sump and drain line freeze up.	• Lag water sump down to drain system and drain line downstream.
High concentration water in stream	• High water level in immediate storage tank.	• Water sump fills up more quickly.	• Install high interface level alarm on sump.
More flow	• LCV fails open	• Tank overfills	• Install high level alarm on LIC.
More temperature	• High intermediate storage tank.	• High pressure in tank.	• Install adequate warning of high temperature.

Table 29: Factors involved in HAZOP Analysis of Grease Trap

8.4 Membrane Bio-Reactor

Deviation	Causes	Consequences	Recommendations
Less flow	• Feed line or valves blocked. • Aging of the membrane. • Valve on retentate side open.	• No efficient separation. • Overpressure.	• Check of valves and lines • Membrane substitution.
More flow	• Membrane failure. • Feed flowrate and temperature increase.	• Purity loss. • Overpressure. • No separation • Recovery increases	• Fit a relief valve. • Maintenance of instrumentations. • Check of valves and lines.
Low temperature	• Steam feed valve in heat exchanger partially closed. • Heat exchanger control fails.	• Condensate film on membrane surface. • No efficient separation.	• Fit a temperature alarm. • Membrane cleaning.
More temperature	• Steam feed valve in heat exchanger sticks open. • Heat exchanger control fails.	• Membrane can be damaged. • No efficient separation. • Higher permeate flow rate.	• Fit and control a temperature alarm. • Maintenance of instrumentations.

Table 30: Factors involved in HAZOP Analysis of MBR

8.5 High Pressure Pump

Deviation	Causes	Consequences	Recommendations
Pressure	• Increase pressure due to overflow • Decrease in pressure due to restricted flow	• Pump damage. • Recirculation. • More pump power. • Cavitation in pump	• Flow regulation and control.
Temperature	• High or low temperature	• Increased risk of cavitation.	• Temperature regulation and control of columns. • Flow regulation and control of tanks
Flow	• More or less flow	• Reduced pump efficiency. • Chances of cavitation. • Chances of recirculation.	• Flow regulation and transmittance

Table 31: Factors involved in HAZOP Analysis of HP Pump

8.6 RO Membrane

Deviation	Causes	Consequences	Recommendations
No pressure	• Blocked inlet and outlet of the pump • Pump Failure • Fouling of check valves • Manual valve failure	• Line Trip, and no produce permeate water	• Install switch on manual valve as safety lock • Install auto vent on line
Low pressure	• Decrease in level of Raw Water Vessel regard to inlet suction • Strainer blockage • Pump Corrosion	• Line Trip, and no produce permeate water	• Controlling of manual valves • Installing moisture sensor near sand filter pump
Low flow	• No regular manual valve in outlet of Raw Water Pump, Concentrate of Reverse Osmosis, High Pressure Pump • Failure in pump suction • Check valve blockage	• Line Trip, and no produce permeate water	• Controlling of manual valves • Regular backwash of sand filter. • Periodical inspection & maintenance

High flow	• No regularize manual valve. • Mechanical failure in flange. • Start accidental pump	• Line Trip, and no produce permeate water and cracking pipe	• 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, diffusion of Acid on place	• Maintenance & periodical repairing

Table 32: Factors involved in HAZOP Analysis of RO

Chapter 9: Simulation

9.1 Home

Figure 5: Home screen of DOW WAVE software

We have performed our simulation using the DOW WAVE software. As it can be seen we have selected the RO system.

We have specified our Feed Water Flow Rate as 4000 m^3/day.

The Product (Permeate) Water Flow Rate is 3760 m^3/day indicating the 94% recovery.

9.2 Feed Water

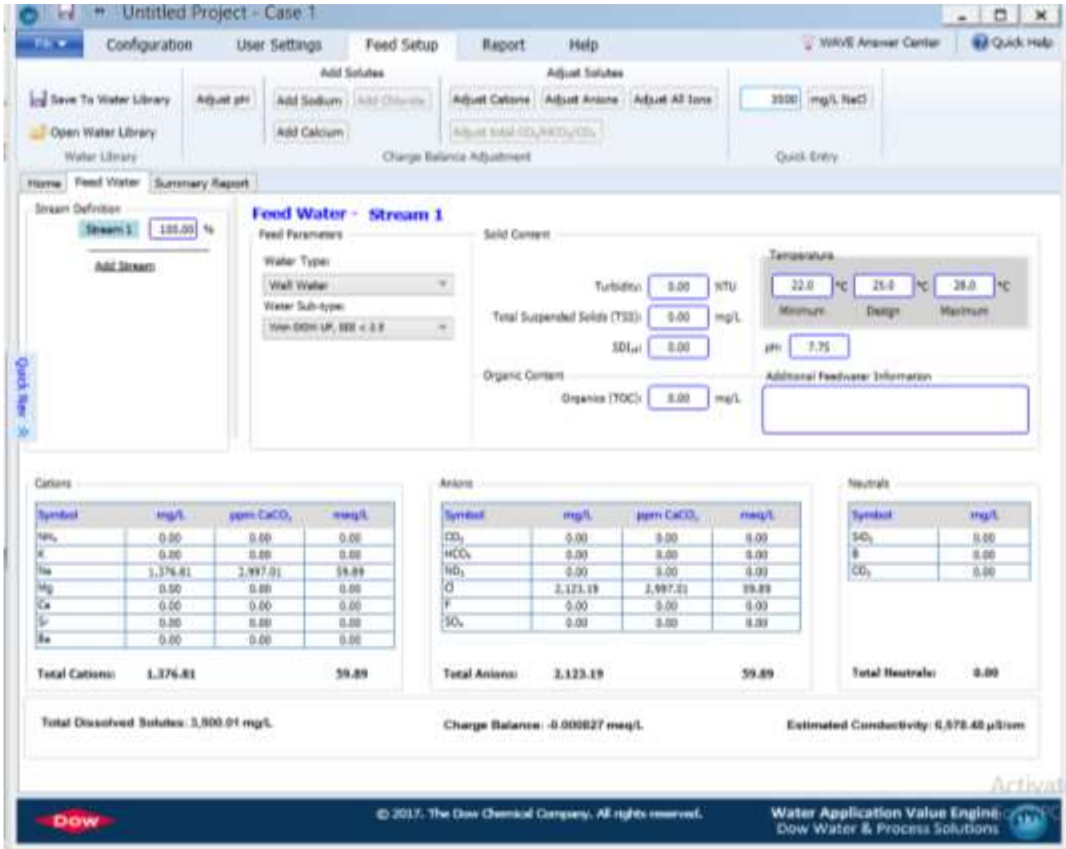


Figure 6: Details of Feed Water in DOW WAVE software

Water Type is selected as Well Water as it contains TDS in the range from 1500 – 5000ppm and our water has 3500ppm TDS.

