



UNIVERSITI PUTRA MALAYSIA

***CONCENTRATION OF PASSION FRUIT JUICE THROUGH FORWARD
OSMOSIS SYSTEM***

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ABSTRACT

Forward osmosis is the process of spontaneous water diffusion across a semi-permeable forward osmosis membrane based on the difference in solute concentrations on either side of the semi-permeable membrane. This study focus on developing forward osmosis as alternative to concentrate passion fruit juice and to minimal the losses of nutritional properties. This study will be studying the effectiveness of increasing concentration of passion fruit juices by alternating the concentrations of the DS and flow rate of fruit juices and DS through the membrane. From the result, it can be concluded that, as the flow rate of solutions and concentration of DS increased, the transmembrane flux and concentration of feed juice increased as well. From this study, the highest increment of passion fruit juice concentration was $10.7 \pm 0.14\%$ Brix at 6M DS concentration and flow rate of 2.4 L/min. Nutritional content were retained well by forward osmosis process compared to commercial fruit juices. Moreover, fouling of forward osmosis will also be studied using scanning electron microscope (SEM), it was concluded that as the concentration and flow rate increased, there will be more particulates accumulate on the surface of membrane and fouling will be more significant. In conclusion, forward osmosis can be an alternative measure to concentrate fruit juices with minimal impact to environment compared to other methods.

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LIST OF ABBREVIATIONS

DS – Draw Solution

FO – Forward Osmosis

ICP - Internal concentration polarization

NaCl – Sodium Chloride

SEM – Scanning Electron Microscope



Chapter 1 INTRODUCTION

According to The 2010 Dietary Guidelines for Americans, it is recommended that in a 2000 kcal diet per day, one should have 9 servings of fruits and vegetables per day, 4 servings of fruits and 5 servings of vegetables. (Liu, 2013) However, many people could not take sufficient of servings of fruits and vegetables in their daily life. Hence, consuming fruits and vegetables is promoted as food and nutrition policy. (Rekhy,et al., 2014) Hence, there are different forms of consumption of fruits and vegetables such as blends, smoothies, juices, fermented and fortified juices available in market for consumption.

Fruit juices is a type of liquid foods and they are important sources of vitamins, phenolic compounds, anthocyanins and carotenoids. The intake of fruit juices has been proven to decrease the health issues of oxidative stress such as inflammation, cardiovascular diseases, cancer, and aging-related disorders. (Escudero-López,et al., 2016) Juices extracted or pressed from fruits or vegetables are highly nutritious, as they contain vitamins, minerals, and other beneficial constituents. However, the shelf life of fresh fruit juices is short, which they can only last between 24 hours and 2-3 days. (Mia Y, 2019)

For the production flow of fruit juices, it mainly divided into crushing of fruit, filtration of fruit juices, evaporation of fruit juices and lastly pasteurisation of fruit juices. Evaporation is a unit operation which convert liquid into vapour and leaving behind a concentrated solution or a higher boiling point liquid. The concentration of fruit juices requires the part-removal of water without changes in the composition of solids, leaving all the original solid components, such as fruit sugars, minerals, and vitamins, to the more concentrated solution. Concentration of fruit juices, a major unit operation in the fruit-processing industry, is of critical importance as it determines the quality of the final product such as flavour, colour, aroma, appearance and mouth feel. (Fazaeli, et al., 2011)

Hence, the dewatering of juice products is necessary to ensure their stability and reduce their preservation and transportation costs. (Kim,et al., 2019)

Dewatering or concentrating the juice is commonly conducted through evaporation (thermal process.). High amount of water will be removed and normally the target Brix value of juice concentrates are above 50 Brix value. However, thermal treatments may induce several chemical and physical changes that impair the organoleptic properties and may reduce the content or bioavailability of some nutrients; in most cases, these effects are strongly dependent on the food matrix. Moreover, the efficacy of treatments can also be affected by the complexity of the product and microorganisms. (Petruzzi, et al., 2017) The thermal processing concentration process might lead to loss of fresh juice flavour and colour as well as the development of a cooked taste. Besides, thermal treatment requires heat energy and might cause impact to environment.

The complexity of fruit derivatives implies a wide range of nonenzymatic browning reactions caused by thermal treatments. The colour changes in fruit extract can be due not only to the browning reaction, but also to the thermal destruction of pigments present in the extracts. Heating of juice containing anthocyanins causes the discoloration of deep red colour, and further heat treatment will cause a brown colour. There were some reports of the effects of sugar and its degradation products, including the acceleration of anthocyanins breakdown and enhancement of non-enzymatic browning reactions during thermal concentration. (Cemeroglu,et al., 1994)

After dewatering of fruit juices, the dewatered fruit juice will go through pasteurisation to kill the microorganisms. For thermal processing technologies of fruit juices, pasteurisation is usually used as generally this method is cost-effective as it can ensure microbial safety and enzyme deactivation in fruit juices. Thermal processes to lengthen shelf life of fruit juice can be classified according to the intensity of heat treatment. (Miller,et al., 2012). The thermal processes can be categorised into ultrahigh temperature (UHT), HTLT (high temperature long time), HTST (high temperature short time), MTLT (mild temperature long time), MTST (mild temperature short time).

Recently there are consumers that demand for a technology able to retain freshness and also ensure food safety, hence the interest had been switched to

nonthermal processing methods, to replace evaporation process to concentrate fruit juices. (Santhirasegaram,et al., 2016)

In recent years, membrane processing such as microfiltration, ultrafiltration, nanofiltration, reverse osmosis and forward osmosis has been found to be the most promising alternative for clarification and concentration of fruit juices. Membrane technology is a good alternative way compared to traditional juice clarification and concentration processes as they require less manpower, reduce operating cost and low temperature. Membrane processing is a low temperature process in which the organoleptic quality of the juice is almost retained. The advantages of these membrane processes over traditional methods are lower thermal damage to product, increase in aroma retention, less energy consumption, and lower equipment costs. Membrane concentration of fruit juice not only provides microbiological stability but also permits economy in packaging and distribution of the finished product due to a reduction in bulk by weight and volume. (Bhattacharjee,et al., 2017)

However, there are disadvantages for using membrane processing technologies, which is membrane fouling. Membrane fouling will cause a decline in flux with the time of operation, blocking the membrane pores and hence reduce the membrane permeability. The degree of membrane fouling determines the frequency of cleaning, the lifetime of the membrane, the membrane area needed and consequently costs, design and operation of membrane plants. (Bhattacharjee,et al., 2017)

Forward osmosis is a process of spontaneous water diffusion across a semi-permeable forward osmosis membrane based on the difference in solute concentrations on either side of the semi-permeable membrane. For the working principle of forward osmosis, the diffusion of water can be explained by the second law of thermodynamics. Besides, from an entropy point of view, maximum disorder in a system consisting of two aqueous solutions with different solute concentrations separated by a semi-permeable membrane, this process is achieved when enough water has diffused from the low concentration side to the high concentration side to eliminate the difference in solute concentration. (Guide to forward osmosis membranes, 2019)

Forward osmosis is a technology utilising a membrane to treat two liquid streams. The liquid on one side of the membrane feed solution (FS), where it has lower osmotic pressure. While on the other side of the membrane is the draw solution (DS) that has a higher osmotic pressure. During forward osmosis, a semi-permeable membrane is used to separate between FS and DS. Due to the difference in osmotic pressure, water passes through the membrane from the FS to the DS side, hence this will increase concentration of the feed solution and dilute the DS. Usually, during forward osmosis, no physical pressure is needed. Therefore, the only energy demand results from the pumping of FS and DS through the flow channels. (Haupt & Lerch, 2018) Forward osmosis is a membrane process, which is capable of concentrating liquid foods without product deterioration. (Sant'Anna, et al., 2012)

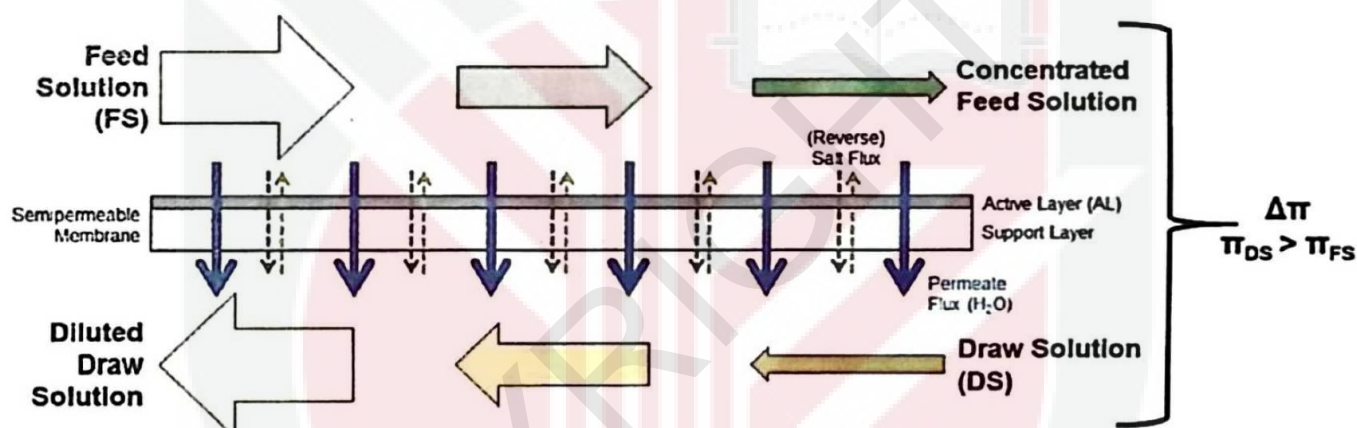


Figure 1: Schematic illustration of the forward osmosis process with membrane active layer facing towards the feed solution (Haupt & Lerch, 2018)

The advantages of forward osmosis include low energy consumption, simultaneous treatment of two streams in one treatment step, easy removability of fouling layers due to absence of compression, and also treatment of liquids that are not suitable for other membrane processes.

For the membrane used in forward osmosis, mostly the membranes used are asymmetric porous membranes. In asymmetric porous membranes, the structure and transport properties change across the membrane thickness. An asymmetric membrane normally consists of a dense layer of 0.1–1 μm thick and supported by a highly porous, 100–200 μm thick support layer.

The dense layer provides most of the selectivity for the membrane. The separation properties are determined by the chemical structure, the size of the pores (0.4–1 nm) and the thickness of the skin layer. It is believed that the porous substrate provides mechanical support for the thin and fragile selective layer and has little effect on the separation performance of the membrane. However, recently the effects of the chemical properties of the support layer, for example hydrophilicity or hydrophobicity, and pore structure, for instance pore size and porosity, on composite membrane transport have been re-evaluated.

Asymmetric cellulose acetate and cellulose triacetate (CTA) membranes were widely used by researchers in forward osmosis applications. The advantages include providing the support and active rejection layer are formed in the same process – phase inversion of a precursor dope solution followed by hot water annealing. In addition, cellulosic membranes are quite hydrophilic, giving a good water flux performance and low propensity to fouling, good mechanical strength, and membrane components are readily available commodities.

On the negative side, cellulosic membranes must be kept within a narrow operational window (pH 4-6 and temperature below 30°C) in order to maintain operational integrity. This excludes cellulosic membranes from being used for treatment of harsh industrial waste waters.

The general equation describing water transport in the FO process is:

$$J_w = A(\pi_{\text{Draw solution}} - \pi_{\text{Feed}} - \Delta P)$$

where J_w is the water flux, A is the water permeability constant of the membrane, $\pi_{\text{DrawSolution}}$ is the osmotic pressure of the draw solution, π_{feed} is the osmotic pressure of the feed solution and ΔP is the difference pressure between the two solutions (which is close to zero, but not negligible, in FO processes,). This equation assumes that the solutes from the osmotic agent solution are totally impermeable to the membrane, and it does not consider the concentration polarization phenomenon. These are typical assumptions for osmotic concentration. (Sant'Anna, et al., 2012)

To evaluate the operation performance of forward osmosis, there are many parameters shall be considered. The main parameters were type and concentration of draw solution, draw solution regeneration technology, high permeate flux combined with low concentration polarization, membrane performance and fouling during long-term operation, membrane cleaning strategies, reverse salt flux and substance diffusion through the membrane.

In conclusion, forward osmosis is a promising solution for the energy-efficient water usage in manufacturing industries. For now, there were researches conducted on forward osmosis application in food and beverage industry, chemical industry, pharmaceutical industry, coal processing, micro algae cultivation, textile industry, pulp and paper industry, electronic industry, and car manufacturing. Besides, there were also papers published regarding application of forward osmosis in heavy metal elimination and cooling water treatment and also wastewater treatment. (Haupt & Lerch, 2018) For environmental impact, forward osmosis also cause less negative impact to the environment and is a safe process.

1.1 Problem Statement

Food processing is one of the major means to produce safe foods for consumer's use. Most of the food products in stores are produced in either one or more than one type of food processing technologies. The retention of nutrient components of fruit juices during processing is an important criterion to produce better quality fruit products. Stability of nutrient components during processing vary from product to product and processing methods. (Yetenayet & Hosahalli, 2015)

For the production flow of fruit juices, it mainly divided into crushing of fruit, filtration of fruit juices, evaporation of fruit juices and lastly pasteurisation of fruit juices. Evaporation is a unit operation which convert liquid into vapour and leaving behind a concentrated solution or a higher boiling point liquid. The concentration of fruit juices requires the part-removal of water without changes in the composition of solids, leaving all the original solid components, such as fruit sugars, minerals, and vitamins, to the more concentrated solution. Concentration of fruit juices, a major unit operation in the fruit-processing industry, is of critical importance as it determines the quality of the final product such as flavour, colour, aroma, appearance and mouth feel. (Fazaeli, et al., 2011) However, during evaporation of fruit juices to concentrate it, the losses of nutrients will occur. During evaporation, foods are susceptible to thermal damage, depending on the time-temperature profile of the process. The examples of thermal damage during evaporation are non-enzymatic (Maillard) browning, induction of 'cooked taste' in fruit juices, loss of carotenoid pigments, for instance the loss of lycopene in tomato juice, and protein denaturation. (Berk, 2018)

The alternative of processing of concentrating fruit juices includes membrane processing. So, forward osmosis is a good alternative to replace evaporation step of fruit juices. The advantages of forward osmosis include low energy consumption, simultaneous treatment of two streams in on treatment step, easy removability of fouling layers due to absence of compression, and also treatment of liquids that are not suitable for other membrane processes. Most

importantly, as forward osmosis does not involve high temperature, hence the thermal destruction towards fruit juices is minimal.

Hence in this study, there are few parameters to be tested during forward osmosis experiments, such as the type of osmotic agent solution (sucrose and sodium chloride solution), flow rate of fruit juice through membrane, affecting the flux during forward osmosis.



1.2 Objective

The objectives of this study are to:

1. To develop forward osmosis system for concentrating passion fruit juice.
2. To evaluate the performance of forward osmosis to concentrate passion fruit juice due to different concentration of draw solution
3. To evaluate the performance of forward osmosis to concentrate passion fruit juice due to different flow rate of both solution.
4. To analyse the nutritional contents of passion fruit juice that undergo forward osmosis process.

1.3 Scope of Study

This study focus on developing forward osmosis as alternative to concentrate passion fruit juice and to minimal the losses of nutritional properties. This study will be studying the effectiveness of increasing concentration of passion fruit juices by alternating the parameters of the osmotic agent solution and flow rate of fruit juices through the membrane. Besides, the nutritional content will also be evaluated by comparing among the fresh juices, forward osmosis concentrated juices, and commercial fruit juices. Moreover, fouling of forward osmosis will also be studied.

Chapter 2 LITERATURE REVIEW

2.1 Passion Fruit Juice

Passion fruit (*Passiflora edulis* Sim.) is a perennial vine of the Passifloraceae family. In the Passifloraceae family, there are 18 genera, and one is *Passiflora* genus that consist of 530 species that 50–60 are edible. The highest genetic diversity in Passifloraceae species is found in Colombia with 167, followed by Brazil (127 species) and Ecuador (90 species). (Schotsmans et al., 2011)

Purple passion fruit is mainly cultivated in Africa and Australasia, while the yellow passion fruit in South America. Usually the shapes are round or ovoid weighing 35g (purple) to 80g (yellow) averagely, showing a smooth surface with the color range from dark-purple with faint, fine white specks, to light-yellow or pumpkin color. Inside the fruit, there are numerous (up to 250) small, hard, edible, black (purple fruit) or dark brown (yellow fruit) seeds are embedded in double-walled, membranous sacs filled with yellow-orange, pulpy juice in a cavity. The pulp has an intense fragrance with an appealing, musky, guava-like, sub-acid to acid flavor. (Morton, 2013)

To consume fresh passion fruit, it is cut into half and take out the pulp. The pulp is used widely such as fruit salads, desserts, ice cream, and yoghurt or as a topping. After removal of seeds and homogenization, it can also be used to make jam and sauces. Besides, the pure juice can be used for preparation of cocktails or applied in processing industry to make juice blends. Cooking the juice with sugar makes thick passion fruit-flavored syrup.

2.2 Composition of Passion Fruit Juice

Passion fruit contains many types of nutrients, minerals and vitamins, Figure 2 showed the composition of different species of passion fruit and passion fruit juice.

