MINIMIZATION OF ALUMINIUM SILICATES IN COMPOSITE POLYAMIDE RO MEMBRANE: A CASE STUDY AT PP(M)SB

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by

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Dissertation submitted to
the Chemical Engineering Programme Universiti Teknologi PETRONAS
in partial fulfillment of the requirement for the
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CERTIFICATION OF APPROVAL

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Approved by,

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JANUARY 2015

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own expect as specified in the references and acknowledgements. The original work contained herein have not been undertaken or done by unspecified sources or persons

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MOHD HUSAINNI BIN SAAID

ABSTRACT

Boiler feed water requires proper treatment to meet stringent requirement before entering into utilities boilers .Advance in membrane technology allows economical treatment of municipal water instead of using chemical of ion exchange technology. Reverse Osmosis (RO) membrane separation process has been found to be the best membrane technology available to remove aluminium silicate (Al_2SiO_5) of salts fouling cake layer from feed water. In this research, municipal water from Syarikat Air Melaka (SAM) was supplied to PP(M)SB (PETRONAS Penapisan (Melaka) Sdn. Bhd.) and was treated via of BW30-4040 tubular thin film composite polyamide RO membrane. To achieve optimum Al_2SiO_5 removal, permeate flux and percentage of salts rejection were investigated in relation to Transmembrane Pressure (TMP), feed pH and feed-water concentration. The experimental results indicated that of BW30-4040 membrane improved its performance by having optimum value at 16 bar TMP, temperature of 30^{o}C, 150 ppm of feed water concentration and pH at 7. Activated alumina proves removal of Al_2SiO_5 is 96.25 % of 2.5 ppm dosing rate with 300 L/m^2.hr of permeate flux. Addition of UF membrane improve salt rejection to 98.18 % and 90% recovery with comparison of ROSA 9.1 (Reverse Osmosis System Analysis) with 98.74% rejection and 91.54 % recovery with acceptable percentage of error. This work shows RO membrane is feasible and technically viable to be used for optimum Al_2SiO_5 removal from municipal feed water with the help of activated alumina and pre-treatment of ultra-filtration (UF) membrane. Besides, the treated water (permeate) fulfils the watering standards and can be used for boiler feed water users and steam generation for boiler and heat recovery steam generator (HRSG).

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CHAPTER 1: INTRODUCTION

1.1 Background

Production of boiler feed water (BFW) requires a very high quality of permeate water in *Petronas Penapisan Melaka (PP(M)SB).* Due to Revamp Project, BFW production (m^3/hr) has increased 20% from normal production of conventional treatment plant thus required additional treatment facilities to support the increment. With proven economic analysis and wide removal of variety of contaminants, Reverse Osmosis & Electro-deionization (ROEDI) plant is commissioned on December 2009.Municipal water from city water tank is pumped to ROEDI plant and further filtered by multimedia filter (MMF), activated carbon filter (ACF),and RO pre-filter. These pre-treatments work to meet RO composite polyamide membrane requirements with the help of chemical injection of anti-scalant (*Hypersperse*) and coagulating agent (*Solisep*).

In short, performance of RO is totally dependent on its pre-treatment since the system are designed to remove salts, not foulants, scalants and not designed to be fouled and cleaned frequently [1]. The autopsy results showed the membrane was fouled by Al_2SiO_5 deposition in hallow- RO fibers and damage RO membranes due to permanent deterioration. Therefore, re-emergence of ultra-filtration membrane technology has been upgraded in the control of fouling during service operation and by improved foulant removal techniques. This system designs specifically is to remove foulants and cleaned effectively. The research would focuses on minimization of Al_2SiO_5 cake layer fouling effect on RO membrane with installation of UF membrane, studying factor of affecting RO performance and non-reactive reagents approaches. In this paper, influence of different operating parameters on performance of polyamide RO membrane for removal of aluminium silicate will be discussed.

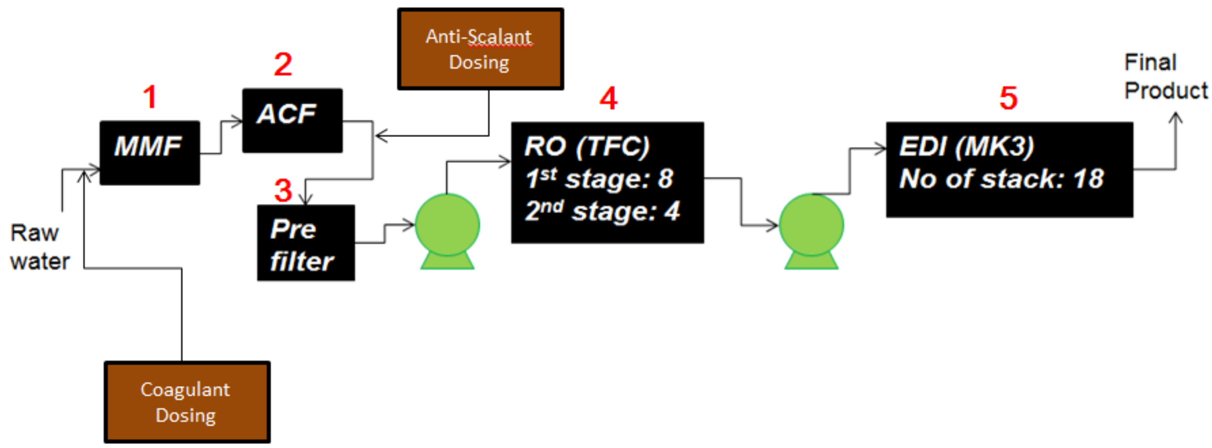

Figure 1: Block Diagram of ROEDI in PP(M)SB [2].

The block diagram above shows a water treatment plant in PP(M)SB with its pretreatment. Starting with multimedia filter per train and a common standby unit are provided. At any point of time, all the three multimedia filters (1) will be in service. When one multimedia filter undergoes backwash, the other two units will provide the complete flow. Activated carbon (2) filter per train and a common standby unit are provided. At any point of time, all the three activated carbon filters will be in service and pass through pre-filters (3). When one multimedia filter undergoes backwash, the other two units will provide the complete flow. One train of RO membrane system (4) will be provided per train. Each train will provide a permeate flow of 73 m^3/h. With two trains operating, the total permeate flow will be 146 m^3/h. Each RO train consists of 2 stages and the array configuration will be 8:4. Each pressure vessel will have 6 elements. The RO recovery will be 76%.Then, two train of electro-de-ionization (EDI) (5) will be provided per train. Each train will provide a product flow of 65m^3/h. With two trains operating, the total product flow will be 130m^3/h. Each unit of EDI consists of 18 stacks and the E-Cell recovery will be 90%. E-Cell reject will be recycled to the RO system inlet feed. A 100 m^3 RO Reject/Backwash Tank will be provided. RO Reject Water will be utilized for MMF and ACF backwash. Finally, demineralized water will be sent to deaerators for oxygen removal process.

1.2 Problem statement

Recent finding of PP(M)SB autopsy membrane analysis shows the presence of aluminium and silica compound fouled on the membrane. Autopsy result in February 2012 analysis give the first signal, triggered higher concentration of aluminium by 12% and silica by 34% in feed water quality as compared to SAM basis. According to utilities technologists, last replacement of RO membrane was made on December 2012 and according to GE vendor's information, the membrane should be able to be used till December 2015. Unfortunately, off-specifications were detected much earlier on September 2013. The issue of higher aluminium and silica continuously affect RO performance with difference of 54% Al and 25% Si as compared to basis and further mitigation has been made by replacing RO membrane. Failures of maintaining quality of polyamide membrane cause shortage of permeate water produced. Therefore, installation of UF membrane with optimum design of quality parameters could assist to reduce Al_2SiO_5 fouling onto RO polyamide membrane.

Table 1: Comparison of autopsy results of RO polyamide membrane [3]

Design value		**Autopsy Feb 2012**		**Autopsy Sept 2014**	
	%	Primary Composition	%	Primary Composition	%
Loss of Ignition	< 35	Loss of Ignition	49	Loss of Ignition	64
Aluminium	**< 3**	**Aluminium**	**12**	**Aluminium**	**7**
Silica	**< 15**	**Silica**	**34**	**Silica**	**20**
Iron	< 1	Iron	3	Iron	2
Sulphur	< 2	Sulphur	1	Sulphur	2
Phosphorus	< 3	Phosphorus	1	Phosphorus	4
Calcium	< 24	Calcium	0	Calcium	1

1.3 Objectives

The objectives of this project are:-

- **To analyze the effectiveness of RO membrane with the introduction of UF pretreatment to remove** Al_2**SiO_5 and compare with simulation of RO quality software provided by DOW.**

  Feed water salt concentration would be measured by introducing additional pretreatment unit prior to RO membrane and pre-filter and also chemical analysis.

- **To study the optimum operating parameters for removal of AI_2SiO_5 in RO membrane.**

  Current data of feed water concentration, transmembrane pressure, temperature and pH of the system will be studied with salt passage, recovery and permeate flux analysis.

- **To investigate the effect of non-reactant material in reducing AI_2SiO_5 cake layer (fouling).**

  Each reagent will be added to the system with solution of Al_2SiO_5 before and the result of after 30 minutes will be analyzed in term of physical appearance , settling time and concentration TDS.

1.4 Scope of study

The research study emphasizes on reducing Al_2SiO_5 fouling issue onto RO polyamide membrane since quantity of permeate water had been dropped, causing off-specification of quality parameters and reduce membranes lifespan. Therefore, RO pilot plant is used to run experiments based on the objectives highlighted with an appropriate time framework .This pilot plant uses same type of RO membrane (spiral wound) and same material of polyamide (Model of BW30-4040) as in the PP(M)SB.

The scope of this study can be described as:

- Experimental procedure to stimulate the RO pilot plant with installation of ultra-filtration prior to RO membrane.

- RO operating parameters (trans-membrane pressure, pH, temperature and concentration of feed).

- Effect of using activated alumina particles especially on dosing effect, physical separation with respect to time taken to deposit and salt rejection towards to reducing the fouling effects.

CHAPTER 2 : LITERATURE REVIEW

2.1 Introduction

The previous research had been done specialized on solving fouling issues. It can be summarized that, prevention technique commonly follows two distinct approaches, namely usage of anti-scalant to inhibit scale formation in the system and installation of RO pre-treatment process to reduce metal anions and cations concentration before membrane filtration [4]. The table shows previous techniques and approaches towards reducing or removing scaling. Based on the table below, there are several approaches has been done to remove or reduce the concentration (percentage) of several foulants in various type of feed water samples. From this, the author identified another approach to be used to meet the objectives is by using non-reactive particle like activated alumina and soda lime in reducing aluminium and silica cake layer [5].

Table 2: Earlier Researches and descriptions

No	Author	Technology/ Material used	Experimental Approach	Focus of removal
1.	Bouguerra. Mnif et.all [6]	Activated Alumina	Based on comparison of effect sorption parameters.Stirring time pH,concentration, absorbent dose,foreign ions,	Boron removal
2.	Bouguerra, Ali et. all [7]	Activated Alumina	Adsorption isotherm and its correlation, equilibrium, kinetic study, 1st and 2nd order corelation	Silica removal
3.	Isabel, Angeles,& Ruben[8]	By softening process with addition of magnesium salt with optimum pH activated alumina,	85% of silica was removed from the system at pH of 11.5	Silica removal

4	Amy, Benjamin et all [9]	Iron and Manganese coated sand	Used all approaches and state cost analysis each of following	Arsenic removal
5	Chris & Anne [10]	Biological reactors	reduce membrane fouling by pretreating feed water using biological reactors to remove organic nutrients that support formation of fouling biofilms	Chlorine removal
6	Cheng, Chen & Yang [11]	Lime soda Ash with help of ferric chloride and alum	For the high silica water source, the dose combination of lime (90 mg/L), soda ash (300 mg/L), sodium aluminate (25 mg/L) and anionic polymer (0.05 mg/L) was adequate for silica control: a dosage of 175 mg/L caustic soda alone was adequate for the same level of silica removal. The use of caustic soda (NaOH) as a single chemical was found a viable alternative to the lime-soda precipitation aid process.	Silica removal
7	Den & Wang [12]	Electrocoagulation	The test managed to remove 80% silica from feed water with intensity of 5 A and retention time of 30 minutes	Silica removal

2.2 Parameters affecting RO membrane

Other than that, study of parameters affecting RO membrane performance in reducing Al_2SiO_5 fouling is also important to ensure the experiment run smoothly. From this study, we can predict optimum value for TMP, temperature, pH and concentration of feed water.

2.2.1 Transmembrane Pressure (TMP)

TMP is closely related to increase of hydraulic resistance in the fouled membrane [13]. This phenomenon is due to the narrowing of the flow channels across membrane surface caused by fouling [14,15]. Apart from that, fouling activity due to high TMP can be classified into four different classes. A group of researchers from Australia stated [16]:

1- Colloidal/particulate fouling due to the accumulation of colloidal.
2- particulate matters, organic as a result of deposition of organic macromolecules,
3- Inorganic fouling which is precipitation of inorganic salts.
4- Bio-fouling due to microorganisms [17].

Inorganic fouling or scaling is the formation of hard mineral deposit on the membrane surface as solid while water become supersaturated liquid by inorganic salts [18]. It is referred as precipitation or crystallization fouling which reduce the membrane pore size and permeability of water to pass through. The term scale refers to adherent inorganic fouling feed deposits in place [19]. In addition, high pressure membrane operations cause relative concentration of dissolved salts concentrated four to ten times, depending on the operating recovery and rejection efficiencies [20]. It causes permanent damage to RO membrane by slowing the rate of permeate flux and the quantity of product water produced. Autopsy reports showed the membrane has experienced serious organic and inorganic fouling due to Al_2SiO_5 formations. Therefore, increment of TMP as it needs to cater and filter presence of cake layer rather than to remove salts in water solution due to this fouling. Hence, design approach recommends the use of a low fouling composite polyamide RO membrane with a resistance to organic fouling especially of Al_2SiO_5 [17].

2.2.2 Temperature

Another important study of factors affecting RO performance is temperature. As to fulfill the environment’s requirement, ambient temperature range must below than 40ºC [18]. If the temperature is higher than this range, the possibility of membrane to be damaged will be high. As a result membrane pore will increase its’ size thus allowing aluminium and silica accumulated and distracted water flow in permeate channel, producing less quality product water. As water temperature rises, water flux also will be linearly increased and producing higher diffusion rate of water through membrane channel. Temperature also increases membrane salt passage due to higher diffusion Al_2SiO_5 in membrane. In addition, high temperature operation of municipal water RO processes could enable higher recovery of permeates and lowers energy consumption of the system. As a result operating parameters will reach it's limiting recovery (at elevated temperature) thus will creates an increased risk of a catastrophic fouling event especially on metal ions like Al [21]. In general, an aspect of temperature is very important factor in controlling the fouling effects of Al and Si with normalization of feed pressure and temperature.

