



UNIVERSITI PUTRA MALAYSIA

***CLARIFIED PASSION FRUIT JUICE CONCENTRATION USING
FORWARD OSMOSIS MEMBRANE WITH POTASSIUM SORBATE AS
DRAW SOLUTION***

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OSMOSIS MEMBRANE WITH POTASSIUM SORBATE AS DRAW SOLUTION**

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**PROJECT REPORT SUBMITTED IN PARTIALLY FULFILLMENT OF THE
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ABSTRACT

Forward osmosis (FO) is an osmosis process which induces by an osmotic pressure gradient between feed solution (FS) and draw solution (DS). Due to the difference in solute concentration, the osmotic pressure difference is created and forces the permeates from FS to transfer across the semipermeable membrane to DS. This study establishes a FO system to concentrate clarified passion fruit juice by using cellulose triacetate (CTA) membrane and potassium sorbate solution (2M to 5M) as DS. In this study, transmembrane flux and Brix were evaluated by using different concentrations of DS. The highest average of transmembrane flux ($6.705 \text{ L/m}^2 \text{ hr}$) and highest increased of Brix value ($0.57^\circ \pm 0.03$) were observed when using 5M potassium sorbate. When 5M sodium chloride solution was compared with the performance of 5M potassium sorbate solution, it showed greater significance on transmembrane flux ($7.790 \text{ L/m}^2 \text{ hr}$) and Brix increment ($0.73^\circ \pm 0.07$). The event of reverse salt diffusion (RSD) was observed as traces of DS (potassium sorbate or sodium chloride), which were found through the Fourier-transform infrared spectroscopy (FTIR) spectrum analysis of concentrated clarified passion fruit. More fouling on the surface CTA membrane was found when conducted FO process at 5M when compared with 2M of potassium sorbate. When compared to commercial passion fruit juice which concentrated through evaporation, clarified passion fruit juice concentrated by forward osmosis preserved the quality of juice better.

ABSTRAK

Osmosis maju (FO) adalah process osmosis yang didorong oleh perbezaan tekanan osmotic antara larutan suapan (FS) dan larutan penarik (DS). Disebabkan perbezaan kepekatan zat terlarut, perbezaan tekanan osmotic dihasilkan dan menyebabkan pengaliran air dari FS ke DS melalui membran. Dalam kajian ini, satu FO system telah dibentuk untuk memekatkan jus buah markisa yang diklarifikasikan dengan menggunakan membran selulosa triacetate (TCA) dan larutan kalium sorbate (2M hingga 5M) sebagai DS. Dalam penyiasatan ini, fluks transmembran dan Brix dinilai melalui penggunaan DS dalam kelarutan yang berbeza. Purata fluks transmembrane ($6.705 \text{ L/m}^2 \text{ jam}$) yang dan pertambahan Brix ($0.57^\circ \pm 0.03$) tertinggi didapati semasa 5M kalium sorbat digunakan. 5M larutan natrium klorida digunakan untuk membuat perbandingan dengan prestasi 5M larutan kalium sorbat, natrium klorida didapati mempunyai kesan yang lebih ketara berbanding dengan 5M kalium sorbat dari aspek fluks transmembran ($7.790 \text{ L/m}^2 \text{ jam}$) dan pertambahan Brix ($0.73^\circ \pm 0.07$). Kejadian resapan garam terbalik (RSD) berlaku semasa sisa kalium sorbate dan natrium klorida didapati dalam jus buah markisa yang diklarifikasikan dan dipekatkan melalui spektroskopi inframerah-transformasi Fourier (FTIR). Membran CTA yang menggunakan 5M kalium sorbat didapati mempunyai kotoran di permukaannya. Secara keseluruhan, kotoran diperhati dalam FO system yang menggunakan jus buah markisa yang diklarifikasikan adalah tidak serius. Secara perbandingan, jus buah markisa diklarifikasikan dan dipekatkan melalui FO dapat mengekalkan quality jusnya dengan lebih baik daripada jus buah markisa komersial yang dipekatkan oleh proses evaporasi.

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LIST OF ABBREVIATIONS

FO - forward osmosis
 FS - feed solution
 DS - draw solution
 RSD - reverse salt diffusion
 CP - concentration polarisation
 ICP - internal concentration polarisation
 ECP - external concentration polarisation
 ALFS - active layer facing feed solution
 ALDS - active layer facing draw solution

CHAPTER 1 INTRODUCTION

1.1 Background

Recently, fruit juice is considered a popular beverage among the consumer as they think it is a healthier choice among the beverages in the market (Caswell, 2009). Fruit juice can be freshly squeezed and being transported to the retailer within 24 hours or make it into concentrate which has a longer shelf life and can be processed into drinks. For concentrate, the juice is extracted and concentrated by vacuum evaporation or multi-stage evaporation (Jiao & Cassano, 2004).

Dewatering of liquid food is important to preserve the product by increasing the product stability, improve shelf-life, and reduce transportation costs (Kim et al., 2018). Based on the methods of processing liquid foods, concentration is needed as it eases the process of handling, packaging, storage and transporting and prolonged shelf life as low water activity inhibits the growth of microorganisms (Drioli et al., n.d.). Method of concentrating fruit juice can be classified as thermal and non-thermal methods.

For thermal method, multi-stage evaporation is used to concentrate fruit juice. Evaporation is advantageous as it has a low maintenance cost, able to remove high percentage of water (Blandin et al., 2020). In multi-stage evaporation, it can be done up to 4 to 6 times to reduce water content in the fruit juice. This method is energy-intensive and caused certain nutrients to deteriorate, change in flavour due to vapourisation of volatile flavouring compounds and intensification of nonenzymatic browning (Junyi, 2018). Due to most of the nutrients are heat sensitive, nutrients deterioration is an issue

that could not be avoided in conventional thermal based method of dewatering (Wenten et al., 2021).

Since the thermal-based method has such shortcomings, membrane technology has been a replacement for the thermal-based process to achieve dewatering purposes. For example, microfiltration (MF) and ultrafiltration (UF) are applied in the food industry to remove particle that is in the range of 0.01 to 1 μm under low operating pressure. Reverse osmosis (RO) has the ability to retain the smallest organics, heavy metals, salts and has proven to be less energy-intensive than thermal-based concentration process. RO is replaced by nanofiltration (NF) as RO operates at high pressure and is limited by fouling propensity. Process of UF operates in intermediate properties where the size of molecular can be retained and the operating pressure is intermediate (Blandin et al., 2020). Osmotic distillation (OD) is another recent membrane technology that can also be known as osmotic evaporation. In OD, two liquids with different solute concentrations are separated with microporous membranes. Vapour-liquid interface is formed due to prevention of aqueous solution to penetrate through microporous membranes, vapour is transferred across the membrane under vapour pressure difference. Another process which is similar to OD, membrane distillation (MD) is proposed to concentrate liquid food. MD has high rejection to ions, macromolecules, colloids, cells and other nonvolatile compounds. However, OD and MD have still remained in pilot scale (Drioli et al., n.d.).

In 1960, forward osmosis (FO) is being introduced in food concentrating. FO is a membrane technology where osmotic pressure differential (also called solute concentration) is the driving force between feed solution (FS) and draw solution (DS). The permeation of water through the membrane is from low concentration (feed side) to

high concentration (draw solution). FO is advantageous and preferable than thermal-based method and other membrane technology (Blandin et al., 2020). For example, FO process does not need pressure pump to force water to transport across the membrane since water flux is generated by the difference of osmotic pressure. It is operated at ambient temperature, thus thermal degradation on food is not a concern thus food quality is well preserved. Also, FO has high recovery rate and small amount of DS is disposed and less pollution is caused, DS can be recovered after the process and it can be reused (Anna et al., 2012).

Although FO has many advantages, it still has some shortcomings that affect the process such as fouling, concentration polarization (CP) and reverse salt diffusion (RSD). Due to lack of hydraulic pressure, the fouling caused by FO is low and is less irreversible than other pressure-driven membranes (Eyvaz et al., 2018). Fouling occurred in FO membrane is fixable as it can be cleaned by rinsing and osmotic backwashing (Haupt & Lerch, 2018). Concentration polarization of FO consists of external concentration polarization (ECP) and internal concentration polarization (ICP), where ICP is most concerned. ICP is affected by the nature of membrane such as membrane orientation and membrane porous support structure (G. Li et al., 2013).