We have set our 3500ppm for NaCl as we don't actually have the specification of the salts in the water and as NaCl is a common salt found in the water of food industry, which is the category for Engro Foods.

Water Sub-type is selected as "With DOW UF, SDI<2.5" as our MBR has a UF Hollow fiber membrane provided by DOW.

pH is selected as 7.75 which is that of our water.

Temperature is selected as 25°C with variation of 3°C.

9.3 Reverse Osmosis Specification

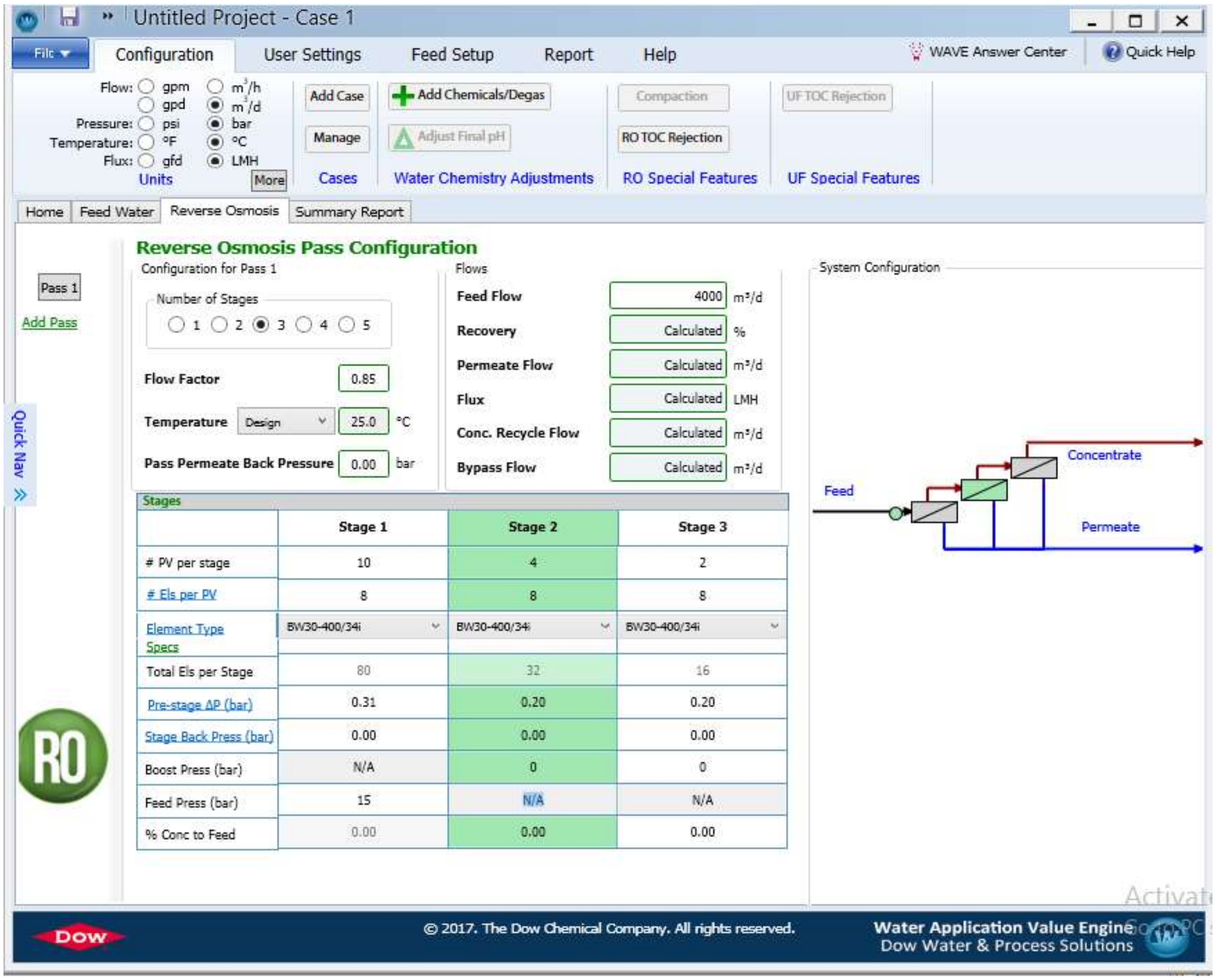


Figure 7: Details of Reverse Osmosis panel of the software

Number of stages is selected as 3 as shown in designing chapter.

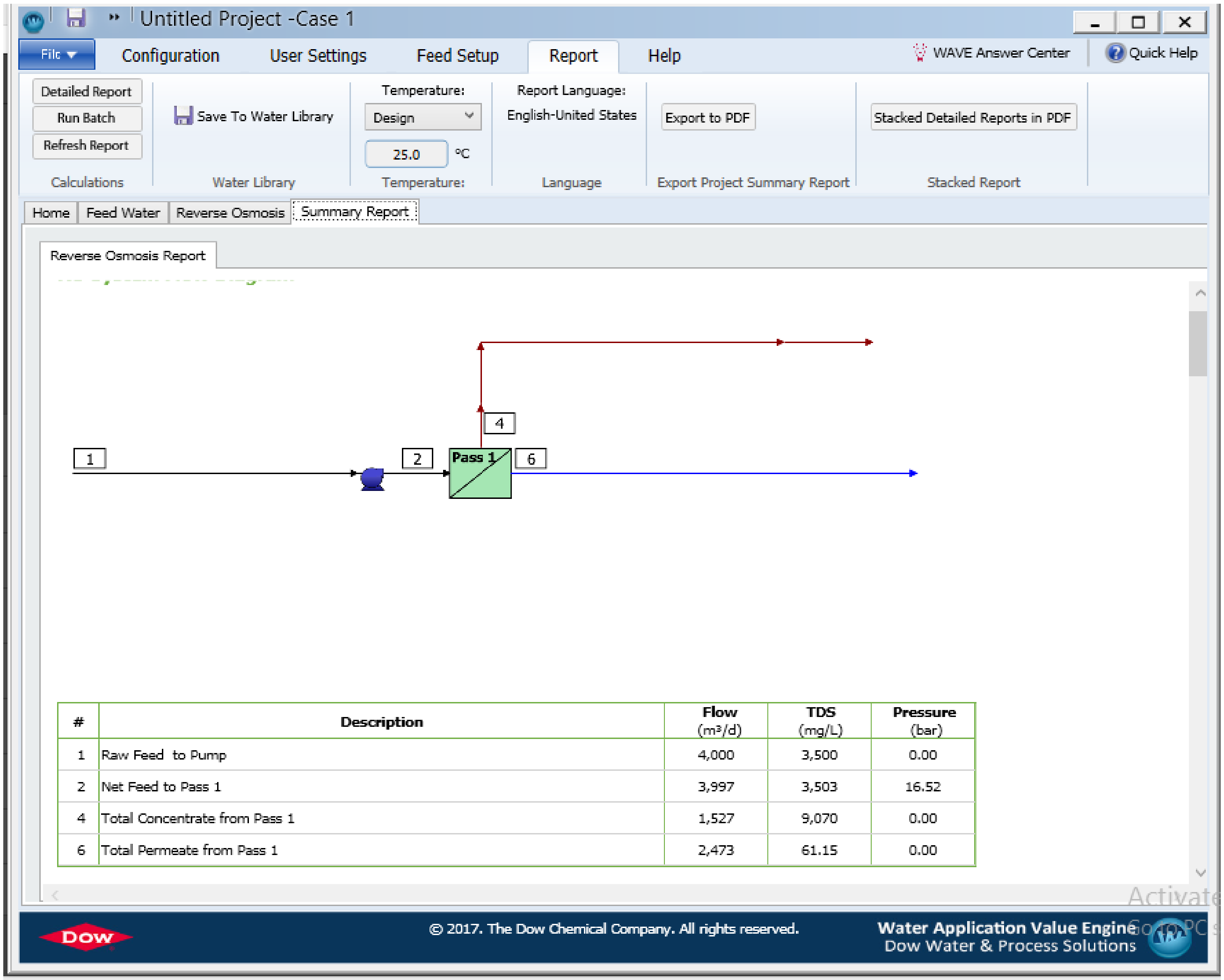
No. of Pressure vessels selected for first stage is 10, for second stage is 4 and for third stage is 2 as calculated in designing chapter.