Table 1
Nutritional characterization (mean values) of *Passiflora* spp. pulps (g/100 g of edible part), yellow passion fruit juice (g/100 g) and correspondent co-products, as reported by some authors in the past decade.

Proximate	Pulp					Juice		Co-products			
	<i>P. edulis</i> Sims	<i>P. edulis</i> f. <i>flavicarpa</i> Deg	<i>P. alata</i> Curtis	<i>P. ligularis</i> Juss	<i>P. mollelimina</i> L.H. Bailey	<i>P. edulis</i> f. <i>flavicarpa</i> Deg		Fresh peel (g/100 g)	Peel flour (g/100 g)	Fiber concentrate (g/100 g dry matter)	Seeds (g/100 g)
Moisture (g)	72.93	85.62	84.12	76.3	92.6	84.21		87.64	7.42	9.3	10.8
Energy (kcal)	97	51	58.51	94	25	60		29.91	122.95	58.0	398.04
Protein (g)	2.20	0.39	1.35	2.4	0.5	0.67		0.67	8.87	6.2	10.8
Fat (g)	0.70	0.05	0.10	2.8	0.1	0.18		0.01	3.39	0.8	23.4
Carbohydrates (g)	23.38	13.60	13.05	17.3	6.2	14.45		6.78	14.24	6.5	36.06
Total dietary fiber (g)	10.4	0.2	0.70	4.2	0.6	0.2		4.33	60.08	81.5	17.48
Insoluble dietary fiber (g)	—	—	—	—	—	—		—	39.96	46.0	—
Soluble dietary fiber (g)	—	—	—	—	—	—		—	20.13	35.5	—
Ash (g)	0.80	0.34	0.68	1.2	0.6	0.49		0.57	6.00	5.0	1.46
Minerals											
Calcium (mg)	12	4	4.76	10.0	8.0	4		44.51	—	—	0.54
Iron (mg)	1.60	0.24	1.06	0.9	0.4	0.36		0.89	—	—	0.2
Magnesium (mg)	29	17	19.82	—	—	17		27.82	—	—	1.54
Phosphorus (mg)	38	13	34.95	64.0	18	25		—	—	—	1.25
Potassium (mg)	348	278	375.42	—	—	278		178.40	—	—	0.85
Sodium (mg)	28	6	—	—	—	6		43.77	—	—	2.98
Zinc (mg)	0.10	0.05	—	—	—	0.06		0.32	—	—	0.055
Copper (mg)	0.086	0.053	—	—	—	0.06		0.04	—	—	0.013
Vitamins											
Ascorbic acid (mg)	30	29.8	24.66	20.0	52	18.2		—	—	—	—
Riboflavin (mg)	0.130	0.131	—	0.11	0.04	0.101		—	—	—	—
Niacin (mg)	1.5	2.46	—	1.6	1.5	2.24		—	—	—	—
Folate (µg)	14	7	—	—	—	8		—	—	—	—
Choline (µg)	76	4	—	—	—	4		—	—	—	—
Vitamin A (µg)	64	36	—	5	20	47		—	—	—	—
β-carotene (µg)	743	419	570	—	—	525		—	—	—	—
	(Rodríguez-Amaya, 2012)	(Rodríguez-Amaya, 2012)	(de Souza, Pereira, Queiroz, Borges, & Carneiro, 2012)	(Duarte & Paull, 2015)	(Duarte & Paull, 2015)	(Rodríguez-Amaya, 2012)	(Zeraik et al., 2010)	(Lima et al., 2016)	(Martínez et al., 2012)	(Liu et al., 2008)	

Figure 2 Composition of Passion Fruit (Corrêa, et al., 2016)

2.3 Forward Osmosis

Forward osmosis (FO), is also known as direct osmosis, is a promising membrane technology. FO as a concept for concentrating foods dates back to the 1960s, and its only driven force is a difference in osmotic pressure. The water transfer occurs from the feed side (low concentration) to the draw solution side (high concentration) across a semi-permeable membrane till the osmotic pressure difference between both sides is close to zero. (Rastogi, 2014)

2.3.1 Principles of Forward Osmosis

Forward osmosis is a technology that uses a membrane to treat two liquid streams. The liquid on one side of the membrane feed solution (FS), where it has lower osmotic pressure. While on the other side of the membrane is the draw solution (DS) that has a higher osmotic pressure. During forward osmosis, a semi-

permeable membrane is used to separate between FS and DS. Due to the difference in osmotic pressure, water passes through the membrane from the FS to the DS side, hence this will increase concentration of the feed solution and dilute the DS. Usually, during forward osmosis, no physical pressure is needed. Therefore, the only energy demand results from the pumping of FS and DS through the flow channels. (Haupt & Lerch, 2018) Forward osmosis is a membrane process, which is capable of concentrating liquid foods without product deterioration. (Sant'Anna, et al., 2012)

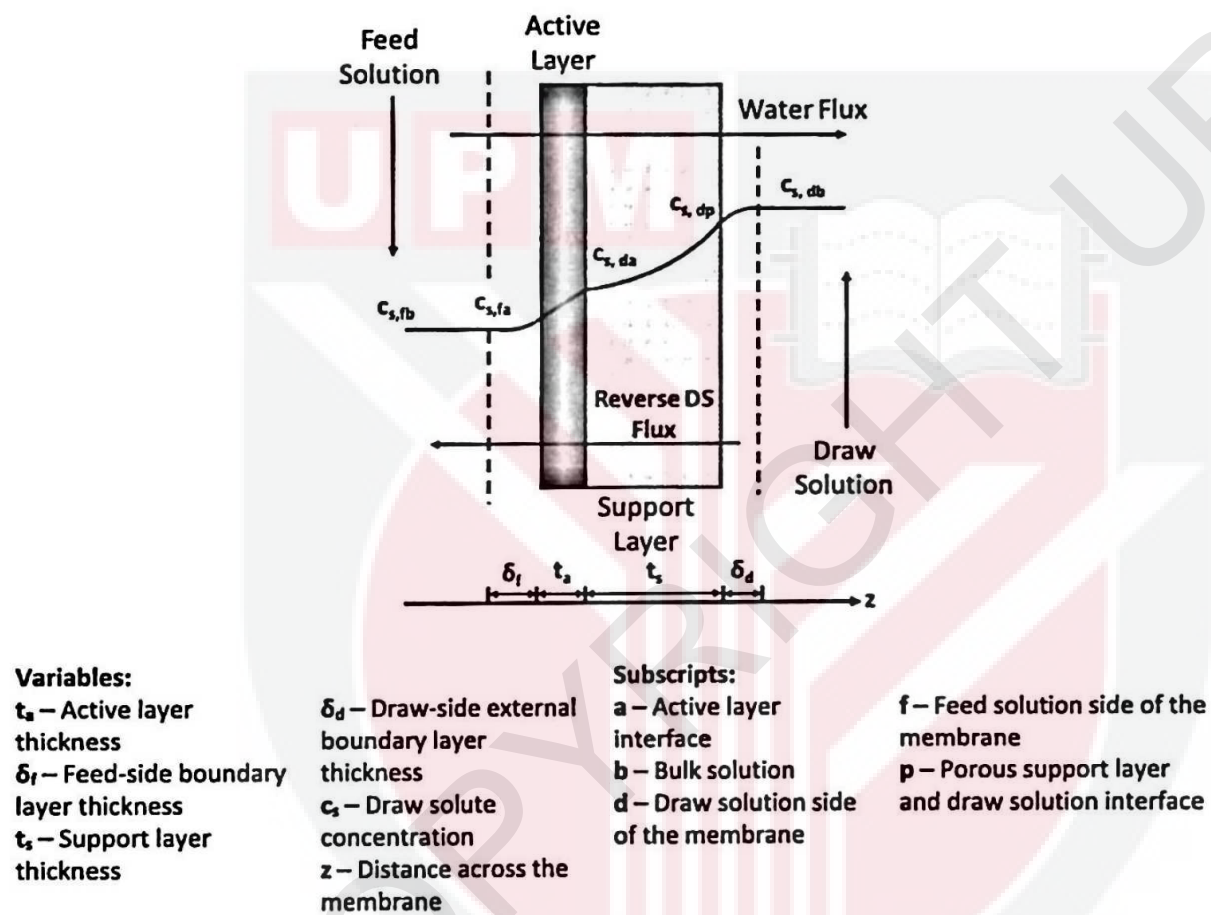


Figure 3 Steady state concentration profile across an asymmetric forward osmosis membrane (Martin, et al., 2020)

2.3.2 Draw Solution

Draw solution is important during forward osmosis process. During forward osmosis process, water will flow from feed solution with low osmotic pressure to draw solution with high osmotic pressure. From the beginning of the experiment, the concentrated draw solution is the driving force of the experiment. (Tzahi Y, et al., 2006)

Different types of draw solutions used by previous researches are shown in Table 2 in next section. Table 1 shows the viscosity of sodium chloride solution at temperature of 35°C according to the reference.

Table 1 Viscosity of Different Sodium Chloride Concentration (Ozbek, 1977)

Concentration of sodium chloride solution (M)	Viscosity (cp)
1.0	0.7856
1.5	0.8237
2.0	0.8683
2.5	0.9187
3.0	0.9741

2.4 Research on Forward Osmosis Technology

In year 1970s, the first research on forward osmosis technology was done. In this research, two lab-scale plants with 13 and 58cm² of membrane surface area was used, where the feed solutions are deionized water, copper solution, chromium solution, and wastewater from a fish and shell fish processing plant. For the type of membrane used, 10 commercial reverse osmosis membranes and one self-manufactured cellulose triacetate membrane were tested. However, this research was stopped due to there are no suitable forward osmosis membranes were available. (Haupt et al., 2018)

2.4.1 Effectiveness of Concentration of Fruit Juices using Forward Osmosis

Fruit and vegetable juices are often concentrated to reduce its volume and safe transportation and storage costs. Moreover, natural colorants are obtained from fruit juices by concentration. This concentration is conventionally done by pressure-driven membrane filtration processes like reverse osmosis or thermally driven evaporation. (Rastogi, 2014)

In a study done by Beaudry et al. (1990), forward osmosis process had successfully concentrated orange juice up to 42 °Brix using a 72 °Brix sugar syrup as the draw solution, and they achieved an average water flux of 1.3 kg m⁻² h⁻¹ at a process temperature of 30 °C. Authors refrigerated the feed stream in each concentration stage, which resulted in a high retention of the flavor and color of the juice concentrate. The low temperature and pressure applied in the system were critical to the maintenance of sensorial characteristics of the beverage.

Sensorial and centesimal analysis of raspberry juice concentrated by FO and by vacuum evaporation were conducted. The direct osmotic concentration from 10 to 45 °Brix was performed with 69 °Brix corn syrup as the osmotic agent at 25 °C. The treatment by both processes resulted in small anthocyanin losses, low polymerized pigment enhance and no flavor difference, which showed that both juices were of good quality and were comparable to commercial samples.

(Wrolstad, et al., 1993) The FO-concentrate juice exhibited a strong raspberry aroma and flavor, compared well to some commercial samples.

In a research done by Dova et al. (2007) treated sucrose/glucose solution by FO in a flat sheet module with an aromatic polyamide RO membrane at room temperature and obtained an average water flux of $4.5 \text{ kg m}^{-2} \text{ h}^{-1}$ using the same osmotic solution. Using a modified FO module at ambient temperature and low pressure ($\sim 4 \text{ bar}$), with NaCl as the osmotic medium (4 mol L^{-1}), fresh tomato juice was concentrated from 5.5 °Brix to 16 °Brix with an osmotic flux of $3.26 \text{ kg m}^{-2} \text{ h}^{-1}$ (Petrotos, et al., 2010). The authors also verified that the red color of the tomato paste was much more intense in the concentrate produced by FO than by vacuum evaporation and that the processed product by FO was microbiologically stable.

The processing of pineapple juice was also evaluated by Babu et al.(2006). Using a specific membrane for FO, the authors achieved $1.59 \text{ kg m}^{-2} \text{ h}^{-1}$ of water flux and a TSS concentration increase from 12 to 60 °Brix at 25 °C with a 4 mol L^{-1} NaCl solution as the osmotic agent. Because there is a diffusion of salt solutes from the draw solution to the feed, it is of public concern to minimize the salt content in the juice. Therefore, the authors also evaluated the combination of NaCl and sucrose as the osmotic agent. Among others, the combination of 2.75 mol L^{-1} of NaCl and 0.9 mol L^{-1} of sucrose yielded an average water flux of $1.15 \text{ kg m}^{-2} \text{ h}^{-1}$, with low rate of NaCl transport to the pineapple juice. This sample exhibited less saltiness, more sweetness and better overall acceptability in the sensorial evaluation compared to sucrose–salt combinations as the osmotic agent, and it exhibited a high score on the acceptability analysis of the juice. The use of mixed osmotic agent (sucrose 40% (w/w) and sodium chloride 12% (w/w) gave better result, which were higher flux with 0.58% of salt migration, which was low. The authors also showed that the reconstituted juice characteristics were similar to those of the fresh juice, for instance, the pH of fresh juice was 3.62 while the pH of reconstituted juice was 3.70, and the content of ascorbic acid in fresh juice was 12.5 mg/100ml, while the content of ascorbic acid in reconstituted juice was 12.1 mg/100ml.

Similar results were reported by Nayak et al. (2010) when they reconstituted kokum extract, which supports FO as a potential alternative to conventional industrial treatments for concentrating food beverages. The authors concentrated anthocyanin extract from kokum by FO with 6 mol L⁻¹ NaCl as the osmotic solution at 30 °C and obtained an average water flux of 15 kg m⁻² h⁻¹. The TSS content increased 25-fold, from 2 to 52 °Brix. The authors showed that the extract treated by FO exhibited better nutritional and sensorial properties, less non-enzymatic browning and a higher retention of hydroxycitric acid and anthocyanins compared to that concentrated by a thermal treatment. In another study done by Nayak et al. (2011), the authors concentrated beetroot, pineapple and grape juice using the same osmotic agent at 25 °C, and obtained average water fluxes of 7.5, 6.5 and 4 kg m⁻² h⁻¹, respectively. The betalain and TSS concentrations in beetroot juice were found to increase from 51 to 3000 mg L⁻¹ and TSS from 2.3 to 52 °Brix, respectively. For the grape juice, anthocyanins and TSS were concentrated from 105 to 715 mg L⁻¹ and from 4.4 to 54 °Brix, while pineapple has increased from 2.3 to 52 °Brix, respectively.

A study was done by Kim et al. (2019), dewatering and concentration of grapefruit juice was done to improve the membrane performance, fouling control and also product quality. In this work, grapefruit juice was dewatered using a commercial thin-film composite FO membrane that exhibited stable performance. This study also investigated the challenges of forward osmosis as a dewatering process and their possible improvements to achieve practical dewatering of grapefruit juice. In this study, it is shown that the juice dewatering performance increased with the increase of concentration of osmotic agent which is sodium chloride solution up to 3M. However, when the concentration of sodium chloride increased to 4M and 6M, the dewatering rates decreased significantly. The satisfactory performance of the tested membrane suggested that to improve the efficiency of forward osmosis to concentrate fruit juices, processing time could be shortened using high performance membranes. However, processing time is not solely determined only by the membrane performance, but also other factors such as viscosity of concentrated juice and also membrane fouling caused by impurities.

Moreover, the fouling behavior during forward osmosis was also studied. It was found that fouling happens during forward osmosis was mainly because instant accumulation of pulp on the membrane active layer surface. It is difficult to detach the fruit pulp from the membrane. The research was done by Kim et al. (2019) using non-filtered and 1 μ m-filtered grapefruit juice, from the result shown the fouling layer that severely blocks the osmotic membrane during the forward osmosis process and the layer comprises of large-sized suspended constituents. Hence, the suspended constituents larger than 0.45 μ m shall be separated from the bulk feed solution to avoid membrane fouling.