Draw solution (DS) is a concentrated solution which can draw water molecules from FS through the membrane, a suitable DS to be used in food concentration is crucial as unsuitable DS may result in RSD, growth of microorganism which caused by fouling, change in taste, odour and nutrient of FS (An et al., 2019a). The common use of DS in previous FO for food processes are NaCl, MgCl₂ and sucrose while in this project potassium sorbate, a common preservative in food industry is used.

In this case, FTS H2O flat sheet membrane, cellulose triacetate (CTA) membrane is manufactured by using derivatives of cellulose. This membrane possesses characteristics such high hydrophilic nature and low fouling propensity which is suitable for FO system especially in dewatering food products. Wenten et al. (2021) reported that by fabricating a CTA using phase inversion technique, a highly porous sublayer in between two selective skin layers can prevent penetration of salt and other solutes in DS to membrane porous support. Thus, it will produce low salt leakage and less internal concentration polarization in FO process (Rastogi, 2014). Overall, it performs better than commercial RO membrane and thin film composite membrane which typically used in previous FO research.

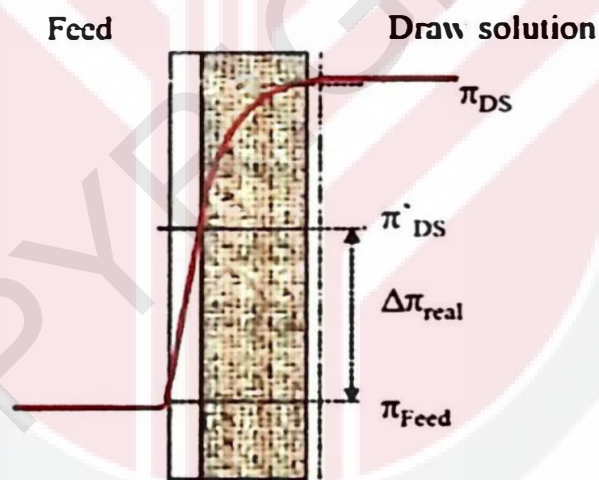


Figure 1-1: Schematic mechanism of FO in a food model system indicating water transport through membrane from feed solution to draw solution, which is placed towards active layer (Anna et al., 2012).

In FO process, active layer is generally placed at the FS side while support layer is placed at DS side, this orientation is called active layer facing feed solution (AL-FS mode). In AL-FS mode, the external concentration polarization (ECP) will be lower and

the difference of osmotic pressure will be higher. This eventually will lead to high water flux through the FO membrane, lesser damage will bring to the membrane (Anna et al., 2012). Equation 1.1 below describes the water transport across FO membrane:

$$J_w = A(\pi_{Draw\ Solution} - \pi_{Feed} - \Delta P) \quad 1.1$$

J_w is the water flux, A is the water permeability constant of the membrane, $\pi_{Draw\ Solution}$ is the osmotic pressure of the DS, π_{Feed} is the osmotic pressure of the FS and ΔP is the difference pressure between two solutions.

Several factors that can affect the performance of FO such as selection of DS, concentration of DS, water flux, RSD, ICP, fouling, water recovery in the regeneration process (Wenten et al., 2021). In this case, fouling is mostly caused by the accumulation of substances such as pectin, tannins, proteins, starch and hemicellulose. Thus, to enhance water flux in FO system, pectin in passion fruit juice is removed by using enzyme treatment to minimize fouling on the CTA membrane. In enzyme treatment, pectinase is added into fruit juice and incubated at 50 °C for 1 hour and deactivated before being centrifuged. After pectin and suspended particles are removed, a clear and clarified passion fruit juice is obtained. In this study, concentration of DS is manipulated to determine the performance of FO process on clarified passion fruit juice. The results are also used to do comparison with performance of FO on passion fruit juice without enzyme treatment. Lastly, the quality of concentrated clarified passion fruit is evaluated.

1.2 Problem Statement

In fruit juice processing, thermal based method, evaporation has been a common method to concentrate the fruit juice due to ease to conduct, low maintenance cost and higher removal of water. However, high temperature process is detrimental to heat-sensitive nutritious components such as anthocyanins, carotenoids, vitamins and bioactive proteins (Anna et al., 2012). Thus, more suitable method, FO is chosen to concentrate fruit juice.

Besides, fruit juice appearance is one of the important factors for the consumer while cloudiness is a common problem in fruit juice production. The cloudiness of fruit juice is basically due to pectin, hemicellulose, lignin, protein and metal. Colloid is formed when pectin concentration is high, contributes to cloudiness. To ensure clear fruit juice is produced, enzyme treatment by pectinase is suggested to remove pectin in it. Also, removal pectin in fruit juice would enhance water flux in FO (Sandri et al., 2011).

1.3 Objectives

The objectives of this study are to:

- i) To evaluate the performance of forward osmosis process on concentrating clarified passion fruit juice using different concentrations of potassium sorbate as draw solution.
- ii) To analyse quality of clarified passion fruit juice that undergo forward osmosis from aspect of Brix, pH, Fourier-transform infrared spectroscopy, ascorbic acid content, L^* , a^* and b^* .

1.4 Scope of Study

This study focuses on the performance of forward osmosis in dewatering clarified passion fruit juice and compares with previous study on dewatering unclarified passion fruit juice. Concentration of draw solution will be manipulated to study the change of transmembrane flux. By comparing to fresh juice, commercial fruit juice, clarified passion fruit juice and concentrated clarified passion fruit juice, effect of forward osmosis towards nutritional content can be investigated. RSD will be identified through tracing potassium sorbate using Fourier-transform infrared spectroscopy (FTIR). Lastly, fouling in forward osmosis will be studied by observing the image of membranes under Field Emission Scanning Electron Microscope (FESEM).

CHAPTER 2 LITERATURE REVIEW

2.1 Passion Fruit

Passion fruit (*Passiflora edulis* Sim.) is origin from Passifloraceae family which this family consists of 18 genera. Passiflora genus is one of the genera which comprises 50-60 edible species out of 530 species. Passion fruit can be differentiated into two species based on colour, purple passion fruit (*P. edulis* f. *edulis*) and yellow passion fruit (*P. edulis* f. *flavicarpa*). Both are considered quite similar in terms of few properties, only colour of the peels are distinguishable.

Originally, passion fruit is from Brazil and it is planted by other countries due to the rising demand. Purple passion fruit is primarily grown in Africa and Australasia while the yellow passion fruit is being grown in South America. Most of the supply of passion fruit comes from the plantation in South America, Africa, India, Australia, New Zealand and some of the members of South-East Asia countries. Overall, the best cultivation conditions for purple and yellow passion fruits are elevations of 650-2000m and 0-1300m respectively. At 26.5°C, it gives optimum development for the growth of passion fruit (Schotsmans & Fischer, 2011).

The appearance of passion fruit is round or oval with smooth, leathery skin with dark purple or light yellow colour. The average weight for purple and yellow passion fruits are 35g and 80g with an average of 3 mm of the outer skin. It can be found in black (purple fruit) or dark brown (yellow fruit) seeds which are hard and small but edible. Inside the

passion fruit, it is filled with yellow-orange pulp juice while the seeds are firmly attached to the inner wall.

There are many usages of passion fruit, it can be made into tea, jam, ice cream, beverages, wine, cake, medicines and so on. Traditionally, passion fruit juice is believed that it is effective in cough, constipation, insomnia and arthralgia treatment (He et al., 2020). Passion fruit consists of variant elements of nutrition, the nutritional composition of passion fruit is shown in the figure below.

Table 7.1 Nutritional characteristics of purple and yellow passion fruit. Ranges are presented.