No. of elements selected for each vessels is 8 as selected in the designing chapter.

Element type is selected as BW30-400/34i as is suitable for our feed water.

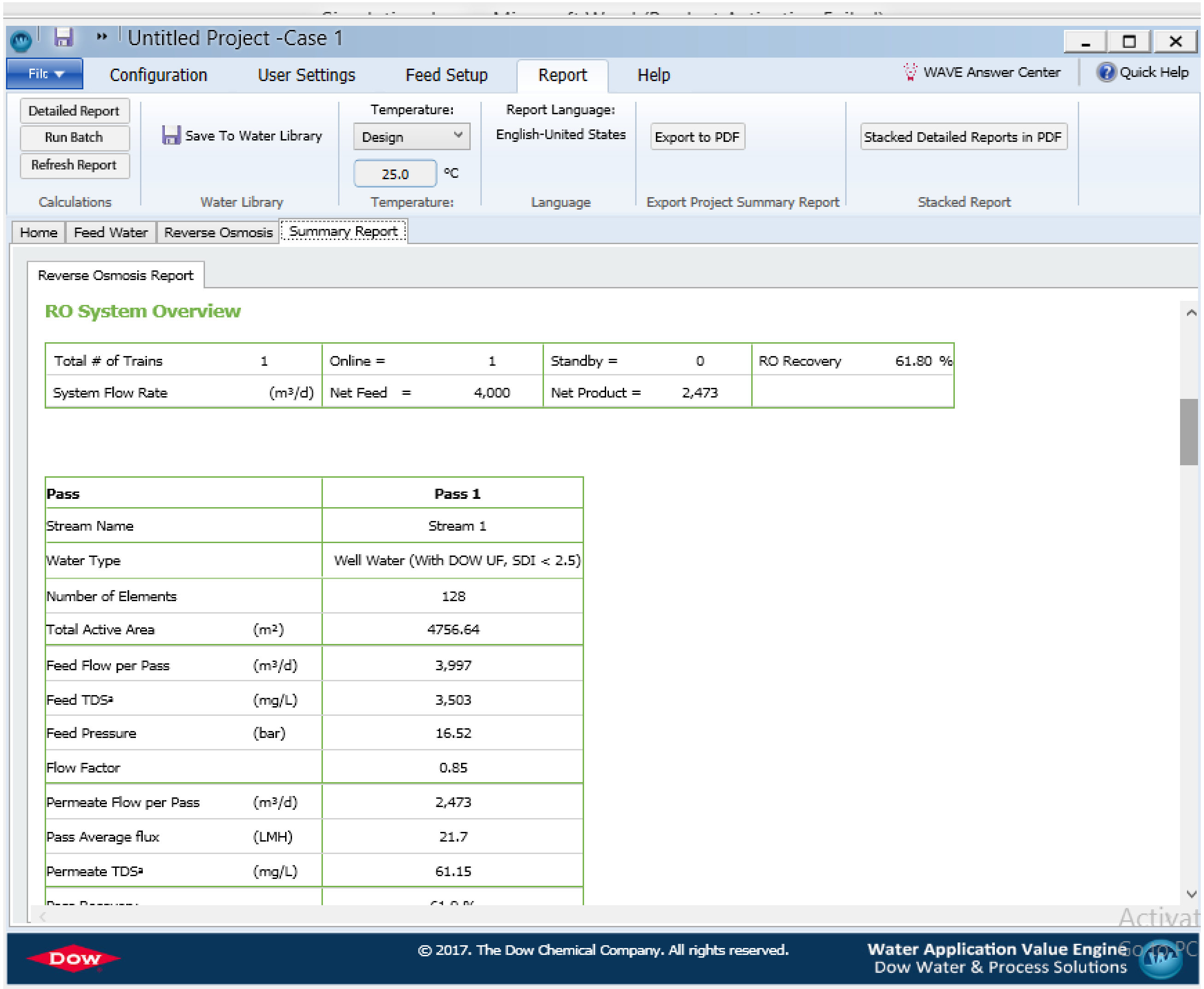
Feed pressure is specified here as 15 bars as known earlier.

9.4 Summary Report



#	Description	Flow (m³/d)	TDS (mg/L)	Pressure (bar)
1	Raw Feed to Pump	4,000	3,500	0.00
2	Net Feed to Pass 1	3,997	3,503	16.52
4	Total Concentrate from Pass 1	1,527	9,070	0.00
6	Total Permeate from Pass 1	2,473	61.15	0.00