2.2.3 pH value

Study of pH in RO membrane proved the efficiency to minimize AI_2 SiO_5 fouling in the system where it acts on dissociation of the functional groups of aluminium silicate compounds [22]. It can be explained by the relationship between feed pH and permeate flux. Suggested pH range for PP(M)SB RO system is between (8-10) for overall normal process and chemical cleaning activity. Previous study agree pH controlling had the greatest effect in controlling Al residual [14] .This is stated by LANXESS that poor pH controlling condition could cause severe precipitation of aluminium on RO membrane surface [5]. So it is advised to have a normal pH range 7- 9 since solubility of Al is at pH of 6.5 except at pH 8 and in the presence of humic acid which cause force repulsive [23] and [24].

The variation of pH applied to permeate concentration (TDS) and recovery are resulting on several decrements of salt rejection and recovery for higher pH usage. It affects separation performance by increasing hydration and absorption capacity [23]. To know the threshold limit silica removal and RO recovery are actually determined by the removal - saturation - recovery curve. When the pH is adjusted above eight, the rate of silica removal is raised to above 95% before entering RO membrane, besides adding activated alumina to increase the turbidity of water enhanced the particles settling velocity [25]. Chen also suggested pH at 10 is the optimal condition for maximum removal of Al_2SiO_5 for brackish water due to its electrostatic attraction at high pH. In short, different pH applied in feed will result different rate of AI_2SiO_5 fouling removal [26]. Thus, experimental approach is necessary to figure out the best pH for minimization of Al_2SiO_5 in RO polyamide membrane.

2.2.4 Concentration of feed water

Direct deposition of Al_2SiO_5 causing membrane scaling and once deposited this scale would be extremely difficult to remove without damaging the membrane [27]. This argument was supported by another researcher who run experiments on the effect of silica to nano-filtration (NF) membrane; aluminium and silica is major fouling agent to NF [28]. The author, to conclude excess Al_2SiO_5 compounds will deposit onto NF membrane surface which promote high quantity silicate in the feed. Therefore, Si concentration could play a major role in RO membrane fouling, even though the rejection rate of silicate itself is not high: the rejection percentages of silicate were only 10-20% in both the pilot plant and laboratory experiments. Excessive accumulation of Al also suggests that Al residuals probably caused the membrane fouling by forming aluminium silicates or aluminium hydroxide [28]. Based on the argument, Al is the major problem to RO system which can possibly leads to fouling.

Besides this problem, typical factors of Al fouling could be categorized from four possible cases [14], aluminium flocculants carry over from pre-treatment to RO membrane [29], post-precipitation of aluminium flocculants due to poor pH control, reaction of aluminium with silica, forming aluminium silicates and natural mineral silt (3) and colloidal Al_2SiO_5 (4). As a result, failure to maintain any of these factors would cause inorganic polymerization [30]. In this case, silica polymerizations are not only affected by the high concentration of aluminium, but calcium also catalyzes the formation of Al_2SiO_5. The ratio of Al: Si resulting to 1:2, where two silicates need one Al atom to form a precipitate of Al_2SiO_5. A literature review was found only single study about aluminium silicate fouling in RO system under ambient condition [32] and the ratio of 1:1 (Al:Si) and both clays are crystalline. However, silica also can interact with Al in many different ways as its hydroxide can act as a substrate for silica polymerization on the membrane surface [33] and Al ions can also adsorb onto surface sites when silicic acid and silica oligomers polymerize [34].

In addition, Al residual may interact with ambient silica within membrane system to cause unexpected Al_2SiO_5 where silica and silicates can act as nucleation site for further fouling by others and may increase the rate of organic fouling [1]. The impacts of precipitation ended by having rapidly accumulation on the membrane surface, losses in flux, low salt rejection, probably because of an increased concentration gradient of particles on the membrane surface [27]. There were also attempts to balance both anions and cations by considering ratio of precipitate and chemical balance (stoichiometry) [30].Generally, factors affecting RO membrane performance are actually assisting individual to focus on issues and common problems took place in industry. By studying this, formation of silicate could be reduced through improving pre-treatment and applying non-organic materials to avoid formation of this fouling.

2.3 Reverse osmosis normalization data

As indicated by the second of objective, normalized data like temperature, permeate flow, feed pressure, permeate pressure and recovery directly affect the amount of permeate water and quality that RO membrane can produce. Since these controlled parameters are constantly changing, it is quite impossible to compare performance of certain parameters at one point to another. Normalizing RO data allows the user to compare performance of an RO membrane to a set standard which does not depend on changing operating conditions. It will help to a direct condition of the RO membrane and show true performance and health of RO membrane. Cause of misleading data can be avoided from this approach. With this, the Al_2SiO_5 concentration can be minimized at optimum condition and maintain the quality of RO membranes and its pretreatment.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Project Flow of the experimental work

Literature Review

- Preliminary research on the related topic regarding recent studies.
- Understanding the concept of reverse osmosis, factors affecting RO membrane, activated alumina and properties of Al_2SiO_5 formation.
- Identified the variables of the project. Study on the procedure to use RO pilot plant.

Experimental flowchart

- Design experiment of pilot plant with UF pre-treatment by analyzing performance of quality parameters.
- Prepare HCl or NaOH and equipment (ie: stirrer, filter paper) required for the experimental work (MSDS).
- Understand and Familiarize RO pilot plant in the laboratory.
- Follow the instructions and step -by-step pretreatment in RO pilot plant.
- Prepare various pH, temperatures, and pressure and concentration samples for RO performance test.

Data Extraction

- Conduct experiment, collect data and analyze the data.
- Plot graphs of each result and repeat experiment for three times
- Chemical analysis by using FTIR [35], compare it with simulation result by using RO Simulation Analysis (ROSA 9.0)
- Formulate results and discussions.

Conclusion

- Conclude the findings.
- Prepare progress report and final dissertation.

Figure 2: Flowchart of the experimental work

3.2 Experimental methodology

3.2.1 Materials, RO pilot plant and RO simulation software

For experiment 1, municipal feed water will be used in this experiment and put into feed water tank of 90 L. The experiment is performed using a thin film composite polyamide spiral wound RO membrane. The module consisted of Filmtec Spiral wound with composite polyamide membrane module (model no. BW30-4040) with effective area of 306.5 in^2, module length of 38.95 in, and diameter of 3.163 in. The pure water flux was 10 m^3/day and salt rejection of 95.00-99.00% for 3000 ppm and below, 16 bar feed pressure and at 30 ºC feed water temperature with pH 7-11.The setup is shown in figure 3. The membrane is basically equipped with RO pilot plant with UF pre-treatment, booster pump (mixing purposes), high pressure RO pump, (TDS 1 , TDS2) meter reading and permeate meter for feed and permeate channel. RO simulation software is a system design analysis where it need water quality data input and parameters (pH, temperature, concentration of feed and pressure) in order to run its simulation. Besides that, the ROSA is design analysis software where it requires water qualities data, type of membrane used, operating parameters, silt density index, and pre-treatment or chemical injection if required. Then, it will suggest design value based on input available to the system. By having this, the experimental data can be compared with simulation data in order to see the gap between these values. All of these parameters were then compared with the standards and repeated three times to verify the results. It is the latest software promoted by DOW Company can be used to compare the results for this experiment.

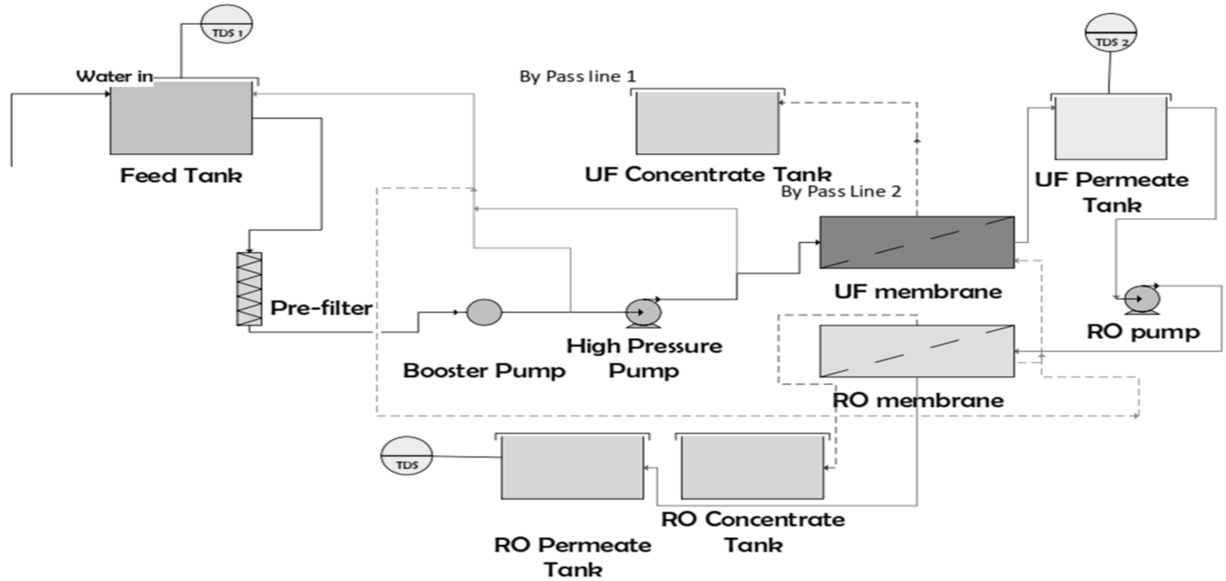

Figure 3: UTP RO Pilot Plant

3.2.2 Preparation of sample

Municipal feed water is collected and analyzed as feed water analysis before starting the experiment. While non-reactant particles are prepared by measuring the concentration of Al_2SiO_5 (based on PP(M)SB current feed water analysis and design value) in series of reagent flasks at a constant pH 8.0-9.0.The pH is adjusted either with dilute 0.1 M HCl or 0.1 M NaOH. Samples were collected after a fixed time interval and filtered through RO membrane. The filtrates were analyzed. Similar experiments were carried out by varying solution pH values. Different pressure applied was studied to each experiment which is run for 50 minutes to reach equilibrium. Filtrates were analyzed for residual TDS concentration for salt rejection [36]. Addition of alumina as non-reactant material to be mixed with feed for the third experiment. Activated alumina is a granulated form of aluminium oxide with 98% of the total weight with size of 1 mm. It is porous and has very high surface area of $287m^2/g$. It is considered as chemical process to reduce ions in solution on the oxide surface. Feed water is passed continuously into the system with 2.5 mg/L of the alumina concentrations.

3.2.3 RO formulation

The transmembrane pressure (TMP) is defined as the average pressure applied across the membrane minus the pressure on the permeate side. Others claimed TMP as the pressure required to force water through the membrane and is the feed pressure less the filtrate pressure with requires higher pressure for tighter membrane. It can be calculated using the following equation [37]:

$$\Delta P = \frac{P_i + P_0}{2} - P_p \qquad (1)$$

Where P_i and P_0 are feed and retentate pressures, respectively, and P_p is the atmospheric permeate pressure. Because P_p is atmosphere pressure ($P_p = 0$ gauge pressure), the TMP is the arithmetic average of the feed and retentate pressure.

On the other hand, permeation flux (PF) presents the amount of permeate or the product rate. PF is volume of permeate (V) collected per unit membrane area (A) per unit time (t). It is measured with considering the area and volume of feed water supply [38]:

$$PF = \frac{V}{At}\ (Lh^{-1}m^{-2}) \qquad (2)$$

Rejection is a measure of how well a membrane element performing rejection activities where the passage of dissolved ions [39].

$$R\ (\%) = \frac{C_f\ \text{-}\ C_p}{C_f} \times 100 \qquad (3)$$

Where C_p represents concentration of a particular component (TDS, TSS, COD, individual cations and anions, and salinity) in permeate, while C_f is its feed concentration.

3.3 Project Timeline & Milestone for FYP 1 and FYP 2

Basically, the project will have its own timeline. For this research, the author needs to understand to conduct simple experiment to study effect of feed water quality to membrane. Here, the outline of each step is actually the objective of the experiment. The results of experimental laboratory will be sent for characterization by FTIR. By having this, the author can estimate proper time and place to complete each part of the experiment.

Table 3: Project Timeline and Milestone

	Milestone	FYP 1															FYP 2														
	Process																														
No	Activties / Tasks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	**Selection project title**																														
2	**Introduction**																														
	Meeting with SV																														
	Lab Safety induction																														
3	**Research Work**																														
	concept of RO membrane																														
	Methodology preparation																														
	Literature Review Preparation																														
	Draft for Extended Proposal																														
	Submission of Lab Request Form																														
4	**Submission of extended Proposal**																														
	Proposal Defence Preparation																														
5	**Proposal Defence**																														
6	**Project Work Continue**																														
	Introduction to RO pilot plant																														
	Submission of Interim Draft Report																														
8	**Submission of Interim Report**																														
	Preparation of Lab Work																														
	Lab Work Experiment																														
	RO softare simulation ROSA 9.1																														
9	Progress Report Preparation																														
10	**Progress Report Submission**																														
11	**Pre-SEDEX**																														
12	Finalized Lab Work																														
13	Industrial Site Visit and Sampling																														
	Preparation for final report																														
14	Submission of draft final report																														
15	**Submission of Dissertation (Soft Bound)**																														
	Submission of Technical Paper																														
	Viva Preparation																														
16	**Viva**																														
17	**Submission of Dissertation (Hard Bound)**																														

CHAPTER 4: RESULT & DISCUSSION

In this part, all of the result will be discussed through graph and supported with justifications. This is to ensure objectives of the experiments relate to gained result and discussion. It is proven the water quality of Lembaga Air Perak (LAP) affect the RO system performance and system design. It is because existing ions and particles inside the water samples can disturb flow of water through membrane and reacts with Al_2SiO_5 as well. Thus, some findings show result of after using this water towards RO performance.

4.1 Effectiveness of RO membrane with UF pre-treatment and RO simulation

An experiment is conducted to measure the effectiveness of membrane by introducing UF pre-treatment into the system. At first, the water quality data is gathered from LAP so that the simulation can be run to get design value based on similar type of system and membrane used. It is also to measure the validity and reliability data of RO simulation and RO pilot plant. The validity result is shown to see the correlation of two methods.