Table 2 Summary of Previous Studies on Forward Osmosis

Juice Product	Draw Solution	Type of membrane	Transmembrane Flux (kg m⁻² h⁻¹)	Final Brix of Juice Product	References
Orange	72° Brix Sugar Syrup	-	1.3	42° Brix	(Beaudry, et al., 1990)
Raspberry	69 °Brix Corn Syrup	-	-	45° Brix	(Wrolstad, et al., 1993)
Fresh tomato	Treated sucrose/glucose solution	Aromatic polyamide RO membrane	3.26	16 °Brix	(Petrotos, et al., 2010)
Pineapple	NaCl solution	Direct osmosis membranes	1.59	60 °Brix	(Babu,et al., 2006)

Pineapple	NaCl and sucrose mixture	Direct osmosis membranes	1.15	60 °Brix	(Babu,et al., 2006)
Kokum extract	NaCl solution		15	52 °Brix	(Nayak,et al., 2010)
Beetroot (Beta vulgaris)	NaCl solution	cellulose triacetate	7.5	52 °Brix	(Nayak,et al., 2011)
Pineapple (Ananas comosus)	NaCl solution	cellulose triacetate	6.5	52	(Nayak,et al., 2011)
Grape (Vitis vinifera)	NaCl solution	cellulose triacetate	4	54	(Kim et al., 2019)

2.4.2 Osmotic Pressure of Draw Solution during Forward Osmosis

Osmotic pressure is significantly important in forward osmosis. The net driving force of FO which is defined as osmotic pressure gradient ($\Delta\pi$) between the feed solution and draw solutions. Generally, when the draw solution concentration increased, the water flux will also increase. (Law et al., 2018)

Table 3 Summary of Different Draw Solutions on Forward Osmosis

Draw solution	Molecular weight	Osmotic pressure (kPa)	Concentration (mol/L)	Temperature (°C)	References
NaCl	58.44	4850.4277	1.0	-	(Law et al., 2018)
NaCl	58.44	1823.85	1.0	25	(Hamdan,et al., 2015)
NaCl	58.44	3952.0	1.0	30	(Liu,et al., 2020)
NaCl	58.44	8410.0	2.0	30	(Liu,et al., 2020)
NaCl	58.44	10840.0	3.0	30	(Liu,et al., 2020)
NaCl	58.44	14690.0	4.0	30	(Liu,et al., 2020)
MgCl ₂	95.211	7498.05	1.0	25	(Hamdan,et al., 2015)
Sucrose	342.3	2735.78	1.0	25	(Hamdan,et al., 2015)
Maltose	342.3	2634.45	1.0	25	(Hamdan,et al., 2015)

2.5 Other Application Area by Forward Osmosis Process

Instead of concentrating fruit juices, there are wide application area using forward osmosis which will be described as below.

2.5.1 Treatment of Secondary Effluent from Industrial Wastewater Treatment Plant using Forward Osmosis Technology

Wünsch et al. (2017) investigated the FO treatment of secondary effluent from an industrial wastewater treatment plant. Wastewater originates from chemical industry. In this research study, three different draw solutions were evaluated, which were sodium chloride, magnesium chloride and sodium sulfate solution, at fixed concentration of 1 mol/L. From this study, magnesium chloride solution was the best draw solution because it delivered the highest permeate flux and lowest reverse salt flux.

2.5.2 Increase of Concentration of Milk and Whey using Forward Osmosis

A study was conducted by Chen et al. (2019) regarding a pilot scale study on the concentration of milk and whey by forward osmosis. The concentration of skim milk and whey was investigated at a pilot scale using forward osmosis membranes with an installed membrane area of 24 m². The pilot plant was operated in batch mode using a draw solution (48–57 g/L of NaCl) that mimics the potential brine streams available in a dairy processing plant.

During the study, it was found that solids concentration of 21 wt% for skim milk and 15 wt% for whey achieved through FO. During forward osmosis, uncharged, small organic molecules migrated from the feed to the draw solution. Besides that, study shows that fouling was minimal and readily removed using enzyme cleaning. Furthermore, energy demand of forward osmosis is lower than reverse osmosis. During the process, the draw solution is waste brine, where its concentration will decrease after the process, becoming diluted waste brine.

2.5.3 Dehydration of polyvinyl chloride (PVC) latex using Forward Osmosis Technology

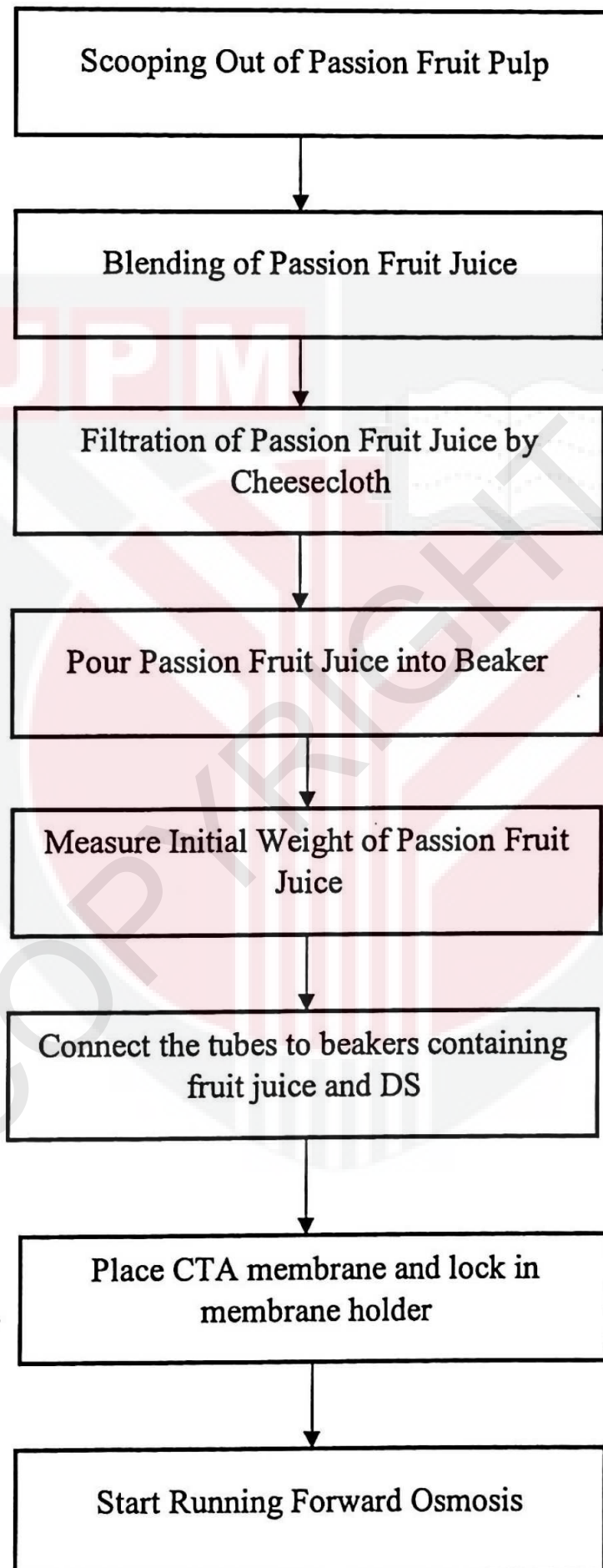
Takahashi et al (2016) had done an interesting research on application of forward osmosis application. However, the feed solution was not circulated through the membrane test cell but was placed in a reservoir above the membrane. Besides, they used synthetic seawater, which is 0.8-1.8M of sodium chloride solution as draw solution. After running the experiment through 24 hours, the PVC latex reached 75wt%, which is desirable result. However, cake layer formation occurred in the end of experiment. So, they propose to have a PVC final concentration of 60-64%.

2.5.4 Application in Pharmaceutical Industry using Forward Osmosis Technology

There are researched on using forward osmosis technology to treat pharmaceutical liquids. Cui, Y (2018) conducted a research that aim to recover the organic solvents and reject the active pharmaceutical ingredients. In this case, the organic solvent was to pass through the membrane instead of water to dilute the draw solution. From this study, it was concluded that the average solvent fluxes were between 0.32 ± 0.07 and 3.82 ± 0.37 L/(m².h).

Chapter 3 METHODOLOGY

3.1 Overall Process Flow Chart



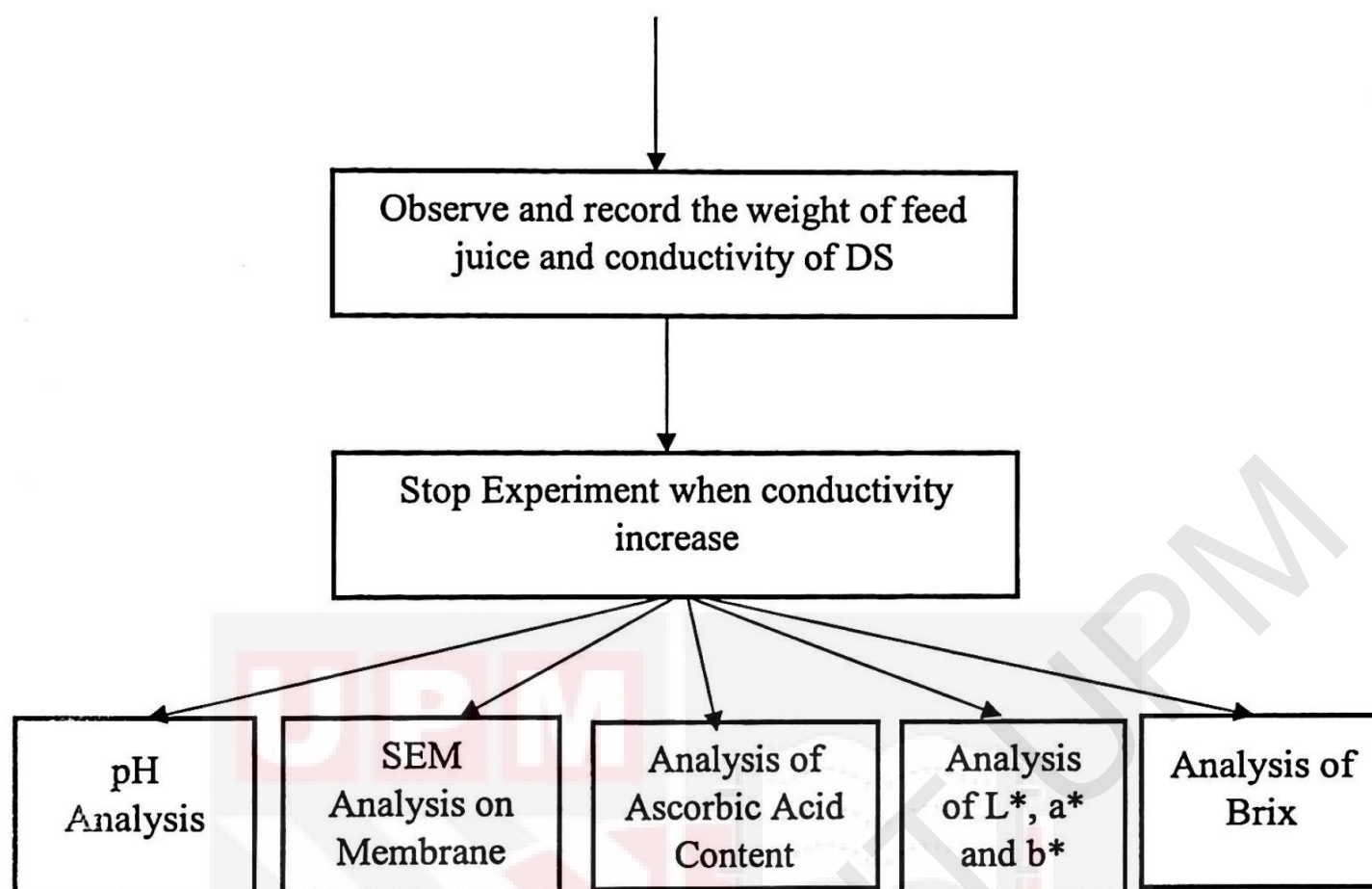


Figure 4 Overall Process Flow Chart

3.2 Materials and Apparatus

1. Peristaltic Pump (BT600-2J, Longer Pump)
2. Cellulose triacetate membrane (CTA membrane) (305 x 305mm, STERLITECH, USA)
3. Refractometer (Atago, Tokyo)
4. Tube (Masterflex)
5. Membrane Holder (SIA 312029)
6. Conductivity Meter (HI8733, Hanna Instrument)
7. Weighing balance (TX3203L, Shimadzu)
8. Viscometer (DV-II +, Brookfield)
9. Burette (SCHOTT DURAN)
10. Pipette (SCHOTT DURAN)
11. Volumetric Flask (NICE)
12. Conical Flask (SCHOTT DURAN, 500ml)
13. Beaker (SCHOTT DURAN, 250ml, 500ml, 1000ml)
14. Measuring Cylinder (SCHOTT DURAN, 500ml)
15. Blender (Panasonic)
16. Cheesecloth
17. Passion fruit pulp (Extra Natural Sdn Bhd, Kepong)
18. Sodium chloride solution (1M, 1.5M, 2.0M, 2.5M, 3.0M)
19. 0.005 mol L⁻¹ iodine solution
20. Starch indicator solution

3.3 Feed and Draw Solutions

3.3.1 Preparation of Draw Solutions

To prepare draw solutions, sodium chloride solution with different concentrations were prepared. Sodium chloride solutions were prepared by dissolving sodium chloride into distilled water according to different proportion to make different concentrations as shown in Table 1.

Table 4 Mass of sodium chloride needed for different concentrations

Concentration of sodium chloride solution (M)	Mass of sodium chloride dissolved in 250ml distilled water (g)
1.0	14.61
1.5	21.92
2.0	29.22
2.5	36.53
3.0	43.83
6.0	87.66

During the experiment, osmotic pressure will also be calculated with the equation of $P = cRT$, where

$$c = \frac{\text{Mol of Solution (mol)}}{\text{Volume of solution (L)}}, R = 8.31 \times 10^3 \text{ Pa L K}^{-1} \text{ mol}^{-1}, T = 307.15\text{K}$$

Calculation will be attached in appendix.

3.3.2 Preparation of Feed Solutions

To prepare the feed solution, which is passion fruit juice. The passion fruit pulp will be purchased from Extra Natural Sdn Bhd. Passion fruit pulp were scooped out into beakers. Then, the passion fruit pulp were blended using blender. Passion fruit seeds were removed through a sieve. Strain the juice through cheesecloth to remove seeds and pulp which may cause fouling in the membrane. The clarified passion fruit juice will be collected as feed solution.

3.4 Measurement of Brix Value of Fruit Juices

To measure concentration of fruit juice, Brix value is measured. Brix measurement is an application in the food and beverage industry among others. Strictly speaking, the Brix measurement is the determination of pure sucrose content in water:

$$1 \text{ degree Brix (}^{\circ}\text{Bx)} = 1\text{g of sucrose / in 100g of solution}$$

The sweet tastiness of fruit or vegetable is affected by the level of soluble solids in a fruit or vegetable. Meanwhile, soluble solids are usually reported in values of $^{\circ}\text{Brix}$. $^{\circ}\text{Brix}$ values are important because they can be measured objectively and they relate to a subjective criterion that buyers and eaters use to assess vegetable quality—flavour or sweetness. $^{\circ}\text{Brix}$ values of a solution are measured using a device called a refractometer. Refractometers measure the refractive index of a solution to calculate a soluble solid concentration. Functionally, the refractive index quantifies dissolved solids based on changes in the direction of a light beam that passes through a liquid containing invisible dissolved or suspended solids. In general, the greater the amount of these "solids" in the liquid, the more light is bent when passing through it. All things being equal, the extent of this refraction also hinges on the temperature of the solution. Therefore, some refractometers adjust the values they report to account for the solution temperature.

Handheld refractometer was used to measure concentration of passion fruit juice before and after the forward osmosis. Distilled water will be dropped on the

sensor and zero-ed in order to standardize the reading. The samples were dropped on the sensor and the Brix value will be measured automatically.



3.5 Forward Osmosis Membrane

A membrane is essential to carry out forward osmosis setup. The forward osmosis membrane used in this experiment is cellulose triacetate membrane, purchased from STERLITECH Corporation, with the size of 305 x 305mm. The membrane is in flat sheet and packaged in 1% sodium metabisulfite water solution.

For the flat sheet of cellulose triacetate membrane, the smooth side is the rejection layer, which is opposite of the embedded support side. The cellulose triacetate membrane is tolerant to maximum 2 ppm of chlorine and pH range of 3 to 7. The maximum temperature of cellulose triacetate membrane is 50°C. Hence, before unpacking the package it is allowed to be stored at room temperature, however once the package is opened, it is required to store the membrane in the chiller. The porosity, as known as the pore size of the membrane is 5 micron.

While operating forward osmosis process using CTA membrane, it is necessary to maintain higher pressure on the retentate feed side. The draw solution side shall be controlled to have some pressure and flow to keep minimum transmembrane pressure at 5psi or above.

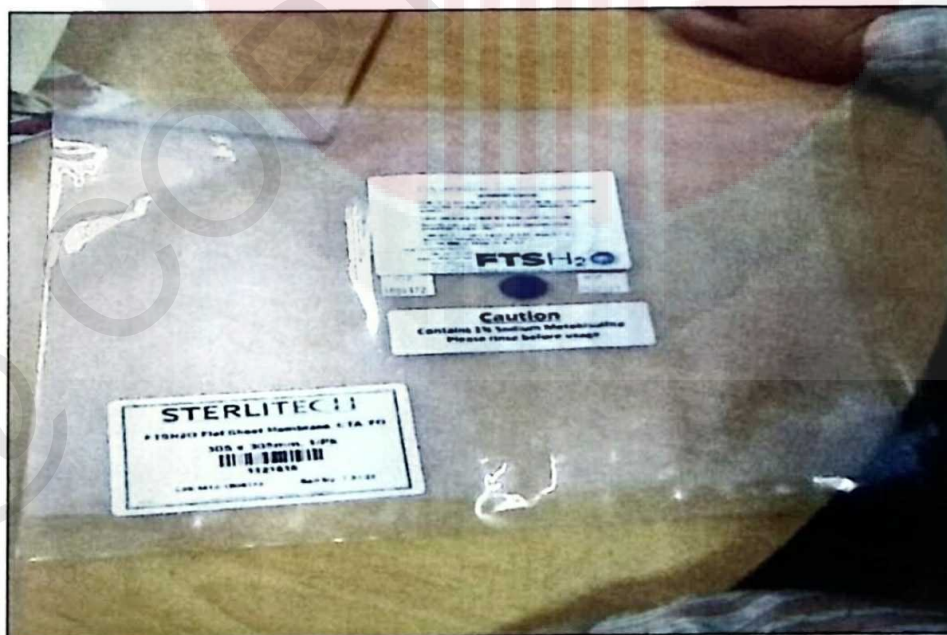


Figure 5 Cellulose triacetate membrane used in experiment

3.6 Set Up of Forward Osmosis System

This forward osmosis system was set up as illustrated in Figure 5. The set-up of forward osmosis system includes cellulose triacetate membrane, pump, beakers, weighing machine and membrane holder. The two beakers will be served as solution tank for feed solution and draw solution. The contact area of the membrane is 0.001964 m^2 .