Parameter	Purple		Yellow	
	Min	Max	Min	Max
Weight (g)	34.49	55.86	85	165
Diameter (cm)	4.35	5.57	6	8.5
Length (cm)	4.68	5.37	7	11
pH	2.97	4.64	2.8	3.15
Soluble solids content (%Brix)	11.9	17	11	21.4
TA (%)	0.5	5.7	2.2	4.5
Moisture (%)	71.83	72.57	55	79
Proteins (%)	2.2	3.1	0.7	
Fat (%)	0.07	0.7	0.2	
Glucose (%)	1.93	2.27		
Fructose (%)	1.95	2.25		
Sucrose (%)	2.67	3.13		
Citric acid (%)	2.58	3.42		
Malic acid (%)	0.22	0.38		
Fibre (%)	11.84	13.76		
Ash (%)	0.47	1.887	0.5	
Sodium (mg 100 g ⁻¹ FW)	7.08	30		
Potassium (mg 100 g ⁻¹ FW)	100	764		
Calcium (mg 100 g ⁻¹ FW)	6.06	53	3.8	
Magnesium (mg 100 g ⁻¹ FW)	16	29		
Iron (mg 100 g ⁻¹ FW)	0.6	1.6	0.4	
Vitamin B6 (mg 100 g ⁻¹ FW)	0.236			
Vitamin C (mg 100 g ⁻¹ FW)	20.9	30	20	40
Vitamin E (mg α -tocopherol equivalent 100 g ⁻¹ FW)	0.05	1.12		0.8

Figure 2-1: Nutritional composition of purple (*P. edulis* f. *edulis*) and yellow (*P. edulis* f. *flavicarpa*) passion fruit (Schotsmans & Fischer, 2011).

2.2 Forward Osmosis

Forward osmosis is considered a natural phenomenon of osmosis, it transports water across the membrane by the driving force, osmotic pressure difference. It transports water from a region of lower osmotic pressure to a region of higher osmotic pressure across a selectively permeable membrane. The side with low osmotic pressure and needed to be concentrated is called feed solution (FS) while the other side is draw solution (DS) with higher osmotic pressure. The process is able to operate without the exertion of physical pressure. It is considered low energy consumption as energy is only needed to pump FS and DS through the flow channels next to the membrane. It is advantageous from the aspect of low energy consumption and low fouling (Haupt & Lerch, 2018).

2.3 Draw Solution

Draw solution is the side with higher osmotic pressure, the selection of DS is very important to the process of liquid food concentration. Aspects such as osmotic pressure, viscosity, reverse salt diffusion (RSD), internal concentrative polarisation (ICP), toxicity and regeneration. Normally, DS used are sodium chloride, sucrose, glucose, sea bittern and potassium sorbate. Comparing with commonly used DS, sodium chloride, potassium sorbate is a better selection of DS due to it has a higher molecular weight, 160.22g/mol than 58.44g/mol than sodium chloride, this ensures that there will be a low possibility for RSD to occur as large molecule will be rejected by the FO membrane. Potassium sorbate has higher water solubility, 0.676g/g which is higher than 0.366g/g of sodium chloride. Besides, potassium sorbate is a widely used food preservative, it will not affect the taste

of the product. It is also non-volatile, it is easier to re-concentrate for reuse (An et al., 2019).

2.4 Concentration Polarisation

Concentration polarisation (CP) is a phenomenon where the water flux through membrane FS is concentrated on the membrane surface. The real effective osmotic pressure gradient is lower than the osmotic pressure difference between inlet FS and DS. Hence, there will be a lower permeate flux than expected. There are two types of CP will occur in FO process. External concentration polarisation (ECP) occurs on the membrane surface while internal concentration polarisation (ICP) happens within the porous support layer of the membrane (Nicoll & Limited, 2019).

FO membrane consists of active layer (AL) and support layer (SL). The orientation of membranes can be active layer facing FS (ALFS mode) or active layer facing DS (ALDS mode), different orientations will cause different ICP such as dilutive ICP and concentrative ICP. In FO, where FS is facing AL and DS is facing SL, dilutive ICP will occur. Water is diffused from feed to AL and diffused to SL and then to the bulk through the boundary layer. If DS has low molecular weight, DS will diffuse to SL to the interior surface of AL before transmembrane flux can occur. The concentration at interior surface of AL is far lower than in bulk solution. ICP will be setting up due to diffusion of water from the interior surface of AL and DS into SL. However, in ALFS mode, there will be less ECP to be happened (Nayak et al., 2011).

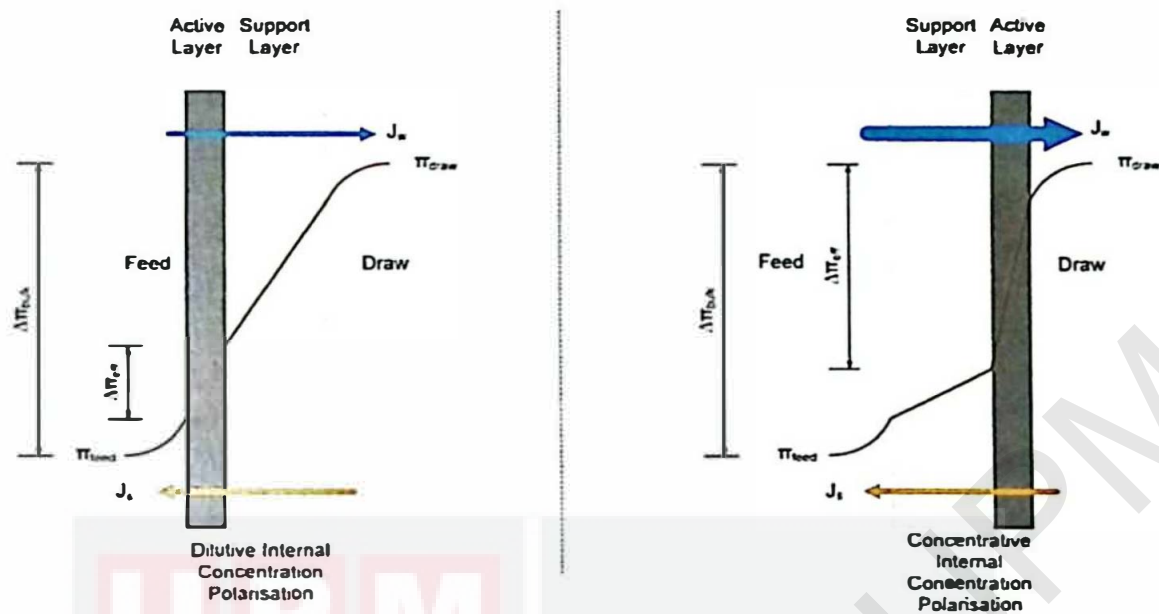


Figure 2-2: Dilutive internal concentration polarization and concentrative internal concentration polarization (Nicoll & Limited, 2019).

2.5 Membrane Fouling

Fouling in FO process is less than other membrane processes and it is more reversible and easier to be cleaned. However, it is still a problem for FO process. For ALFS mode, the fouling has occurred at external, where the foulants are deposited at active layer. Internal fouling will happen in ALDS orientation, it can happen at any location and is difficult to be cleaned. Thus, ALFS orientation is suggested to be practiced as it is reversible and low possibility to happen (Eyvaz et al., 2018).

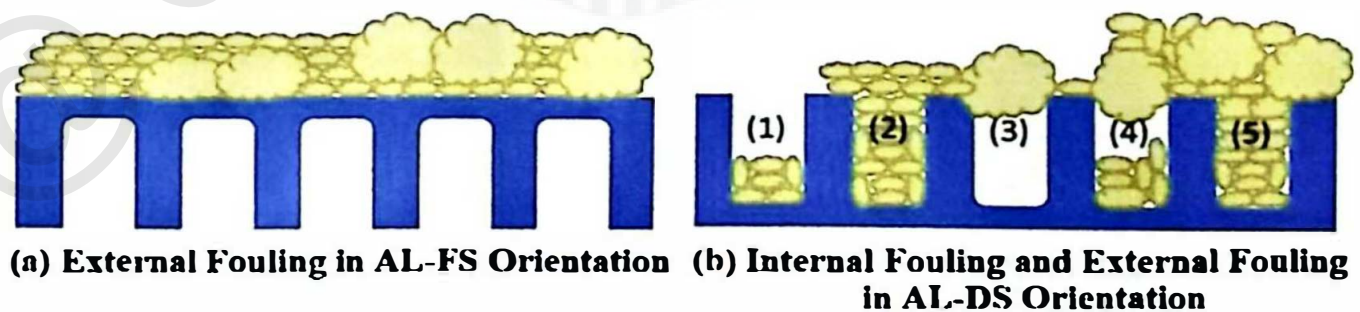


Figure 2-3: Fouling type in FO membrane (Eyvaz et al., 2018).