4.1.2 RO simulation data analysis

From the table below, aluminium and silica concentrations increased dramatically as compared to RO design value. While other elements still can be controlled under the design value and existing system. The formation of Al and Si is clay minerals which known as Kaolin. A hydrous Al_2SiO_5 have a soft surface and white mineral and may easily deposit in RO membrane. This water quality data is required to compare with PP(M)SB water quality supplied from Syarikat Air Melaka (SAM). As the tabulated data shown in table 4, both these water have same amount of constituents like conductivity, total dissolved solid, silica and also aluminium. With this, the author chooses to use LAP water sample due to its same data with SAM.

Table 4: Selected element analysis from UTP tap water the source was taken from LAP (Lembaga Air Perak, Seri Iskandar Branch, 2012-2014).

Element		LAP	PP(M) /RO	SAM
	Unit	Value	Value (<)	Value
Ammonium	Mg/L	0.018	-	0.01
Aluminum	**Mg/L**	**0.232**	**0.1**	**0.252**
Potassium		0.410	4.5	0.57
Sodium	Mg/L	1.123	6.1	1.19
Magnesium	Mg/L	0.74	1	0.48
Calcium	Mg/L	0.99	1.3	0.72
Strontium	Mg/L	0	0	0
Barium	Mg/L	0	0	0
Carbonate	Mg/L	32.9	60	-
Bicarbonate	Mg/L	0	0	0
Nitrate	Mg/L	0.015	1.22	-
Chloride	Mg/L	0.483	2	3
Fluoride	Mg/L	0.5	1	0.54
Sulfate	Mg/L	2.408	3	2.0
Silica	**Mg/L**	**43**	**15.0**	**41.2**
Boron	Mg/L	0.01	0.1	0
TDS	Mg/L	43.2 with RO (1.67)	138	45.04
TSS	Mg/L	1.36	10	1.93
Conductivity	Us/L	55.77	100	59.7

Table 5: Stage analysis: 1^{st} and 2^{nd} stage of RO membrane

Stage	Element	Recovery	Permeate flow (m3/hr)	Permeate TDS (mg/L)	Feed flow (m3/hr)	Feed TDS (mg/L)	Feed Press (bar)	Permeate Press (bar)
1	1	0.11 with salt rejection of 98.5%	0.03	0.54	0.3	40.42	3.66	0.34
2	1	0.10 with salt rejection of 98.5%	0.03	0.67	0.27	45.22	3.23	0.12

From the table above, reading of total dissolved solid (TDS) rejection shows an equal value of salt rejection. From the result, it is about 98.5% system recovery for first and second stage where the recycle or reject water is fed into the feed line and thus further filtered by RO. The Al_2SiO_5 are filtered with reverse osmosis treatment and pre-treatments from the simulation. The result of rejection based on the element analysis is recorded with high percentage of recovery is maintained.

4.1.3 RO Pilot Plant and FTIR analysis

After completing with selection of water quality for feed water, the required information of final product are compared. Here, the introduction of ultra-filtration separation before RO membrane is tested to study the effectiveness of pretreatment to reduce Al_2SiO_5. Further final products of experimental works are further analyzed with FTIR analysis in term of surface area reduction. Below are the average values of 3 different types of samples. Feed water sample containing high Al_2SiO_5 with concentration of 40.42 ppm is run constantly to get another two samples from UF outlet and RO outlet. Findings of the experiments can be seen below from the salt rejection percentage TDS formed, transmembrane pressure and recovery.

Table 6: Comparison of results with UF membrane for RO pilot plant and simulation from aspect of salt rejection and TDS.

Sample/ Rejection	[A] TDS reading from RO Simulation Analysis (ROSA) Theoretical Value	[B] TDS reading (experimental lab equipment)	Fourier Transform Infrared Spectroscopy (FTIR) Area % T/cm.
Feed Outlet (ppm)	40.42	38.3	1716.47
UF Permeate (ppm)	-	4.3	6887.78
RO Permeate (ppm)	0.51	0.43	14343.19
Salt Rejection (%)	98.74	98.9	90
Percentage error (%) of TDS Feed Outlet between A and B with	5.24 % difference is accepted 0.14		
Percentage error (%) of TDS RO permeate between A and B with	15.6 % reduction of permeate improvement quality.		
Percentage error (%) of salt rejection between A and B	**Since 0.14% is less than 5 %, then the result is accepted.**		

Table 7: Comparison of results with the use of UF membrane for RO pilot plant and simulation from aspect of transmembrane pressure and recovery.

Sample/ Permeate flow	[A] TDS reading from RO Simulation Analysis (ROSA) Theoretical Value	[B] TDS reading (experimental lab equipment)
Feed Outlet ($L / m^2 h$)	0.3	0.957
UF Permeate($L / m^2 h$)	-	0.5634
RO Permeate($L /m^2 h$)	0.27	0.876
TMP Recovery (%)	90.00	91.54
Percentage error (%) of TMP recovery between A and B with	1.68 % difference is accepted	

From the result comparison of salt rejection, it is proved that installation of pre-treatment of UF and pre-filter can minimize Al_2SiO_5 layer cake in the membrane. RO simulation uses feed water with silt density index less than or equal to 3.0 has demonstrated less total dissolve solid as compared to the expected criteria given by Lembaga Air Perak. Salt rejections as well as recovery of both results from the optimal condition are actually resulting more than 90% which make the percentage of error less than 5 percent. Meanwhile, chemical bonding of aluminium and silica compounds shows reduction of area (transmittance/wavelength) when each of the outlets (Feed, UF and RO) are taken and analyzed by FTIR. This indicates, reduction of composition (by percentage) of compound has been decrease for about 90% from the initial composition. In general, the result is accepted with consideration of total dissolve solid (TDS) performance from feed, UF outlet and RO outlet. In term of permeate quantity, TMP records the highest value of recovery. Calculation of permeate per feed resulting 90 % recovery from simulation value and 91.54% by experimental means. Al_2SiO_5 is reduced in the water samples which give better result of TDS as mention in the previous table.

4.1.4 Validity and reliability of the result

From table 8 below, the presence of UF membrane is just to minimize the fouling effect of RO membrane. It acts a buffer point to ensure lighten polymerization of aluminium silicates cake layer onto RO membrane. Experimental value (using UF membrane) gives maximum salt rejection 88.77 % while RO membrane 98.74%. This result can be seen in table 1 which application of UF in RO system line is actually improved pattern quality of permeates flow whenever different TMP is applied. This means quality of salt passage or fouling effects towards RO membrane will be less suffered, differ from direct feed to RO membrane. Thus, fouling effect can be reduced from passing through RO membrane. Beside that flow reversals (backwashing) in both membranes also reduce cake layer formation onto membrane but forward process must be controlled as well. Frequent backwash will decrease performance of membrane and defect structures and layers compartment.

The experiments are conducted in 3 times and average values are shared. Internal and external validity are structured and encompassed according to the research methodology. Feed water samples are closely analyzed and continuously proceeds from one to one quality. The results obtained are fixed to the selected focus of study on effectiveness of using pre-treatment as compared to not. To verify, some parameter is tested between experimental and simulation data.

Table 8: Comparison of RO and UF membrane (Simplified form)

Specification	Reverse Osmosis Pilot Plant		Percentage of improvement (%)
	RO membrane	UF membrane	
Salt Rejection			
Feed Stream	38.3	38.3	
UF Permeate	-	4.3	
RO Permeate	0.43	-	
Rejection	98.87	88.77	10.1
Flux (L/m^2h)	Area of membrane = 303.43 m^2		
Feed Stream	290.38	290.38	
UF Permeate	-	255.805	
RO Permeate	273.08	-	
Recovery (%)	94.04	88.09	5.95

From the table 9 below, comparison of both simulation and experimental work is less than 1% for rejection at temperature of 30^{o}C, pH 7, TMP of 16 bar and low concentration as suggested from the literature. In recovery, error of 4.04% is calculated from two different methods. Thus, it is confirmed graph and data collection is valid and reliable.

Table 9: Percentage of error of simulation and experimental work

Specification	Comparison between experimental and simulation (RO membrane)		Percentage of error (%)
	RO pilot plant	ROSA 9.0	
Salt Rejection			
Feed Stream	38.3	40.42	
RO Permeate	0.43	0.51	
Rejection	98.87	98.74	0.13
Flux (L/m^2 h)	For pilot plant value based on area of membrane flux		
Feed Stream	290.38	0.30	
RO Permeate	273.08	0.270	
Recovery (%)	94.04	90.0	4.04

4.2 Optimum operating parameter to minimize Al_2SiO_5 fouling

In this part, results of experiment are demonstrated. Finding of optimum conditions for RO polyamide membrane separation (permeate flux and salt rejection) can be explained through stated data. Laboratory works examined four important parameters to run RO pilot plant for high quality water treatment.

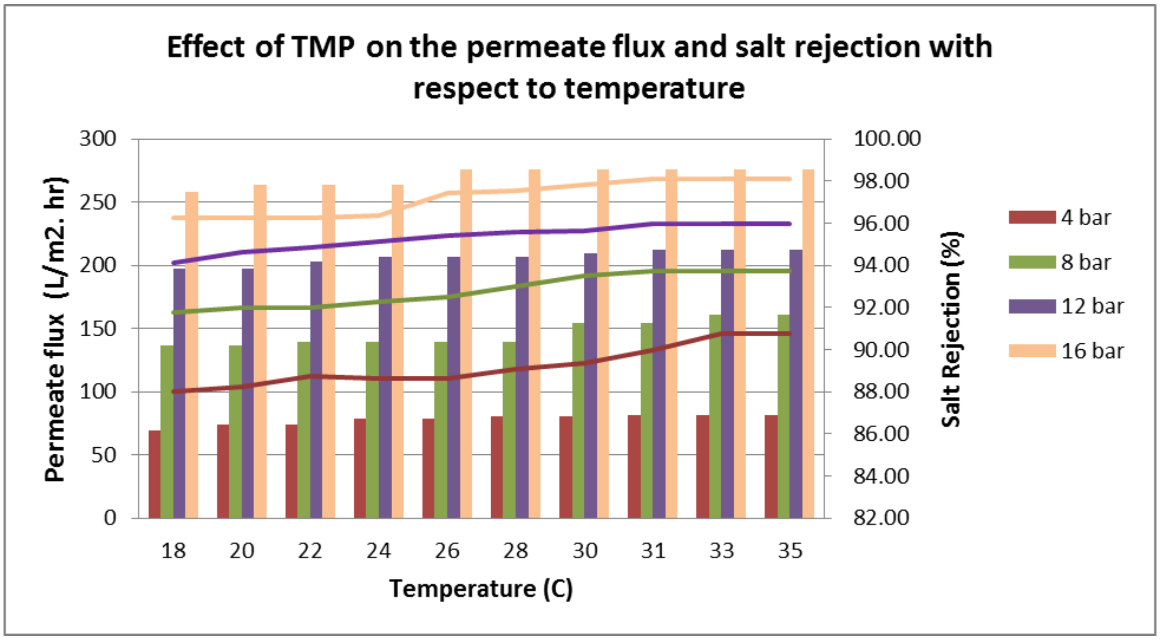

Figure 4: Effect of TMP on the permeate flow and salt rejection with various temperatures.

From the graph above, it can be seen that TMP of 16 give highest maximum value of permeate flow (275.5 $L.m^2/hr$) and salt rejection (99%). Since the maximum pressure of RO membrane can withstand a pressure at 16 bar. According to Hydranautic, in order of to have high permeated flow and salt rejection, the required transmembrane pressure should be high [14]. This will allow high recovery of feed water with less reject water. The fouling of Al_2SiO_5 can be reduced with high transmembrane pressure [40]. Since, UF filtration proves in minimizing the cake layer of fouling, then RO membrane will further help to polish remaining Al_2SiO_5. Silica polymerization also can be reduced due to high pressure applied. Thus, requires frequent backwash activity for pre-treatment and RO membrane. Otherwise, deterioration of membrane will take place and cause low permeates flux and salt rejection. In short, a pressure of 16 bar is recommended for minimizing aluminium silicate fouling in the solution.

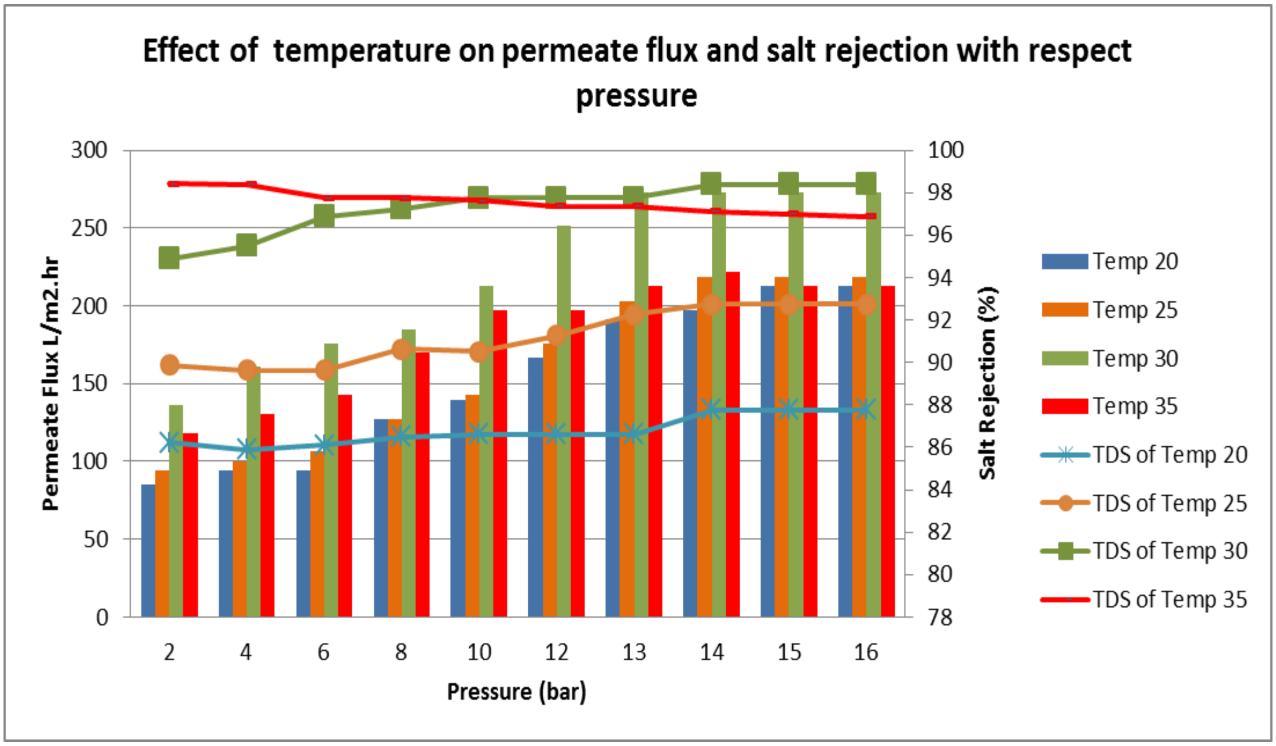

Figure 5 Effect of temperature on permeate flux and salt rejection against pressure.