To set up the experiment, the beakers will be filled in with feed solution and draw solution. The cellulose triacetate membrane will be cut into proper size which can fit in the membrane holder. The flow rate of juice will be adjusted by adjusting the pump power. To place the membrane into the membrane holder, the member is cut into the size according to the size of membrane holder and its radius is measured to calculate its surface area. There are two different side in one membrane, the rougher part of the membrane will be facing downwards while placing in the membrane holder, it will be in contact with the draw solution. Meanwhile, the smoother (active layer) part of membrane will be facing upwards while placing in the membrane holder.

Before start the experiment, the forward osmosis shall be run through in distilled water as draw solution and feed solution for 1 hour or until the reading is stabilized.

The weight of both solutions will be measured using weighing balance and recorded. The concentrations of both feed and draw solutions will also be measured and recorded. The transmembrane flux will be calculated based on the formula:

$$J_w = \frac{\text{Volume of solution (L)}}{\text{Surface area of membrane (m}^2\text{) x Duration of interval (hr)}}$$

The volume of solution is calculated by multiplying density of solution to the change of weight of the solution during the experiment. The duration of interval is taken as the time interval where we take reading during the experiment.

However, as the flow rate of feed solution increased, the tube transferring solution to and from membrane shall be taken care of from time to time. When the flow rate increased, the friction between the pump and tube increased and will cause the tube to tear and caused leakage of feed solution. Similar failures were observed in other experimental studies done by researchers, one of the research conducted by Yuan Xu (2010), while conducting forward osmosis experimental studies and observed major leakage of draw solution at a pressure of ~ 3 bar and caused the experiment to be stopped. The leakage was due to the failure of the glue between the two pieces of membranes under the applied pressure.

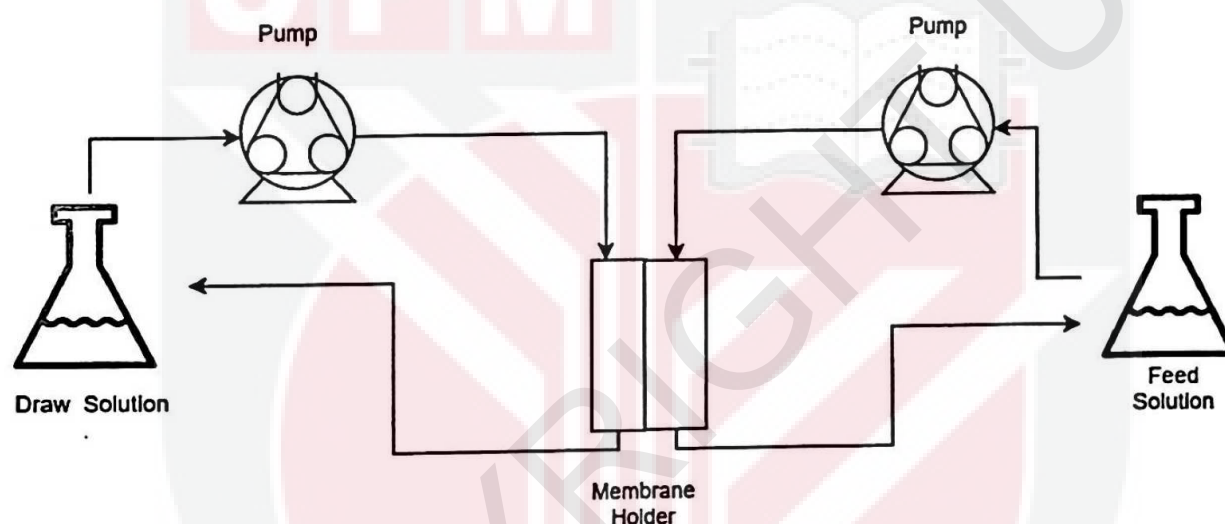


Figure 6 : Apparatus for forward osmosis process

In this study, two variables that been studied were; (i) salt concentration (DS) from 1.0 to 6.0 M and (ii) flow rate of solution between 0.8 to 2.4 L/min. Each experiment was carried out duplicate.

3.7 Measurement of Ascorbic Acid in Solution

In order to investigate the difference of ascorbic acid content in feed solution, redox titration using iodine solution method was used to determine the content of ascorbic acid in the fruit juice. This method determines the vitamin C concentration in a solution by a redox titration using iodine. The sample was pipetted 20ml into a 250ml conical flask and add 150ml of distilled water and 1ml of starch indicator solution. Then, the sample was titrated with 0.005 mol L⁻¹ iodine solution, the endpoint of the titration was identified as the first permanent trace of a dark blue-black colour due to the starch-iodine complex.

Then, calculations will be done to calculate the content of ascorbic acid. The moles of iodine reacting will be calculated based on volume of titrate, then number of moles of ascorbic acid can be calculated based on equation below :



CHAPTER 4 RESULTS AND DISCUSSION

4.1 Introduction

There were total 9 analysis were done on forward osmosis which included osmotic pressure, flow rate of feed juice, transmembrane flux, increment of Brix value, concentration of draw solution, conductivity of draw solution and properties of different types of passion fruit juices, such as fresh passion fruit juice, commercial passion fruit juice and passion fruit juice after going through forward osmosis and analysis of fouling on membrane surface using scanning electron microscope (SEM).

4.2 Osmotic Pressure of Sodium Chloride at Different Concentration

Osmosis is simply the flow of solvent molecules through the membrane from higher solvent concentration to lower solvent concentration. Thus, osmotic pressure is the most important parameter for a draw solute as it determines the potential application in the FO process. The osmotic pressure is related to the concentration of solute by the following equation of $P = cRT$. The osmotic pressure for the sodium chloride (NaCl) was calculated at temperature, 34°C, and Figure 6 showed that its osmotic pressure increases linearly with concentration of salt. At concentration of 1 M, the osmotic pressure of NaCl is 2552kPa, then it increased to 3825kPa at 1.5M, and it increased to 7649kPa at 3.0M of sodium chloride concentration. The osmotic pressure was the highest at 15314 kPa at 6.0M of DS concentration. Details calculation were attached in appendix section.

In the research done by Liu et al (2020) the osmotic pressure increased with the increase of concentration of $MgCl_2$, NaCl, and imidazolium ILs aqueous solutions. In the result, the osmotic pressure had risen sharply with salt concentration in the aqueous solution, especially in the case of $MgCl_2$. However, the aqueous solutions of ILs, exhibited a mild increase in the osmotic pressure with increasing the solute concentration. For $[C_8mim]Cl$ and $[C_{10}mim]Cl$ with a

relatively long alkyl chain, there is almost no increment in osmotic pressure with progressively increasing the content of ILs in the aqueous solutions. The result fit with the result in research.

However, in the data obtained by Liu et al (2020), the osmotic pressure is slightly different with experimental data. For 1M of NaCl solution, the osmotic pressure was 3.952×10^6 Pa, while for 2M of NaCl solution, the osmotic pressure was 8.41×10^6 Pa, while for 2.5M of NaCl solution, the osmotic pressure was 1.084×10^7 Pa, and 1.469×10^7 Pa for 3M of NaCl solution. The difference is due to the concentration of sodium chloride used and surrounding temperature throughout the experiment was different compared to other experimental studies and these are the two key factors for calculation of osmotic pressure of sodium chloride solution.

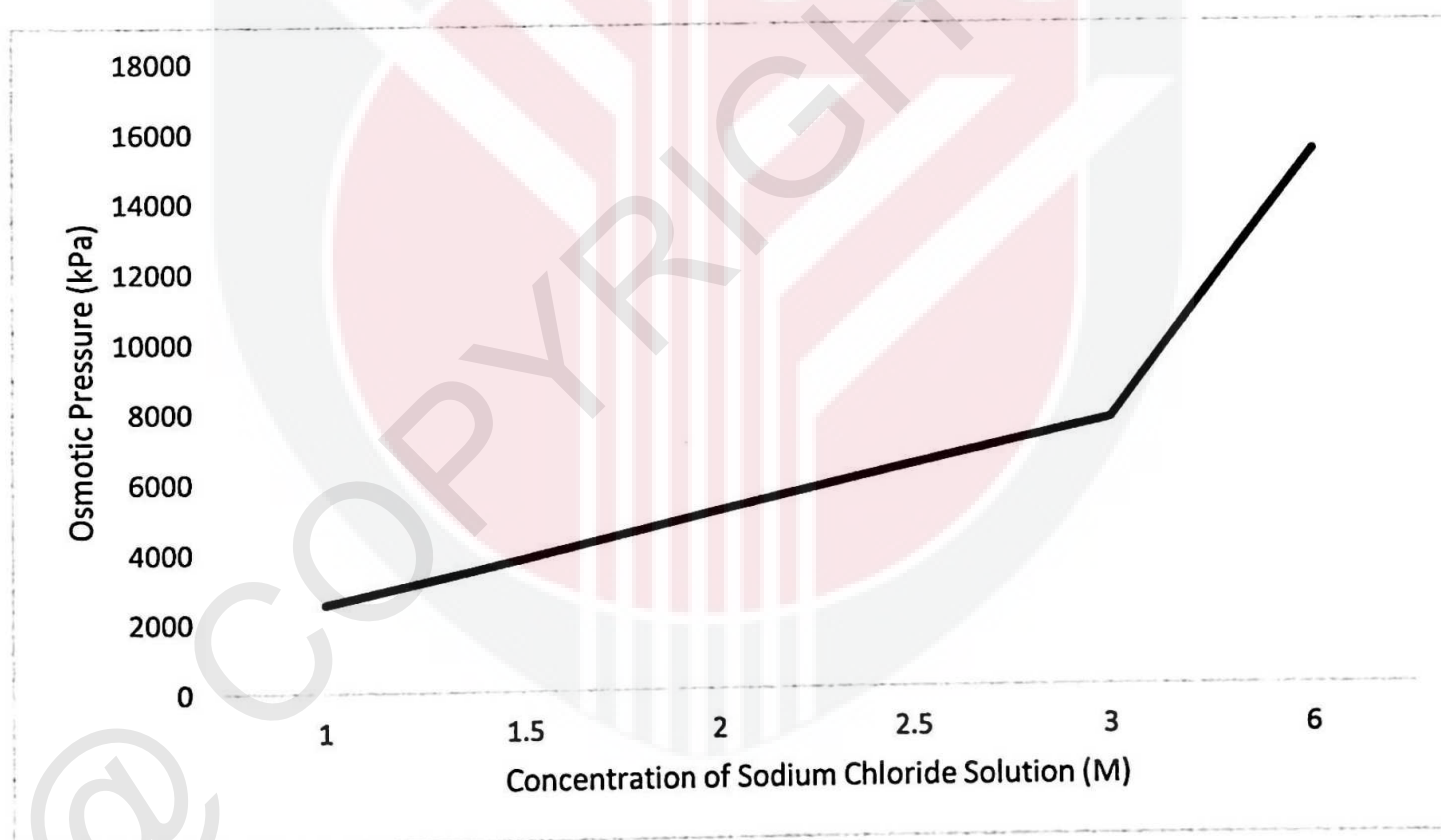


Figure 7 Osmotic Pressure of Sodium Chloride at Different Concentration

4.3 Comparison of Transmembrane Flux of Passion Fruit Juice with Distilled Water at Different Flow Rate

Generally, the transmembrane flux of water is higher than that of passion fruit juice. The reason is because that the transmembrane flux formula is :

$$J_w = \frac{\text{Volume of solution (L)}}{\text{Surface area of membrane(m}^2\text{) x Duration of interval (hr)}}$$

While the volume loss of solution was calculated based on density of the liquid, the density of water is lower than that of passion fruit, where the density of water is 997 kg/m³ and viscosity of 0.725cp, while density of passion fruit juice is 1050 kg/m³ and its viscosity is 20cp. (Engineers Edge, 2020) As the density and viscosity of passion fruit juice were higher, so it will affect the flow of feed solution throughout the experiment as well as in calculation of transmembrane flux. This result that showed in Figure 7, is in line with the theory of the density of a fluid affects its viscosity. Fluids with more mass per unit volume are heavier and require more energy to move them and shear less easily. The more viscous, or less slippery, a fluid the harder it is to get shearing between layers. The high viscosity prevents rapid velocity changes occurring between layers. The sub layer in viscous fluids is thicker than in low viscosity fluids. (Sondalini, n.d)

Moreover, lower flow rate of solution also indicated a lower transmembrane flux. This result was in line with the study done by Ashfaq et al. (2018) the flow rate of pure water and wastewater had caused increment of flux respectively, and also a study done by Kim et al. (2019), where the viscosity takes effect on the transmembrane flux of forward osmosis. In conclusion, from this result, the higher density and viscosity of solution had caused lower flow rate and hence the lower transmembrane flux.

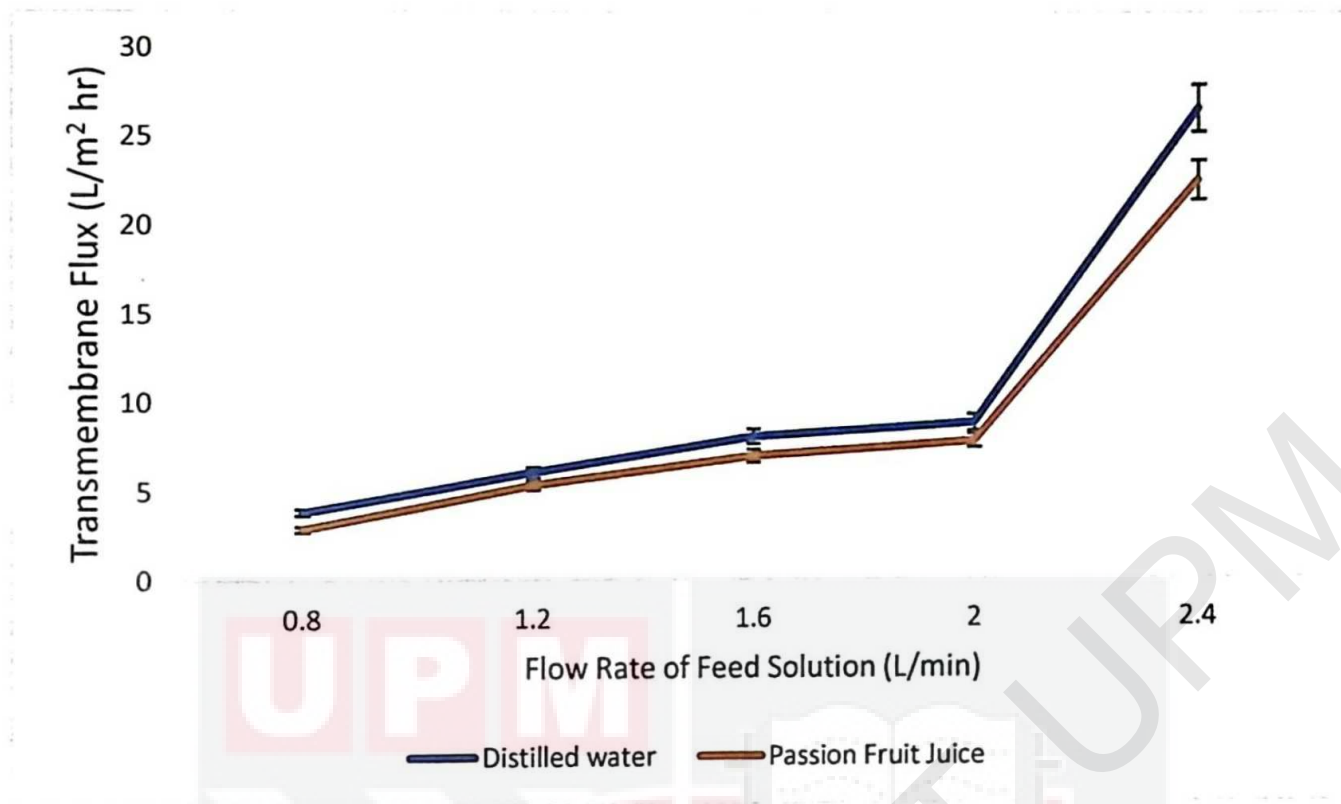


Figure 8 Average Transmembrane Flux of Distilled Water and Passion Fruit Juice at different flow rate

4.4 Effect of flow rate of passion fruit juice on transmembrane flux

Passion juice was used as a feed solution and NaCl as draw solution to evaluate the effect of flow rate of feed solution on transmembrane flux performance. The range of flow rate that been conducted for the forward osmosis process were at 0.8 L/min, 1.2 L/min, 1.6 L/min, 2 L/min, 2.4 L/min. Both feed and draw solution were maintained at the same flow rate. The molar concentration (1 M with 2.552×10^6 Pa of osmotic pressure) of the draw solution (sodium chloride solution) was remain constant for this experiment.