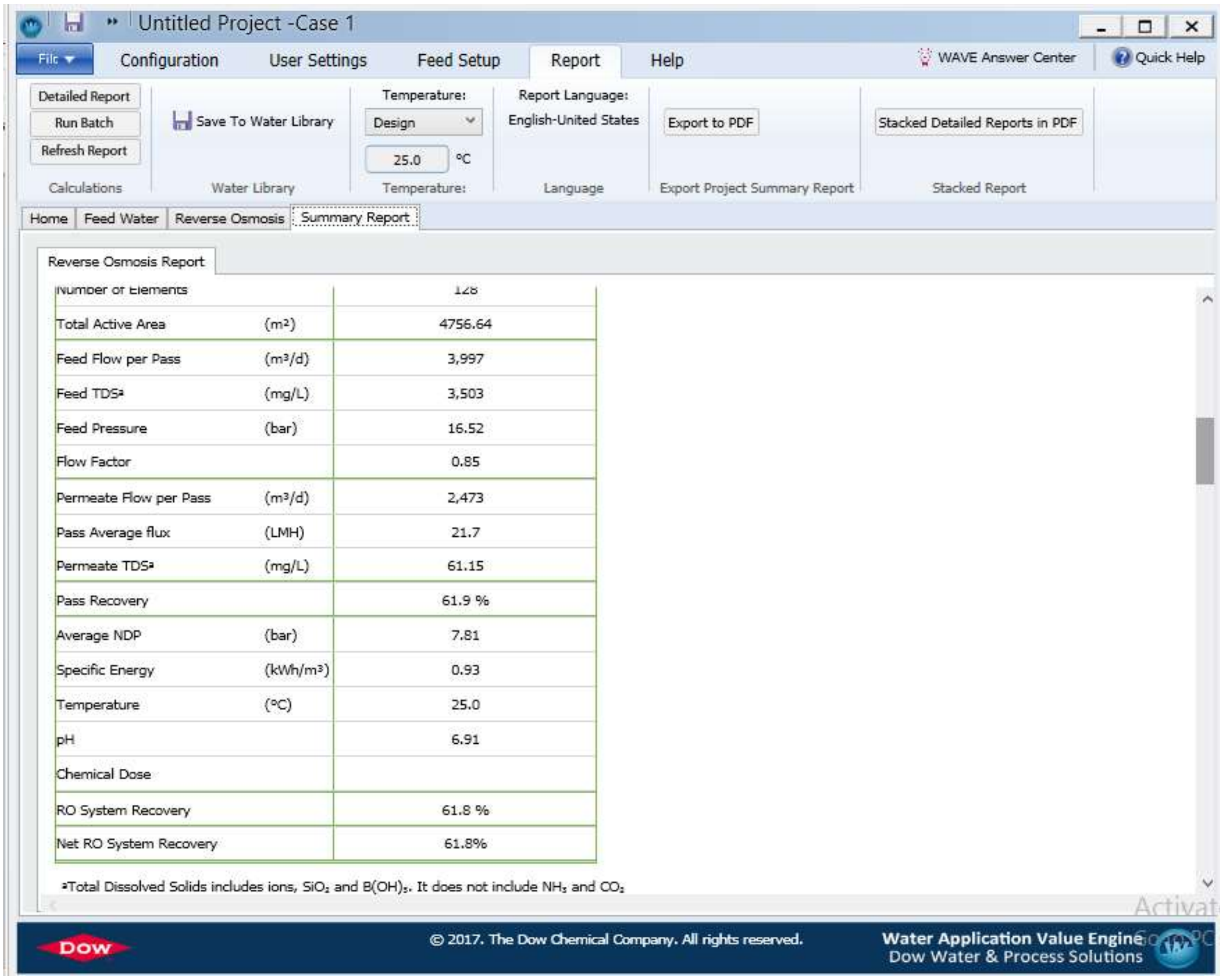
Figure 8a: Results of the simulation



Total # of Trains	1	Online =	1	Standby =	0	RO Recovery	61.80 %
System Flow Rate	(m³/d)	Net Feed =	4,000	Net Product =	2,473		

Pass		Pass 1
Stream Name		Stream 1
Water Type		Well Water (With DOW UF, SDI < 2.5)
Number of Elements		128
Total Active Area	(m²)	4756.64
Feed Flow per Pass	(m³/d)	3,997
Feed TDS[a]	(mg/L)	3,503
Feed Pressure	(bar)	16.52
Flow Factor		0.85
Permeate Flow per Pass	(m³/d)	2,473
Pass Average flux	(LMH)	21.7
Permeate TDS[a]	(mg/L)	61.15