2.6 Previous Studies of Juice Concentration Using Forward Osmosis

Based on the research of Garcia-Castello & McCutcheon (2011), the process of FO has succeeded in dewatering press liquor derived from orange production. The experiment was manipulated by concentrations of DS at 2M and 4M, the process is conducted at 20 °C, using cellulose acetate (CA) membrane and the flow rate was fixed at 1 L min⁻¹ for FS and DS. The results showed that when the concentration of DS increased, the concentration yield increased however the increment was not as expected to be two folds. From the research, they found that there was a sharp decrease in permeate flux in every test due to the initial fouling of the membrane. The fouling was primarily due to the presence of pectin, it will form a cake or gel on the surface of the membrane. This layer will lead to concentration polarization and interfere driving force difference created by DS. Once the fouling was formed, the flux change was independent of the concentration of DS. Concentration yield for solutions containing pectin was 1.44 folds while for solution without pectin was 3.67 folds when the concentration of DS was 4.0 M. It is advisable to remove pectin before the dewatering process is conducted.

Fresh watermelon juice was tested by Rebecca et al. (2020) using FO system, the concentrate was compared in terms of Brix, lycopene and citrulline content, total soluble phenolics, antioxidant activity and sensory properties with other concentrates by other methods. The fresh watermelon juice can be concentrated until 65° Brix while the terms above were 45% higher than thermal-based method concentrate. Short season fruit is recommended to be concentrated by using FO system to maintain the taste, flavor and nutrients as FO technology is well suited to concentrate fruit juice in a large scale.

There was also research done on integrating FO with membrane distillation using potassium sorbate as DS in FO system. Apple juice was concentrated at 25 °C using 2.0 M potassium sorbate solution as DS, the final concentrate was increased from 10.6 to 45.1° Brix with $5 \text{ Lh}^{-1} \text{ m}^{-2}$ water flux. The study was comparing by using sodium chloride and potassium sorbate as DS. It showed that the water flux for 2.0 M potassium sorbate was lower than 2.0 M sodium chloride. However, the salt flux was lower, 0.04g/L if 2.0 M potassium sorbate was used compared to 2.0 M sodium chloride, 0.20g/L. Also, the trace concentration of potassium sorbate in the juice was 0.45g/L which was lower than the permitted amount in food. Thus, potassium sorbate gave low occurrence of reverse salt flux, the usage was safe and did not affect the flavour (An et al., 2019).

Anna et al. (2016) found that by manipulating the flow rate of FS and DS, and concentrations of DS, the water permeate flux increased when both flow rate and concentration DS increased while sodium reverse flux was only affected by the concentration of DS. The jaboticaba juice was concentrate using cellulose triacetate (CTA) membrane at 25°C, the highest water permeate flux, $3.59 \text{ Lh}^{-1} \text{ m}^{-2}$ and highest salt flux, $389.5 \text{ m}^{-2} \text{ h}^{-1}$ was found when 6.0 M sodium chloride was used. Pectin interacted with calcium ions will form gel layer cake on the surface, this gave severe fouling to the membrane and affect the water permeate flux. When 4.0 M sodium chloride flowed at 125 mL min^{-1} and 6.0 M sodium chloride flowed at 50 mL min^{-1} , both presented similar average water permeate flux. It was believed the severe gel cake formation due to pectin had decreased the CP on the surface and hence increased water transmembrane flux.

Based on the research of Nayak et al. (2011), by using cellulose triacetate membrane and 6.0 M sodium chloride as DS at flow rate 100mL min^{-1} for at least two cycles (6 hours per cycle), concentration of juice can increase at least 12 fold. It was found that beetroot was concentrated for two cycles and gained 52° Brix (22.6 fold) and the betalains in beetroot was rose from 50.92mg L^{-1} to 2.91g L^{-1} (57.1 fold). For pineapple juice, the concentration was increased from 4.4 to 54° Brix (12 fold). Meanwhile, after four cycles of circulation, concentrate grape juice had increment from 4.4 to 54° Brix (12.3 fold) for total soluble solids and increment of 6.8 folds in anthocyanin, from 104.85mg L^{-1} to 715.6mg L^{-1} . These previous studies have been summarised in Table 2-1 below.

Table 2-1: Summary of previous studies of juice concentration using forward osmosis.

Type of juice	Type of DS	Type of membrane	Temperature	Water flux (Lh ⁻¹ m ⁻²)	Final brix (°)	Reference
Orange	2.0 M NaCl	Cellulose acetate	20 °C	22.5	18.71	(Garcia-Castello & McCutcheon, 2011)
Orange	4.0 M NaCl	Cellulose acetate	20 °C	35	31.68	(Garcia-Castello & McCutcheon, 2011)
Apple	Potassium sorbate	Thin film composite polyamide	25°C	5	45.1	(An et al., 2019a)
Watermelon	70% glycerol	-	7°C	-	64.83	(Rebecca et al., 2020)
Jacoticaba	6.0 M NaCl	Cellulose triacetate	25°C	3.59	24	(Anna et al., 2016)
Beetroot	6.0 M NaCl	Cellulose triacetate	25 ± 2 °C	11.5	52	(Nayak et al., 2011)
Pineapple	6.0 M NaCl	Cellulose triacetate	25 ± 2 °C	9.5	54	(Nayak et al., 2011)
Grape	6.0 M NaCl	Cellulose triacetate	25 ± 2 °C	8	54	(Nayak et al., 2011)

2.7 Clarification of Fruit Juice by Pectinase

A polysaccharide with α -1 linear chain and 4-linked D-galacturonic acid residue in plant cell is pectin. It is considered the main component in the cell wall of fruits. The cloudiness of fruit juice is mainly contributed by pectin. Although the presence of pectin contributes to nutrition and taste in the juice, it affects the yield in fruit juice production, obstructs water movement during filtering as it gives high viscosity to fruit juice (Singh & Singh, 2015).

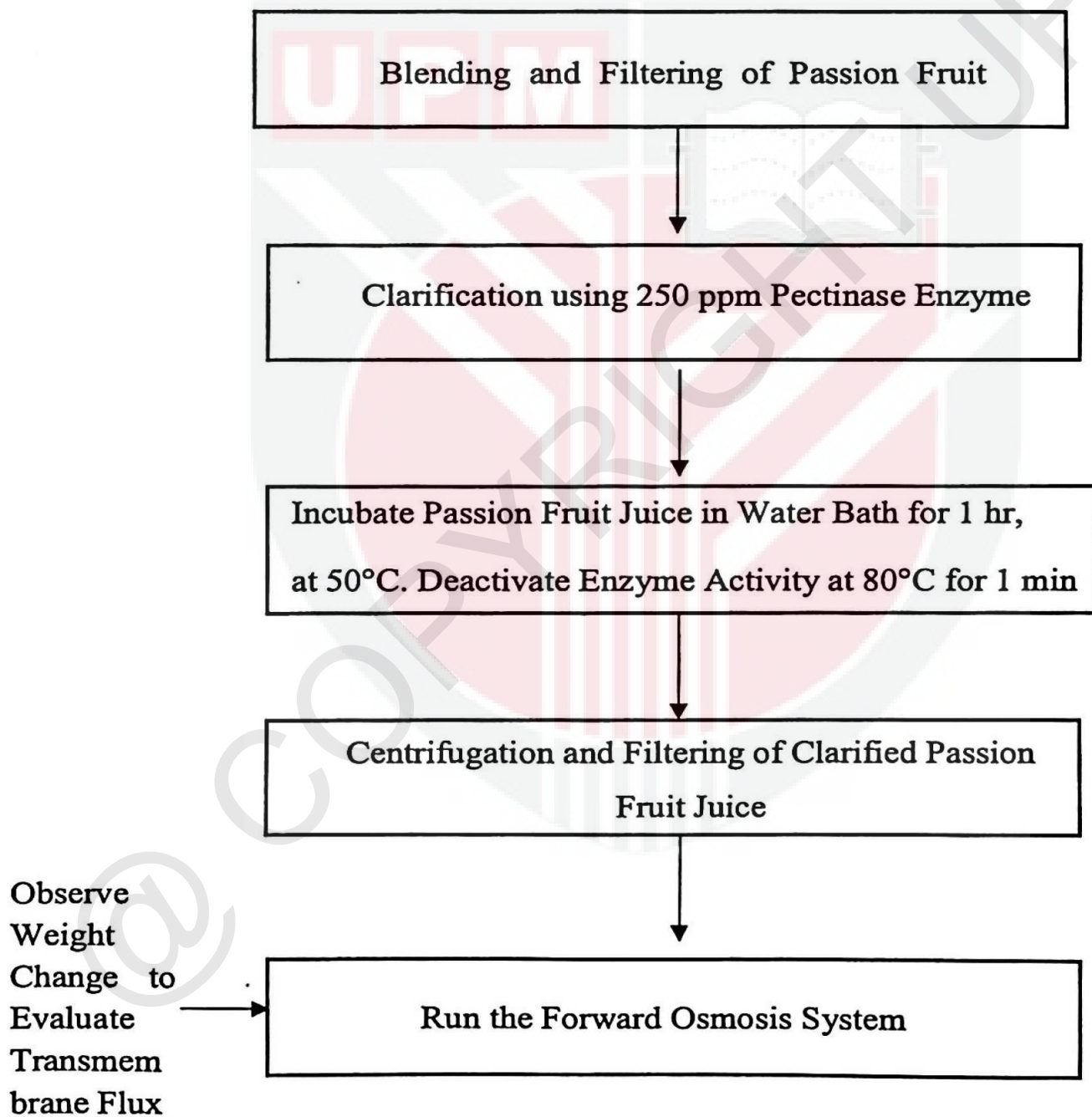
High viscosity in fruit juice due to pectin will inhibit the flow of permeate through the membrane as it enhances concentration polarization. While gel-like structure is formed by pectin and its derivatives, this creates a severe issue in fruit juice production, especially in membrane processes. Fouling is another issue that is normally found in membrane application in fruit juice production. In this case, pectin is one of the substances that will contribute to this issue as deposition of pectin will induce reversible or irreversible fouling (Torras et al., 2011).