The effects of flow rate on trans-membrane flux were shown in Figure 8. Generally, it can be seen that as the flow rate of passion fruit juice and draw solution increased, the transmembrane flux increased as well. For the average transmembrane throughout the experiment, the transmembrane flux at 0.8 L/min was 2.0689 L/m² hr, it increased to 5.0220 L/m² hr when the flow rate was adjusted to 1.2 L/min, and followed by average transmembrane flux of 7.8443 L/m² hr, 10.8029 L/m² hr and 22.5082 L/m² hr for flow rate of 1.6 L/min, 2 L/min and 2.4 L/min, respectively. This shows that the flow rate has great impact on the transmembrane flux. Generally, at 5th minute of processing time, the highest transmembrane flux was observed for all flow rate condition. While flow rate of 2.4 L/min provide the highest value of trans-membrane flux (22.5082 L/m² hr) among all flow rate condition. After 5th minute, the transmembrane flux generally showed a decrease trend. It can be observed that an increase of flow rate might cause a better membrane scouring and hence the flux increased.

In general, the increase of membrane flux with increasing the flow rate of feed solution was attributed to the reduction of the concentrative internal concentration polarization (CICP). CICP is normally, caused by solute concentration increase in the porous support layer at concentrations higher than that in the bulk solution. (Hawari,et al. 2016) This resulted in an increase of concentration of feed solution (passion fruit juice) in terms of concentration and reducing membrane flux from time to time. From the results, it showed the trend of increase of transmembrane flux generally with the increase of solution flow rate.

Besides that, the Brix value which indicated the concentration of feed solution (passion fruit juice) also increased, taking this experimental result of flow rate of 0.8 L/min and 2.4 L/min, the increment of Brix value were $2.4 \pm 0.14\%$ Brix and 3.4 ± 0.57 separately, will be discussed in the next section.

Turbulent flow will be increased by increasing the feed solution flow rate and will promote salt back diffusion from the porous media toward the bulk feed solution. Hence, the osmotic driving force across the FO membrane increased and generated higher membrane flux. Furthermore, increasing the feed solution flow rate may result a slight increase of the hydraulic pressure on the feed side and probably caused this increase of membrane flux. This was proven by the conductivity value throughout the experiment, as the time of running experiment increased, the conductivity decreased as the time goes. Taking 1.5M of sodium chloride solution as an example, initially the conductivity was 103.1mS/cm and as the experiment goes it had decreased to 95.6mS/cm. This will be discussed in the next section.

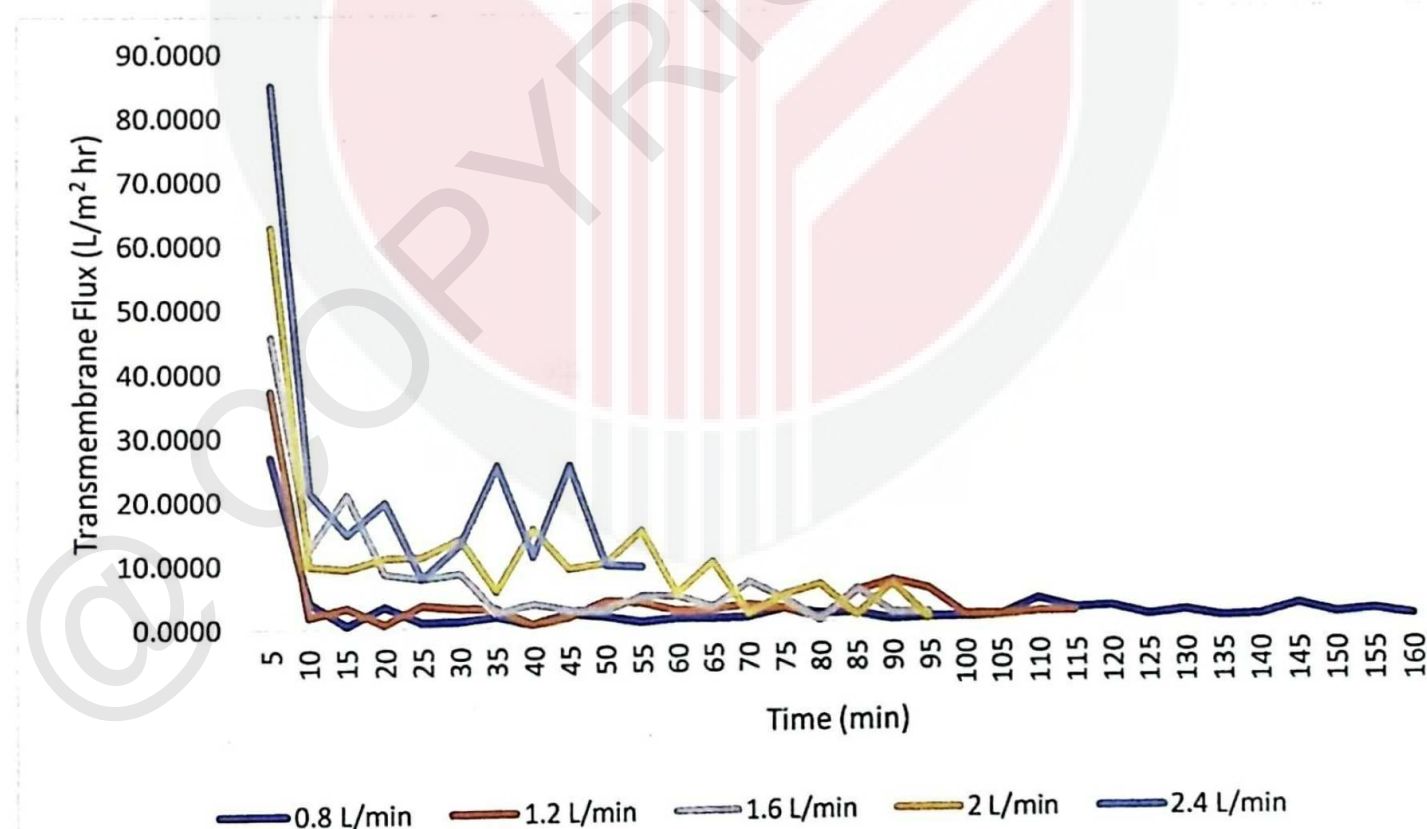


Figure 9 Graph of transmembrane flux versus time

4.5 Effect Of Flow Rate and DS Concentration On Brix Value of Passion Juice

This section discussed on evaluating the effect of flow rate of passion juice on the concentrated passion juice (after completed the FO osmosis process) in terms of Brix value. A series of forward osmosis processes were conducted at flow rate of 0.8L/min, 1.2 L/min, 1.6 L/min, 2 L/min, 2.4 L/min. The same concentration of 1 M draw solution (sodium chloride solution) was applied to the CTA membrane in these experiments. When the flow rate of passion fruit juice at 0.8 L/min, the increment of Brix value was 2.4 ± 0.14 % Brix. The trend showed general increment in Brix value of passion fruit juice from 0.8 L/min to 2.4 L/min and the highest Brix value achieved is 3.4 ± 0.57 % Brix at 2.4 L/min, at 2.4 L/min, when the DS concentration changed to 6.0M, the increment of Brix value was 10.7 ± 0.14 % Brix.

However, when the variable was changed to concentration of draw solution (from 1M to 5 M) and the flow rate was kept constant at 1.6 L/min, the increment of Brix value of passion fruit did not show a steady trend where the brix value decreased for draw solution concentration of 1M to 2M. In contrast, as the DS concentration increased from 2M to 3M, the Brix value increased from 2.15 ± 0.07 % Brix to 2.95 ± 0.07 % Brix. In previous studies conducted by Kim et al. (2019), the dewatering of grapefruit juice through forward osmosis, he has successfully concentrated grapefruit from 4.4% Brix to 54% Brix, with 6.0M of NaCl draw solution, so, another experiments were conducted using flow rate of 2.4 L/min and 6.0M of sodium chloride as draw solution, for 4 hours. In the result, it can be seen that the increment of Brix value is 10.7 ± 0.14 % Brix, which were higher than previous results. However, due to the situation of limited time for experiment as Movement Control Order in Malaysia, further experiments cannot be proceeded.

It can be concluded that, as the flow rate and concentration of draw solution increased, the concentration of fruit juice will also be increased.

Table 5 Increment of Brix Value at different flow rate of passion fruit juice

Flow Rate of Passion Fruit Juice (L/min)	Initial Brix Value (% Brix)	Final Brix Value (% Brix)	Increment of Brix Value (% Brix)
0.80	11.6 ± 0.57	14.0 ± 0.42	2.4 ± 0.14
1.20	11.9 ± 0.14	14.6 ± 0.42	2.6 ± 0.28
1.60	12.0 ± 0.28	14.95 ± 0.07	2.95 ± 0.21
2.00	13.1 ± 0.14	16.1 ± 0.14	3.0 ± 0
2.40	12.7 ± 0.71	16.1 ± 0.14	3.4 ± 0.57

Table 6 Increment of Brix Value at different DS concentration

Concentration of Draw Solution (M)	Initial Brix Value (% Brix)	Final Brix Value (% Brix)	Increment of Brix Value (% Brix)
1.0	11.9 ± 0.14	14.65 ± 0.21	2.75 ± 0.35
1.5	12.05 ± 0.07	14.7 ± 0.85	2.65 ± 0.92
2.0	11.9 ± 0.14	14.75 ± 0.35	2.15 ± 0.07
2.5	12.25 ± 0.35	14.9 ± 0.14	2.65 ± 0.49
3.0	13.1 ± 0.14	16.05 ± 0.07	2.95 ± 0.07
6.0 (2.4L/min)	12.3 ± 0.28	23.0 ± 0.14	10.7 ± 0.14

4.6 Comparison of Transmembrane Flux of Passion Juice with Distilled Water at Different Salt Concentration

To evaluate the effect of concentration of draw solution (sodium chloride solution) on the transmembrane flux of distilled water, a series of forward osmosis processes were conducted at different concentration of draw solution which were 1M, 1.5M, 2M, 2.5M and 3M. The same flow rate of passion fruit juice and sodium chloride solution (DS) at 1.6 L/min were used during the experiment.

The transmembrane flux of the juice increased when the concentration of draw solution increased as shown in Figure 9. The increment of transmembrane flux was steady when the draw solution concentration varied from 1 M to 2 M, which was from 5.3250 L/m² hr to 10.3407 L/m² hr, however when the concentration increased from 2 M to 3 M, the transmembrane flux increased rapidly which was from 10.3407 L/m² hr to 29.145 L/m² hr. A higher draw solution concentration could generate a larger osmotic driving force, which leads to a higher water flux across the membrane. In a research study done by Chen (2017) in forward osmosis study on concentrate polyepoxysuccinic acid (PESA), the water flux increased trend when the PESA concentration increased from 0.05 to 0.2 g mL⁻¹. However, the increase of water flux is not linear due to the higher concentration of draw solution reduced its diffusivity, thus leading to serious concentration polarization, which resulted in a non-linear relationship between concentration and transmembrane flux, this also proven by the study conducted by Chen (2017) where the increment of flux was not consistent at increasing PESA concentration. This result suggested that high draw solution concentrations is beneficial resources to improve the membrane water flux.

In a research done by Yuan et al. (2010), where the forward osmosis flux efficiency was drastically reduced at greater draw solution concentration, this has proven that the phenomenon of internal concentration polarization (ICP) was more severe under larger draw solution concentration. ICP is a phenomenon that is build-up of concentration gradients inside forward osmosis membranes during operation, which is not included in this research project.

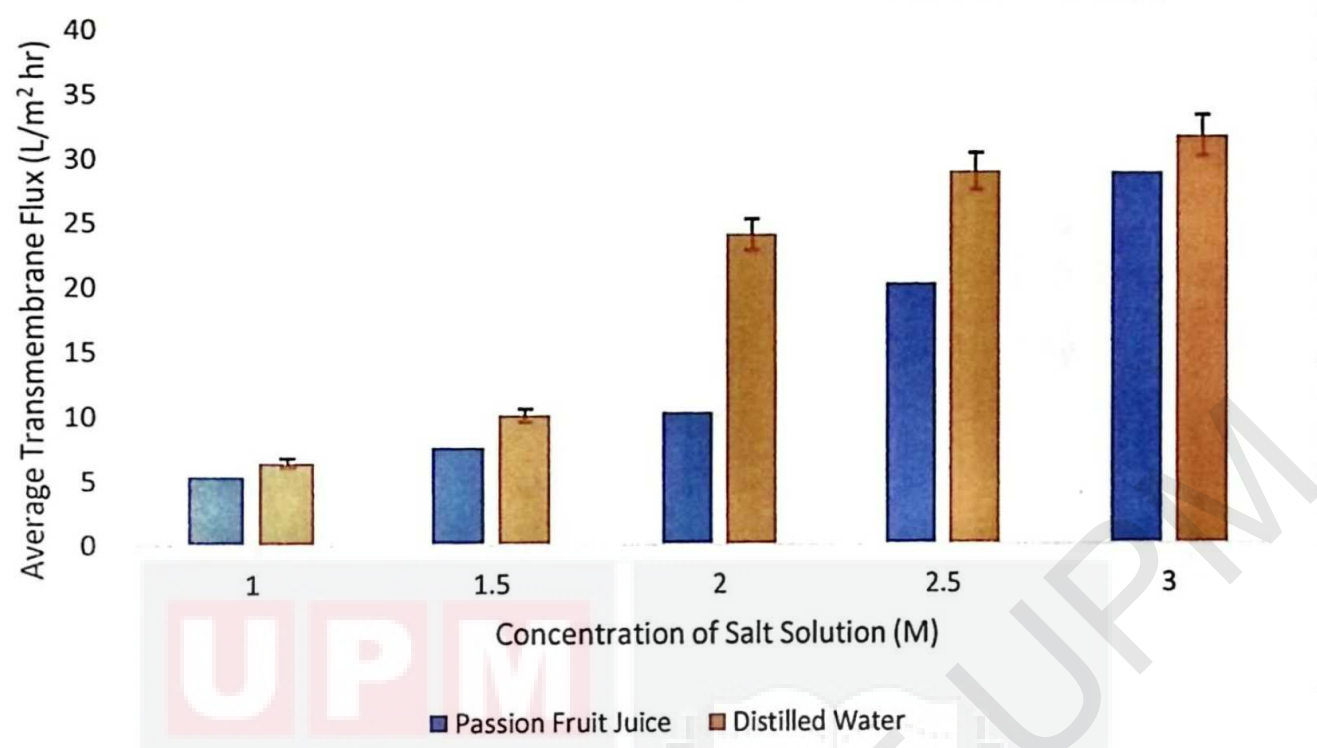


Figure 10 Average Transmembrane Flux versus Salt Concentration

4.7 Effect Of Concentration Of Sodium Chloride Solution On Transmembrane Flux Of Passion Fruit Juice

To evaluate the effect of concentration of draw solution (sodium chloride solution) on the transmembrane flux, a series of forward osmosis processes were conducted at different concentration of draw solution which were 1M, 1.5M, 2M, 2.5M and 3M. Constant flow rate for passion fruit juice and sodium chloride solution (DS) at 1.6 L/min were used during the experiment.

The transmembrane flux of the juice increased when the concentration of draw solution increased. The increment of transmembrane flux was the highest at 5th minute for different draw solution concentrations. Generally, the trend showed that the transmembrane flux increased with the increase of DS concentration. A study was conducted by Yuan et al. (2010), using forward osmosis membrane and feed water as feed solution, their result showed that the transmembrane flux generally increased with the increase of DS concentration. For the DS concentration difference at a high salinity region drove more water flux than that at a low salinity region, which the internal concentration polarization of the FO membrane was not significant under the higher DS concentration. At last, the osmotic pressures for DS and FS will achieve an equilibrium, and thus the FO process terminates at this point. (Liu, et al., 2020) High concentrations of draw solutions will aid in higher transmembrane flux.

However, it can be seen from result that the increment of transmembrane flux at increasing DS concentration was not consistent, according to Law J.Y (2018), this is due to dilutive internal concentration polarization (ICP) occurred in the porous support layer and reduced the effective osmotic pressure gradient across the membrane. The ICP effect takes higher influence at higher DS concentration, hence it caused a non-linear flux performance.