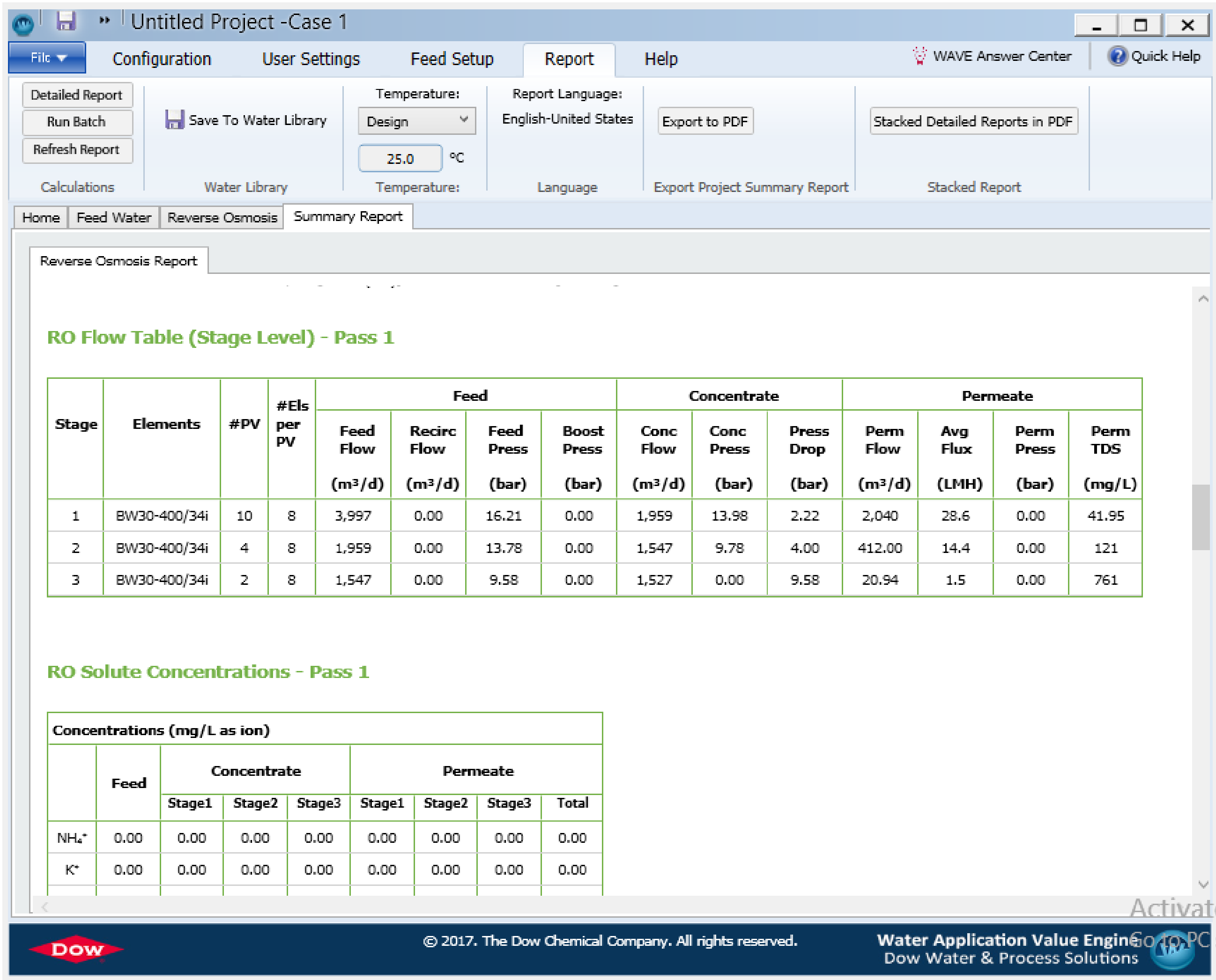
Figure 8b: Results of simulation 1



Number of Elements		128
Total Active Area	(m^2)	4756.64
Feed Flow per Pass	(m^3/d)	3,997
Feed TDS[a]	(mg/L)	3,503
Feed Pressure	(bar)	16.52
Flow Factor		0.85
Permeate Flow per Pass	(m^3/d)	2,473
Pass Average flux	(LMH)	21.7
Permeate TDS[a]	(mg/L)	61.15
Pass Recovery		61.9 %
Average NDP	(bar)	7.81
Specific Energy	(kWh/m^3)	0.93
Temperature	(°C)	25.0
pH		6.91
Chemical Dose		
RO System Recovery		61.8 %
Net RO System Recovery		61.8%

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

Figure 8c: Results of simulation 1



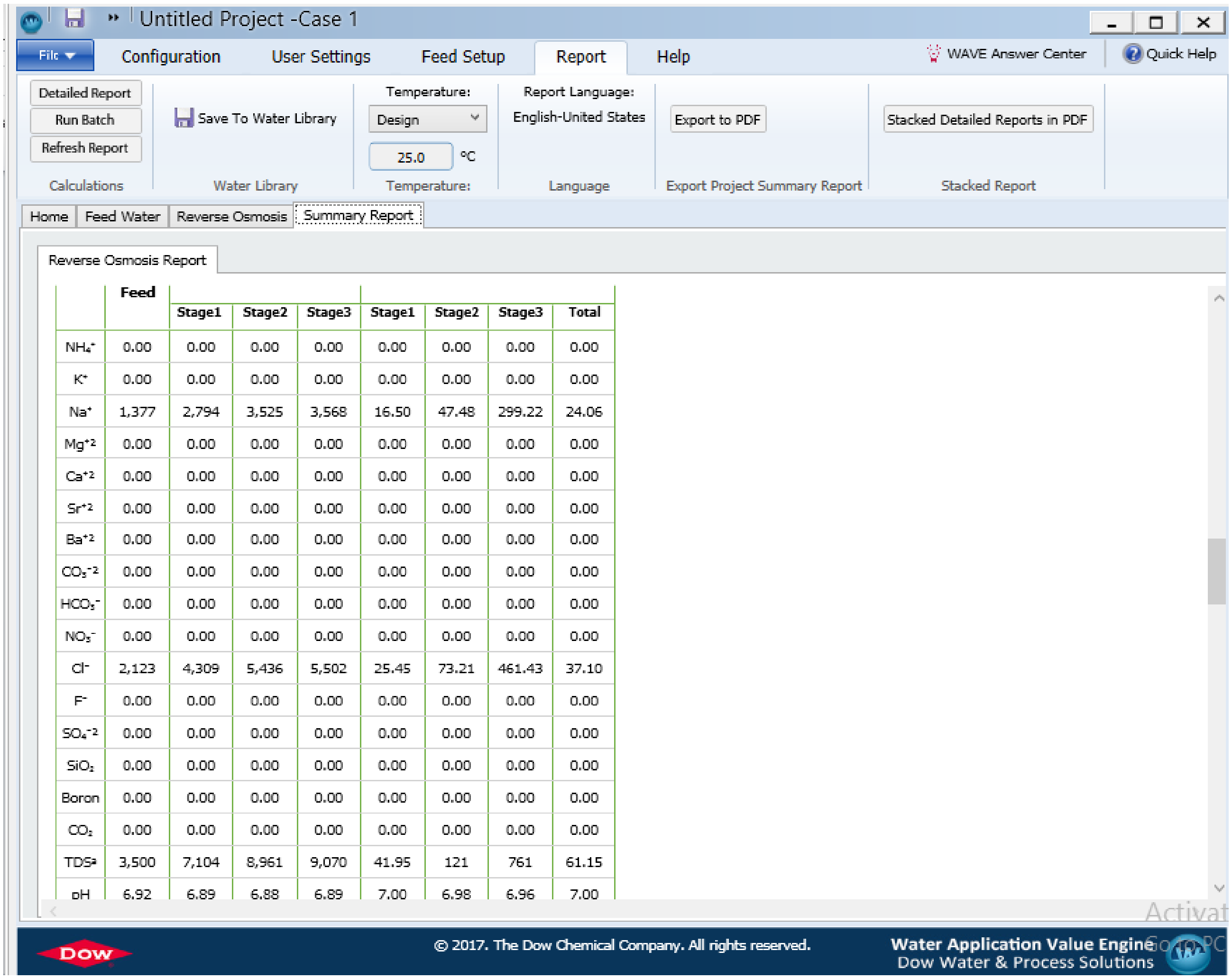
RO Flow Table (Stage Level) - Pass 1

Stage	Elements	#PV	#Els per PV	Feed				Concentrate			Permeate			
				Feed Flow (m³/d)	Recirc Flow (m³/d)	Feed Press (bar)	Boost Press (bar)	Conc Flow (m³/d)	Conc Press (bar)	Press Drop (bar)	Perm Flow (m³/d)	Avg Flux (LMH)	Perm Press (bar)	Perm TDS (mg/L)
1	BW30-400/34i	10	8	3,997	0.00	16.21	0.00	1,959	13.98	2.22	2,040	28.6	0.00	41.95
2	BW30-400/34i	4	8	1,959	0.00	13.78	0.00	1,547	9.78	4.00	412.00	14.4	0.00	121
3	BW30-400/34i	2	8	1,547	0.00	9.58	0.00	1,527	0.00	9.58	20.94	1.5	0.00	761

