SIMULATION STUDY ON FORWARD OSMOSIS DESALINATION PROCESS

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SIMULATION STUDY ON FORWARD OSMOSIS DESALINATION PROCESS

SYAZA SYAFIQAH BINTI MUHAMAD KAMEL

Thesis submitted in partial fulfillment of the requirements for the award of the degree of Bachelor of Chemical Engineering

Faculty of Chemical and Natural Resources Engineering
University Malaysia Pahang

JUNE 2015

SUPERVISOR’S DECLARATION

“I hereby declare that I have read this thesis and in my opinion this thesis has fulfilled the requirement for the award of the Degree of Bachelor of Engineering (Chemical)”

Signature :

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Date :

STUDENT'S DECLARATION

"I declare that this thesis entitled 'Simulation Study of Forward Osmosis Desalination Process' is the result of my own research except as cited in references. The thesis has not been accepted for any degree and it is not concurrently submitted in candidature of any degree."

Signature :

Name : Syaza Syafiqah binti Muhamad Kamel

Date : 30 June 2015

“

So remember Me; I will remember you. And be grateful to Me and do not deny Me.

”

(Surah Al-Baqarah: 152)

“

Studied diligently, do not play and do the best make us proud of you!.

”

(Mom and Dad; Siti Hanizah, Muhamad Kamel)

To my family members,

my friends,

my fellow colleagues,

and all faculty members

And for those who keep be by my side and said

“You can do it and you’re the best!!!”

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Last but not least, to my family members. Thank you.

ABSTRACT

The current scenario of Malaysia water crisis demands innovative and novel technologies that not only provide elevated throughput and productivity, but also ensures optimum energy efficiency at the same time. Launching a RM 60Million new water desalination plant is Sarawak (Choice, 2013) reflects the necessity of seawater desalination in Malaysia. Today, the most consistent and reliable technology to extract fresh water from seawater is the reverse osmosis (RO) process. However, the energy is consumed by this process, including the pressure exchangers at the brine stream. Furthermore, it also faces the issue of membrane fouling. In the turn of the new century, scientists have shown keen interest in forward osmosis (FO) process in order to address the challenges faced by the RO process. FO is an osmotically driven membrane process that takes advantage of the osmotic pressure gradient to drive water across the semipermeable membrane from the feed solution (low osmotic pressure) side to the draw solution (high osmotic pressure) side. FO delivers many potential advantages such as less energy input, lower fouling tendency, and higher water recovery than others technologies. Objective of this study is to perform FO desalination of seawater simulation for the whole process in Aspen Plus and to study the optimum parameter for FO membrane desalination process which is ammonia bicarbonate and also to estimate the electrical equivalent of energy required and compare it with other desalination processes. Methodology in simulating FO desalination process is going to be develops using Aspen Plus and other software's. FO desalination process unit is created in Aspen Plus and the model is develops in Microsoft Excel. A validation of FO desalination is done by running the FO desalination simulation at the same condition with the experimental and the result of FO desalination is compared.

ABSTRAK

Senario semasa krisis air Malaysia menuntut teknologi inovatif dan baru yang bukan sahaja memberikan daya pemprosesan yang tinggi dan produktiviti, tetapi juga memastikan kecekapan tenaga optimum pada masa yang sama. Melancarkan RM60 million baru tumbuhan penyahgaraman air Sarawak (Pilihan, 2013) mencerminkan keperluan penyahmasinan air laut di Malaysia. Hari ini, teknologi yang paling konsisten dan boleh dipercayai untuk mengambil air tawar dari air laut adalah reverse osmosis (RO) proses. Namun , tenaga yang digunakan oleh proses ini, termasuk penukar tekanan pada aliran air garam tersebut. Selain itu, ia juga menghadapi masalah pengotoran membran. Pada awal abad baru ini, ahli-ahli sains telah menunjukkan minat dalam osmosis hadapan (FO) Proses untuk menangani cabaran yang dihadapi oleh proses RO . FO merupakan proses membran osmotik didorong yang mengambil keuntungan dari kecerunan tekanan osmosis untuk mendorong air melalui membran semi permeabel dari penyelesaian makanan (tekanan osmosis rendah) sebelah kepada penyelesaian cabutan (tekanan osmotik yang tinggi) sampingan. FO memberikan banyak keuntungan yang mungkin timbul seperti input kurang tenaga, fouling kecenderungan yang lebih rendah , dan pemulihan air yang lebih tinggi daripada teknologi lain-lain. Objektif kajian ini adalah untuk melakukan FO penyahgaraman simulasi air laut untuk keseluruhan proses di Aspen Plus dan untuk mengkaji parameter optimum untuk FO membran proses penyahgaraman yang ammonia bikarbonat dan juga untuk menganggarkan bersamaan elektrik tenaga yang diperlukan dan membandingkannya dengan penyahgaraman lain proses. Metodologi dalam simulasi proses penyahgaraman FO akan menjadi memaju menggunakan Aspen Plus dan perisian lain. FO proses penyahgaraman unit dibuat di Aspen Plus dan model ini berkembang dalam Microsoft Excel. Satu pengesahan FO penyahgaraman dilakukan dengan menjalankan penyahgaraman simulasi FO pada keadaan yang sama dengan eksperimen dan hasil FO penyahgaraman dibandingkan.

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LIST OF SYMBOLS

J_W Water Flux

σ Reflective Coefficient

$\Delta\pi$ Osmotic Pressure driven

A Area of Transportation across membrane

Sh Sherwood number

Re Reynolds number

Sc Schmidt number

dh Hydraulic diameter

L Length of Channel

k Mass Transfer Coefficient

D Solute Diffusion Coefficient

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1 INTRODUCTION

1.1 Research Background

With rapid economic development and dramatic increase in population, Malaysia is facing unprecedented challenges of water and energy supplies.70% of Malaysians use more water than they should. At 226 liters per person every day, we take for granted our wealth of water and good rainfall. But the dangerous pattern may lead to a serious water crisis. FO process has viable prospect for seawater desalination by extracting water molecules from the seawater into a draw solution. In addition to the applications of FO available in literature (Cath et al, 2006). In fact, water and energy are inextricably linked to each other. Making freshwater available is an energy-intensive process, and generating power often requires a large amount of water (C.W. King, 2008; G.M. Geise, 2010) A new desalination technology, Forward Osmosis (FO) can reduce the cost of water desalination further as compared to that of RO. Forward Osmosis just like RO, is a membrane process but here, natural osmotic pressure gradient rather than hydraulic pressure is made use of to create the driving force for water to permeate through the membrane. A ‘Draw ‘solution that has a significantly higher osmotic pressure than the saline feed water is used at the other side of the membrane. FO applies the similar basic concept as of RO, whereby in both processes, a semi permeable membrane is used for water transportation. However, the driving force in the FO process is created naturally by the concentration difference between the saline feed water and a highly concentrated draw solution (ammonia-carbon dioxide) across the membrane, which substitutes the high pressure pump required in the RO process. Fresh water diffuses from sea water towards the ammonia- carbon dioxide draw solution as presented in Figure 1. Hence, lesser energy is required for the FO process compared to the RO process. Thermal energy is required to separate fresh water from the draw solution (Danasamy, 2008). Draw solution composed of ammonium salts formed from the mixture of Ammonia and Carbon dioxide gases was found to be most effective in terms of economy, osmotic pressure, easiness of removal and reuse.

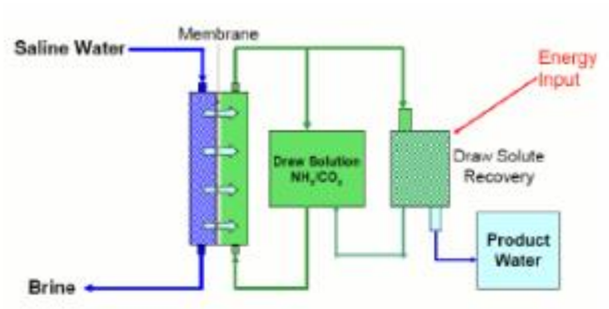

Figure 1.1: Diagram of Forward Osmosis Unit

It could be prudently employed for seawater desalination due to its low energy consumption and lower fouling propensity. Unlike the former method, forward osmosis has potential in achieving high water flux besides it only use low energy which leads to low operating cost and also operates in low temperature and pressure (Cath et al, 2006; Zhao et al, 2012). It was further investigated by McGinnis and Elimelech that the major advantages of the Forward Osmosis process include high feed water recovery, brine discharge minimization and relatively low energy requirements and cost.

The economics of membrane separation processes depend on process design. The simulation of a process allows easy evaluation and optimization of the operating variables and process configurations, thereby giving more insight in the influence of important parameters on process design. Most commercial process simulator or flow sheeting packages have built-in process models and optimization toolboxes, thus offering a convenient and time saving means of examining an entire process. A wide variety of software directed at process engineering is presently available. However, membrane modules containing an internal membrane process model are hardly ever implemented in this software.

A frequently used in industry and academe is Aspen Plus. This is steady-state modular simulation package used as tool to simulate and design chemical processes (Inc. A. T., 2002). The separation process was modeled on Aspen Plus database. In Aspen Plus, all unit operation models can handle electrolytic system and it is possible to model a system containing sour water solutions with dissolved NH3, CO2, as the database provides specialized thermodynamic models and built in data to represent the non-ideal behavior of liquid phase components., apart from the fact that the user has little or no control over the calculations after the simulations run has started. Although a built-in stand-alone model for forward osmosis processes is not available in the standard version of Aspen Plus, a detailed membrane model can be implemented and used as a user supplied subroutine. This can however be very complicated and time consuming.