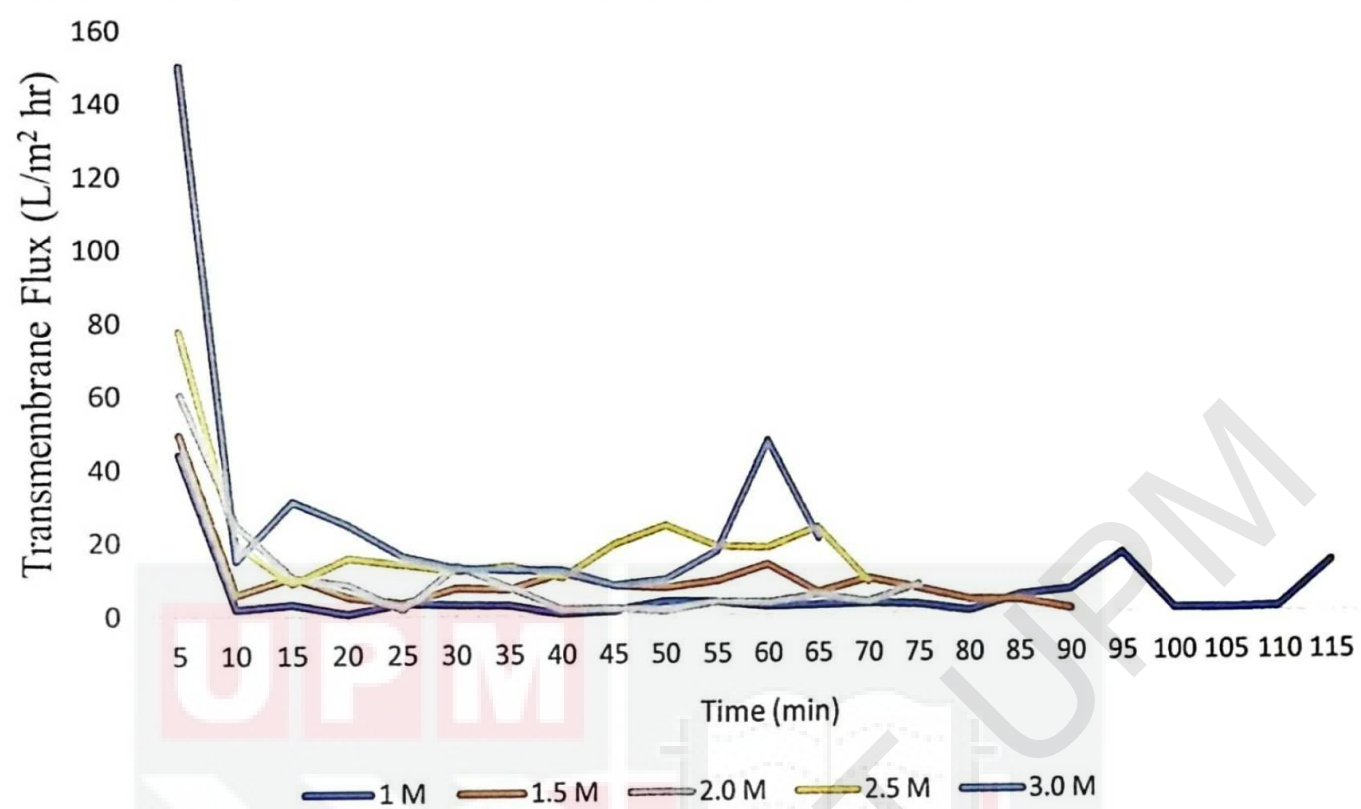


Figure 11 Graph of transmembrane flux versus time

4.8 Effect of Sodium Chloride Solution Concentration On Conductivity

As the NaCl solution concentration increased as shown in Figure 11, the conductivity of draw solution increased. Ions conduct electricity due to their positive and negative charges. When electrolytes dissolve in water, they split into positively charged (cation) and negatively charged (anion) particles. As the dissolved substances split in water, the concentrations of each positive and negative charge remain equal. This indicates that the conductivity of water increases with added ions, it remains electrically neutral.

As the experiment was carried out, the conductivity of the NaCl solution decreased and until after it achieved point of osmotic equilibrium, which is a phenomenon that the osmotic pressure of the both solutions on opposite side of the membrane, which were feed solution and draw solution, became equal. Osmotic equilibrium indicated the net transfer of water across the membrane is zero. (Phuntsh et al., 2014) If similar solutes are present on both sides of the membrane, the equilibrium means that they have the same or equal concentrations. Since in this experiment the two solutions were different, so the osmotic equilibrium means that the net transfer of water from feed solution to draw solution stopped, and backflow of water from draw solution to feed solution happened, this situation will be indicated where the conductivity started to increase. So, the conductivity value shall be observed carefully to ensure success of the experiment.

As compared to the conductivity of passion fruit juice, which is 5.2mS/cm, sodium chloride solution has a higher conductivity. During the experiment, the experiment was stopped when the conductivity increased, which means the backflow of salt solution. The conductivity has to be observed all the time and once it has showed the increase trend, the experiment has to be stopped to get accurate result.

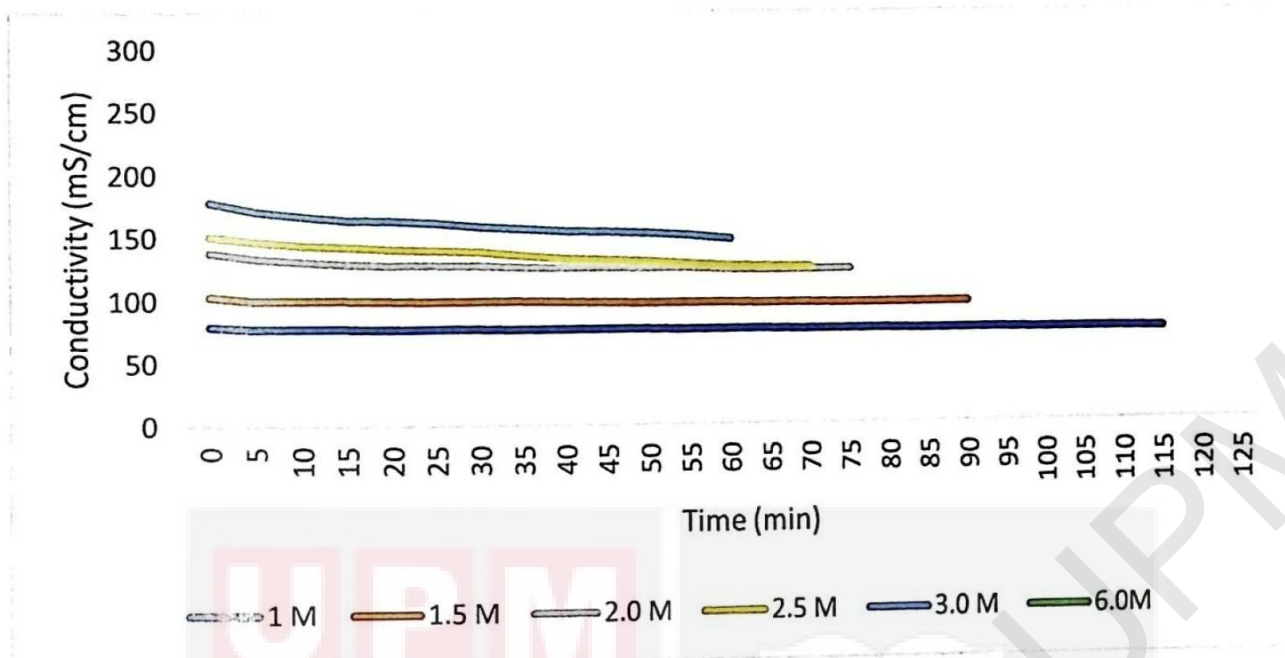


Figure 11 Graph of Conductivity versus Time at different DS concentration

Table 7 : Effect of concentration of draw solution on conductivity

Concentration of Salt Solution (M)	Conductivity (mS/cm)
1.0	80.84 ± 4.691
1.5	103.1 ± 0.1414
2.0	138.2 ± 0.5657
2.5	151.4 ± 0.2828
3.0	178.0 ± 0.2828
6.0	281.55 ± 1.55

4.9 Analysis of Fouling on CTA Membrane using Scanning Electron Microscope (SEM)

In order to analyse the fouling on the forward osmosis membrane, SEM method is used to analyse the membrane. For the analysis of raw forward osmosis membrane, fouling occurs when a cake/gel layer forms on surface of forward osmosis membrane and it will block the internal pores especially the porous support layer. In the CTA membrane there are two layers, which are active layer-feed solution (AL-FS) and active layer-draw solution (AL-DS).

In this analysis, the active layer-feed solution will be analysed for fouling, which is to analyse the fouling on the side of membrane facing the flow of passion fruit juice. In this orientation, fouling occurs when the foulant in passion fruit juice solution deposits on the surface of the membrane active layer, hence it has caused a layer of fouling on the surface. This phenomenon is also known as external fouling. (Lee et al.,2020)

For the result of raw membrane analysis, it can be seen that there is no fouling on the surface and this can be used as a control to compare between fouling on other membranes. When the flow rate of FS and DS was 1.2 L/min and at DS concentration of 1M, there were few particulates accumulated on the surface, when the DS concentration increased to 3M, there were more particulates accumulated on the surface, external fouling has occurred. When the flow rate had increased to 2.0 L/min and at DS concentration of 3M, there were more particulates accumulated on the membrane surface and compared to flow rate of 1.2L/min, the particulates at 2.0 L/min were smaller and the amount were more.

From this analysis, it can be concluded that, as the DS concentration and flow rate of FS and DS increased, membrane fouling are more significant. Membrane fouling can be optimized by taking flow rate of solutions and concentrations of solutions into consideration.

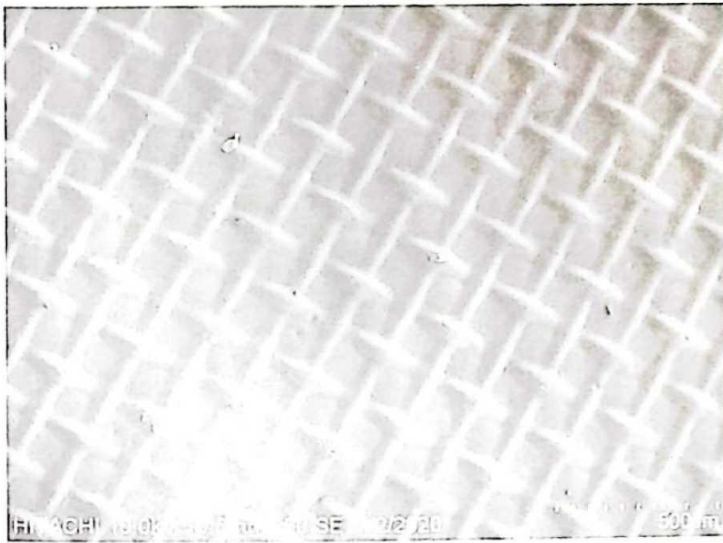


Figure 13 Raw CTA Membrane

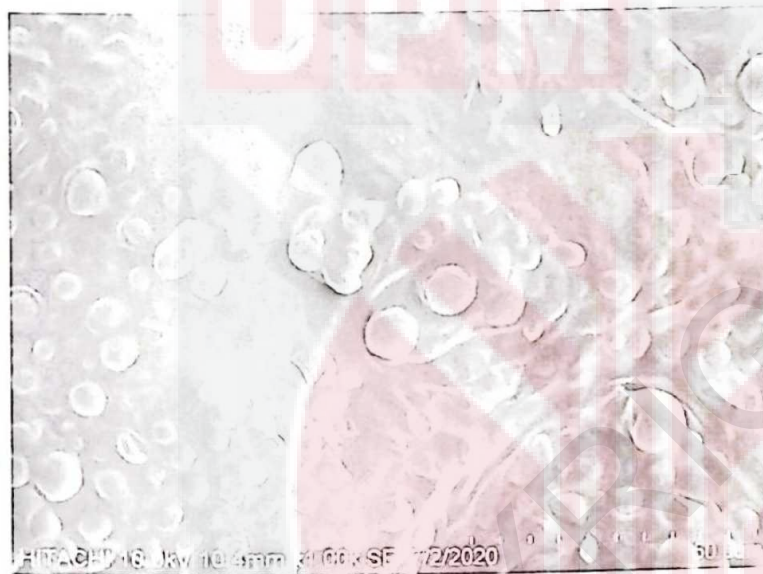


Figure 14 CTA Membrane at 1.2L/min, 1M DS

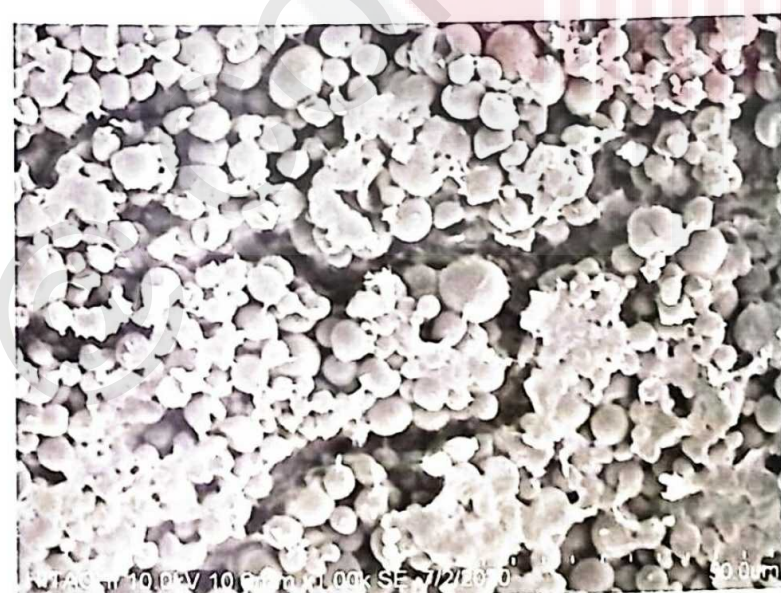


Figure 15 CTA Membrane at 1.2 L/min, 3M DS

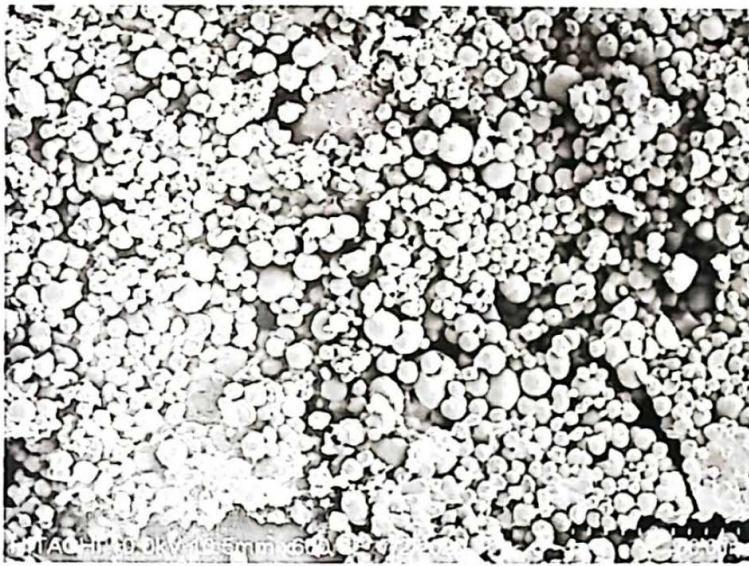


Figure 16 CTA Membrane at 2 L/min, 3M

4.10 Effect of FO membrane treatment on Passion Fruit Juice quality

Generally, forward osmosis process is possible to concentrate passion juice from $13.0 \pm 0.21\%$ Brix to $15.15 \pm 0.93\%$ Brix. The result was calculated based on average of all Brix value that were involved in forward osmosis experiment. Beaudry et al (1990) reported that for the process of forward osmosis to concentrate orange juice, the Brix value increased up to 42 °Brix using a 72 °Brix sugar syrup as the draw solution, and they achieved an average water flux of $1.3 \text{ kg m}^{-2} \text{ h}^{-1}$ at a process temperature of 30 °C. In this research, the concentration of soluble solids content increased from 13.0% Brix to 15.22% Brix averagely. Commercial passion fruit juice were purchased and the process of concentrating passion fruit juice are evaporation process, a thermal process which will destruct the nutritional content of passion fruit juice. Concentrated passion fruit juice after forward osmosis can be made into tablet form or to be an effervescent tablet for the source of Vitamin C.

For the increment of passion fruit juice concentration, due to unexpected situation, higher DS concentration experiments could not be conducted, so in this result, the average increment of Brix value of passion fruit juice were low.

Table 8 Characteristics of concentrated passion juice obtained by forward osmosis and evaporation

Analysis	Fresh Juice (Feed solution)	Commercial Passion Juice	Passion Fruit juice that undergo forward osmosis treatment
pH	3.11 ± 0.04	3.55 ± 0.05	3.11 ± 0.02
Soluble solids content (°Brix)	13.0 ± 0.21	15.0 ± 0.13	15.15 ± 0.93
L*	46.37 ± 0.18	42.35 ± 0.23	47.85 ± 0.48
a*	4.02 ± 0.23	2.34 ± 0.43	2.48 ± 0.38
b*	27.52 ± 0.19	25.15 ± 0.21	29.15 ± 0.27
Content of Ascorbic Acid	16.4 ± 0.43	12.3 ± 0.47	16.3 ± 0.97

CHAPTER 5

CONCLUSION AND RECOMMENDATION

In conclusion, this study is to develop forward osmosis system for concentrating passion fruit juice, evaluate the performance of forward osmosis to concentrate passion fruit juice at different operating variables such as flow rate of solutions and concentration of sodium chloride. Besides, the nutritional properties of passion fruit juice were also analysed. The main equipment used in this study is lobe pump, forwards osmosis membrane, membrane holder, scanning electron microscope (SEM) and conductivity meter.