4.2.1Effect of different temperature on permeate flux and salt rejection of AI_2SiO_5

From the figure 5, it can be observed that temperature 30°C is the best optimum value by giving highest rate of permeates flux and salt rejection as compared to other. Property of polyamide membrane is very sensitive to changes of feed water temperature causing impact on the quality and quantity of permeate water produced. For every increment of 1˚C will cause 1% high of salt rejection. The increases of water flux almost linearly constant at high TMP is due to diffusion rate for salt water through the membrane. The lower viscosity of warmer water allows water to flow easily into the membrane [41].

From the graph, increase in temperature by 5 ◦C causing high value of salt rejection for instance from 25◦C to 30 ◦C, the rejection value increase from 93 to 98 % when pressure varies from 14 to 16 bar. The curve seem to be constant as pressure reach 14 bar to 16 bar, it shows an optimum range for salt rejection.

However, temperature of 35 ◦C shows a slow decrement of rejection when pressure increases. It is because salt diffusion through the membrane is higher as water temperature is highest at 35◦C [41].In general, the ability of a membrane to tolerate elevated temperature increase operating attitude and cleaning activity. It is also suggested to have a lower pressure in summer and high pressure for winter. The variable frequent drive (VFD) can be used to adjust the speed of RO pump to run according to the feed water temperature. Here it is suggested having a 30 ˚C for reducing aluminium silicate at pressure of 16 bar.

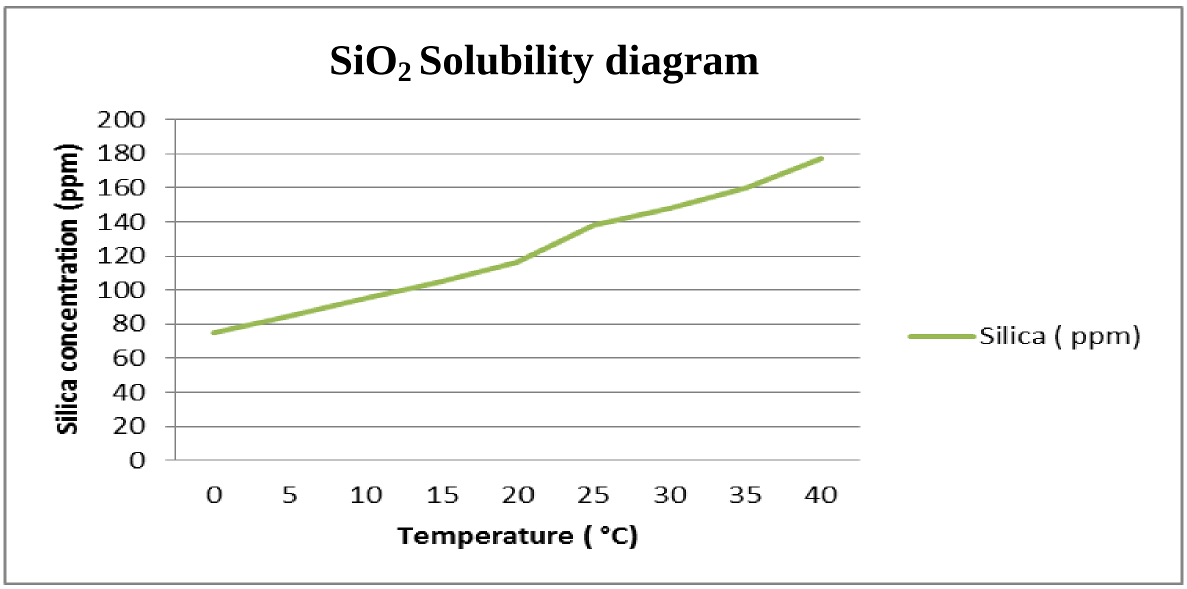

Figure 6: Silica solubility as a function of temperature [41].

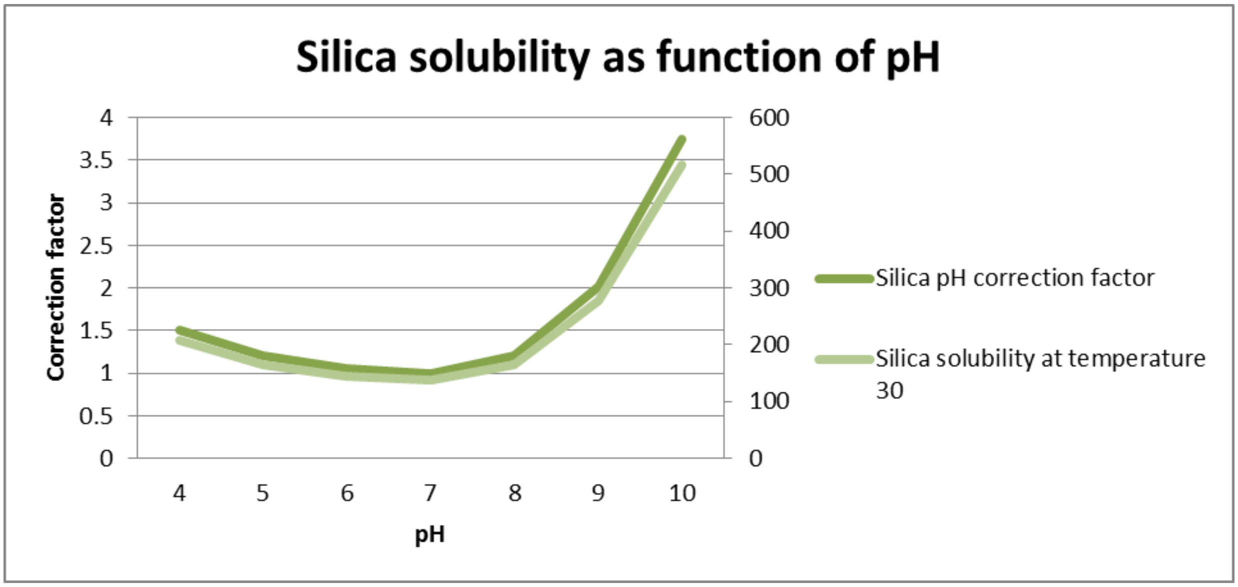

Figure 7: Silica solubility as function of pH [41]

Other than that, the temperature also depends on silica concentration. When aluminium is present, Al_2SiO_5 would form quickly due to its reaction properties [18]. This means it is more soluble when the pH is less than 7 and more than 7.5 as shown in figure 7. As a result, soluble silica will limits recovery of RO system due to potential of scaling and the difficulty to remove silica scale from the membrane. By having anti-scalant, the control can be only below than 200 ppm concentration. Thus, based on figure 6 and 7, the best option of pH to minimize Al_2SiO_5 is at 7 which supports major finding of optimum value of the parameter at temperature of 30°C and 150 ppm. This fouling cause high pressure drop, low production of permeate water, and causes low rejection of silica.

4.2.2 Effect of different concentration to permeate flux and salt rejection of AI_2SiO_5

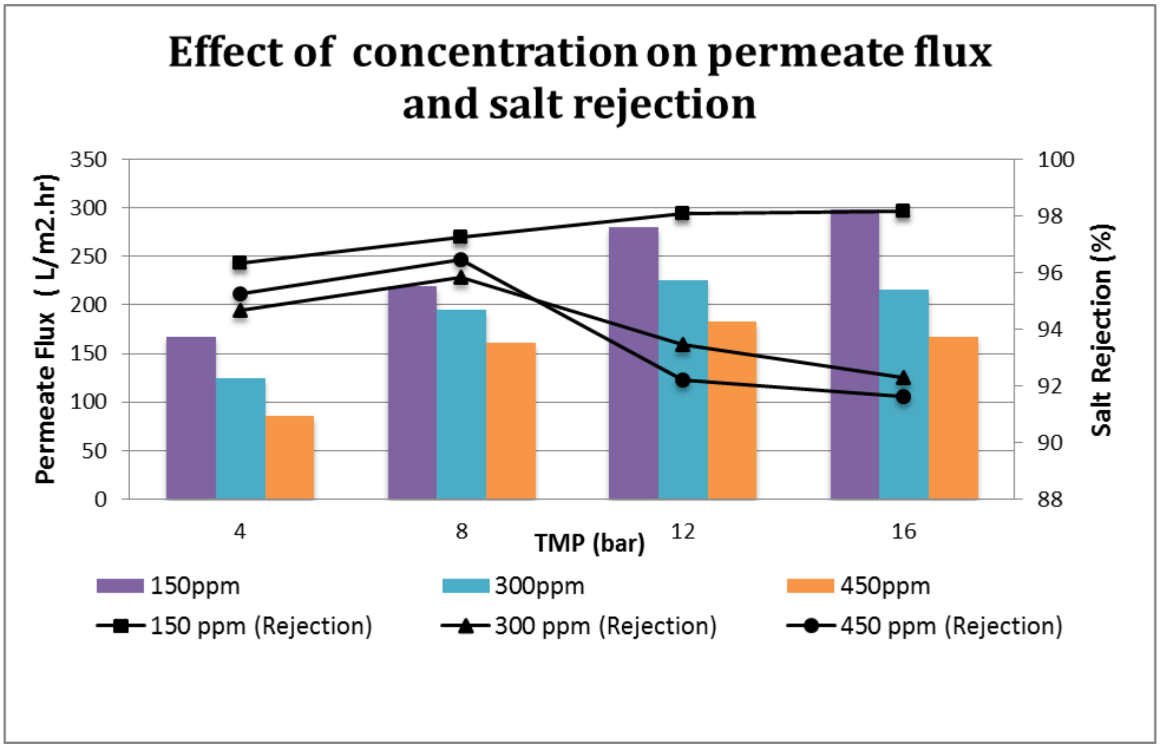

Figure 8: Effect of feed water concentration on permeate flux and salt rejection.

When the concentration of feed increases, the permeate flux decrease accordingly. The highest permeate flux obtained at range of 150 ppm, 300ppm and 450 ppm are 298.3, 212.4 and 176.0 L/m^2h with salt rejection of 98.9%, 94.3% and 91.45% respectively. From the graph, RO permeate flux and salt rejection decrease with high TMP applied when it reach more than 8 bar, 300ppm and 450 ppm trends of line graph decrease to 94% and 91% with also permeate flux to 205 L/m^2h and 192 L/m^2h . This can be explained from high concentration applied, the surface become crowded with surfactant molecules causing polarization effect to increase resulting on high accumulation of ions fouling onto the membrane and reduce permeate flux as well [41]. In addition, high polarization effect causing membrane pore blocking and promote resistance factor over membrane surface [13].The process will favor at low concentration, less fouled accumulation on membrane surface due to unblocking membrane pore, thus making permeate flux is higher at lower feed concentration throughout the separation process. The findings show salt rejection of different concentration increase with higher TMP applied.

The percentage salt rejection reduced from 98.9% to 97.45% for feed 150 ppm concentration respectively. However, TMP more than 16 bars will be expected to reduce its salt rejection and permeate flux. As the system design of total dissolve solid should be less than 160 ppm, concentration of aluminium or silica need to be controlled by using effective anti-scalants so that formation of aluminium silicates also can be minimized. Thus, it is advised for system which have a serious problem of this fouling to ensure feed concentration of controlled parameters is less than 160 ppm (depending on treatment design value).In short, concentration of 150 ppm and below is an optimum value to minimize aluminium silicate fouling layer.

4.2.3 Effect of pH towards salt rejection and permeate flux of RO membrane

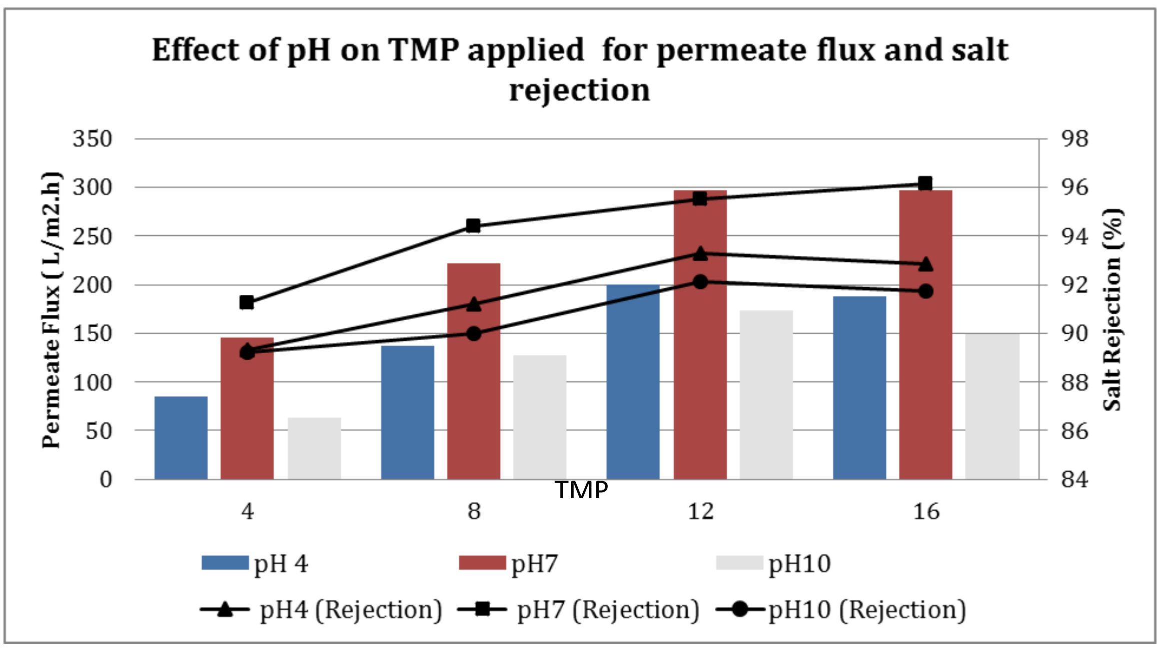

Figure 9: Effect of pH on permeate flux and salt rejection

It is observed that the percentage salt rejection decrease with increase of feed pH. The percentage of salt rejection shows a significant decrement pattern as the feed pH at alkaline and acidic condition, but increase as in normal pH value applied. The result shows pH of 7 give maximum salt rejection 97.2% and 300 L/m^2.h permeate flux flow rate. This phenomenon can be explained through electrostatic repulsion between solute and the membrane. The dissociation of acids at alkaline pH enhances the rejection because of the charge repulsion occurring between compounds and membrane surface and vice versa. Rejection drops at higher and lower pH due to stems from ionic state of the ions being rejected and changes of molecular level with membrane itself. But when apply to neutral feed water, both of the situation changed and reflected on low permeate flux and salt rejection. Alkaline and acidic compounds will trigger formation of fouling layer on the membrane surface and causing concentration polarization. In summary, the polyamide membrane best work at pH of 7 for reducing Al_2SiO_5 fouling based on its capacity pH range from 2 till 11 and theory of this membrane mention most species best at 7 only.