RO Solute Concentrations - Pass 1

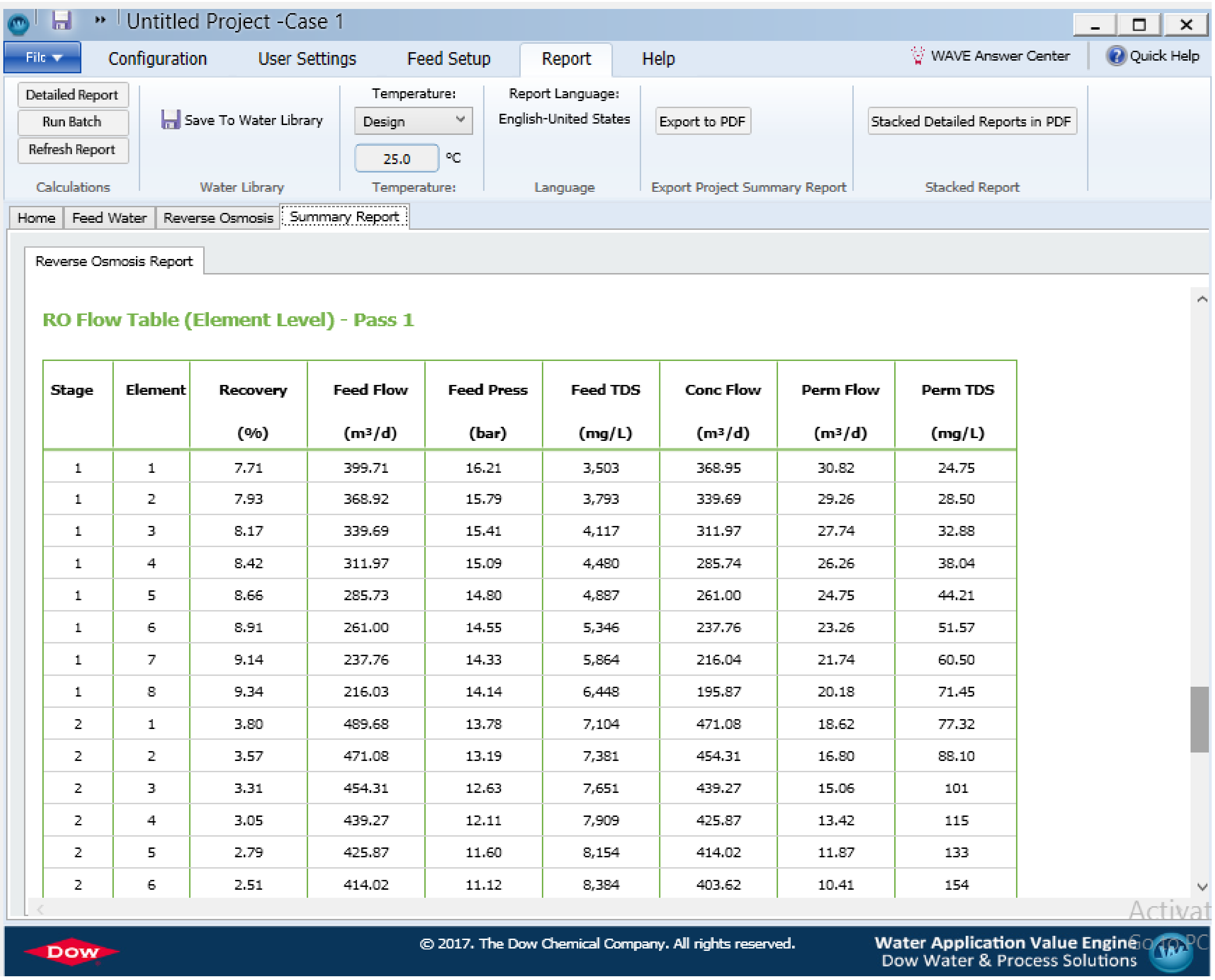
Concentrations (mg/L as ion)								
	Feed	Concentrate			Permeate			
		Stage1	Stage2	Stage3	Stage1	Stage2	Stage3	Total
NH_4^+	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K^+	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Figure 8d: Results of simulation 1



	Feed							
		Stage1	Stage2	Stage3	Stage1	Stage2	Stage3	Total
NH_4^+	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K^+	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na^+	1,377	2,794	3,525	3,568	16.50	47.48	299.22	24.06
Mg^{+2}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca^{+2}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr^{+2}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ba^{+2}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO_3^{-2}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HCO_3^-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NO_3^-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cl^-	2,123	4,309	5,436	5,502	25.45	73.21	461.43	37.10
F^-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SO_4^{-2}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SiO_2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Boron	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO_2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TDS[a]	3,500	7,104	8,961	9,070	41.95	121	761	61.15
pH	6.92	6.89	6.88	6.89	7.00	6.98	6.96	7.00