Furthermore, after starting and running the simulation, this USER model is implemented in the code of Aspen Plus as a subroutine, and as consequence the user has no longer control over it once program execution starts. This makes the users completely dependent on the way Aspen Plus handles this model and makes it difficult to direct the simulation in response to the results.

Objective of this study is to develop methodologies of FO desalination seawater process using Aspen Plus simulator software and investigate parameters influence the desalination seawater process.

1.2 Problem Statement

Forward osmosis is a remarkable new technology that turns muddy, contaminated water or seawater into new clean water that can be drink. There are many factors that affecting the rate of forward osmosis in order to obtain a high water flux. Some of the factors are temperature and concentration of draw solution. As forward osmosis is a new technology, there is a few simulation program have been develop. However, only a few modeling program for forward osmosis process across the membrane had been developed. Thus, this study intends to study the desalination seawater of draw solution on forward osmosis process across the membrane for the whole process through a simulation program.

The problem in this situation is since forward osmosis is the most preferred technologies that we have to see the improvement of the process and the way to comprehend the process without ever going to put up a pilot plant. Even by improving a readily built plant, it will costs time and money. It is sufficient to answer the question that continually arises and 'trial and error' efforts to provide meaningful insight are costly and potentially dangerous. With reliable thermodynamic data, realistic operating conditions and the rigorous Aspen Plus equipment models, they can simulate actual plan behavior. Using the aspen plus, the actual pilot plant size can be build and the forward osmosis process can be comprehended.

1.3 Research Objective

This study is guided by the following research objectives:

1. To perform methodologies of Forward Osmosis desalination seawater process using Aspen Plus simulator software.
2. To analyze the electrical equivalent of energy required for FO desalination seawater compared to other desalination technologies. (RO and Multi Stage Distillation).
3. To investigate the parameter that could influences the Forward Osmosis desalination of seawater process.

1.4 Research Scope

In order to achieve the objectives stated above, the following scopes of study have been drawn. The simulation procedure is performed by:

1. Perform forward osmosis unit created in Visual Basic for Application software and connected with Aspen Plus.

2. Finding a forward osmosis unit user model code.

3. Generate data from the ASPEN PLUS simulation and validate it with data from journal.

4. Forward osmosis process is run with different set of parameter and analyze the data for optimal separation.

2 LITERATURE REVIEW

2.1 Forward Osmosis Background

Forward osmosis is one of the new technologies used in the water treatment especially seawater and brackish water desalination and for the purification of the contaminated water sources (McGinnis, 2007). Generally, this technologies is highly used in industrial field because of its capability to remove difficult solutes in a waste streams. Forward osmosis is referred as a process that involves osmotic membrane where it diffuses polluted water spontaneously through a semi-permeable membrane from a low osmotic region (feed solution) to high osmotic region (draw solution) in order to produce hygienic water which can be drink safely (Cath et al, 2006; Gruber, 2011; D.H. Jung, 2011; Zhao et al, 2012). Figure 2.1 show the process of forward osmosis. In forward osmosis, the membrane is located in between of feed solution and draw solution (permeate).

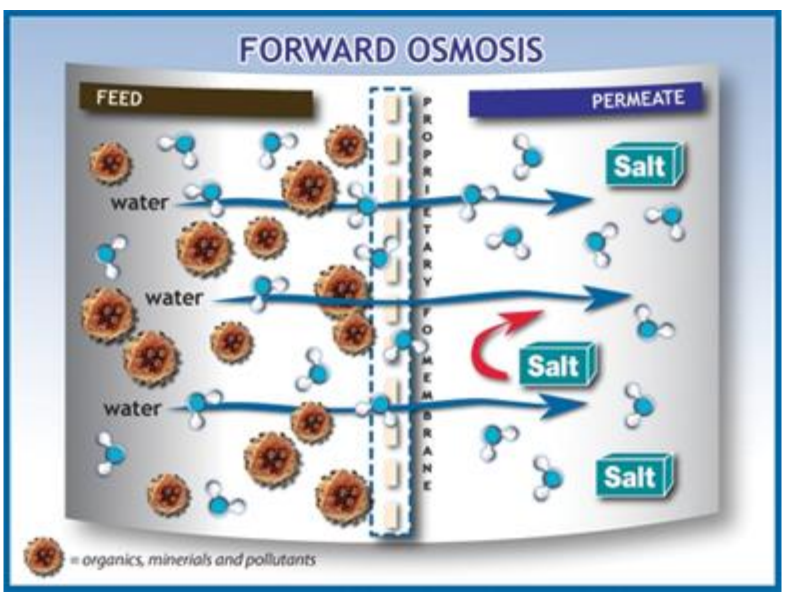

Figure 2.1: Forward Osmosis Process

During the process, the contaminated water will directly separate from the feed solution. The feed solution is used by the draw solution to force the water to pass through the semi-permeable membrane and as a result, the draw solution will be diluted while the feed solution will be more concentrated. Due to this reason, the initial concentrations of both feed and draw solution will not be equal. The semipermeable membrane will acts as an obstacle to block all the larger molecules from passing through the membrane and only allows the small molecules such as water to pass through it. Water passes from one chamber to the next by diffusion until the solids concentration on both sides of the membrane are equal. That higher osmotic potential in the salt "draw" solution is the power source nature provides to drive the filtration process. The water moves through the membrane, is filtered in the process and dilutes the higher concentration salt water on the permeate side.

Forward osmosis is said as an emerging technology due to its potential to reduce the shortage of water and energy (Cath et al, 2006; Chung et al, 2012). Before forward osmosis, there are many other ways that have been used throughout the years to treat the water and one of the methods is by osmosis. Along with the technology development, the usage of the osmosis method is extended from water treatment to power generation. This is because water obtained from this method is more pure and the process is much easier. In past few years, the latest technology which is forward osmosis is introduced to the industries. Due to the potential shown by forward osmosis in water supply and power generation, forward osmosis is mostly preferred in wastewater treatment, desalination, power generation and food processing fields (S. Zhao, L Zhou, D. Mulcahy, 2012). Differ with reverse osmosis, forward osmosis is more preferred because it can be conducted in low hydraulic pressure, has low membrane fouling and requires less energy which leads to lower cost (Cath et al., 2006; Zhao et al., 2012). Besides the water treatment and power generation, forward osmosis also have been used for others applications.

They are differences between forward osmosis and reverse osmosis from the Table 2.1 it can be concluded that forward osmosis is higher in advantages than reverse osmosis.

Forward Osmosis	Reverse Osmosis
Technology status: • Innovative process solution now fully operational & commercially available (Al Khaluf, Oman – the world's first commercial FO plant began operation in 2010). • Competitive advantages over RO. • Significant further process improvements to come.	**Technology status:** • Mature, well established technology (Coalinga, California - the world's first commercial RO plant began operation in1965). • Little further improvement likely
Membrane Fouling: • Extremely low inherent fouling - low pressure, diffusion driven process. • Possibility to consider reduced pre-treatment.* site dependent • FO Membranes are chlorine tolerant allowing effective treatment for bio-fouling	**Membrane Fouling:** • High pressure - prone to fouling, hydraulic forces increase fouling - a key issue. • RO Membranes are not chlorine tolerant.
Energy Consumption: • Typically up to 30% less than RO. • The more difficult the feedwater the higher the energy saving.	**Energy Consumption:** • Typically up to 30% more than FO. • Any degree of fouling, higher than FO.
Operational Cost: • Less than RO due to higher availability, less chemical cleaning and fewer membrane replacements. • Extended membrane life- FO membrane life typically twice that of the equivalent RO membrane.	**Operational Cost:** • More than FO due to lower availability, higher energy costs, more chemical cleaning and membrane replacements.
Boron Removal: • Inherently high removal, without the need for post treatment (less than 1 ppm).	**Boron Removal:** • Poor removal and may require additional costly post treatment system
Ease of Operation: • Very similar to RO, but with less frequent cleaning and increased membrane life.	**Ease of Operation:** • Similar to FO but more frequent cleaning and reduced membrane life.

Table 2.1: Comparisons between Forward Osmosis and Reverse Osmosis

2.2 Application of Forward Osmosis

Recently, this forward osmosis technology is applied to a range of industries. This technology is separated into three fields which are life science, water and energy (Zhao et al., 2012). In the life science fields, forward osmosis are extensively used in food and pharmaceutical processing (Cath et al., 2006; Zhao et al., 2012). In food processing, forward osmosis is usually used to concentrate beverages and liquid foods. Since the forward osmosis process can be operated at low temperature and pressure, it helps to maintain the food quality and nutritional value such as flavour, aroma, colour and vitamins (Cath et al., 2006). For pharmaceutical industry, forward osmosis helps in controlling the drugs release (Cath et al., 2006).

As for water and energy, it is applied in wastewater treatment (Cath et al.,2006), landfills leachate (Cath et al., 2006), seawater desalination (Kessler, 1976; McCutcheon et al, 2005; Zhao et al., 2012) and power generation (Yip et al, 2010). Landfill leachate contains many types of pollutants such as organic and inorganic compounds, dissolved heavy metals and total dissolved solids (TDS). Normally, landfill leachate is treated by using the wastewater treatment facility. However, among all of the compounds contains in the landfill leachate, the TDS is not only untreated but on the other hand enlarged the concentration of the TDS (York et al, 1999). Thus, in order to treat the TDS, forward osmosis has been used and it is proved that forward osmosis is very efficient in treating landfill leachate (York et al., 1999). Before forward osmosis is introduced, desalination and water treatment was treated by using the former membrane technologies such as reverse osmosis.