Thus, the removal of pectin is necessary for juice production to achieve stability and clarification. This process is conducted by pectinase through hydrolysis of pectin into oligosaccharide. Pectinases comprises of polygalacturonase, pectin lyases, pectin esterase, pectate lyases which can be synthesized by pathogenic fungi and bacteria such as *Aspergillus* sp., *Penicillium*, *Fusarium moniliforme* and *Trichoderma* sp (Ramadan, 2019).

CHAPTER 3 METHODOLOGY

3.1 Overall Process Flow Chart

In this study, the experiment started with preparation of passion fruit juice, clarification of fruit juice before FO system was run. The processes were summarized as flow chart below:



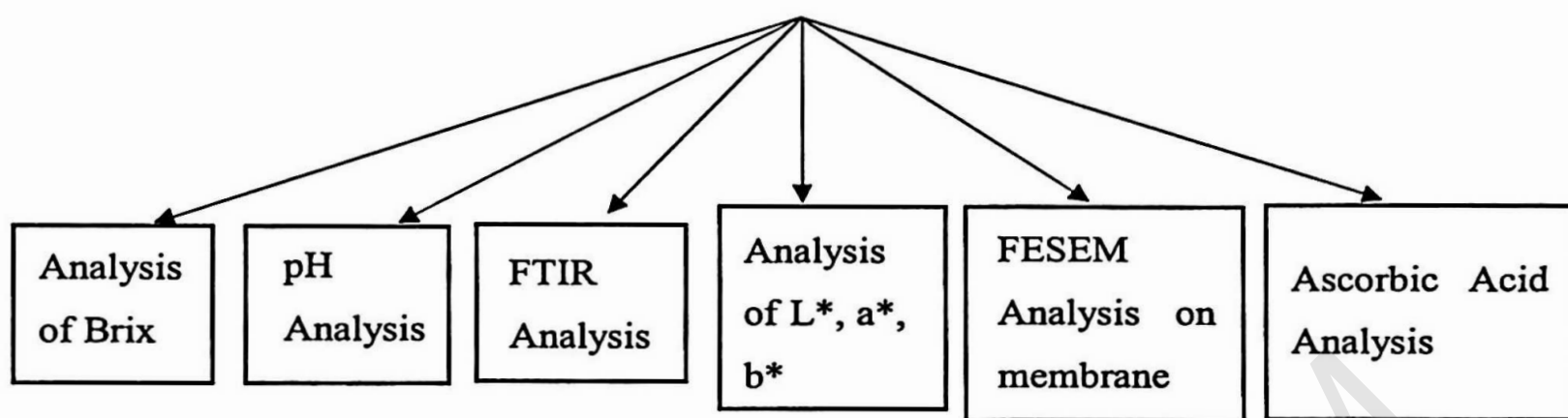


Figure 3-1: Process flow diagram of clarified passion fruit juice preparation and forward osmosis process.

3.2 Preparation of Feed Solution

Clarified passion fruit juice will be used as FS in this experiment. Frozen passion fruit pulp with seed was bought from Extra Natural Sdn. Bhd. Passion fruit pulp with seed was blended together in a blender (MX-GM 1011, Panasonic). The juice will be filtered through a sieve to remove seeds and fiber and finally strain the juice through a cheesecloth to get filtered juice. Some of the juice was kept in the chiller for further use and analysis.

Before adding pectinase, the filtered juice was diluted with ratio passion fruit juice: distilled water = 2:1. Diluted passion fruit juice was mixed with pectinase enzyme (Sigma-Aldrich) to clarify the juice, 250 ppm of pectinase enzyme was added into 1 L of juice. The juice was incubated in the water bath (WNB, memmert) at 50°C for 1 hour. After 1 hour of incubation, it was heated on hot plate (FAVORIT) until 80°C for 1 minute to deactivate pectinase activity. By using benchtop centrifuge (UNIVERSAL 320, Hettich), the enzyme-treated juice was centrifuged at 9000 rpm for 15 minutes and filtered through 110nm filter paper to get a clear filtrate. The clear filtrate will be used in the following experiments, 500ml of clarified passion fruit juice was used for each experiment (Phung et al., 2019).

3.3 Preparation of Draw Solution

Potassium sorbate (Sigma-Aldrich) was purchased from Evergreen Engineering & Resources, will be used as DS in the experiment. It was prepared into different concentrations by dissolving different amounts of potassium sorbate into distilled water. The ratio of FS to DS was 1:1. Thus, 500 ml of different concentrations of potassium sorbate solutions were prepared respectively for each experiment. 5M sodium chloride solution was prepared to do comparison with other studies.

Table 3-1: Mass of potassium sorbate needed to prepare different concentrations of solution.

Concentration of Potassium Sorbate Solution (M)	Mass of potassium sorbate dissolve in 500 ml of distilled water (g)
2.0	150.22
3.0	225.33
4.0	300.44
5.0	375.55

Table 3-2: Mass of sodium chloride needed to prepare different concentrations of solution.

Concentration of Sodium Chloride Solution (M)	Mass of potassium sorbate dissolve in 500 ml of distilled water (g)
5.0	146.10

3.4 Forward Osmosis Membrane

Cellulose triacetate (CTA), 305 x 305 mm bought from STERLITECH, USA is used in the FO system. To minimize hydrolysis, the pH of the FS and DS must be in the pH range of 4-6 and temperature less than 35°C. The membrane was stored by immersing it in distilled water in the chiller. The CTA membrane was placed and locked in the membrane holder before the experiment was started. The circular membrane cell was with 0.045 m diameter x 0.051 m depth. CTA membrane was cut according to the size of the porous metal sheet of the membrane holder. The diameter, thickness and approximate area of the porous metal sheet were 0.051m, 0.001m and 0.002043 m² respectively. During the experiment, CTA membrane was placed on the porous metal sheet, with the smooth surface (active layer) was facing FS while the rough surface facing DS, the experiment was running in ALFS mode. After the experiment, CTA membrane was transferred to Petri dish and placed it into desiccator for drying purpose. The porous metal sheet and membrane holder were cleaned properly to avoid rusting and blockage. The porous metal sheet was immersed in 0.5% sodium hypochlorite solution for 1 day to clean the sheet surface.

To test on the efficiency of the FO membrane system, the data of transmembrane flux when distilled water was used to run in FO system for 1 hour was compared with study of (Swat Yin, 2020). From Table 3-3 below, it was showed that performance of FO membrane system in her study was greater than current study. This may be due to faulty in storage and cleaning. Due to Movement Control Order (MCO), cleaning and storage process were challenging where the time to enter the laboratory was restricted and limited. Also, the membrane system had kept for long time without regular maintenance (due to

MCO) before conducting current study. Thus, the performance of the membrane system may be affected.

Table 3-3: Comparison of average transmembrane flux at different concentration of sodium chloride.