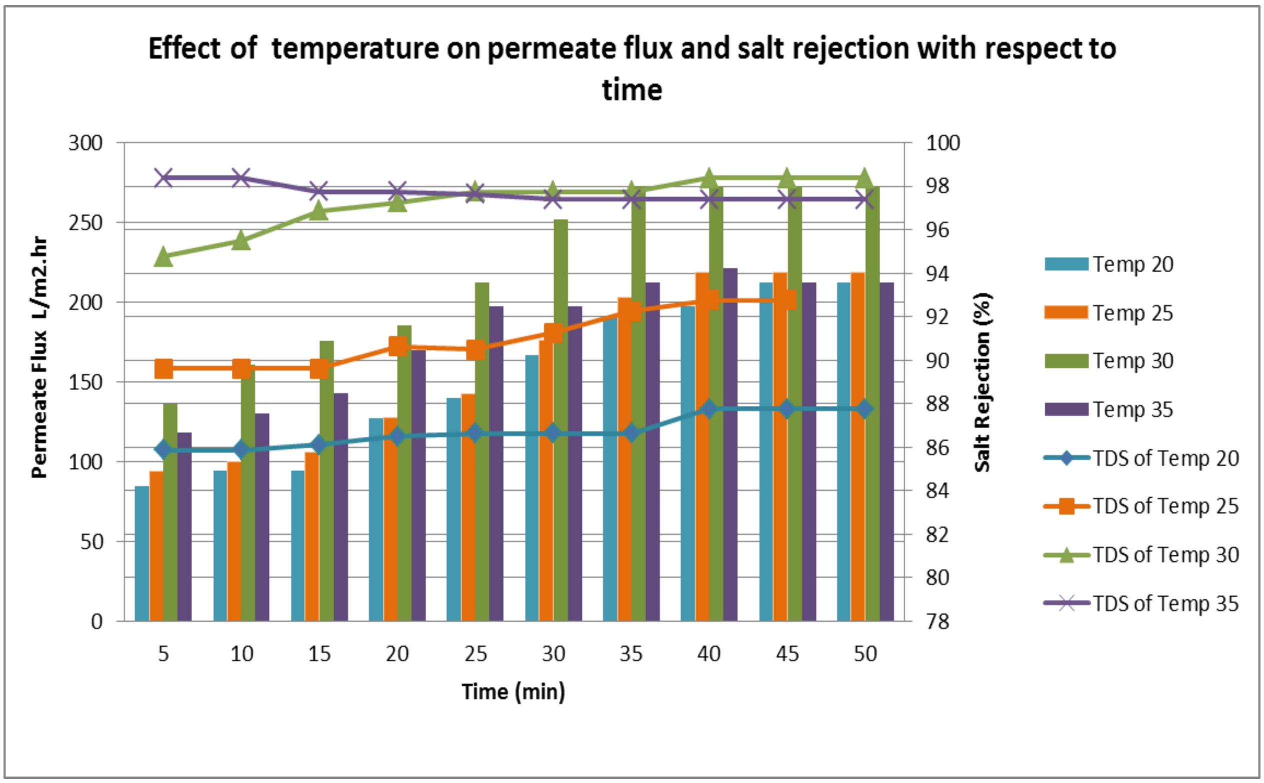

Figure 10: Effect of temperature on salt rejection and permeate flux with respect to time

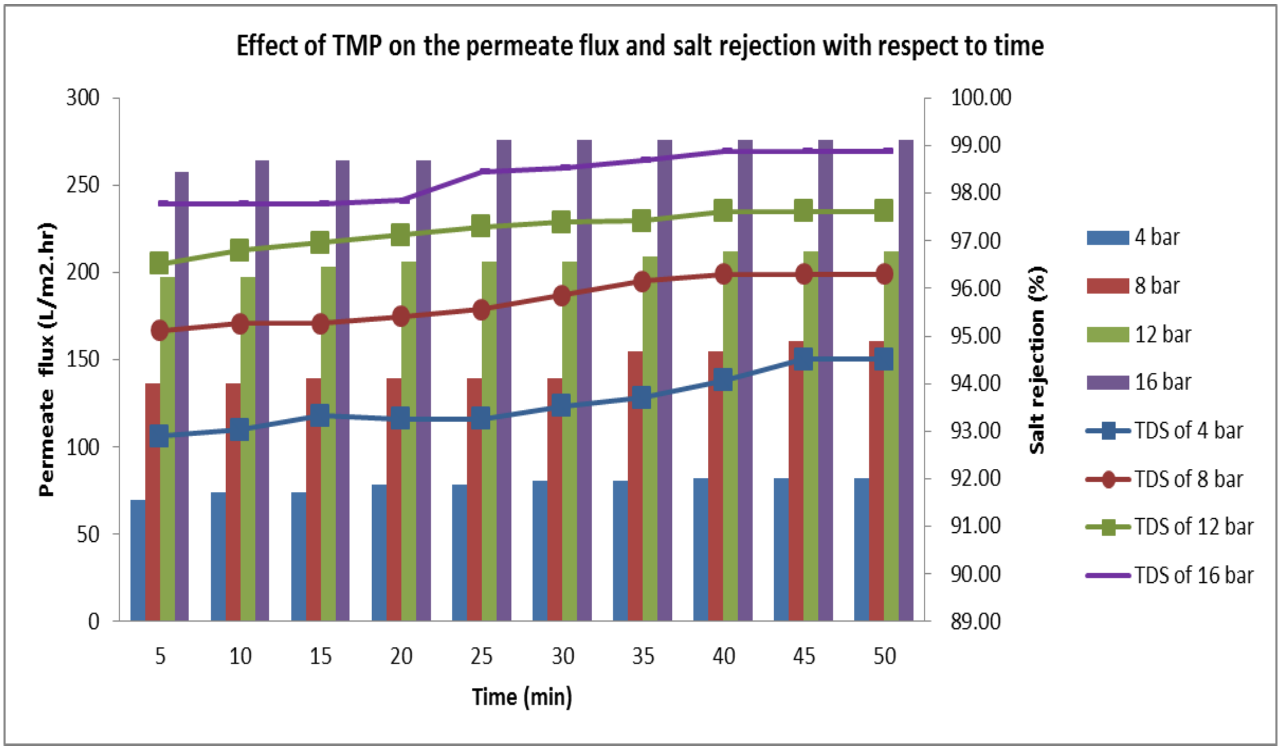

Figure 11:Effect of TMP on the permeate flux and salt rejection with constant time

From the figure 10 and 11, highest value of permeate flux are observed at 4, 8, 12, and 16 bars are 81.2, 162.4, 210 and 272.2 L/m^{2}h, respectively at constant time of 50 minutes. The results show increase in TMP will cause an increase of permeate flux in the experiment. This phenomenon can be explained from the Darcy's law which mentioned increase in pressure causing higher the permeate flux collected [35]. In this case, higher driving force of high TMP was applied across the membrane causing the system to push water molecules to pass through its semi permeable membrane which could result in higher permeates flux [19] while Al_2SiO_5 will move to reject line.

Higher product water with high TMP actually explained the study of concentration polarization. Concentration polarization occurred with high osmotic pressures that exist due to tendency of water to move from low solute concentration to high solute concentration. It will result in reduced flux and increased the probability of fouling development onto surface of the RO membrane [29]. From the graph, it can be seen concentration polarization of silicates can be reduced by applying high TMP thus increase the salt rejection with constant time. Once reduced, higher amount of permeate water and high salt rejection can be achieved.

Based on the graph Optimum Parameters of RO polyamide membranes are:

- TMP : 16 bar
- Temperature : 30 ºC
- pH : 7
- Concentration : 150 ppm with the average salt rejection of 98.5%

Which give the highest value of salt rejection (%) and permeate flux ($L/m^2.h$).

4.3 Effect of using activated alumina

In this experiment, the author investigates the effect of non-reactant material in reducing AI_2SiO_5 cake layer (fouling) by using activated alumina. The procedure of the experiment had been explained in the methodology part and conditions in experiment 1 with TMP of 16 bar, pH of 7 and temperature of 30^oC. The experiment focuses to determine the effect non reacting agent in reducing the cake layer of aluminium silicate from different type point of views. From the result shown, activated alumina improved the objective of experiment in minimizing effect of cake layer of Al_2SiO_5. In spite of this, the percentage of rejection decreased after mixing from 57.0 ppm to 5.0 ppm. As compared to normal process, Al_2SiO_5 concentration's decrease from 52ppm to only 8.0 ppm. Thus, introducing of activated alumina is actually increased the concentration of feed water Al_2SiO_5 concentration by 8% initially.

From the figure 12 below, presence of alumina enhances positive value of salt rejection to 96% at pressure of 14 bar but slightly decrease when reach 15 bar onwards. This rapid increment originated from the role of alumina to membrane separation. According to Wang [40], the effectiveness of alumina is highly dependent on pH value of the aluminium silicate solution. Since pH value of 7 is maintained, the free charges of aluminium silicate cause little electrostatic attraction to drive minimization of fouling layer with the help of alumina. Here, the role of alumina is to control colloidal fouling's rate of the system instead of using RO and UF membrane only [6]. Close interaction between alumina Al_2SiO_5 give a high quantity of permeate flux rate and also rejection rate.

The positive side of this experiment shows stage by stage increment at various TMP applied except at 8 and 10 bar especially on permeates flux. This is due to the same rate of permeate water pass through RO membrane at this pressure. However, the rate of permeate flux increase till 14 bar and decrease at 15 and 16 bar onwards. The use of alumina actually decrease pressure applied in the system as compared to Al_2SiO_5 only. The blockage of membrane is identified after quality and quantity parameter decline as pressure increase.

Other than that, the experiment is validated as the R^2 value for each parameter is more than 0.9 to 1 .Each of the experiment is repeated for three times and average of reading is taken to ensure the reliability of experiment according to international standard proposed by membrane technology for reverse osmosis application in water treatment plant. In conclusion, activated alumina helps to reduce the colloidal fouling layer of Al_2SiO_5 in the RO system by increase the permeate flux and percent of salt rejection in range of acceptable value. Hence it hope, further study to improve activated alumina performance by adjusting its optimal dosing rate, effect of string time and present of foreign anions to investigate effect towards typical problem of colloidal fouling in reverse osmosis water treatment system especially fouling cake layer of Al_2SiO_5.

Table 10: Data of activated alumina and Al_2SiO_5 in feed water of RO pilot plant

TMP	EXP 1					EXP 2				
	Permeate flow	Area (m2)	Permeate flux	TDS	Salt Rejection	Permeate flow	Area (m2)	Permeate flux	TDS	Salt Rejection
4	0.36	303.43	109.2348	12	90.90909091	0.36	303.43	109.2348	11.6	91.21212121
5	0.4	303.43	121.372	13	90.15151515	0.37	303.43	112.2691	11.2	91.51515152
6	0.42	303.43	127.4406	12	90.90909091	0.36	303.43	109.2348	11.3	91.43939394
7	0.55	303.43	166.8865	9.1	93.10606061	0.56	303.43	169.9208	10.8	91.81818182
8	0.48	303.43	145.6464	8.1	93.86363636	0.49	303.43	148.6807	10.5	92.04545455
9	0.49	303.43	148.6807	7.7	94.16666667	0.55	303.43	166.8865	10	92.42424242
10	0.72	303.43	218.4696	7	94.7761194	0.68	303.43	206.3324	9.4	92.98507463
11	0.7	303.43	212.401	7	94.7761194	0.73	303.43	221.5039	8.1	93.95522388
12	0.67	303.43	203.2981	6.1	95.44776119	0.71	303.43	215.4353	7.2	94.62686567
14	1	303.43	303.43	5.1	96.19402985	0.97	303.43	294.3271	5.5	95.89552239
15	0.91	303.43	276.1213	5	96.26865672	0.93	303.43	282.1899	5.2	96.11940299
16	0.92	303.43	279.1556	5.1	96.19402985	0.93	303.43	282.1899	5.6	95.82089552

TMP	EXP 3						Average	
	Permeate flow	Area (m2)	Permeate flux	TDS	Salt Rejection	Permeate flow	Permeate flux	TDS
4	0.38	303.43	115.3034	12.1	90.83333333	0.366666667	111.2576667	90.98484848
5	0.39	303.43	118.3377	11.5	91.28787879	0.386666667	117.3262667	90.98484848
6	0.38	303.43	115.3034	10.8	91.81818182	0.386666667	117.3262667	91.38888889
7	0.57	303.43	172.9551	10.1	92.34848485	0.56	169.9208	92.42424242
8	0.51	303.43	154.7493	10	92.42424242	0.493333333	149.6921333	92.77777778
9	0.54	303.43	163.8522	8.9	93.25757576	0.526666667	159.8064667	93.28282828
10	0.68	303.43	206.3324	7.7	94.25373134	0.693333333	210.3781333	94.00497512
11	0.77	303.43	233.6411	6.9	94.85074627	0.733333333	222.5153333	94.52736318
12	0.79	303.43	239.7097	6.2	95.37313433	0.723333333	219.4810333	95.14925373
14	0.9	303.43	273.087	5	96.26865672	0.956666667	290.2813667	96.11940299
15	0.89	303.43	270.0527	5.2	96.11940299	0.91	276.1213	96.16915423
16	0.95	303.43	288.2585	5.5	95.89552239	0.933333333	283.2013333	95.97014925