However, energy issue had been arise when the former technologies was used (Fane, 2011). Forward osmosis also has been used for osmotic bioreactor membrane and direst fertigation which is for the fertilizers. For all of this applications, forward osmosis is preferred due to several benefits where it can operates in low hydraulic pressure (Cath et al., 2006; Gruber et al., 2011) and higher osmotic pressure (Zhao et al., 2011). Low hydraulic pressure leads to lower tendency of the membrane to foul (Gruber et al., 2011)where lower membrane fouling caused the water product to be increased and longer the membrane life (Zhao et al., 2012). Besides, forward osmosis only requires low energy consumption for water transport (Chung et al., 2012; Zhao et al., 2012). As consequences from the lower energy needed, it can reduce the process costs and increase the water flux produce by forward osmosis (Zhao et al., 2012). In order to obtain pure water with a higher water flux in the water treatment, there are many parameters involved which can affect the rate of forward osmosis. FO has proven excellent operation in terms of durability, reliability and water quality in highly polluted waters, e.g. Hydropack Emergency Supply product (HTI). FO has shown flexibility and applicability due to scalability of the membrane system (Schrier, 2012) Next, reduced fouling propensity (A. Achilli T. C., 2009 and S. Lee, 2010) and simple cleaning (L.A. Hoover, 2011 and K. Lutchmiah, 2011) compared to RO. FO can be applied for dewatering feeds (K.B. Petrotos, 2001 and H. Zhu, 2012), useful for effective anaerobic digestion of wastewater, and is simpler, greener and higher in efficacy than traditional dewatering treatments (Chung et al, 2012).

2.3 The Draw Solution: Ammonium Carbon Dioxide/Bicarbonate

FO process is affected by a number of factors such as type of FO membrane, concentration of the draw solution, type of draw solution, and the regeneration process (Victor Yangali-Quintanilla, 2011; Robert L. McGinnis, 2007). Using a draw solution of two highly soluble gases -- ammonia (NH3) and carbon dioxide (CO2) -- satisfies the ideal draw solution criteria discussed above. The concentrated draw solution is made by dissolving ammonium bicarbonate salt (NH4HCO3) in water. The high solubility in conjunction with a relatively low molecular weight of the salt leads to a very high osmotic efficiency. Shows that osmotic pressures far greater than that of seawater can be generated with our draw solution, providing the necessary driving forces for high potable water flux and high recovery (S.K. Yen, 2010).

Separation of the fresh product water from the draw solution can be achieved with relative ease (A. Achilli T. C., 2010). Upon moderate heating (near 60°C), ammonium bicarbonate can be decomposed into ammonia and carbon dioxide gases. The gases can then be removed from solution by low-temperature distillation using relatively low energy. Other gas separation processes, such as membrane based technologies, can also be used. The estimated value of electrical equivalent of energy consumed in the Forward osmosis desalination techniques is compared with the prevalent techniques whereas the energy requirement values for the other desalination techniques apart from the Forward Osmosis are quoted from (Semiat, 2008).

It is clearly evident that the thermal energy required in the Forward osmosis desalination technique is much less than that required for evaporation based thermal desalination processes, Multi Effect distillation and Multi Stage Flash distillation (Darwish M.A., 1997). Moreover, electrical equivalent of the thermal energy required in FO desalination is in the range comparable to the Reverse Osmosis technology, which is considered to be the most energy efficient process for desalination purposes. The FO process currently being investigated uses a recyclable solute composed of ammonium salts. These salts (a mixture of ammonium bicarbonate, ammonium carbonate and ammonium carbamate) are formed when ammonia and carbon dioxide gases are mixed in an aqueous solution (McGinnis, 2005; McCutcheon, J. R., 2005) The salts are highly rejected by the semipermeable membrane used in FO and are highly soluble, leading to the reliable generation of high osmotic pressures for the FP process (see Figure 2.3).

Once the concentrated draw solution is used to effect separation of water from the saline feed source, the subsequently diluted draw solution may be treated thermally to remove its ammonium salt solutes, producing fresh water as the primary product of the FO process. This thermal separation of draw solutes is based on the useful characteristic of these salts to decompose into ammonia and carbon dioxide gases when the solution is heated. The temperature at which this occurs is dependent on the pressure of the solution. If a vacuum distillation column is used for this separation, the temperature of heat required can be quite low, in the range of 35-40°C given an ambient temperature of 15-20°C. The use of this ammonia-carbon dioxide draw solute thereby allows for effective desalination of saline feed water sources using little more than low-grade heat (very little electricity is required for unpressurized process pumping). Furthermore, the high osmotic pressures that solutions of this type may generate allow for very high feed water recoveries. This has the benefit of reducing brine discharge volumes, electrical requirements for feed water pumping and process capital costs (Cath et al, 2006).

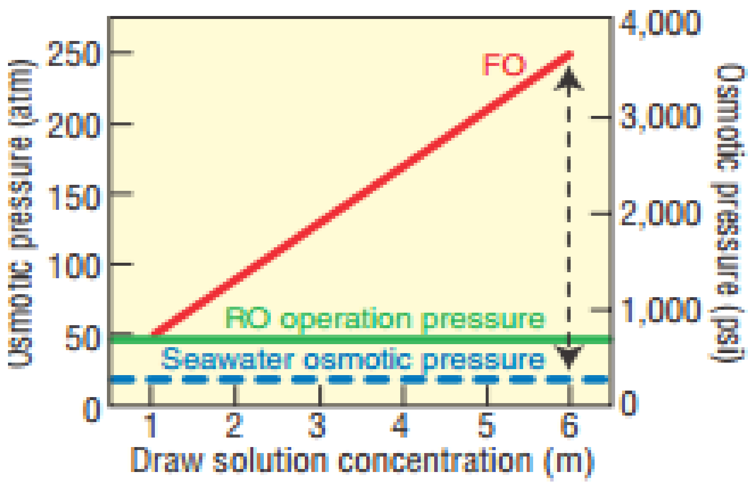

Figure 2.3: Osmotic pressure as a function of ammonia-carbon dioxide draw solution concentration.

2.4 Process design concept

In the ammonia-carbon dioxide forward osmosis process, a semi-permeable membrane is used to separate fresh water from seawater. The FO process uses the natural tendency of water to flow in the direction of higher osmotic pressure, thus effectively the fresh water permeate from the seawater without using high pressure pump. In order to achieve effective FO desalination, the draw used must have high osmotic pressure and contain solutes which are simple and economic to remove and reuse. In the ammonia-carbon dioxide FO process, the draw solution is composed of ammonium salts.

Once the osmotic pressure gradient created by FO process has caused fresh water to flow across the membrane from the seawater into the draw solution, the diluted draw solution must be treated for the recovery of ammonium salts. This separation is based on the thermal decomposition of ammonium bicarbonate, carbonate and carbamate salts into ammonia and carbon dioxide gases at an appropriate temperature and pressure. This heating, decomposition and the stripping and recycling of ammonia and carbon dioxide gases may be accomplished in single or multiple distillation column.*producing as its products fresh water and the re-concentrated draw solution for reuse in the FO membrane system. The product water from this process may be specified to contain significantly less than 1 ppm ammonia and carbon dioxide, as is appropriate for potable use. A schematic diagram of the ammonia-carbon dioxide FO process is shown in Fig 2.4.

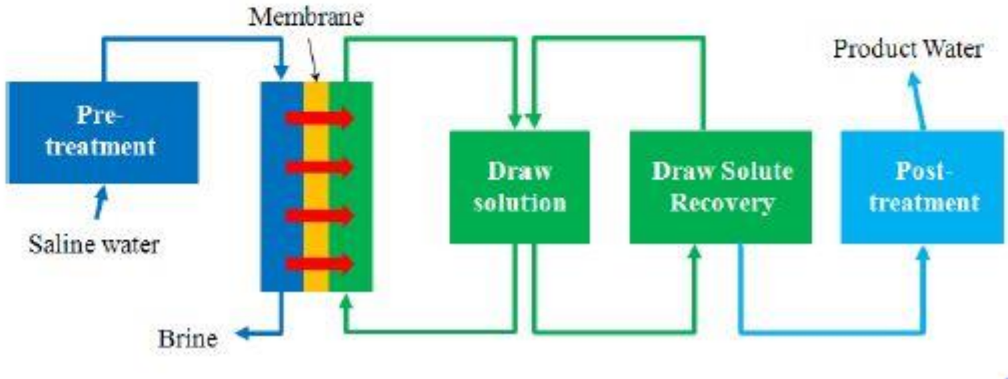

Figure 2.4: Concept of Forward Osmosis desalination process

2.5 Simulation Software

Based on the above models, Window-based, user-friendly design software was developed using Excel Visual Basic for Applications (VBA) to simulate a forward osmosis unit. The software consists of two major parts. The first is a simulation program that is able to simulate a flow sheet containing a forward osmosis unit. The user can specify which of the mentioned models should be used for calculating the membrane process. There is also an option that enables this part of the program to do several follow up simulations which is sensitivity of analysis, thereby varying a specified variable in the way the user would like to. The second part consists of a design program, capable of determining the number of membrane units.

With these two parts of the program, both the performance of a membrane with known properties and the requirements for a membrane unit for a known process performance can be calculated. In order to use the possibilities of this software for the simulation of a hybrid process, a link with Aspen Plus had to be established. This was done according to the training manual for running Aspen Plus with Microsoft Excel/Visual Basic, provided by Aspen Technology (Inc. A. T., 2002) that describes the establishment of data exchange between Aspen Plus and Excel VBA.