Concentration of Sodium Chloride (M)		Average Transmembrane Flux (L/m ² hr)
Swat Yin's Study	Current Study	
2	-	23.450
3	-	30.122
-	5	22.575

3.5 Set Up of Forward Osmosis System

A lab-scale FO setup was shown in Figure 3-2: Schematic diagram of the laboratory scale forward osmosis membrane unit system. The membrane of FO was placed in a membrane holder and it was placed and supported in between two solutions. Clarified passion fruit juice (FS) and potassium sorbate solution (DS) are circulated in co-current mode to reduce strain on the suspended membrane (G. Li et al., 2013). The solutions were pumped by peristaltic pumps (BT600-2J, Longer Pump) at 1.5 L/min. The FS and DS were run in closed loop and the membrane was oriented in the ALFS orientation.

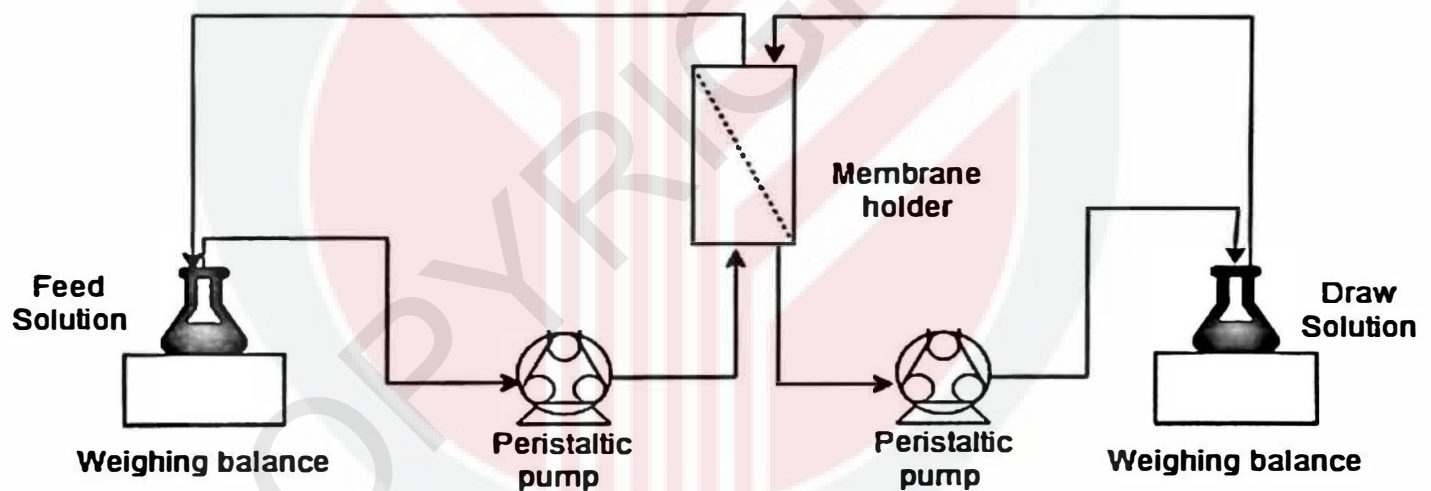


Figure 3-2: Schematic diagram of the laboratory scale forward osmosis membrane unit system.

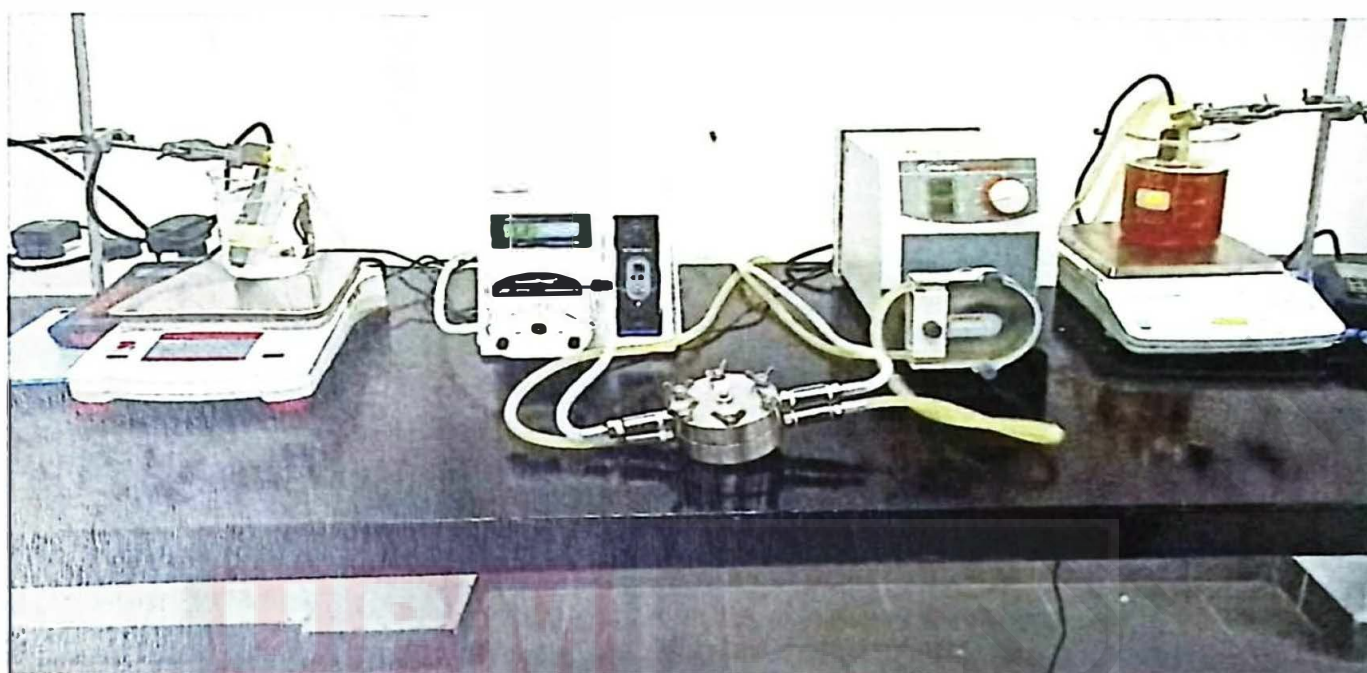


Figure 3-3: Set up of forward osmosis system with distilled water (left) and potassium sorbate solution (right).

Before the experiment, distilled water was run through the FO system for at least 1 hour to allow stabilization in the system. Then, the tubes (Masterflex) were connected to beakers with FS and DS where the volume of FS to DS was in ratio 1:1 to ensure there was no significant effect on the osmotic pressure when water was transferred and the change in flux with time will be small. Tubes connected to the membrane holder and beakers were needed to ensure no leakage or air bubbles as these will affect the reading. Conductivity meters (HI8733, Hanna Instrument) were immersed into both solutions to measure the change in conductivity.

During the experiment, weight of both solutions and conductivity value were measured and recorded at every 5 minutes using an electronic balance (TX3202L, Shidmazu). The weight change was used to calculate the transmembrane flux using Equation 3.1 below. In this case, the effective surface area of membrane was 0.002043m^2 .

Before and after the experiment, Brix value of the fruit juice was being measured using refractometer (PAL-BX/RI, Atago) for thrice.

$$J_w = \frac{\text{Volume of solution (L)}}{\text{Surface area of membrane (m}^2\text{)} \cdot \text{Duration of interval (h)}} \quad 3.1$$

In this study, concentrations of DS were manipulated while the flow rate for both FS and DS were maintained at 1.5 L/min. The concentration of DS was varied in such concentrations, 2.0 M, 3.0 M, 4.0 M to 5.0 M. Each experiment was conducted in duplicates in room temperature in the range of 25 ± 2 °C for 4 hours. Due to MCO and time constraints, sodium chloride solution was managed to run at only 5M, while 5M and 4M of potassium sorbate solution were only conducted once.

3.6 Measurement of Brix

Digital refractometer was used to measure concentration of the clarified passion fruit juice, concentration of fruit is also defined as Brix. 1° Brix is referred to 1 g of sucrose dissolved in 100 g of solution. Concentration of clarified passion fruit juice was measured and recorded for the clarified fruit juice and concentrate after the FO process was done for 4 hrs. Before use, the digital refractometer was cleaned with distilled water, one drop of solution was dropped on the sensor of the refractometer and the reading shown was recorded. When a new sample was tested, the dropper was cleaned with distilled water. For each sample, three readings were taken to obtain an average Brix value.