From the first analysis, it can be concluded that as concentration of sodium chloride solution (DS) increased, the osmotic pressure will also increase. As we compare transmembrane flux of distilled water and passion fruit juice separately, both as feed solution, it is concluded that the higher density and viscosity of feed solution will cause lower transmembrane flux.

From the analysis done, it can be concluded that, as the flow rate of passion fruit juice and draw solution increased, the transmembrane flux increased as well. However, the increment of flow rate of feed solution was at most 3.4% Brix for passion fruit juice.

Besides, it can also be concluded that the higher the concentration of sodium chloride solution (draw solution), the higher the transmembrane flux of forward osmosis. As the experiment was carried out, the conductivity of the NaCl solution decreased and until after it achieved point of osmotic equilibrium, which also indicated the experiment has to be stopped. Besides, the connecting tube transferring the solutions has to be observed from time to time.

Generally, forward osmosis process is possible to concentrate passion juice from $13.0 \pm 0.21\%$ Brix to $15.15 \pm 0.93\%$ Brix. Since the first set of experiment result is unsatisfactory, another set of experiment was carried out using 6M of sodium chloride draw solution and 2.4 L/min flow rate, and a higher Brix value was

observed. However due to restriction of time and unexpected situation, further experiments could not be carried out. It is suggested that higher DS concentration and longer experiment time to carry out future forward osmosis laboratory work.

For the fouling of forward osmosis membrane, it was concluded that as the concentration and flow rate increased, there will be more particulates accumulate on the surface of membrane and fouling will be more significant.

In the future research, forward osmosis can be used as a method to concentrate fruit juices other than its existing wide applications such as desalination, wastewater industry, food processing and in pharmaceutical industry. It is suggested that concentrated passion fruit juice after forward osmosis can be made into tablet form or to be an effervescent tablet for the source of Vitamin C. It was recommended that higher draw solution concentration and flow rate can be used to achieve a better process of forward osmosis. Forward osmosis is also an alternative way to concentrate fruit juices and it will not bring harm to the environment.

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Appendix

Work Schedule

Gantt chart provides the development and progress of the research activities within the time constraint. Below is the Gantt chart for semester 1 to semester 2.

Table 9 Gantt chart for semester 1, session 2019/2020

Activity	Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Tittle Conformation														
Literature review & project planning														
Final Proposal writing														
Final Proposal submission														
Final Proposal presentation														
Correction for final proposal														
Equipment preparation														

Table 10 Gantt chart for semester 2, session 2019/2020

Activity	Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Laboratory work														
Article writing														
Submission of draft														
Correction of draft														
Submission of written article														
Research Presentation														

Calculation of mass of sodium chloride solution to different concentrations of NaCl solutions

$$0.250 \text{ L} \times \frac{1 \text{ mole}}{1 \text{ L}} \times \frac{58.44 \text{ g}}{\text{mole NaCl}} = 14.61 \text{ g NaCl}$$

$$0.250 \text{ L} \times \frac{1.5 \text{ mole}}{1 \text{ L}} \times \frac{58.44 \text{ g}}{\text{mole NaCl}} = 21.915 \text{ g NaCl}$$

$$0.250 \text{ L} \times \frac{2 \text{ mole}}{1 \text{ L}} \times \frac{58.44 \text{ g}}{\text{mole NaCl}} = 29.22 \text{ g NaCl}$$

$$0.250 \text{ L} \times \frac{2.5 \text{ mole}}{1 \text{ L}} \times \frac{58.44 \text{ g}}{\text{mole NaCl}} = 36.53 \text{ g NaCl}$$

$$0.250 \text{ L} \times \frac{3 \text{ mole}}{1 \text{ L}} \times \frac{58.44 \text{ g}}{\text{mole NaCl}} = 43.83 \text{ g NaCl}$$

Calculation of osmotic pressure of sodium chloride solution

$$P = cRT$$

$$c = \frac{\text{mol of sodium chloride solution}}{\text{Volume of solution}}$$

$$R = 8.31 \times 10^3 \text{ Pa L K}^{-1} \text{ mol}^{-1}$$

$$T = 307.15 \text{ K}$$

For 1M sodium chloride solution,

$$P = cRT$$

$$= \frac{0.25 \text{ mol}}{0.25 \text{ L}} \times 8.31 \times 10^3 \times 307.15 = 2.552 \times 10^6 \text{ Pa}$$

And applies the same for 1.5M, 2M, 2.5M and 3M.

Calculation of Transmembrane Flux

If the weight change is 0.00923kg, convert the weight change in the unit or litre (L).

$$\text{Density of Passion Fruit Juice} = 1050 \text{ kg/m}^3$$

$$\text{Contact area of membrane} = 1.9635 \text{ m}^2$$

Time interval for reading weight change = 0.0833 hr

$$\frac{(0.00923 \text{ kg.m}^3)/(1050 \text{ kg}) \times (1000 \text{ L})/1\text{m}^3}{(0.0833 \text{ hr}) \times (0.0019635\text{m}^2)} = 53.6005 \text{ L/m}^2.\text{hr}$$

Table 11 Osmotic Pressure of different salt solution concentration

Concentration of Salt Solution (M)	Osmotic Pressure (kPa)
1.0	2552
1.5	3825
2.0	5100
2.5	6375
3.0	7649
6.0	15314

Table 12 Average Transmembrane Flux of Distilled Water and Passion Fruit Juice at different flow rate

Flow Rate of Feed Solution (L/min)	Average Transmembrane Flux of Distilled Water as feed solution (L/m ² hr)	Average Transmembrane Flux of Passion Fruit Juice as feed solution (L/m ² hr)
0.80	0.9663	0.7231
1.20	1.5155	1.3345
1.60	2.0195	1.7487
2.00	2.2146	1.9532
2.40	6.6598	5.6408

Table 13 Average Transmembrane Flux of Passion Fruit Juice and Distilled Water as feed solution

Concentration of sodium chloride solution (M)	Average Transmembrane Flux of Passion Fruit Juice as feed solution (L/m ² hr)	Average Transmembrane Flux of Distilled Water as feed solution (L/m ² hr)
1.0	2.885	3.856
1.5	5.325	6.047
2.0	6.978	8.058
2.5	7.794	8.836
3.0	22.508	26.574

Experimental Data

Table 14 Experimental Data of Transmembrane Flux at Different Flow Rate (Passion Fruit Juice)

Flow Rate of Solution (L/min)	Time (minutes)	Weight Change (g)		Conductivity (mS/cm)		Transmembrane Flux (L/m ² hr)		
		1	2	1	2	1	2	Average
0.8	0	0	0	88	88.2	0	0	0
	5	2.01	7.25	88	88	11.6725	42.1022	26.8873
	10	0.24	1.19	88	88	1.3937	6.9106	4.1521
	15	0.08	0.1	87.3	87.3	0.4646	0.5807	0.5226
	20	0.46	0.69	86.3	86.3	2.6713	4.0070	3.3391
	25	0.21	0.1	85.3	85.3	1.2195	0.5807	0.9001
	30	0.23	0.11	85.1	85.1	1.3357	0.6388	0.9872
	35	0.43	0.1	84.9	84.9	2.4971	0.5807	1.5389
	40	0.09	0.03	84.8	84.8	0.5226	0.1742	0.3484
	45	0.38	0.31	84.5	84.5	2.2067	1.8002	2.0035
	50	0.11	0.34	83	83	0.6388	1.9744	1.3066
	55	0.02	0.12	82.9	82.9	0.1161	0.6969	0.4065
	60	0.15	0.2	82.5	82.5	0.8711	1.1614	1.0163
	65	0.19	0.12	82	82	1.1034	0.6969	0.9001
	70	0.1	0.22	81	81	0.5807	1.2776	0.9292
	75	0.09	0.69	80.9	80.9	0.5226	4.0070	2.2648
	80	0.06	0.42	80.9	80.9	0.3484	2.4390	1.3937
	85	0.08	0.38	80.8	80.8	0.4646	2.2067	1.3357
	90	0.05	0.05	80.7	80.7	0.2904	0.2904	0.2904
	95	0.1	0.1	80.6	80.6	0.5807	0.5807	0.5807
	100	0.08	0.14	80.6	80.6	0.4646	0.8130	0.6388
	105	0.17	0.11	80.5	80.5	0.9872	0.6388	0.8130
	110	0.1	1	80.4	80.4	0.5807	5.8072	3.1940
	115	0.25	0.35	80.3	80.3	1.4518	2.0325	1.7422

	120	0.46	0.22	80.2	80.2	2.6713	1.2776	1.9744
	125	0.09	0.1	80.2	80.2	0.5226	0.5807	0.5517
	130	0.3	0.1	80.1	80.1	1.7422	0.5807	1.1614
	135	0.04	0.03	80.1	80.1	0.2323	0.1742	0.2033
	140	0.06	0.1	80	80	0.3484	0.5807	0.4646
	145	0.08	0.65	80	80	0.4646	3.7747	2.1196
	150	0.12	0.12	79.7	79.7	0.6969	0.6969	0.6969
	155	0.3	0.1	79.6	79.6	1.7422	0.5807	1.1614
	160	0.1	0.03	79.3	79.3	0.5807	0.1742	0.3775
1.2	0	0	0	80	79	0	0	0
	5	10.61	2.21	76.3	78.7	61.6144	26.7712	37.2242
	10	0.49	0.13	76.3	78.6	2.8455	0.7549	1.8002
	15	0.33	0.78	76.2	78.4	1.9164	4.5296	3.2230
	20	0.09	0.12	76.2	77.8	0.5226	0.6969	0.6098
	25	1.11	0.1	76.0	77.5	6.4460	0.5807	3.5134
	30	0.22	0.8	76.0	77.3	1.2776	4.6458	2.9617
	35	0.34	0.64	75.7	77.2	1.9744	3.7166	2.8455
	40	0.1	0.02	75.8	76.9	0.5807	0.1161	0.3484
	45	0.12	0.33	75.6	76.8	0.6969	1.9164	1.3066
	50	0.82	0.45	75.5	76.5	4.7619	2.6132	3.6876
	55	0.01	1.21	75.3	76.3	0.0581	7.0267	3.5424
	60	0.39	0.33	75.1	76.2	2.2648	1.9164	2.0906
	65	0.12	0.67	74.8	76.0	0.6969	3.8908	2.2938
	70	0.11	0.88	74.2	75.9	0.6388	5.1103	2.8746
	75	0.55	0.23	74.0	75.7	3.1940	1.3357	2.2648
	80	0.1	0.12	73.9	75.5	0.5807	0.6969	0.6388
	85	1.42	0.22	73.8	75.4	8.2462	1.2776	4.7619
	90	2	0.21	73.6	75.2	11.6144	1.2195	6.4170
	95	5.25	0.34	73.4	75.0	30.4878	1.9744	16.2311
	100	0	0.33	73.4	74.6	0.0000	1.9164	0.9582
	105	0	0.3	73.2	74.5	0.0000	1.7422	0.8711

	110	0.25	0.15	73.0	74.2	1.4518	0.8711	1.1614
	115	0.11	4.67	72	73.7	0.6388	27.1196	13.8792
1.6	0	0	0	79.5	79.3	0	0	0
	5	6.47	3.26	79.0	78.3	53.8328	37.5726	45.7027
	10	1.5	2.8	78.0	78.2	8.7108	16.2602	12.4855
	15	4.3	2.9	77.9	77.6	24.9710	16.8409	20.9059
	20	1.9	1	77.1	77.2	11.0337	5.8072	8.4204
	25	1.95	0.71	76.9	76.8	11.3240	4.1231	7.7236
	30	1.33	1.57	76.3	76.5	7.7236	9.1173	8.4204
	35	0.33	0.44	75.8	76.3	1.9164	2.5552	2.2358
	40	0.32	0.9	75.3	76.0	1.8583	5.2265	3.5424
	45	0.11	0.76	74.8	75.9	0.6388	4.4135	2.5261
	50	0.09	0.66	74.3	75.4	0.5226	3.8328	2.1777
	55	0.53	1	73.8	75.3	3.0778	5.8072	4.4425
	60	0.94	0.58	73.0	75.0	5.4588	3.3682	4.4135
	65	0.26	0.65	72.4	74.8	1.5099	3.7747	2.6423
	70	1.09	1.1	72.3	74.1	6.3298	6.3879	6.3589
	75	0.99	0.28	72.0	73.2	5.7491	1.6260	3.6876
	80	0.01	0.06	71.2	73.0	0.0581	0.3484	0.2033
	85	0.2	1.55	70.2	72.1	1.1614	9.0012	5.0813
	90	0.12	0.35	68.3	72.0	0.6969	2.0325	1.3647
	95	2.1	0.21	68.3	70.9	12.1951	1.2195	6.7073
2.0	0	0	0	76.2	76.7	0	0	0
	5	12.31	9.33	76.2	76.3	71.4866	54.1812	62.8339
	10	1.03	2.35	76.0	76.0	5.9814	13.6469	9.8142
	15	1.1	2.1	75.7	75.8	6.3879	12.1951	9.2915
	20	2	1.77	75.6	75.4	11.6144	10.2787	10.9466
	25	1.71	2.11	75.4	75.2	9.9303	12.2532	11.0918
	30	2.28	2.5	75.2	75.0	13.2404	14.5180	13.8792
	35	0.41	1.51	75.0	74.7	2.3810	8.7689	5.5749
	40	4.01	1.22	74.5	74.3	23.2869	7.0848	15.1858

	45	2.18	0.89	74.3	74.0	12.6597	5.1684	8.9141
	50	0.33	3	74.3	73.6	1.9164	17.4216	9.6690
	55	4.08	1	74.0	73.2	23.6934	5.8072	14.7503
	60	1.31	0.33	73.8	73.0	7.6074	1.9164	4.7619
	65	2.45	0.87	73.2	72.8	14.2276	5.0523	9.6400
	70	0.05	0.45	72.3	72.4	0.2904	2.6132	1.4518
	75	0.15	1.35	70.9	72.3	0.8711	7.8397	4.3554
	80	0.94	1.11	70.7	72.0	5.4588	6.4460	5.9524
	85	0.01	0.31	70.6	71.8	0.0581	1.8002	0.9292
	90	0.23	1.79	70.4	71.5	1.3357	10.3949	5.8653
	95	0.1	0.02	70.1	70.7	0.5807	0.1161	0.3484
	0	0	0	76.2	76.5	0	0	0
2.4	5	17.49	11.77	76.1	76.2	101.5679	68.3508	84.9593
	10	1.51	5.89	63.8	64.5	8.7689	34.2044	21.4866
	15	3.74	1.33	63.8	64.1	21.7189	7.7236	14.7213
	20	0.08	6.68	64	63.5	0.4646	38.7921	19.6283
	25	0.19	2.44	64.1	62.8	1.1034	14.1696	7.6365
	30	1.9	2.55	64.1	62.7	11.0337	14.8084	12.9210
	35	7.67	1.01	64.4	62.5	44.5412	5.8653	25.2033
	40	3.34	0.43	64.2	62.3	19.3961	2.4971	10.9466
	45	4.19	4.44	64.2	62.3	24.3322	25.7840	25.0581
	50	1.13	2.11	64.3	62.2	6.5621	12.2532	9.4077
	55	2.37	3.01	64.3	62.1	13.7631	17.4797	15.6214

Table 15 Experimental Data of Transmembrane Flux at Different DS concentration (Passion Fruit Juice)

Concentration of Draw Solution (M)	Time (minutes)	Weight Change (g)		Conductivity (mS/cm)			Transmembrane Flux (L/m ² hr)		
		1st	2nd	1st	2nd	Average	1st	2nd	Average
1.0 M	-								
	0	0	0	80	79	79.5	0	0	0
	5	10.61	4.61	76.3	78.7	77.5	61.6144	26.7712	44.1928
	10	0.49	0.13	76.3	78.6	77.45	2.8455	0.7549	1.8002
	15	0.33	0.78	76.2	78.4	77.3	1.9164	4.5296	3.2230
	20	0.09	0.12	76.2	77.8	77	0.5226	0.6969	0.6098
	25	1.11	0.1	76.0	77.5	76.75	6.4460	0.5807	3.5134
	30	0.22	0.8	76.0	77.3	76.65	1.2776	4.6458	2.9617
	35	0.34	0.64	75.7	77.2	76.45	1.9744	3.7166	2.8455
	40	0.1	0.02	75.8	76.9	76.35	0.5807	0.1161	0.3484
	45	0.12	0.33	75.6	76.8	76.2	0.6969	1.9164	1.3066
	50	0.82	0.45	75.5	76.5	76	4.7619	2.6132	3.6876
	55	0.01	1.21	75.3	76.3	75.8	0.0581	7.0267	3.5424
	60	0.39	0.33	75.1	76.2	75.65	2.2648	1.9164	2.0906
	65	0.12	0.67	74.8	76.0	75.4	0.6969	3.8908	2.2938
	70	0.11	0.88	74.2	75.9	75.05	0.6388	5.1103	2.8746
1.5	75	0.55	0.23	74.0	75.7	74.85	3.1940	1.3357	2.2648
	80	0.1	0.12	73.9	75.5	74.7	0.5807	0.6969	0.6388
	85	1.42	0.22	73.8	75.4	74.6	8.2462	1.2776	4.7619
	90	2	0.21	73.6	75.2	74.4	11.6144	1.2195	6.4170
	95	5.25	0.34	73.4	75.0	74.2	30.4878	1.9744	16.2311
	100	0	0.33	73.4	74.6	74	0.0000	1.9164	0.9582
	105	0	0.3	73.2	74.5	73.85	0.0000	1.7422	0.8711
	110	0.25	0.15	73.0	74.2	73.6	1.4518	0.8711	1.1614
	115	0.11	4.67	72	73.7	72.85	0.6388	27.1196	13.8792
	0	0	0	103.2	103.0	103.1	0	0	0