2.6 Membrane separation simulation

Water flux model in FO membrane

FO uses the osmotic pressure different($\Delta\pi$) across the membrane, rather than hydraulic pressure differential (as in RO), as the driving force to transport of water through the membrane. The FO process results in concentration of a feed stream and dilution of a highly concentrated stream the general equation describing water transport FO is

$$J_W = A\sigma\Delta\pi \quad (1)$$

Where J_W is the water flux, A the water constant of the membrane, σ the reflection coefficient. In this equation $\Delta\pi$ represents the osmotic pressure difference across the active layer of membrane. In such processes, the osmotic pressure difference across the active layer is much lower (about 5-20%) than the bulk osmotic pressure difference.* the lower than expected water flux is often attributed to several membrane associated transport phenomena. Specifically, two types of concentration polarization (CP) phenomena.

External Concentration Polarization

When the feed solution flows on the active layer of the membrane, solutes build up at the active layer. This may be called concentrative external CP. Simultaneously, the draw solution in contact with the permeate side of the membrane is being diluted at the permeate-membrane interface by the permeating water. This is called dilutive external CP. Both concentrative and dilute external CP phenomena reduce the effective osmotic driving force.

Knowing the overall effective osmotic driving force is important in determining the performance in FO. Therefore, the concentration at the membrane surface is needed to determine. Determining the membrane surface concentration begins with the calculation of Sherwood number for the appropriate flow regime in a rectangular channel:

$$Sh = 1.85(ReSc\frac{d_h}{L})^{0.33} \text{ (laminar flow)} \quad (2)$$

$$Sh = 0.04Re^{0.75}Sc^{0.33} \text{ (turbulent flow)} \quad (3)$$

Here, Re is the Reynolds number, Sc is the Schmidt number, dh is the hydraulic diameter, and L is the length of the channel. The mass transfer coefficient k, is related to Sh by

$$k = \frac{ShD}{d_h} \qquad (4)$$

Where D is the solute diffusion coefficient. The mass transfer coefficient is then used to calculate what is called the concentrative ECP modulus:

$$\frac{\pi_{F,m}}{\pi_{F,b}} = \exp(\frac{J_W}{k}) \qquad (5)$$

Jw is the experimental permeate water flux, and the $\pi_{F,m}$ and $\pi_{F,b}$ are the osmotic pressure of the feed solution at the membrane surface and in bulk solution, respectively. A dilutive ECP modulus can be define as above, except that in this case, the membrane surface concentration of the draw solute is less than that of the bulk

$$\frac{\pi_{D,m}}{\pi_{D,b}} = \exp(-\frac{J_W}{k}) \qquad (6)$$

Here $\pi_{D,m}$ and $\pi_{D,b}$ are the osmotic pressure of the draw solution at the membrane surface and in bulk solution, respectively. To model the flux performance of the FO process in the presence of ECP, the standard flux equation for FO is given as,

$$J_W = A(\pi_{D,m} - \pi_{F,m}) \qquad (7)$$

It is assumed that salt does not cross the membrane or that the osmotic reflection coefficient has a value of 1. When flux rates are higher this equation must be modified to include both the concentrative and dilutive ECP:

$$J_W = A(\pi_{D,b} \exp\left(-\frac{J_W}{k}\right) - \pi_{F,b} \exp\left(\frac{J_W}{k}\right)) \qquad (8)$$

A diagram depicting concentrative and dilutive ECP with a dense symmetric membrane is given in Fig. 3-8

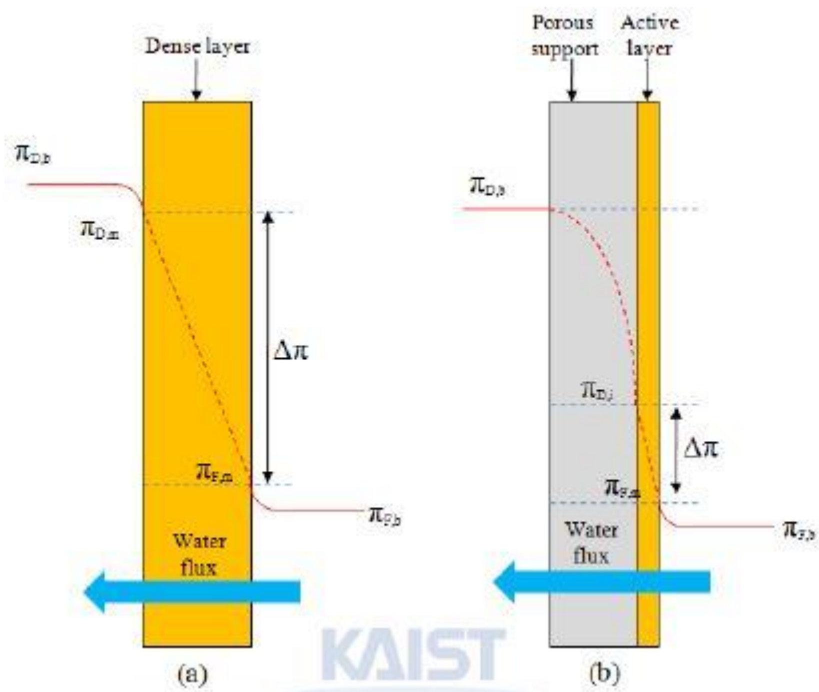

Figure 2-5: A diagram depicting concentrative and dilutive ECP with a dense symmetric membrane. (KAIST)

Aspen plus simulation

Aspen plus offers the option of using Excel Workbook as a user-defined unit operation model for absent units in the simulation. This part illustrates performing the model calculations using external membrane model in Excel subroutine.

In the operating temperature at 25^{o}C, the water flux is calculated with the model equation. The excel solver is used to calculate the implicit equation. Figure shows a standard unit of membrane unit simulation in Aspen Plus. The inlet streams are NaCl solution and ammonium salt solution. These two inlets enter to FO membrane and the information of inlet stream sends to Excel subroutine. The information containing concentration, temperature, and pressure is used to calculate the water flux with the user-defined model. Aspen Plus takes the results about outlet streams.

In standard FO membrane unit operation, NaCl solution, SEAWATER, and ammonium salt draw solution, DRAWSOL, enter to FO membrane. The concentrated NaCl solution, BRINE, and diluted ammonium salt draw solution, DDRAWSOL, come out from the FO membrane.

3 METHODOLOGY

3.1 Research Tool

This research was carried out using Aspen Plus simulator and Microsoft Office Excel 2007 for process flow sheeting to provide data analysis.

3.1.1 Aspen Plus

Aspen plus was utilized in this study of Forward osmosis desalination process. Aspen plus was chosen because it is easy to manipulate the process variables and unit operation technology, as well as fully customizes simulation by using customization and extensibility capabilities. Aspen plus has unique features that propagate information both forward and reverse directions, performing back calculation in non-sequential manner. The bi-directionality often makes iterative calculation unnecessary and faster solution.

3.1.2 Microsoft Office Excel 2007

The most widely used spreadsheet tools that analyze, share and manage information more effectively. This software gives the freedom to import, organize, and explore massive data sets quickly and easily, and the advanced analyses tools help make them right decisions for any situations. It keeps things simple and straight forward. It features calculation, graphing tools, pivot tables and a macro programming language called VBA (Visual Basic for Application).

3.2 Research Activities

3.2.1 Data Collection

A general understanding of the processes must be clear at this particular stage. The key to operate Aspen Plus simulator must be well-known prior to data collection from a selected reviewed journal and previous work to be applied in the simulation.

3.2.2 Validation

For validation of simulation process, the result from journal of Forward osmosis was compared with the simulation result.

3.2.3 Optimization

Optimization was made after the validation process. There are two input variables were identified to be optimized which are flux and concentration. The data obtained was used for further optimization.

3.3 Summary

The research is carried out using Aspen Plus simulator. This simulator was recognized as the research tool because of its unique feature and fast solution. As part of the research methodology, data collection from various reviewed journal was applied to the base case simulation after the overall process was obtained. Then, the validation of Forward Osmosis desalination process was done to distinguish the calculated and simulated results. Lastly, optimization was done by higher flux with the best selectivity. The summary of methodology is shown in Figure 3.1.