Table 11 : Data of Al_2SiO_5 in feed water of RO pilot plant

TMP	EXP 1					EXP 2				
	Permeate flow	Area (m2)	Permeate flux	TDS		Permeate flow	Area (m2)	Permeate flux	TDS	TDS
4	0.33	303.43	100.1319	7.2	93.6283186	0.31	303.43	94.0633	7.2	93.628319
5	0.32	303.43	97.0976	7.2	93.6283186	0.32	303.43	97.0976	7.1	93.716814
6	0.34	303.43	103.1662	7.1	93.7168142	0.31	303.43	94.0633	7.1	93.716814
7	0.5	303.43	151.715	6.8	93.9823009	0.49	303.43	148.6807	6.7	94.070796
8	0.5	303.43	151.715	6.8	93.9823009	0.48	303.43	145.6464	6.6	94.159292
9	0.51	303.43	154.7493	6.7	94.0707965	0.48	303.43	145.6464	6.5	94.247788
10	0.68	303.43	206.3324	6.1	94.1904762	0.71	303.43	215.4353	6	94.285714
11	0.69	303.43	209.3667	5.9	94.3809524	0.72	303.43	218.4696	6.2	94.095238
12	0.68	303.43	206.3324	6	94.2857143	0.72	303.43	218.4696	6.1	94.190476
14	0.91	303.43	276.1213	6.1	94.1904762	0.84	303.43	254.8812	5.3	94.952381
15	0.92	303.43	279.1556	6	94.2857143	0.84	303.43	254.8812	5	95.238095
16	0.92	303.43	279.1556	6.2	94.0952381	0.84	303.43	254.8812	5.1	95.142857
TMP	EXP 3						Average			
	Permeate flow	Area (m2)	Permeate flux	TDS		Permeate flow	Permeate flux	Salt Rejection		
4	0.34	303.43	103.1662	7.2	93.6283186	0.326666667	99.12046667	93.62831858		
5	0.35	303.43	106.2005	7.1	93.7168142	0.33	100.1319	93.68731563		
6	0.34	303.43	103.1662	7	93.8053097	0.33	100.1319	93.74631268		
7	0.52	303.43	157.7836	6.7	94.0707965	0.503333333	152.7264333	94.04129794		
8	0.51	303.43	154.7493	6.7	94.0707965	0.496666667	150.7035667	94.07079646		
9	0.5	303.43	151.715	6.6	94.159292	0.496666667	150.7035667	94.15929204		
10	0.7	303.43	212.401	6	94.2857143	0.696666667	211.3895667	94.25396825		
11	0.7	303.43	212.401	5.3	94.952381	0.703333333	213.4124333	94.47619048		
12	0.69	303.43	209.3667	5	95.2380952	0.696666667	211.3895667	94.57142857		
14	0.86	303.43	260.9498	4.7	95.5238095	0.87	263.9841	94.88888889		
15	0.87	303.43	263.9841	4.5	95.7142857	0.876666667	266.0069667	95.07936508		
16	0.86	303.43	260.9498	4.8	95.4285714	0.873333333	264.9955333	94.88888889		

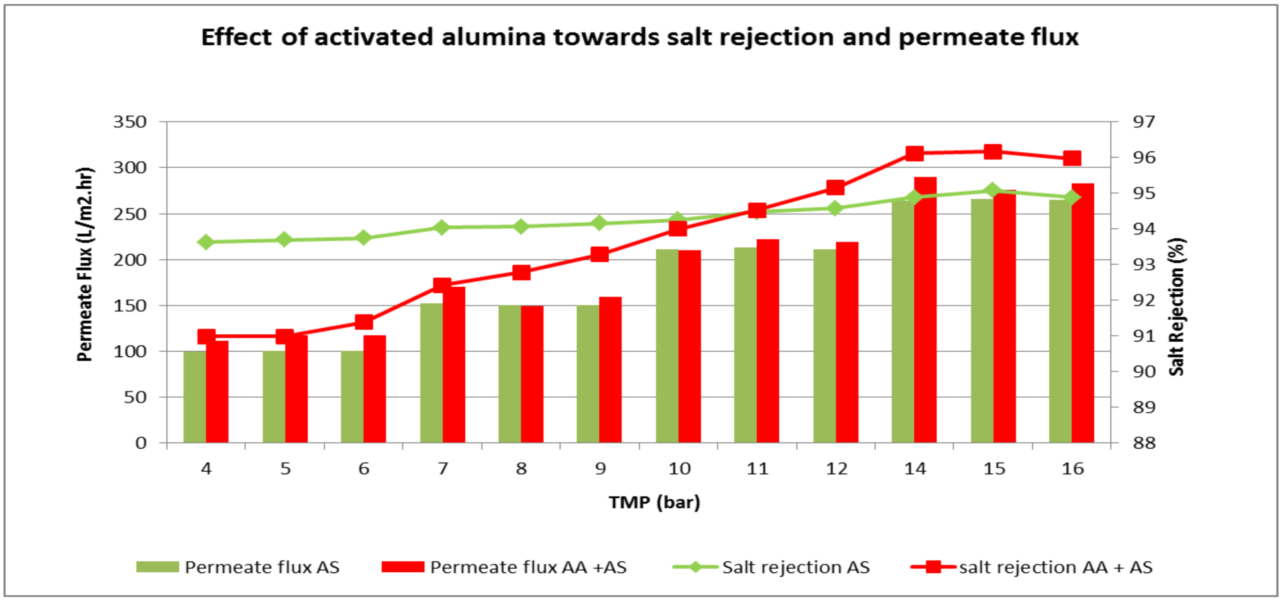

Figure 12:Effect of activated alumina towards salt rejection and permeate flow

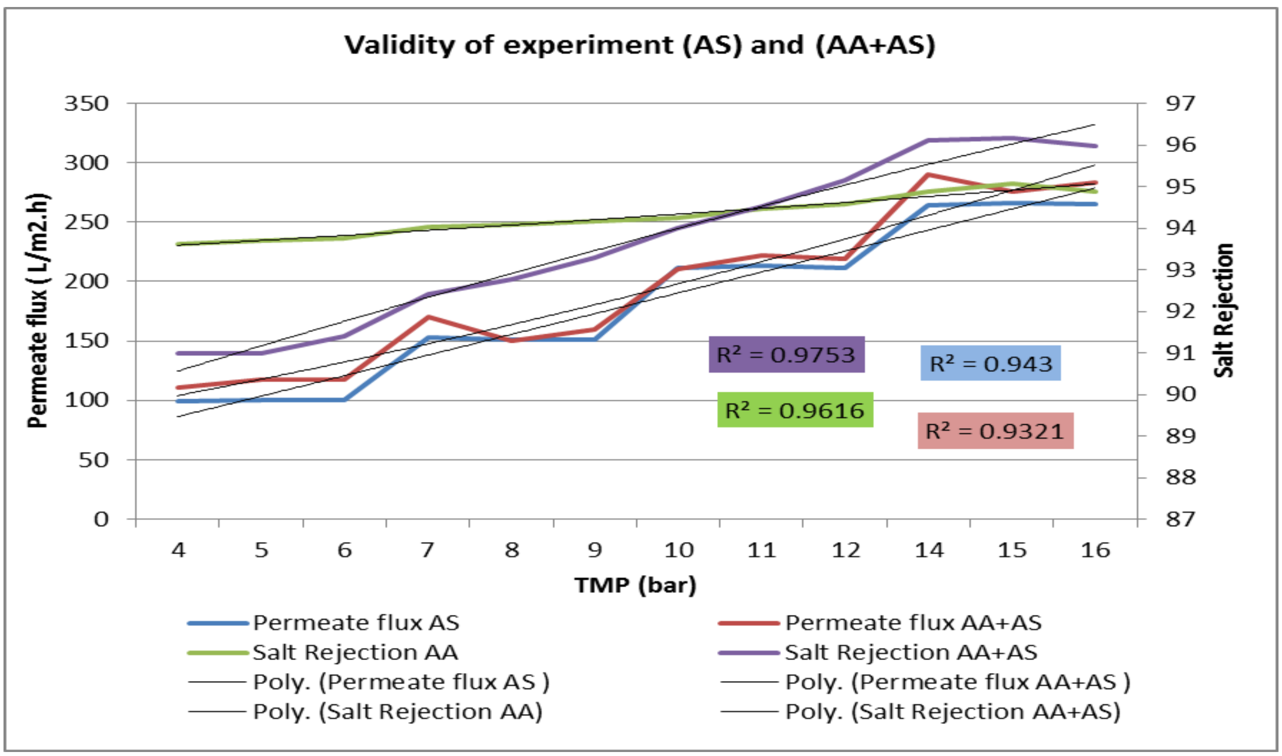

Figure 13: Validity of experiment with and without activated alumina

CHAPTER 5 : CONCLUSION AND RECOMMENDATION

In general, it can be concluded that the composite membrane provides high rejection and also produces good water flux at optimum operating conditions. In this study, the results showed that at TMP of 16 bar, feed-solution concentration of 150 mg/L, temperature of 30 ^{0}C and pH of 7 are the best operating parameters to reduce Al_2SiO_5 fouling generated form SAM feed water. The operating parameters that affect membrane performance, including TMP, feed concentration and pH were discussed systemically. It was observed that permeate flux increase with increasing TMP. Increasing feed concentration more than 150 ppm and feed pH to more than or less than neutral causes permeate flux and percentage rejection to decrease. The pH is found to influence the permeate flux and percentage rejection of feed water since the charge property of surface material of polyamide membranes changes with pH with value of 298 L/m^2.h and 96.3% rejection. The optimum range of pH for higher permeates flux and percentage rejection was found at neutral condition.

Overall, for permeate flux, TMP gave the most impact to reduce fouling layer followed by concentration, pH and use of activated alumina. In term of salt rejection, different feed concentration affects the most followed by different feed pH, while TMP and activated alumina gave the least impact on it. From the water analysis, BW3030 membrane can remove more than 96% by rejection of aluminum silicate by having 16 bar TMP with temperature of 30^{o}C. A study of membrane performances, reveal that UF improves 10.1% rejection and 5.95% recovery of feed water. It is actually reduce fouling effect of aluminum silicates from pass through RO membrane. This work show optimum parameters value, pretreatment of UF membrane and activated alumina improved permeate flux and salt rejection of the RO membrane with 280 L/m^2.h and 97% rejection. Besides, the treated water (permeate) fulfils the watering standards and can be used as boiler feed water and steam generation for boiler and heat recovery steam generator (HRSG).

Recommendations of this project:

- To propose dosing rate of chemical injection for controlling A1 ions concentration based on experimental analysis in RO pilot plant with optimum critical parameters. Since this research doesn't cover on chemical treatment, it is recommend to use any available and effective chemicals to control concentration of Al with optimum parameters from damaging RO system due to its sensitivity [26].
- Besides that, further investigation need to focus on studying the effectives of pH and feed concentration towards polymerization issues of Al_2SiO_5 fouling. The range of concentration should be kept as low as possible in order to maintain RO performance and controlling silica concentration with the help of pH.

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APPENDICES

Appendix 1 : FTIR result

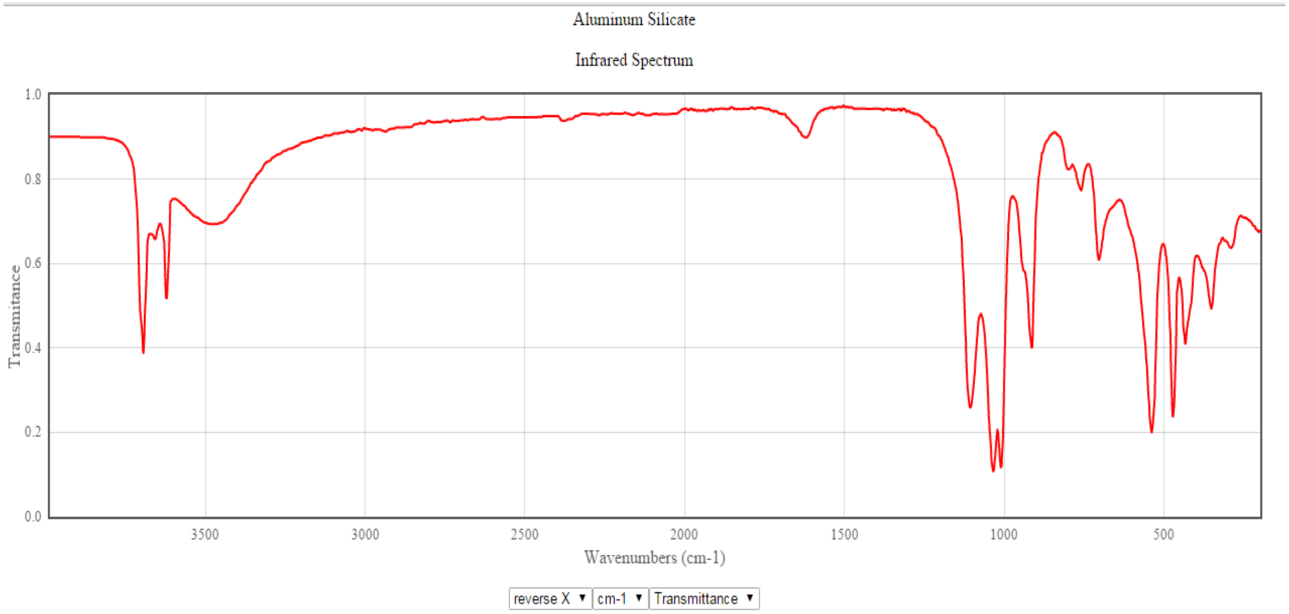


Figure 14:Sample ofaluminium Silicate (FTIR) taken from the website of:http://webbook.nist.gov/cgi/cbook.cgi?ID=B6004665&Mask=80 [39]

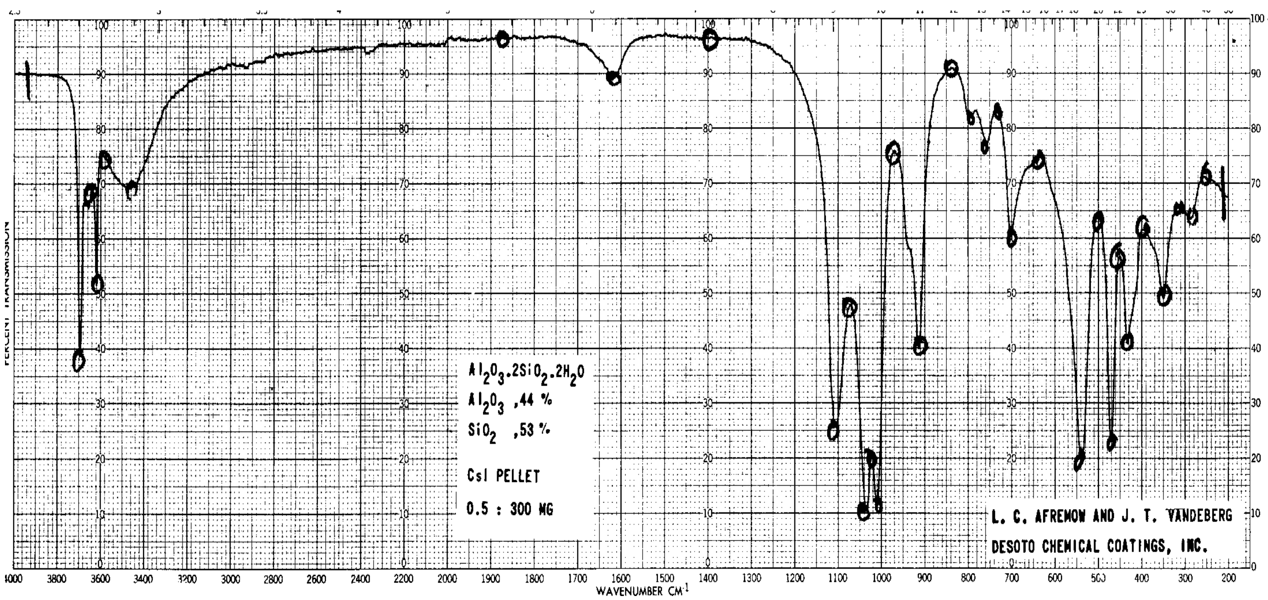


Figure 15 : Sample description of the wavelength vs Transmittance with the existing chemical bond at the concentration of < 150 ppm

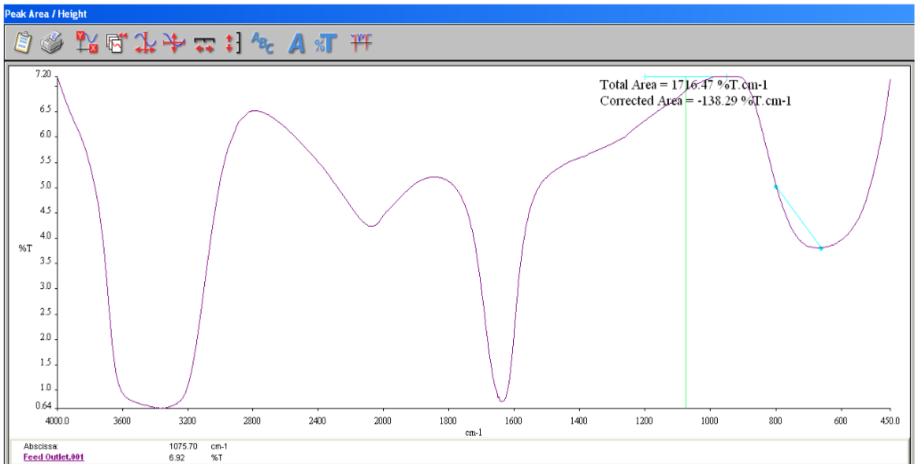


Figure 16: Feed outlet result with accumulated area (below the graph) 1716.47 % T/cm.