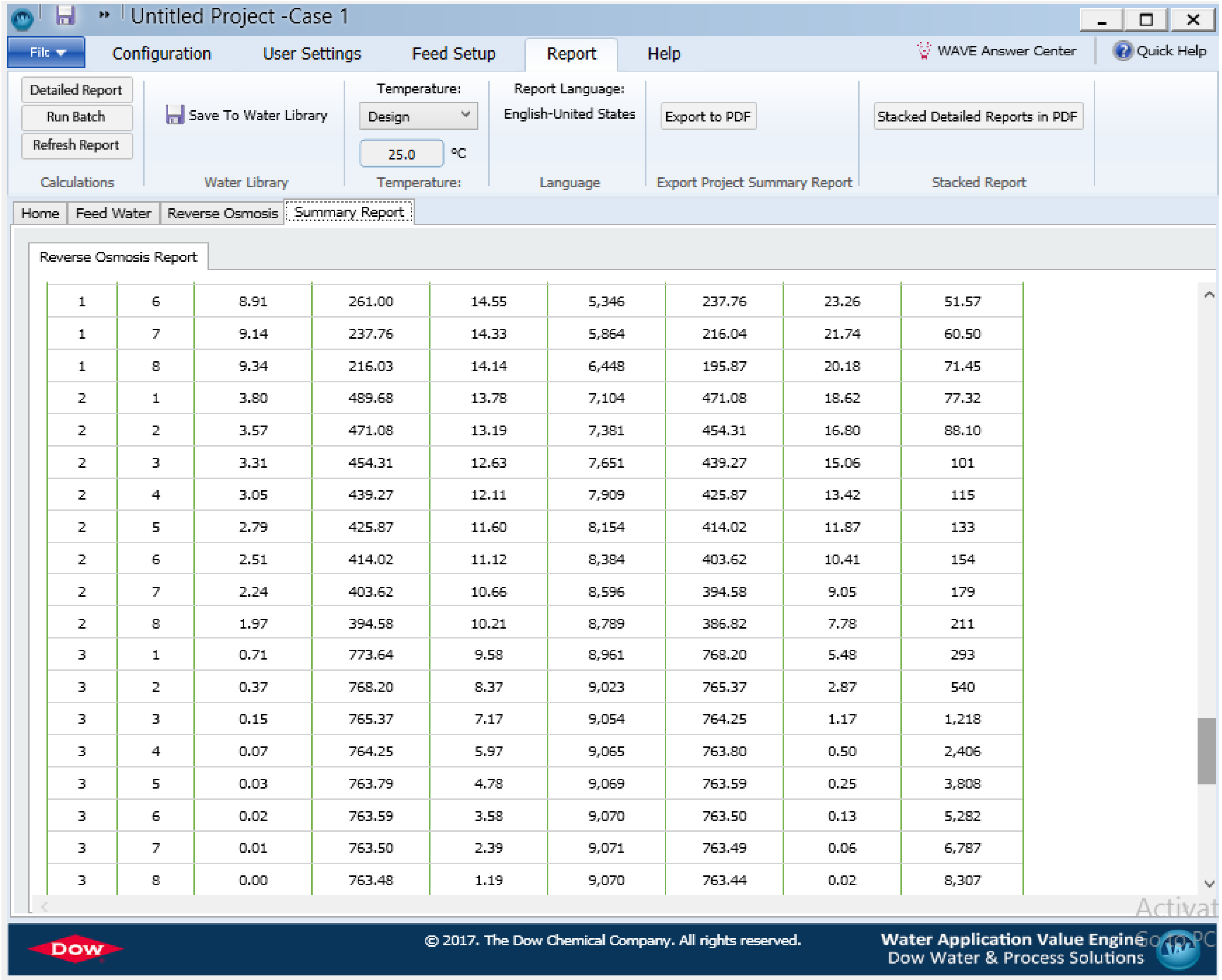
Figure 8e: Results of simulation 1



RO Flow Table (Element Level) - Pass 1

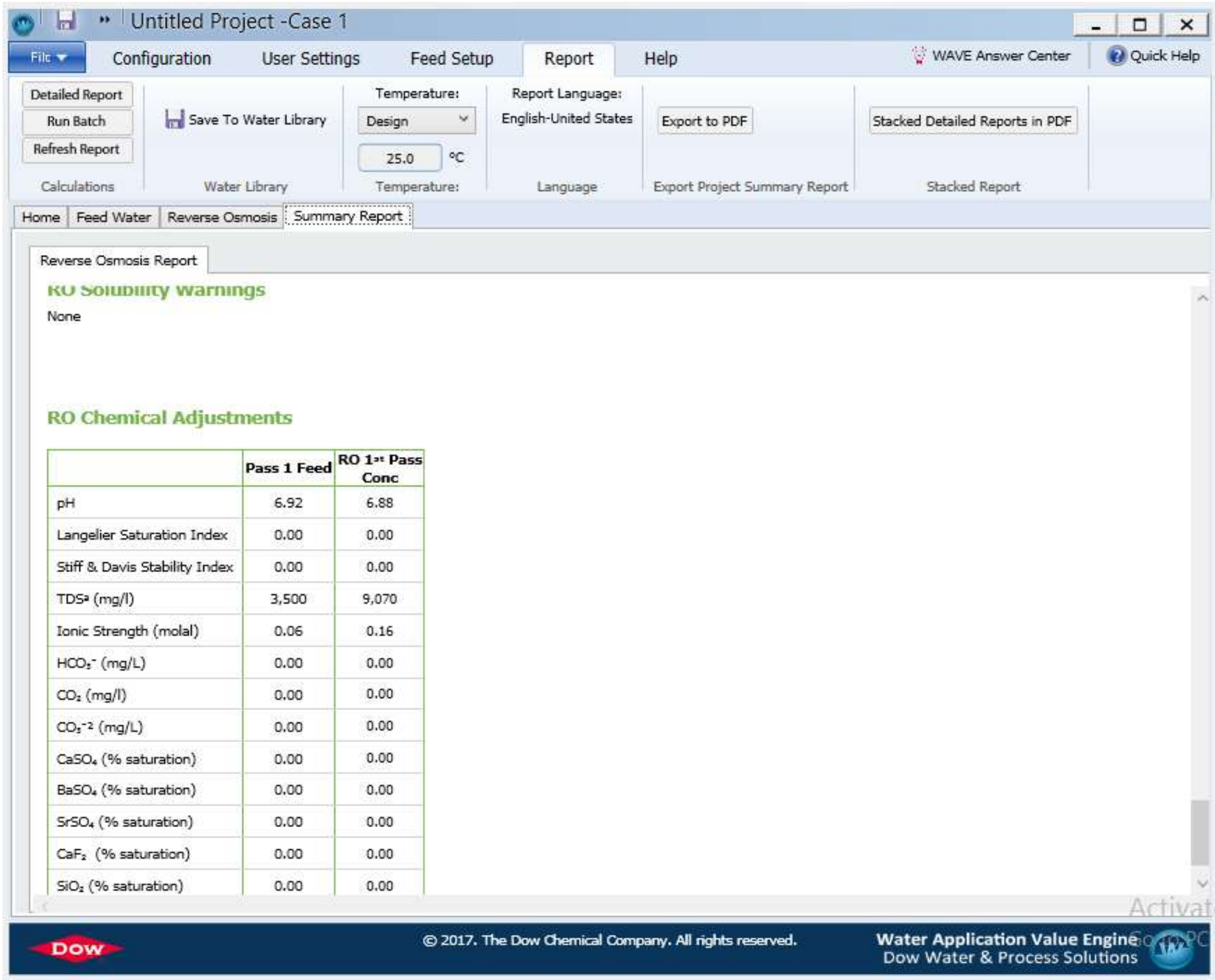
Stage	Element	Recovery (%)	Feed Flow (m³/d)	Feed Press (bar)	Feed TDS (mg/L)	Conc Flow (m³/d)	Perm Flow (m³/d)	Perm TDS (mg/L)
1	1	7.71	399.71	16.21	3,503	368.95	30.82	24.75
1	2	7.93	368.92	15.79	3,793	339.69	29.26	28.50
1	3	8.17	339.69	15.41	4,117	311.97	27.74	32.88
1	4	8.42	311.97	15.09	4,480	285.74	26.26	38.04
1	5	8.66	285.73	14.80	4,887	261.00	24.75	44.21
1	6	8.91	261.00	14.55	5,346	237.76	23.26	51.57
1	7	9.14	237.76	14.33	5,864	216.04	21.74	60.50
1	8	9.34	216.03	14.14	6,448	195.87	20.18	71.45
2	1	3.80	489.68	13.78	7,104	471.08	18.62	77.32
2	2	3.57	471.08	13.19	7,381	454.31	16.80	88.10
2	3	3.31	454.31	12.63	7,651	439.27	15.06	101
2	4	3.05	439.27	12.11	7,909	425.87	13.42	115
2	5	2.79	425.87	11.60	8,154	414.02	11.87	133
2	6	2.51	414.02	11.12	8,384	403.62	10.41	154