3.4 Research Stage

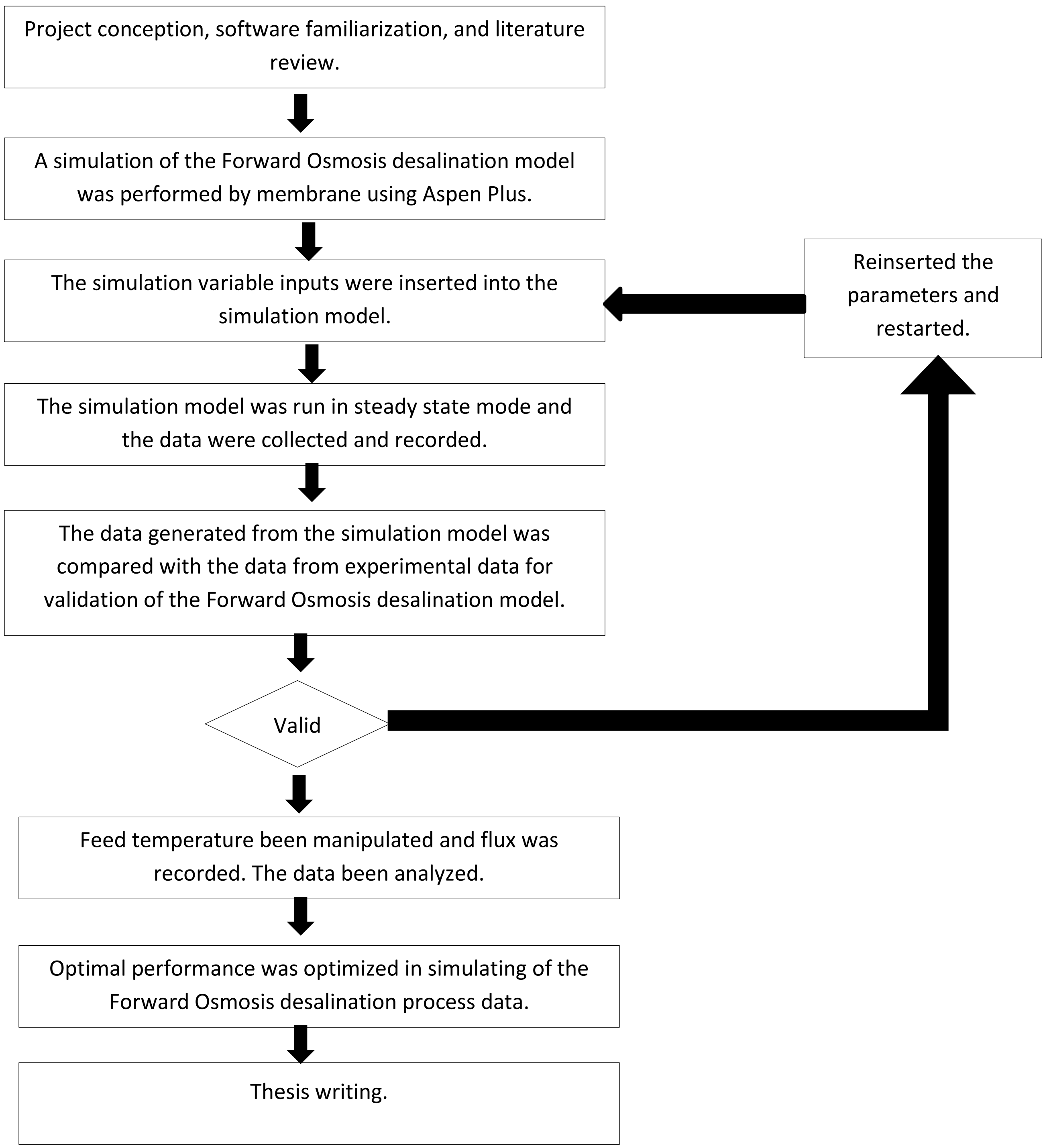

Figure 3.1 Methodology Flowchart

4 RESULT AND DISCUSSION

4.1 Validation of Forward Osmosis Unit

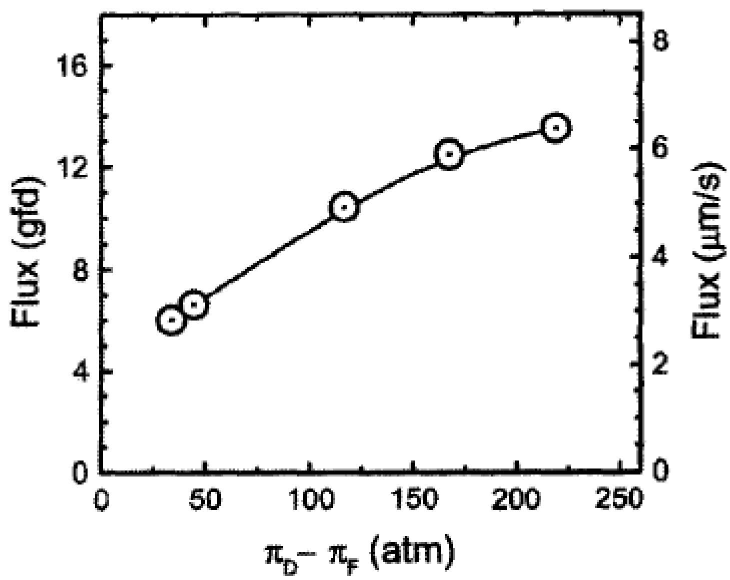

Figure 4.1 FO membrane water flux over a range of osmotic pressure differences (i.e., draw solution osmotic pressure minus feed osmotic pressure).

Graph water flux versus osmotic pressure differences in figure 4.1 was taken from A novel ammonia--carbon dioxide forward (direct) osmosis desalination process, Jeffrey R. McCutcheon a, Robert L. McGinnis b, Menachem Elimelech a*, 2004. From the graph, The water flux is increase with the increase of osmotic pressure differences. The experiment was done with Feed concentration is held constant (0.5 M NaC1) while draw solution concentration is varied. Other experimental conditions: cross flow rate (feed and draw solution) of 30 cm/s and temperature of both feed and draw solutions of 50°C. This graph is use as a reference for validate the simulation of Forward Osmosis unit. According to the characteristic water flux equation for flow across a semi-permeable membrane, when osmotic pressure is the driving force.

After all the data has been generated, all the data generated from the simulation will be compared with the experimental data to ensure the simulation reliability, exactness, and relevant. Graph water flux versus a range of osmotic pressure difference in figure 3.1 was taken from A novel ammonia--carbon dioxide forward (direct) osmosis desalination process, Jeffrey R. McCutcheon a, Robert L. McGinnis b, Menachem Elimelech a*, 2005. From that graph, the water flux is decrease with the increase of osmotic pressure difference. The experiment was done with range of 50 atm to 250 atm. This graph is use as a reference for validate the simulation of forward osmosis membrane desalination process unit.

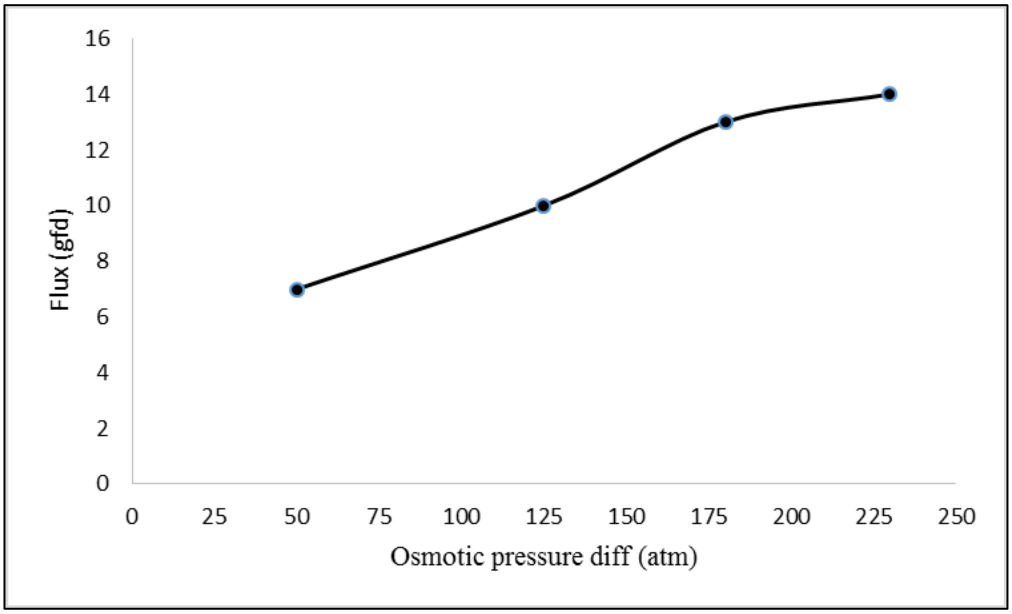

Figure 4.2 simulation result

From the simulation result stated in figure 1.2, the water flux also increases when the osmotic pressure difference is increase. The result from simulation is quite same like the experimental result that was done by Jeffrey R. McCutcheon a, Robert L. McGinnis b, Menachem Elimelech a*, 2006. The forward osmosis membrane unit had been successfully developed using aspen plus and the simulation of forward osmosis desalination process using aspen plus has been verified.

4.2 *Effect of Initial Feed Concentration*

From the graph in figure 1.3, the initial sample concentration has an important influence on the forward osmosis membrane. It provides an important driving force to overcome all mass transfer resistances of all molecules between the aqueous and solid phases (Vladimir *et al.*, 2009). Figure 1.3 shows the effect of initial concentration on forward osmosis membrane unit.

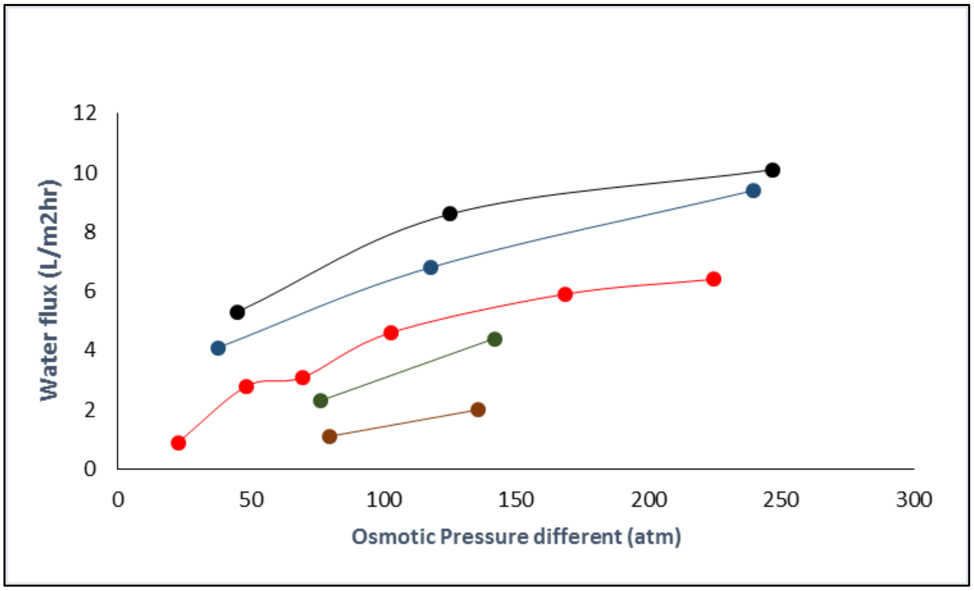

Figure 4.3 Effect of concentration of NaCl in feed with water flux. (Feed temperature at 25°C)

It was observed that the water flux is increasing with increasing of feed and draw solution. The non-linear tendency of water flux in increasing osmotic pressure difference shows the water flux reduction by diluted ICP phenomenon (Gruber et al, 2011). Where, dilutive effect simultaneously occurs on the permeate side, reducing the effective driving force of the draw solution. This phenomenon is intensified by the presence of the porous support (McCutcheon et al, 2006).