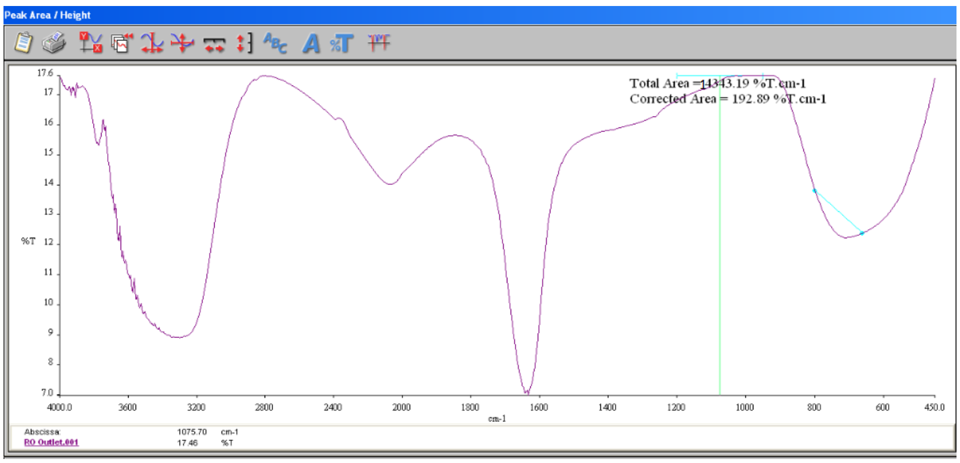


Figure 17: RO Outlet result with accumulated area (below the graph) 14343.19 % T/cm.

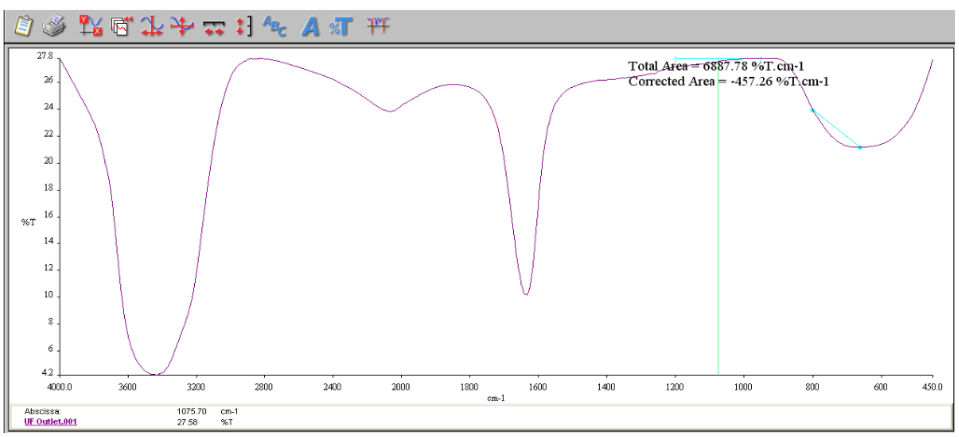


Figure 18: UF Outlet result with accumulated area (below the graph) is 6887.78 % T/cm.

Appendix 2 : Samples of RO outlet, UF outlet and Feed outlet

Figure 19: The sample from three outlet, RO, UF and Feed.

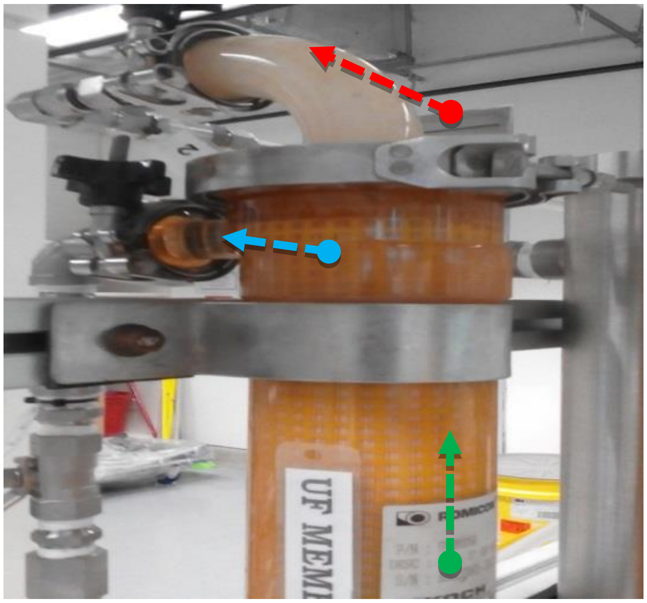


Figure 20 Ultrafiltration part

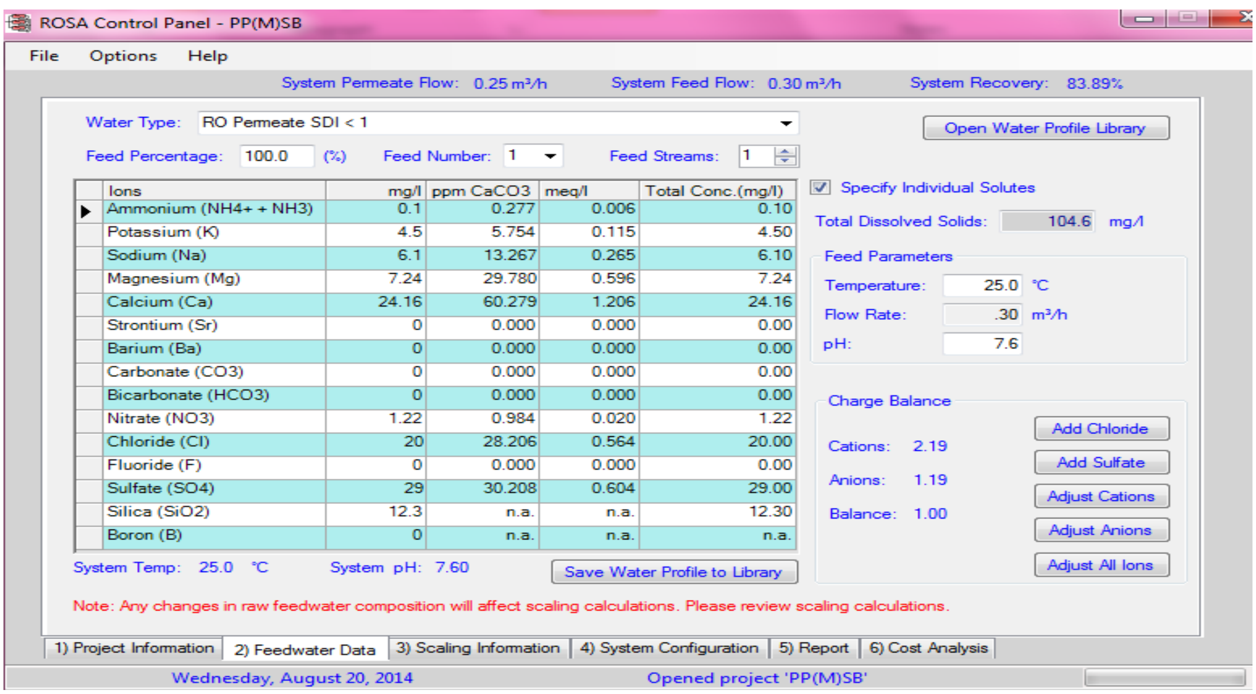
Notes:

Red line – UF reject and recycle

Blue line – UF permeate
Green line – UF Feed from Tank

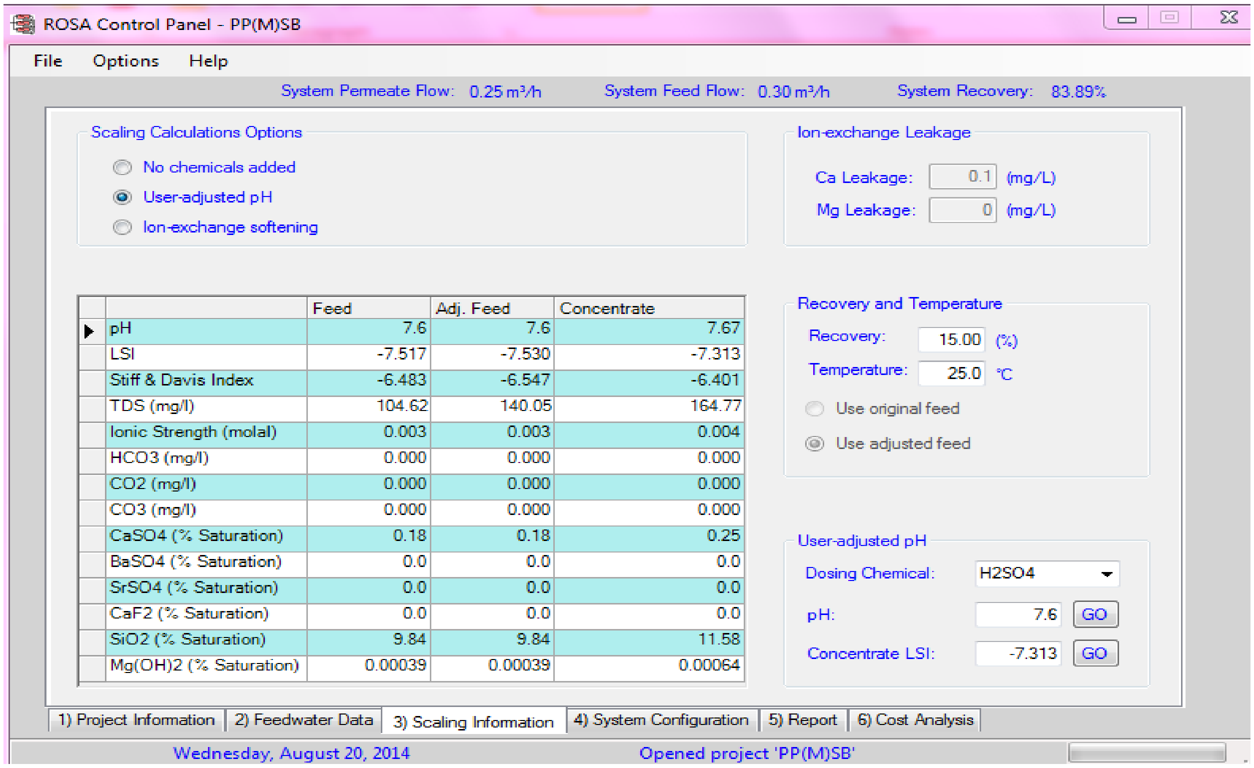
Appendix 3: ROSA Data System Analysis

Figure 21: Project data



Ions	mg/l	ppm CaCO3	meq/l	Total Conc.(mg/l)
Ammonium (NH4+ + NH3)	0.1	0.277	0.006	0.10
Potassium (K)	4.5	5.754	0.115	4.50
Sodium (Na)	6.1	13.267	0.265	6.10
Magnesium (Mg)	7.24	29.780	0.596	7.24
Calcium (Ca)	24.16	60.279	1.206	24.16
Strontium (Sr)	0	0.000	0.000	0.00
Barium (Ba)	0	0.000	0.000	0.00
Carbonate (CO3)	0	0.000	0.000	0.00
Bicarbonate (HCO3)	0	0.000	0.000	0.00
Nitrate (NO3)	1.22	0.984	0.020	1.22
Chloride (Cl)	20	28.206	0.564	20.00
Fluoride (F)	0	0.000	0.000	0.00
Sulfate (SO4)	29	30.208	0.604	29.00
Silica (SiO2)	12.3	n.a.	n.a.	12.30
Boron (B)	0	n.a.	n.a.	n.a.