5	10.23	6.77	100.9	100.1	100.5	59.4107	39.3148	49.3612
10	0.89	1.12	100.8	99.9	100.35	5.1684	6.5041	5.8362
15	1.48	2.22	100.7	99.3	100	8.5947	12.8920	10.7433
20	0.43	1.34	99.6	99.0	99.3	2.4971	7.7816	5.1394
25	0.31	0.88	99.5	98.8	99.15	1.8002	5.1103	3.4553
30	0.32	2.32	99.5	98.3	98.9	1.8583	13.4727	7.6655
35	1.14	1.35	99.2	98.0	98.6	6.6202	7.8397	7.2300
40	2.22	1.78	99.0	97.6	98.3	12.8920	10.3368	11.6144
45	1.86	0.89	97.4	97.4	97.4	10.8014	5.1684	7.9849
50	1.12	1.44	97.2	97.3	97.25	6.5041	8.3624	7.4332
55	1.47	1.67	97.0	97.0	97	8.5366	9.6980	9.1173
60	3.28	1.44	96.4	97.0	96.7	19.0476	8.3624	13.7050
65	0.81	1.22	96.2	96.9	96.55	4.7038	7.0848	5.8943
70	2.11	1.23	95.8	96.7	96.25	12.2532	7.1429	9.6980
75	1.35	1	95.4	96.5	95.95	7.8397	5.8072	6.8235
80	0.65	0.58	95.2	96.4	95.8	3.7747	3.3682	3.5714
85	0.79	0.41	95.0	96.3	95.65	4.5877	2.3810	3.4843
90	0.23	0.12	95.0	96.2	95.6	1.3357	0.6969	1.0163
0	0	0	138.6	137.8	138.2	0	0	0
5	12.5	8.33	134.2	133.3	133.75	72.5900	48.3740	60.4820
10	7.13	1.55	132.1	130.9	131.5	41.4053	9.0012	25.2033
15	0.83	2.78	130.2	128.8	129.5	4.8200	16.1440	10.4820
20	1.71	1.21	128.3	128.2	128.25	9.9303	7.0267	8.4785
25	0.43	0.13	128.0	127.5	127.75	2.4971	0.7549	1.6260
30	1.01	3.68	127.5	126.5	127	5.8653	21.3705	13.6179
35	0.64	2	127.3	124.2	125.75	3.7166	11.6144	7.6655
40	0.4	0.2	127.3	123.4	125.35	2.3229	1.1614	1.7422
45	0.1	0.58	127.2	123.4	125.3	0.5807	3.3682	1.9744
50	0.22	0.12	126.8	123.0	124.9	1.2776	0.6969	0.9872
55	0.2	1.01	126.7	122.3	124.5	1.1614	5.8653	3.5134
60	0.67	0.41	126.3	120.3	123.3	3.8908	2.3810	3.1359

	65	1.33	0.44	125.3	120.1	122.7	7.7236	2.5552	5.1394
	70	0.3	0.8	125.2	120.0	122.6	1.7422	4.6458	3.1940
	75	2.38	0.33	125.0	120.0	122.5	13.8211	1.9164	7.8688
2.5	0	0	0	151.6	151.2	151.4	0	0	0
	5	15	11.77	146.3	148.1	147.2	87.1080	68.3508	77.7294
	10	3.01	3.79	144.3	144.2	144.25	17.4797	22.0093	19.7445
	15	1.98	1.1	142.5	143.2	142.85	11.4983	6.3879	8.9431
	20	0.67	4.79	140.7	141.2	140.95	3.8908	27.8165	15.8537
	25	1.97	2.85	139.2	140.0	139.6	11.4402	16.5505	13.9954
	30	0.42	3.81	138.2	138.2	138.2	2.4390	22.1254	12.2822
	35	1.19	3.53	134.2	135.9	135.05	6.9106	20.4994	13.7050
	40	2.76	0.8	132.9	132.0	132.45	16.0279	4.6458	10.3368
	45	2.9	3.76	130.9	131.46	131.18	16.8409	21.8351	19.3380
	50	5.11	3.33	129.4	130.22	129.81	29.6748	19.3380	24.5064
	55	4.19	2.23	128.3	128.22	128.26	24.3322	12.9501	18.6411
	60	3.38	2.88	126.4	126.11	126.255	19.6283	16.7247	18.1765
	65	4.41	3.79	125.2	125.22	125.21	25.6098	22.0093	23.8095
	70	1.89	1.13	125.2	124.59	124.895	10.9756	6.5621	8.7689
3.0	0	0	0	177.8	178.2	178	0	0	0
	5	38.6	13.1	172.0	170.2	171.1	224.1580	76.0743	150.1161
	10	1.29	3.91	165.9	168.3	167.1	7.4913	22.7062	15.0987
	15	7.02	3.78	162.2	166.2	164.2	40.7666	21.9512	31.3589
	20	0.66	7.91	160.9	165.7	163.3	3.8328	45.9350	24.8839
	25	0.42	5.17	158.9	164.3	161.6	2.4390	30.0232	16.2311
	30	1.23	3.23	154.2	163.0	158.6	7.1429	18.7573	12.9501
	35	0.3	4	152.0	160.7	156.35	1.7422	23.2288	12.4855
	40	2.25	2	149.0	159.7	154.35	13.0662	11.6144	12.3403
	45	1	1.8	148.8	159.2	154	5.8072	10.4530	8.1301
	50	0.93	2.42	147.7	157.8	152.75	5.4007	14.0534	9.7271
	55	0.19	5.78	146.3	154.2	150.25	1.1034	33.5656	17.3345
	60	15.01	1.4	141.3	153.2	147.25	87.1661	8.1301	47.6481

	65	6.09	1.02	143.2	140.2	35.3659	5.9233	20.6446
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Table 16 Experimental Data of Transmembrane Flux at Different DS concentration (Distilled Water)

Flow Rate of Solution (L/min)	Time (minutes)	Weight Change (g)		Conductivity (mS/cm)			Transmembrane Flux (L/m ² hr)		
		1st	2nd	1st	2nd	Average	1st	2nd	Average
0.8	-								
	0	0	0	80	79	80	0	0	0
	5	0.0002	0.0012	76.3	78.7	76.3	1.4634	7.2561	4.3598
	10	0.0001	0.0001	76.3	78.6	76.3	0.4878	0.6098	0.5488
	15	0.0005	0.0007	76.2	78.4	76.2	2.8049	4.2073	3.5061
	20	0.0002	0.0001	76.2	77.8	76.2	1.2805	0.6098	0.9451
	25	0.0002	0.0001	76.0	77.5	76.0	1.4024	0.6707	1.0366
	30	0.0004	0.0001	76.0	77.3	76.0	2.6220	0.6098	1.6159
	35	0.0001	0.0000	75.7	77.2	75.7	0.5488	0.1829	0.3659
	40	0.0000	0.0003	75.8	76.9	75.8	0.0000	1.8902	0.9451
	45	0.0005	0.0003	75.6	76.8	75.6	2.9878	2.0732	2.5305
	50	0.0000	0.0001	75.5	76.5	75.5	0.1220	0.7317	0.4268
	55	0.0001	0.0002	75.3	76.3	75.3	0.9146	1.2195	1.0671
	60	0.0002	0.0001	75.1	76.2	75.1	1.1585	0.7317	0.9451
	65	0.0001	0.0002	74.8	76.0	74.8	0.6098	1.3415	0.9756
	70	0.0001	0.0007	74.2	75.9	74.2	0.5488	4.2073	2.3780
	75	0.0001	0.0004	74.0	75.7	74.0	0.3659	2.5610	1.4634
	80	0.0001	0.0004	73.9	75.5	73.9	0.4878	2.3171	1.4024
	85	0.0000	0.0000	73.8	75.4	73.8	0.3049	0.3049	0.3049
	90	0.0001	0.0001	73.6	75.2	73.6	0.6098	0.6098	0.6098
	95	0.0001	0.0001	73.4	75.0	73.4	0.4878	0.8537	0.6707
	100	0.0002	0.0001	73.4	74.6	73.4	1.0366	0.6707	0.8537

	105	0.0001	0.0010	73.2	74.5	73.2	0.6098	6.0976	3.3537
	110	0.0003	0.0004	73.0	74.2	73.0	1.5244	2.1341	1.8293
	115	0.0005	0.0002	72	73.7	72	2.8049	1.3415	2.0732
1.2	0	0	0	79.5	79.3	79.5	0	0	0
	5	0.0005	0.0001	79.0	78.3	79.0	2.9878	0.793	1.890
	10	0.0003	0.0008	78.0	78.2	78.0	2.0122	4.756	3.384
	15	0.0001	0.0001	77.9	77.6	77.9	0.5488	0.732	0.640
	20	0.0011	0.0001	77.1	77.2	77.1	6.7683	0.610	3.689
	25	0.0002	0.0008	76.9	76.8	76.9	1.3415	4.878	3.110
	30	0.0003	0.0006	76.3	76.5	76.3	2.0732	3.902	2.988
	35	0.0001	0.0000	75.8	76.3	75.8	0.6098	0.122	0.366
	40	0.0001	0.0003	75.3	76.0	75.3	0.7317	2.012	1.372
	45	0.0008	0.0004	74.8	75.9	74.8	5.0000	2.744	3.872
	50	0.0000	0.0012	74.3	75.4	74.3	0.0610	7.378	3.720
	55	0.0004	0.0003	73.8	75.3	73.8	2.3780	2.012	2.195
	60	0.0001	0.0007	73.0	75.0	73.0	0.7317	4.085	2.409
	65	0.0001	0.0009	72.4	74.8	72.4	0.6707	5.366	3.018
	70	0.0005	0.0002	72.3	74.1	72.3	3.3537	1.402	2.378
	75	0.0001	0.0001	72.0	73.2	72.0	0.6098	0.732	0.671
	80	0.0014	0.0002	71.2	73.0	71.2	8.6585	1.341	5.000
	85	0.0020	0.0002	70.2	72.1	70.2	12.1951	1.280	6.738
	90	0.0053	0.0003	68.3	72.0	68.3	32.0122	2.073	17.043
1.6	0	0	0	76.3	77.0	76.7	0	0	0
	5	0.0015	0.0028	76.2	76.7	76.2	9.1463	17.073	13.110
	10	0.0043	0.0029	76.2	76.3	76.2	26.2195	17.683	21.951
	15	0.0019	0.0010	76.0	76.0	76.0	11.5854	6.098	8.841
	20	0.0019	0.0007	75.7	75.8	75.7	11.8902	4.329	8.110
	25	0.0013	0.0016	75.6	75.4	75.6	8.1098	9.573	8.841
	30	0.0003	0.0004	75.4	75.2	75.4	2.0122	2.683	2.348
	35	0.0003	0.0009	75.2	75.0	75.2	1.9512	5.488	3.720
	40	0.0001	0.0008	75.0	74.7	75.0	0.6707	4.634	2.652

2.0	45	0.0001	0.0007	74.5	74.3	74.5	0.5488	4.024	2.287
	50	0.0005	0.0010	74.3	74.0	74.3	3.2317	6.098	4.665
	55	0.0009	0.0006	74.3	73.6	74.3	5.7317	3.537	4.634
	60	0.0003	0.0006	74.0	73.2	74.0	1.5854	3.963	2.774
	65	0.0011	0.0011	73.8	73.0	73.8	6.6463	6.707	6.677
	70	0.0010	0.0003	73.2	72.8	73.2	6.0366	1.707	3.872
	75	0.0000	0.0001	72.3	72.4	72.3	0.0610	0.366	0.213
	0	0	0	80	79	80	0	0	0
	5	0.0395	0.0007	78.3	78.1	78.2	240.915	3.963	122.439
	10	0.0010	0.0023	78.9	77.5	78.2	6.280	14.329	10.305
	15	0.0011	0.0021	78.1	77.0	77.6	6.707	12.805	9.756
	20	0.0020	0.0018	77.5	76.9	77.2	12.195	10.793	11.494
	25	0.0017	0.0021	76.2	76.5	76.2	10.427	12.866	11.646
	30	0.0023	0.0025	76.3	78.7	76.3	13.902	15.244	14.573
	35	0.0004	0.0015	76.3	78.7	76.3	2.500	9.207	5.854
2.4	40	0.0040	0.0012	76.3	78.7	76.3	24.451	7.439	15.945
	45	0.0022	0.0009	76.3	78.6	76.3	13.293	5.427	9.360
	50	0.0003	0.0030	76.2	78.4	76.2	2.012	18.293	10.152
	55	0.0041	0.0010	76.2	77.8	76.2	24.878	6.098	15.488
	60	0.0013	0.0003	76.0	77.5	76.0	7.988	2.012	5.000
	65	0.0024	0.0009	76.0	77.3	76.0	14.939	5.305	10.122
	70	0.0001	0.0005	75.7	77.2	75.7	0.305	2.744	1.524
	0	0	0	75.8	76.9	75.8	0	0	0
	5	0.0673	0.0022	75.6	76.8	75.6	410.366	13.597	211.982
	10	0.0025	0.0059	75.5	76.5	75.5	15.305	35.914	25.60976
	15	0.0073	0.0013	75.3	76.3	75.3	3.350	8.1097	5.7256
	20	0.0001	0.0067	75.1	76.2	75.1	0.366	40.731	20.548
	25	0.0002	0.0024	74.8	76.0	74.8	1.280	14.878	8.0793
	30	0.0039	0.0026	74.2	75.9	74.2	23.780	15.548	19.665
	35	0.0357	0.0010	74.0	75.7	74.0	217.500	6.1585	111.83
	40	0.0003	0.0004	73.9	75.5	73.9	2.073	2.6219	2.347

	45	0.0002	0.0044	73.8	75.4	73.8	1.159	27.073	14.115
	50	0.0001	0.0021	73.6	75.2	73.6	0.793	12.865	6.829
	55	0.0673	0.0202	73.4	75.0	73.4	410.366	122.988	110.61
	60	0.0025	0.0022	73.4	74.6	73.4	15.305	13.597	211.983
	65	0.002	0.0059	73.2	74.5	73.2	4.268	35.914	25.609

Table 17 Experimental Data at 6M DS Concentration

Flow Rate of Solution (L/min)	Time (minutes)	Weight Change (g)		Conductivity (mS/cm)			Transmembrane Flux (L/m ² hr)		
		1st	2nd	1st	2nd	Average	1st	2nd	Average
2.4 L/min	-	-	-	283.1	282	282.55	-	-	-
	0	50	4.3	270.61	278.9	274.755	290.360	24.971	157.666
	20	2	2.6	265.11	275.9	270.505	11.614	15.099	13.357
	30	10.58	4.3	264.31	273	268.655	61.440	24.971	43.206
	40	1.98	7.88	250.22	270.1	260.16	11.498	45.761	28.630
	50	2.23	2.02	240.3	265.3	252.8	12.950	11.731	12.340
	60	3.09	3.2	230.34	255.2	242.77	17.944	18.583	18.264
	70	12.21	3.14	225.63	250.8	238.215	70.906	18.235	44.570
	80	4.9	3.56	223.12	245.8	234.46	28.455	20.674	24.564
	90	2.24	3.22	218.45	238	228.225	13.008	18.699	15.854
	100	4.66	7.11	215.34	230.1	222.72	27.062	41.289	34.175
	110	6	17.73	210.04	228.6	219.32	34.843	102.962	68.902
	120	12.22	9.62	206.77	226.55	216.66	70.964	55.865	63.415
	130	3.01	12.3	203.144	215.6	209.372	17.480	71.429	44.454
	140	3.56	7.62	198.76	207.8	203.28	20.674	44.251	32.462
	150	5.76	10.84	194.63	204.3	199.465	33.449	62.950	48.200
	160	4.47	10.18	192.11	200.3	196.205	25.958	59.117	42.538
	170	4.75	6.14	188.98	198.5	193.74	27.584	35.656	31.620
	180	4.03	3.57	186.46	196.3	191.38	23.403	20.732	22.067
	190	5.18	4.44	184.45	194.24	189.345	30.081	25.784	27.933
	200	6.68	5.45	183.21	190.8	187.005	38.792	31.649	35.221
	210	5.32	19.83	180.3	185.6	182.95	30.894	115.157	73.026
	220	10	4.17	178.55	183.5	181.025	58.072	24.216	41.144
	230	6.69	5.91	176.49	178.4	177.445	38.850	34.321	36.585
	240	10.55	6.86	173.00	174.56	173.78	61.266	39.837	50.552