4.3 Effect of Feed Temperature

Temperature is an important factor governing mass transfer in membrane separation processes, including the FO process. In several practical applications of FO, there can be significant temporal and spatial variation in the temperature of feed solutions, such as secondary treated effluent or seawater. Similarly draw solution can be at higher temperatures than the feed solution as a result of thermal separation and recycling of the draw solution or using higher temperatures to increase the solubility of draw solutions. To observe the effect of temperature, the studies were performed at five different temperatures 20, 25, 30, 35 and 40^{o}C while the concentration were constant at 17238 mg/l respectively. Figure 4 shows that, water and salt permeability increased with increasing temperature in the FO process and based on phuntsho et al. also examined the water flux behaviour with feed and draw solutions of different temperature and found that water flux increased significantly by increasing draw solution temperature Similar results had been reported in Temperature as a factor affecting transmembrane water flux in forward osmosis; Steady-state modelling and experimental validation, Chemical Engineering Journal (Xu et al., 2010).

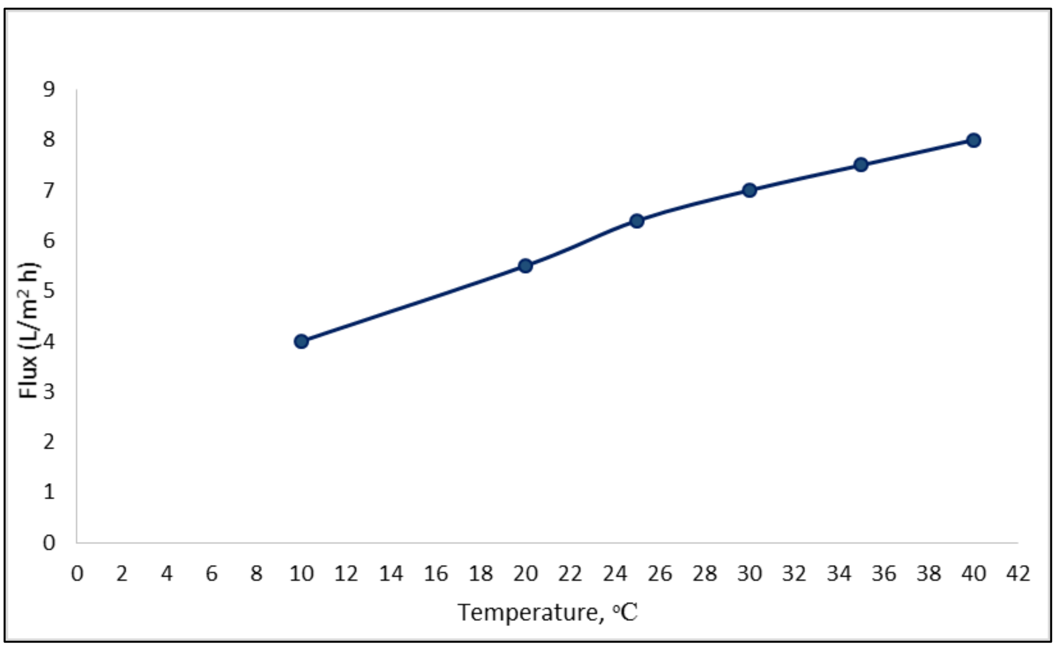

Figure 4.4 Effect of Feed Temperature on Forward Osmosis membrane unit (C_o= 17238mg/L)

5 CONCLUSION

5.1 Conclusion

The validation for forward osmosis desalination process unit using an Aspen Plus simulator had been made. Aspen Plus need to be connected with Microsoft Excel and the forward osmosis membrane model is set in visual basic for application in Microsoft excel. This user friendly software can be use for future study of forward osmosis desalination process. Forward osmosis desalination process had been study and the best condition is to operate at ambient temperature 15-20 or below than 50. This is because it will affect the feed and draw solution concentration as well. Besides, the use of ammonia-carbon dioxide as draw solute thereby allows for effective desalination of saline feed water sources using little more than low grade which has the benefit of reducing brine discharges volume.

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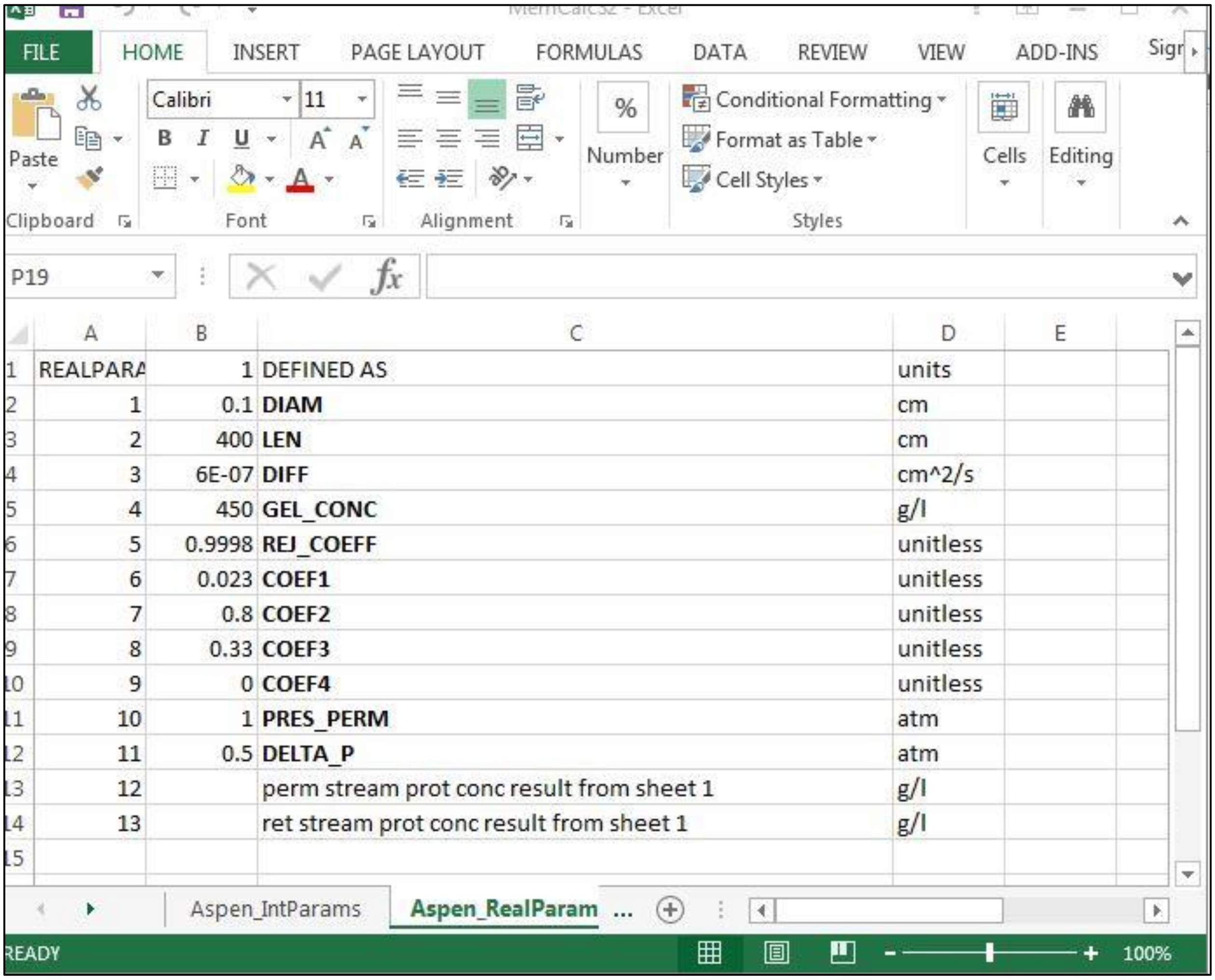
APPENDICES



	A	B	C	D	E
1	REALPARA	1	DEFINED AS	units	
2	1	0.1	DIAM	cm	
3	2	400	LEN	cm	
4	3	6E-07	DIFF	cm^2/s	
5	4	450	GEL_CONC	g/l	
6	5	0.9998	REJ_COEFF	unitless	
7	6	0.023	COEF1	unitless	
8	7	0.8	COEF2	unitless	
9	8	0.33	COEF3	unitless	
10	9	0	COEF4	unitless	
11	10	1	PRES_PERM	atm	
12	11	0.5	DELTA_P	atm	
13	12		perm stream prot conc result from sheet 1	g/l	
14	13		ret stream prot conc result from sheet 1	g/l	
15					