Figure 22: Scaling data and water quality



	Feed	Adj. Feed	Concentrate
pH	7.6	7.6	7.67
LSI	-7.517	-7.530	-7.313
Stiff & Davis Index	-6.483	-6.547	-6.401
TDS (mg/l)	104.62	140.05	164.77
Ionic Strength (molal)	0.003	0.003	0.004
HCO3 (mg/l)	0.000	0.000	0.000
CO2 (mg/l)	0.000	0.000	0.000
CO3 (mg/l)	0.000	0.000	0.000
CaSO4 (% Saturation)	0.18	0.18	0.25
BaSO4 (% Saturation)	0.0	0.0	0.0
SrSO4 (% Saturation)	0.0	0.0	0.0
CaF2 (% Saturation)	0.0	0.0	0.0
SiO2 (% Saturation)	9.84	9.84	11.58
Mg(OH)2 (% Saturation)	0.00039	0.00039	0.00064

Figure 23: pH requirement, temperature and recovery

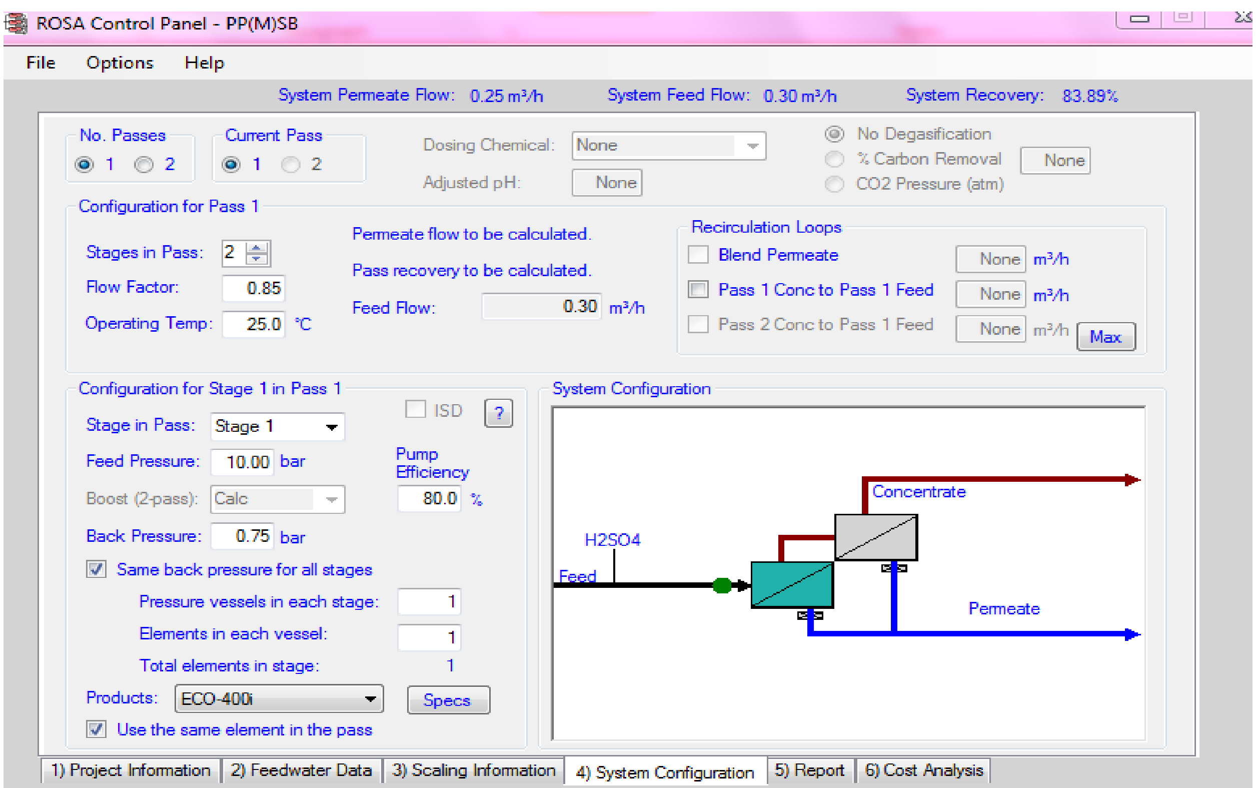


Figure 24: System configuration

Reverse Osmosis System Analysis for FILMTEC™ Membranes — ROSA 9.1 ConfigDB u399339_282
Project: UTP Tap water analysis — Case: 1
Husainni Saaid, UTP 2015 — 12/24/2014

Design Warnings

-None-

Solubility Warnings

-None-

Stage Details

Stage 1	Element	Recovery	Perm Flow (m³/h)	Perm TDS (mg/l)	Feed Flow (m³/h)	Feed TDS (mg/l)	Feed Press (bar)
	1	0.10	0.03	0.51	0.30	40.42	3.66

Figure 25: Project Data

Reverse Osmosis System Analysis for FILMTEC™ Membranes — ROSA 9.1 ConfigDB u399339_282
Project: UTP Tap water analysis — Case: 1
Husainni Saaid, UTP 2015 — 12/24/2014

Project Information: To study the performance of total dissolve solid in Tap Water by using RO Simulation ROSA 9

Case-specific: FYP 2

System Details

Feed Flow to Stage 1	0.30 m³/h	Pass 1 Permeate Flow	0.03 m³/h	Osmotic Pressure:	
Raw Water Flow to System	0.30 m³/h	Pass 1 Recovery	9.92 %	Feed	0.00 bar
Feed Pressure	4.00 bar	Feed Temperature	25.0 C	Concentrate	0.00 bar
Flow Factor	0.85	Feed TDS	40.42 mg/l	Average	0.00 bar
Chem. Dose (100% H2SO4)	0.00 mg/l	Number of Elements	1	Average NDP	3.61 bar
Total Active Area	2.60 M²	Average Pass 1 Flux	11.54 lmh	Power	0.04 kW
Water Classification: Surface or Softened Municipal Water SDI < 3				Specific Energy	1.40 kWh/m³

Stage	Element	#PV	#Ele	Feed Flow (m³/h)	Feed Press (bar)	Recirc Flow (m³/h)	Conc Flow (m³/h)	Conc Press (bar)	Perm Flow (m³/h)	Avg Flux (lmh)	Perm Press (bar)	Boost Press (bar)	Perm TDS (mg/l)
1	BW30-2540	1	1	0.30	3.66	0.00	0.27	3.57	0.03	11.54	0.50	4.00	0.51

Pass Streams (mg/l as Ion)					
Name	Feed	Adjusted Feed	Concentrate	Permeate	
			Stage 1	Stage 1	Total
NH4+ + NH3	0.01	0.01	0.02	0.00	0.00
K	0.31	0.31	0.35	0.00	0.00
Na	0.86	0.86	0.95	0.01	0.01
Mg	0.57	0.57	0.63	0.00	0.00
Ca	0.76	0.76	0.84	0.00	0.00
Sr	0.00	0.00	0.00	0.00	0.00
Ba	0.00	0.00	0.00	0.00	0.00
CO3	0.00	0.00	0.00	0.00	0.00
HCO3	0.00	0.00	0.00	0.00	0.00
NO3	0.02	0.02	0.02	0.00	0.00
Cl	0.70	0.70	0.77	0.00	0.00
F	0.72	0.72	0.80	0.00	0.00
SO4	3.48	3.48	3.86	0.01	0.01
SiO2	32.89	32.89	36.47	0.41	0.41
Boron	0.02	0.02	0.02	0.01	0.01
CO2	0.00	0.00	0.00	0.00	0.00
TDS	40.42	40.42	44.81	0.51	0.51
pH	7.60	7.60	7.60	7.58	7.58

Figure 26: ROSA Report From the simulation, the salt rejection is estimated to be 98.74%

Appendix 4: Fouling layer in Pre-filter

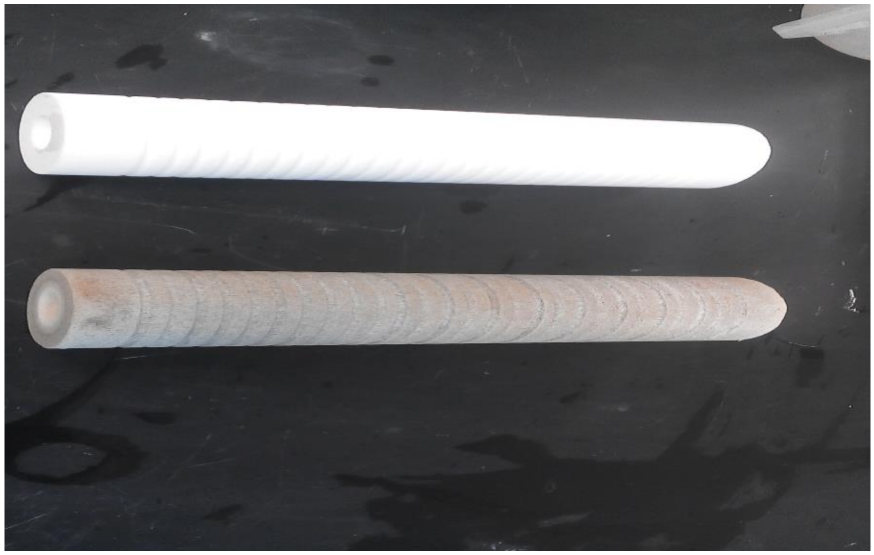


Figure 27: Aluminium silicate fouling layer in pre-filter

Appendix 5 : Activated alumina samples

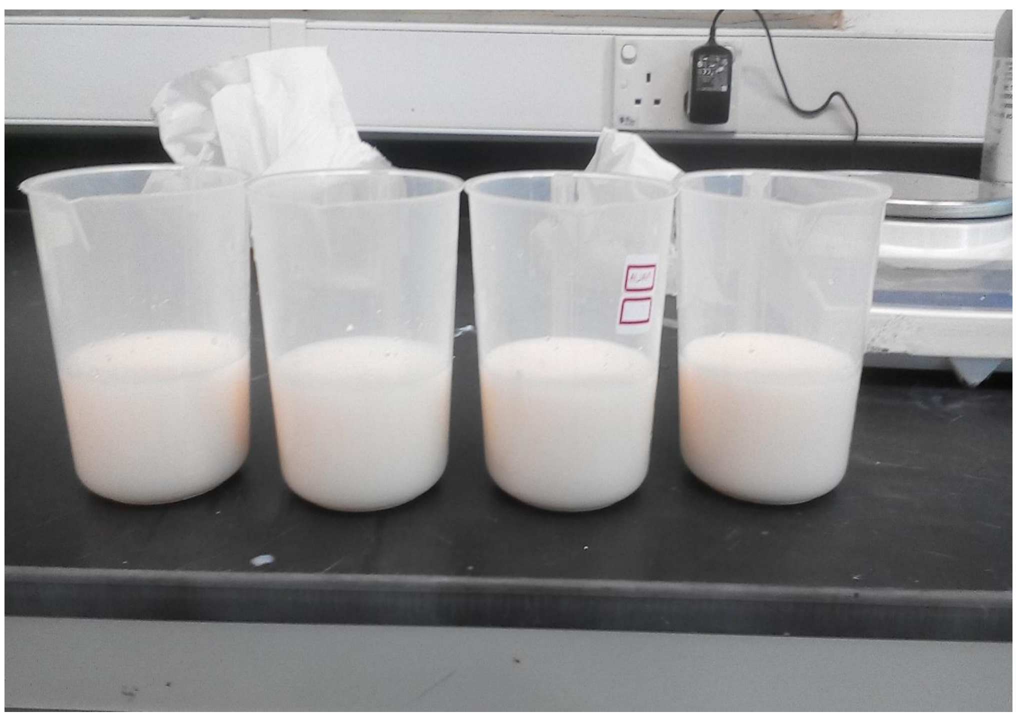


Figure 28: Final product of activated alumina with aluminium silicate

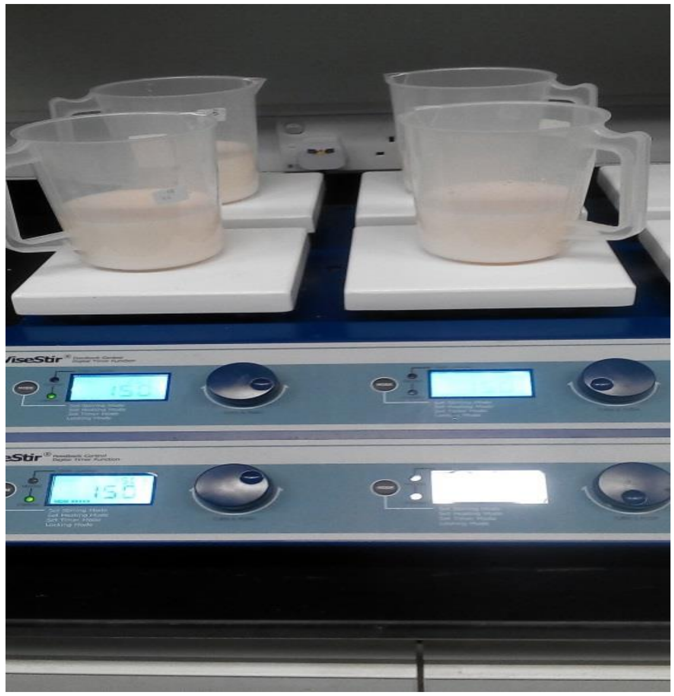


Figure 29: Activated alumina withaluminium silicate and stirrer

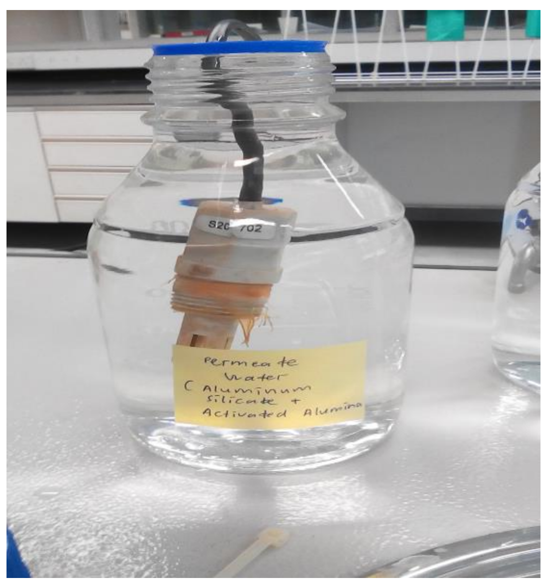


Figure 30: TDS calculation for aluminium silicate and activated alumina solution

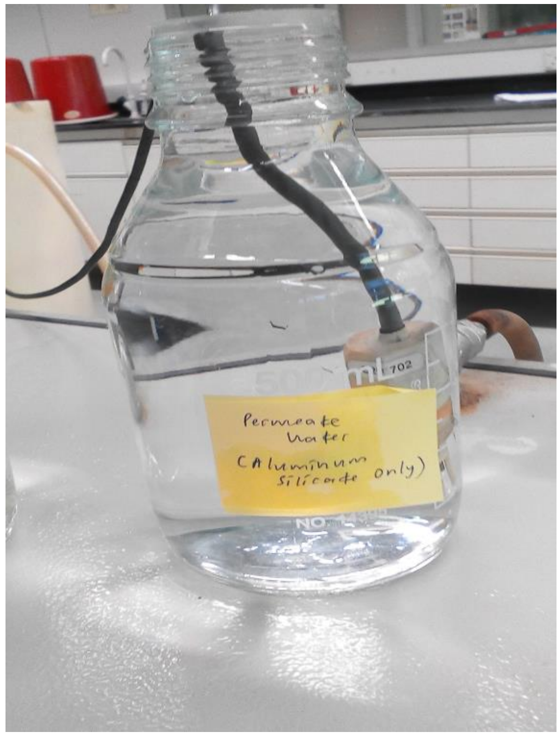


Figure 31: TDS calculation for aluminium silicate only