3.7 Determination of Ascorbic Acid Content

Vitamin C or ascorbic acid is a water soluble acid usually found in fruit and vegetables. Iodine titration method was used to determine the content of vitamin C in the concentrated passion fruit juice after FO process. This method was chosen as the materials used were simple, affordable, reliable and the time of analysis was not more than 5 minutes.

To determine the content of ascorbic acid, the procedures were based on description by Satpathy (2020). Fresh starch indicator solution and 0.005 mol L⁻¹ iodine solution were prepared. Firstly, 0.25 g of soluble starch was weighted and added into 50 ml of near boiling water. Stirred and leave it cool before use. 2 g of dry potassium iodine and 1.3 g of iodine were weighted and dissolved with some distilled water before transferring to 1 L volumetric flask. The solution was added with distilled water until 1 L

mark. 20 mL of concentrated passion fruit juice, 150 mL of distilled water and 1 mL of starch indicator solution were added into 250 mL conical flask. The sample was titrated with 0.005 mol L⁻¹ iodine solution. The endpoint of titration was determined at the moment the sample turned blue after 20 seconds of swirling. The volume used in the titration was recorded while the analysis was carried out twice for each sample to obtain an average value.

When iodine was added during titration, the ascorbic acid was oxidized to dehydroascorbic acid while the iodine was reduced to iodide ions. Excess iodine was reacted with starch indicator to iodine-starch complex in blue when all ascorbic acid has been oxidized. The number of moles of ascorbic acid reacting can be determine using Equation 3.2 below:



3.8 Fourier Transform Infrared Spectroscopy (FTIR)

This analysis was done by Material Characterization Laboratory (MCL), Department of Chemical & Environment Engineering, University Putra Malaysia. Application of Fourier Transform Infrared (FTIR) uses infrared radiation with a wavelength range from 650 to 4000 cm^{-1} to determine specific molecules in the sample through the spectrum.

FTIR (Perkin Elmer, Spectrum 100, USA) was used to identify possible functional groups present in clarified passion fruit juice by attenuated total reflectance (ATR) method. The sample was applied on the crystal and the sample will absorb IR radiation that penetrated beyond the crystal. Four scans were averaged at a resolution of 6 or 4 cm^{-1} , recording spectrum from 4000-650 cm^{-1} (Subramanian & Rodriguez-saona, 2009).

3.9 Field Emission Scanning Electron Microscopy (FESEM)

The morphology of CTA membrane before and after the concentration were determined using Field Emission Scanning Electron Microscopy (FESEM) (FEI, NOVA NANOSEM 230 operated at voltage of 5kV. The samples were sputter coated with gold at 5 mA for 45s prior to FESEM analysis. The images were examined under 0.3 kSE.

CHAPTER 4 RESULTS AND DISCUSSION

4.1 Effect on Transmembrane Flux of Distilled Water and Clarified Passion Fruit Juice at Different Concentrations of Draw Solution

Trend of transmembrane flux of distilled water and clarified passion fruit juice at different concentrations of DS were shown in Figure 4-1 and Figure 4-2 below. Figure 4-3 showed average transmembrane flux of distilled water and clarified passion fruit juice at different concentration draw solution. In overall, transmembrane flux for both distilled water and clarified passion fruit juice increased sharply at the beginning as the system was building up (Law & Mohammad, 2017). For flux in distilled water, it fluctuated and showed little decrement along the process due to dilution in DS when water molecules were transferred to DS compartment. 5M sodium chloride, 5M, 4M, 3M, 2M of potassium sorbate indicated the highest flux at 28.163, 11.961, 11.630, 3.476 and 3.417 L/m² hr respectively.

For clarified passion fruit juice, the flux showed relative stable flux except for flux with 3M potassium sorbate solution and 5M sodium chloride solution. There were sudden increment or decrement in flux for both 5M sodium chloride solution and 3M potassium sorbate solution may due to experimental error or unstable in system. Clarified passion fruit juice that concentrated with 5M, 4M, 3M and 2M potassium sorbate solution showed range of flux within 5.7 to 7.9 L/m² hr, 5.5 to 7.3 L/m² hr, 1.2 to 4.1 L/m² hr and 1.1 to 2.2 L/m² hr respectively. 5M sodium chloride, 5M, 4M, 3M, 2M of potassium sorbate indicated highest flux at 11.996, 8.279, 7.265, 4.111 and 2.253 L/m² hr respectively.

By comparing different FS and different concentrations of DS, the effect on average transmembrane flux was tabulated in Table A-4, and illustrated in Figure 4-3. Generally, it can be concluded that when concentration of DS increased, the average transmembrane increased as well. This was because osmotic pressure increased with molar concentration according to Van't Hoff equation in Equation 4.1 below.

$$\pi = iRCT \quad 4.1$$

Where π is osmotic pressure (kPa), i is dissociation factor (van't Hoff factor), R is gas constant (8.314 kJ/kmol. K), C is molar concentration (kmol/m³) and T is absolute temperature (K). At the condition where the temperature was constant, molar concentration of DS became the important factor in affecting osmotic pressure. It was reported by Hameed (2013) that flux of water increased from 0.84 to 10.22 L/m² hr when the concentration of sodium chloride used to concentrate orange juice increased from 3.5% to 19% by wt.

Furthermore, clarified passion fruit juice had lower average transmembrane flux than distilled water when it was concentrated with different concentrations of DS. More water was transferred across the membrane to DS compartment when distilled water was used as FS. The difference was mainly due to viscosity of FS as another affecting parameter since temperature was maintained at room temperature for both FS throughout the process. Distilled water has density of 997 kg/m³ with viscosity 0.798cp and clarified passion fruit juice which was treated with pectinase has density of 1043 kg/m³ and 9.56 cp (Domingues et al., 2011). Jiao and Cassano (2004) found that viscosity and density of feed increased when the concentration increased. This will give more obstruction for

permeate to diffuse through as the mass coefficients of the permeate were lowered. Higher viscosity was found in more concentrated feed and led to reduction in driving force of permeate flux due to lower osmotic pressure of FS. Thus, transmembrane flux of distilled water at each different concentrations of DS was higher than clarified passion fruit.

Moreover, it was observed that potassium sorbate solution as DS possessed a lower effect in transmembrane flux compared to sodium chloride solution. By comparing both at 5M, sodium chloride had a greater effect in transmembrane flux than potassium sorbate. Performance of FO can be related to viscosity and osmotic pressure of DS. At same concentration, potassium sorbate had higher viscosity and lower osmotic pressure when compared to sodium chloride. An et al. (2019) reported that viscosity of potassium sorbate rose remarkably from 3.57cp to 4.92cp with water flux increment from 10.57 to 13.7 L/m² hr when it increased concentration from 1M to 2M. Meanwhile, sodium chloride had lower increment in viscosity and higher increment in water flux when the salt concentration increased. When concentration of sodium chloride rose from 1 M to 2M, viscosity increased from 3.17cp to 3.43cp while water flux increased from 14.4 to 26.5 L/m² hr.

There was difference of flux between 5M and 4M with 2M and 3M when potassium sorbate solution was used to in FO process. This was probably affected by low efficacy of CTA membrane due to long storage time and improper storage method. Although same type of FO membrane was used, however for 2M and 3M, the CTA membrane used had been kept in distilled water for more than one year in distilled water. While for 5M and 4M, new CTA membrane was used as previous CTA membrane was run out of stock. According to the manufacturer (STERLITECH), the membrane should

keep in moist such as for usage less than 24 hours, it can keep in distilled water. Meanwhile for usage more than 48 hours, it should keep in 1% solution of sodium metabisulfite (SMBS) or 0.5% solution of formaldehyde to prevent microbial growth and to maintain the membrane efficacy by replacing the solution once a month. CTA membrane can be stored for more 1-3 years if it was stored in proper method and suitable condition. Thus, it was suggested to store the membrane in correct method so that the membrane water permeability will not be affected and the data for the experiment could be more precise.