A-1: Excel data for modelling the membrane unit in Aspen Plus

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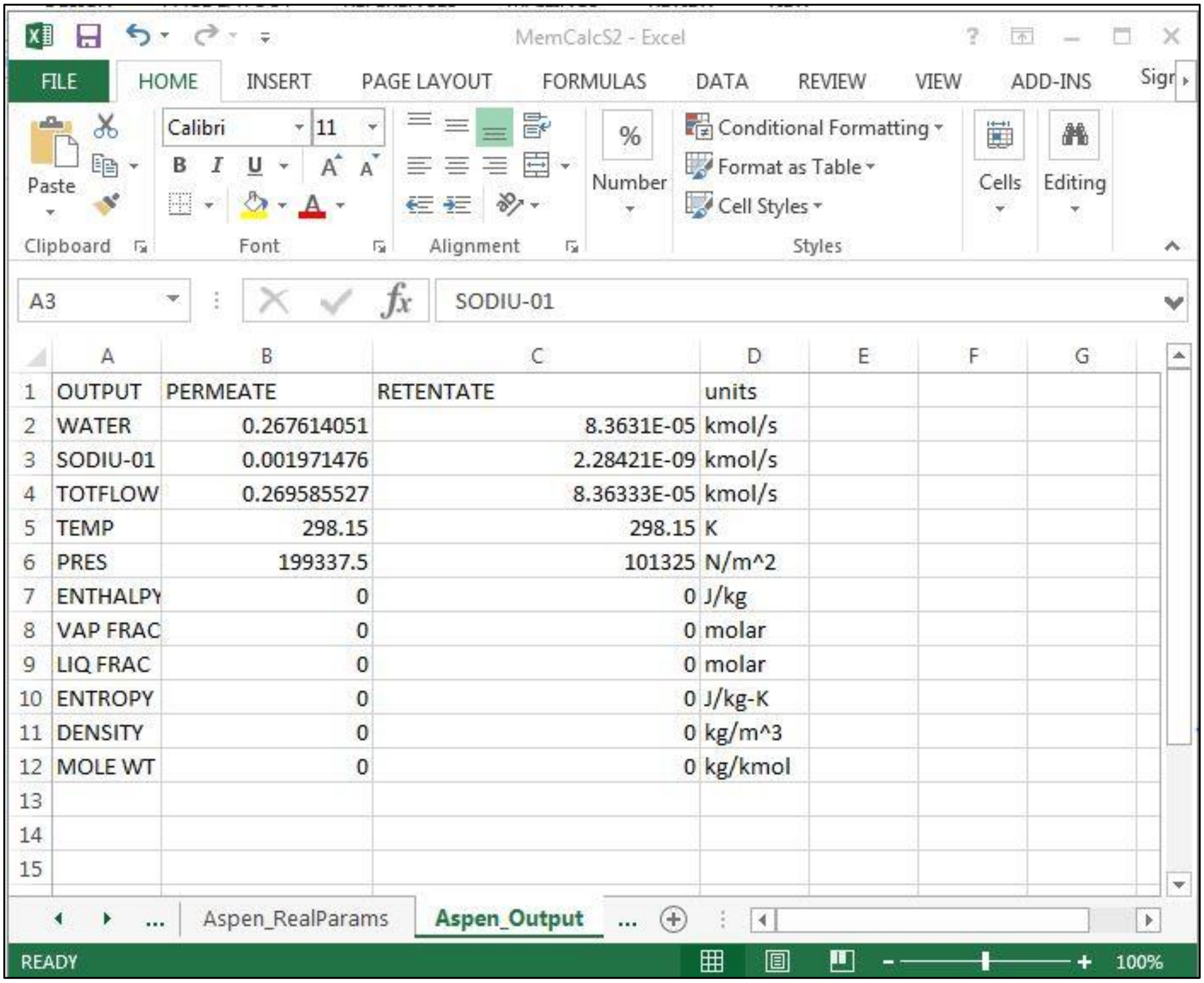
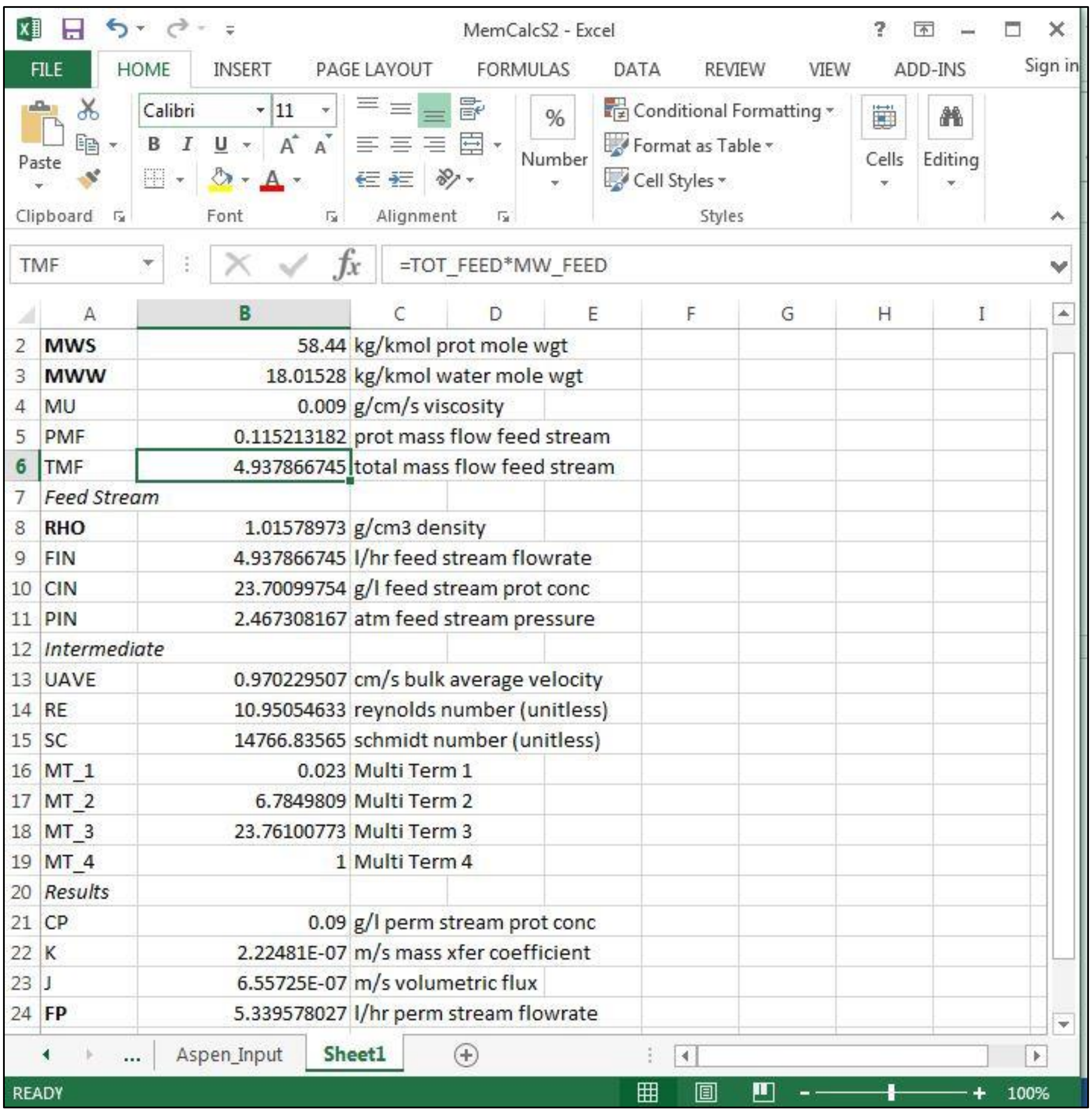


	A	B	C	D
1	OUTPUT	PERMEATE	RETENTATE	units
2	WATER	0.267614051	8.3631E-05	kmol/s
3	SODIU-01	0.001971476	2.28421E-09	kmol/s
4	TOTFLOW	0.269585527	8.36333E-05	kmol/s
5	TEMP	298.15	298.15	K
6	PRES	199337.5	101325	N/m^2
7	ENTHALPY	0	0	J/kg
8	VAP FRAC	0	0	molar
9	LIQ FRAC	0	0	molar
10	ENTROPY	0	0	J/kg-K
11	DENSITY	0	0	kg/m^3
12	MOLE WT	0	0	kg/kmol