Figure 8f: Results of simulation 1



1	6	8.91	261.00	14.55	5,346	237.76	23.26	51.57
1	7	9.14	237.76	14.33	5,864	216.04	21.74	60.50
1	8	9.34	216.03	14.14	6,448	195.87	20.18	71.45
2	1	3.80	489.68	13.78	7,104	471.08	18.62	77.32
2	2	3.57	471.08	13.19	7,381	454.31	16.80	88.10
2	3	3.31	454.31	12.63	7,651	439.27	15.06	101
2	4	3.05	439.27	12.11	7,909	425.87	13.42	115
2	5	2.79	425.87	11.60	8,154	414.02	11.87	133
2	6	2.51	414.02	11.12	8,384	403.62	10.41	154
2	7	2.24	403.62	10.66	8,596	394.58	9.05	179
2	8	1.97	394.58	10.21	8,789	386.82	7.78	211
3	1	0.71	773.64	9.58	8,961	768.20	5.48	293
3	2	0.37	768.20	8.37	9,023	765.37	2.87	540
3	3	0.15	765.37	7.17	9,054	764.25	1.17	1,218
3	4	0.07	764.25	5.97	9,065	763.80	0.50	2,406
3	5	0.03	763.79	4.78	9,069	763.59	0.25	3,808
3	6	0.02	763.59	3.58	9,070	763.50	0.13	5,282
3	7	0.01	763.50	2.39	9,071	763.49	0.06	6,787
3	8	0.00	763.48	1.19	9,070	763.44	0.02	8,307

Figure 8g: Results of simulation 1

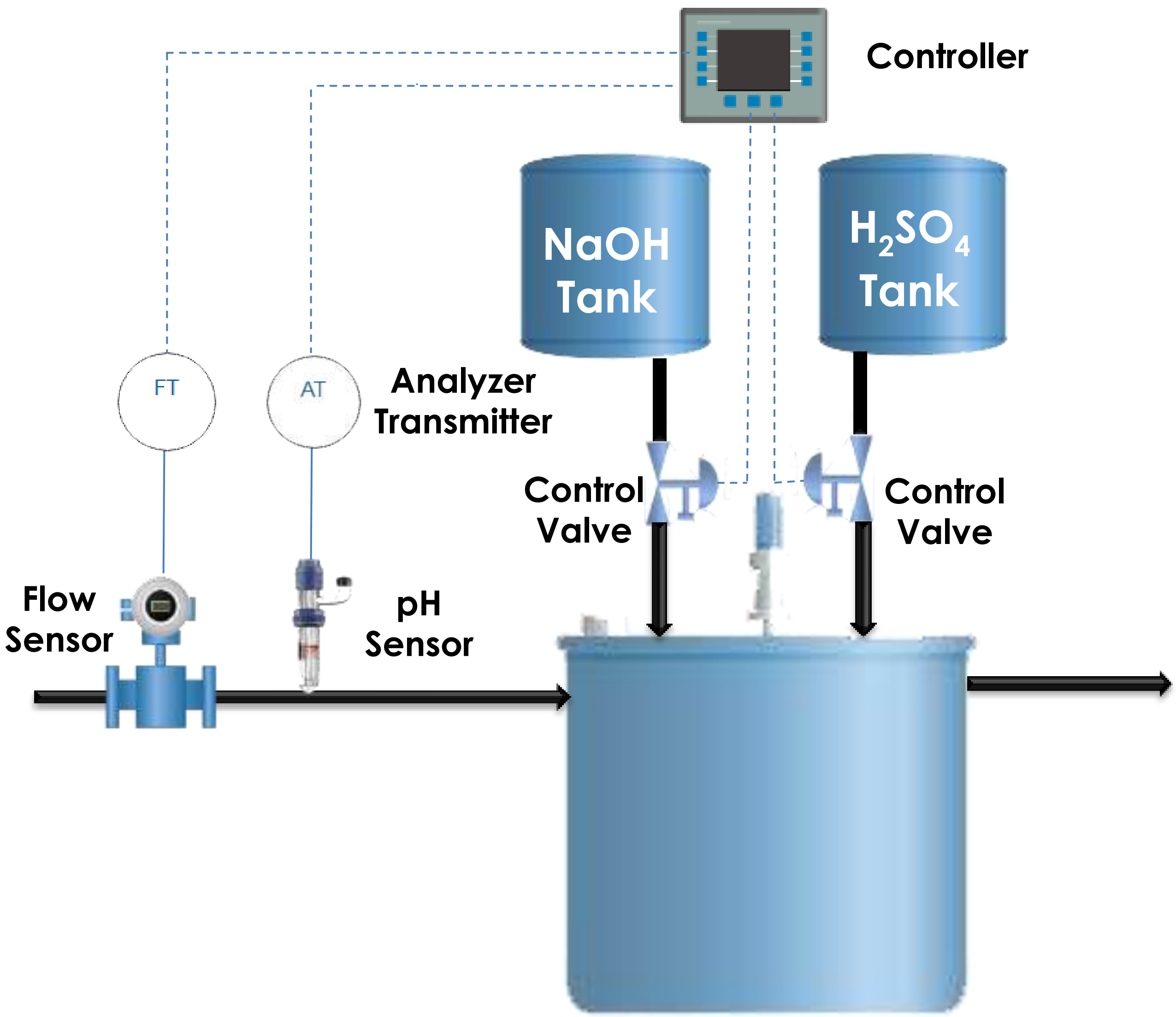


	Pass 1 Feed	RO 1st Pass Conc
pH	6.92	6.88
Langelier Saturation Index	0.00	0.00
Stiff & Davis Stability Index	0.00	0.00
TDS[a] (mg/l)	3,500	9,070
Ionic Strength (molal)	0.06	0.16
HCO_3^- (mg/L)	0.00	0.00
CO_2 (mg/l)	0.00	0.00
CO_3^{-2} (mg/L)	0.00	0.00
$CaSO_4$ (% saturation)	0.00	0.00
$BaSO_4$ (% saturation)	0.00	0.00
$SrSO_4$ (% saturation)	0.00	0.00
CaF_2 (% saturation)	0.00	0.00
SiO_2 (% saturation)	0.00	0.00

Figure 8h: Results of simulation 1

Chapter 10: Instrumentation

Instrumentation was done for Equalization Tank only as this is why it is required the most.



Chapter 11: Conclusions

As supported by various research papers and books, the proposed plant easily achieves all the target parameters. The pH of the water is stabilized to a value of 7.75. Even if there is a slight variance in the process variables, the pH level would still remain in the desired pH range of 7.5-8. Additionally, the flow rate of the water is stabilized reducing the need for oversizing the downstream equipment, thereby, reducing expected costs. The BOD and COD present in the feed water are eliminated. The product FOG levels were not specified but are significantly reduced to a value of 0.75ppm. The TDS, which was the main parameter to be treated, has been reduced below the maximum target of 20ppm to a value of 18.62ppm. Further reduction of TDS may lead to undesirable increase in costs.

Conclusively, it would be beneficial to set up the proposed plant to treat the undesirable parameters so that the water can be recycled back to the process plant.

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