A-2: Excel data for modelling the membrane unit in Aspen Plus

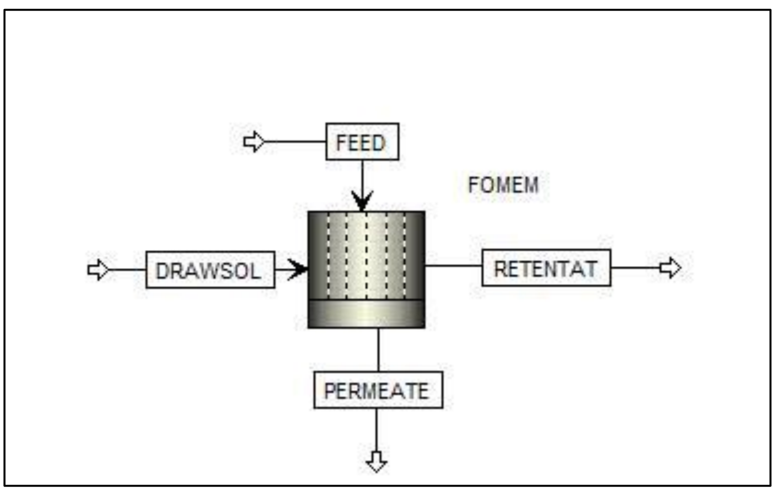


MemCalcS2 - Excel

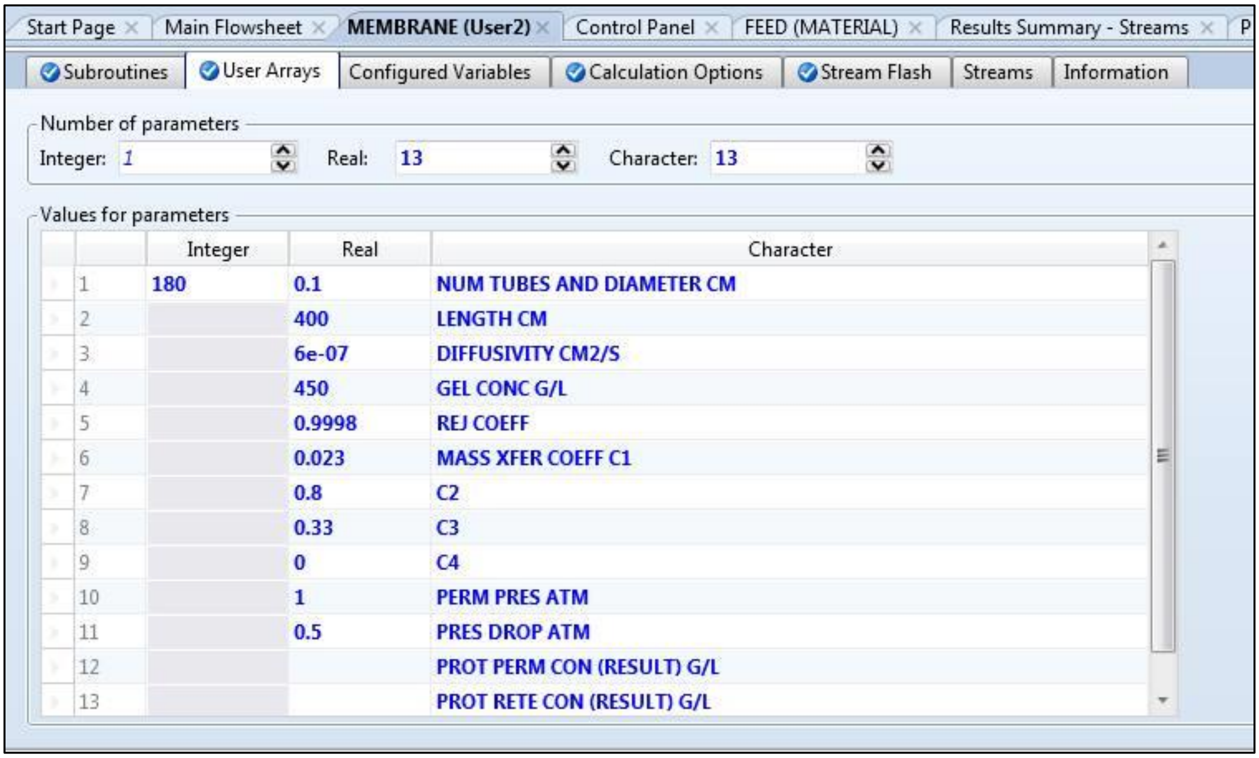
TMF =TOT_FEED*MW_FEED

A	B	C
MWS	58.44	kg/kmol prot mole wgt
MWW	18.01528	kg/kmol water mole wgt
MU	0.009	g/cm/s viscosity
PMF	0.115213182	prot mass flow feed stream
TMF	4.937866745	total mass flow feed stream
Feed Stream		
RHO	1.01578973	g/cm3 density
FIN	4.937866745	l/hr feed stream flowrate
CIN	23.70099754	g/l feed stream prot conc
PIN	2.467308167	atm feed stream pressure
Intermediate		
UAVE	0.970229507	cm/s bulk average velocity
RE	10.95054633	reynolds number (unitless)
SC	14766.83565	schmidt number (unitless)
MT_1	0.023	Multi Term 1
MT_2	6.7849809	Multi Term 2
MT_3	23.76100773	Multi Term 3
MT_4	1	Multi Term 4
Results		
CP	0.09	g/l perm stream prot conc
K	2.22481E-07	m/s mass xfer coefficient
J	6.55725E-07	m/s volumetric flux
FP	5.339578027	l/hr perm stream flowrate

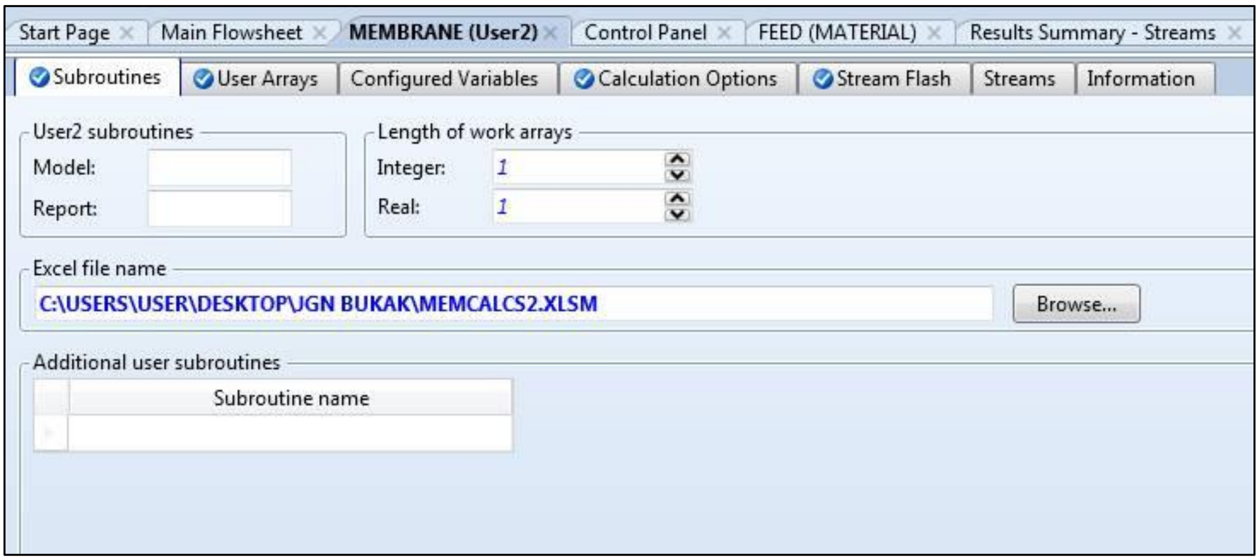
A-3: Excel data for modelling the membrane unit in Aspen Plus



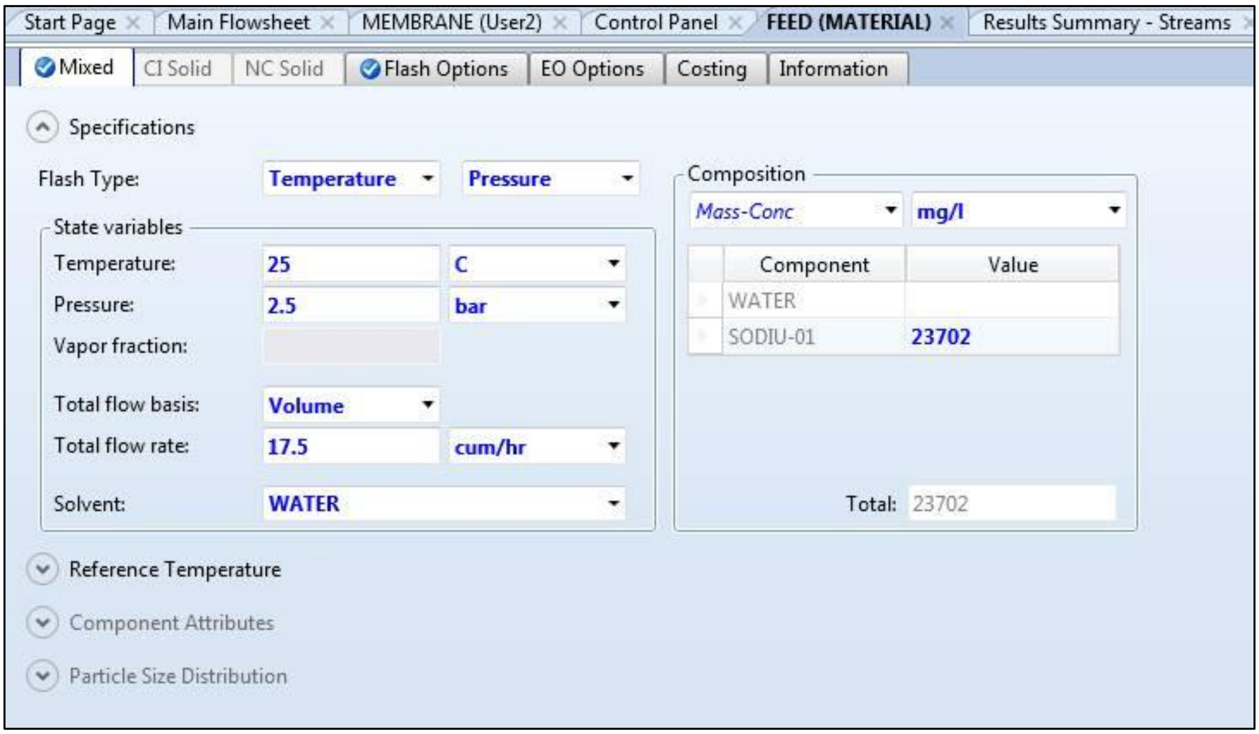
A-4: Flowsheet of forward osmosis membrane in Aspen Plus



A-5: User arrays data for modelling the membrane unit in Aspen Plus



A-6: Subroutines for modelling the membrane unit in Aspen Plus link with Excel file



A-7: Feed and condition data for modelling the membrane unit in Aspen Plus