Comparing with studies done by Swat Yin (2020), she used sodium chloride from 1M to 3M as DS to concentrate passion fruit juice at 1.6L/min. At 2M and 3M of sodium chloride, she obtained average transmembrane flux with 10.450 and 20.122 L/m² hr. While in this study, average transmembrane flux of 2M and 3M of potassium sorbate was 1.472 and 2.054 L/m² hr. The average transmembrane flux using sodium chloride showed higher value compared to same concentration of potassium sorbate although flow rates for both studies were found to be a little different. Lower water flux was observed when higher viscosity of DS was used, as it led to serious CP in FO membrane. The real effective osmotic pressure gradient was lower than the osmotic pressure difference between inlet FS and DS (Nicoll & Limited, 2019). Thus, there will be lower permeate flux than expected. At the same concentration, 2M of sodium chloride showed 93 bar osmotic pressure while potassium sorbate showed 45 bar. This indicated the latter FO system had lower osmotic pressure difference between FS and DS. Therefore, transmembrane flux of distilled water and clarified passion fruit juice were lower when potassium sorbate was used as DS due to high viscosity and lower osmotic pressure.

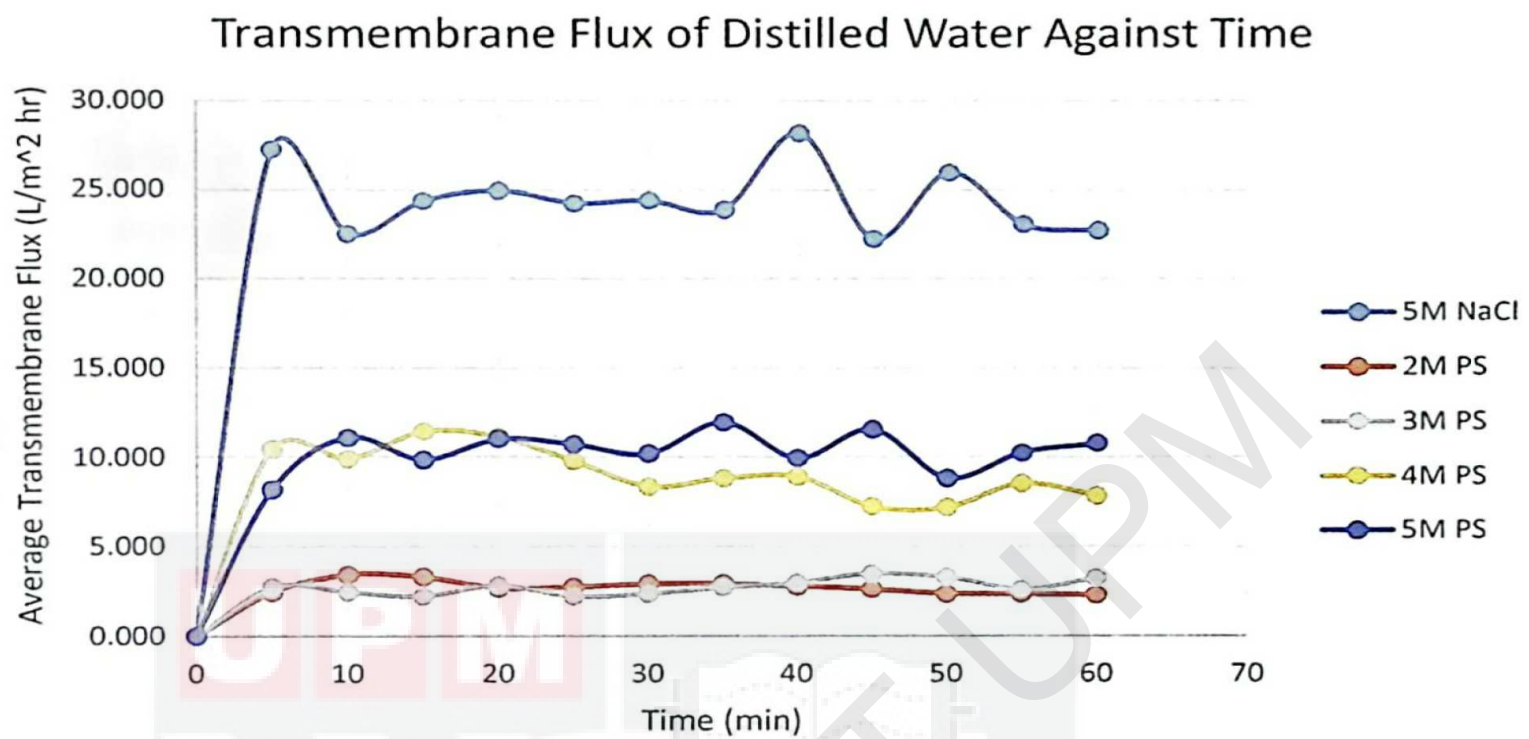


Figure 4-1: Transmembrane flux of distilled water against time at different concentration of draw solution.

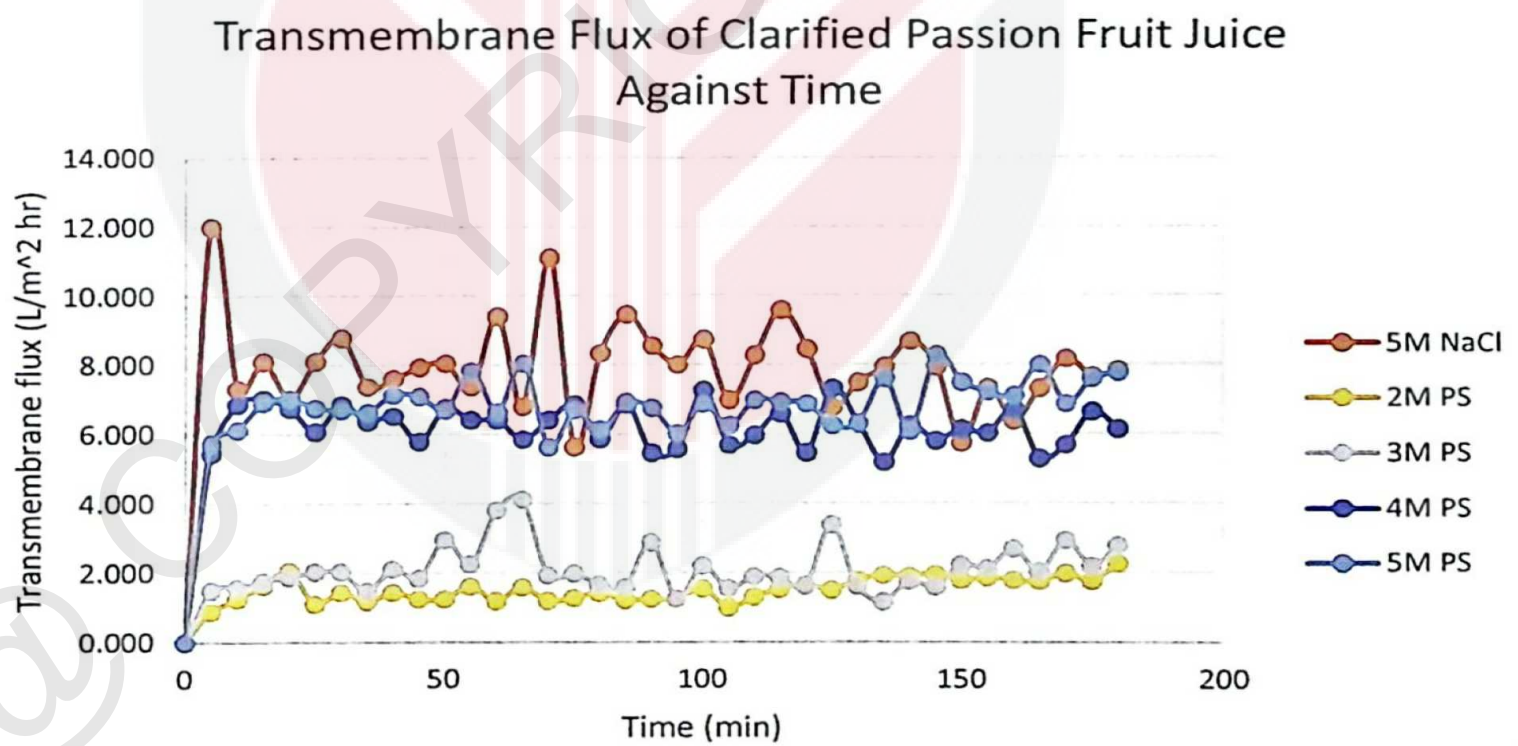


Figure 4-2: Transmembrane flux of clarified passion fruit juice against time at different concentration of draw solution.

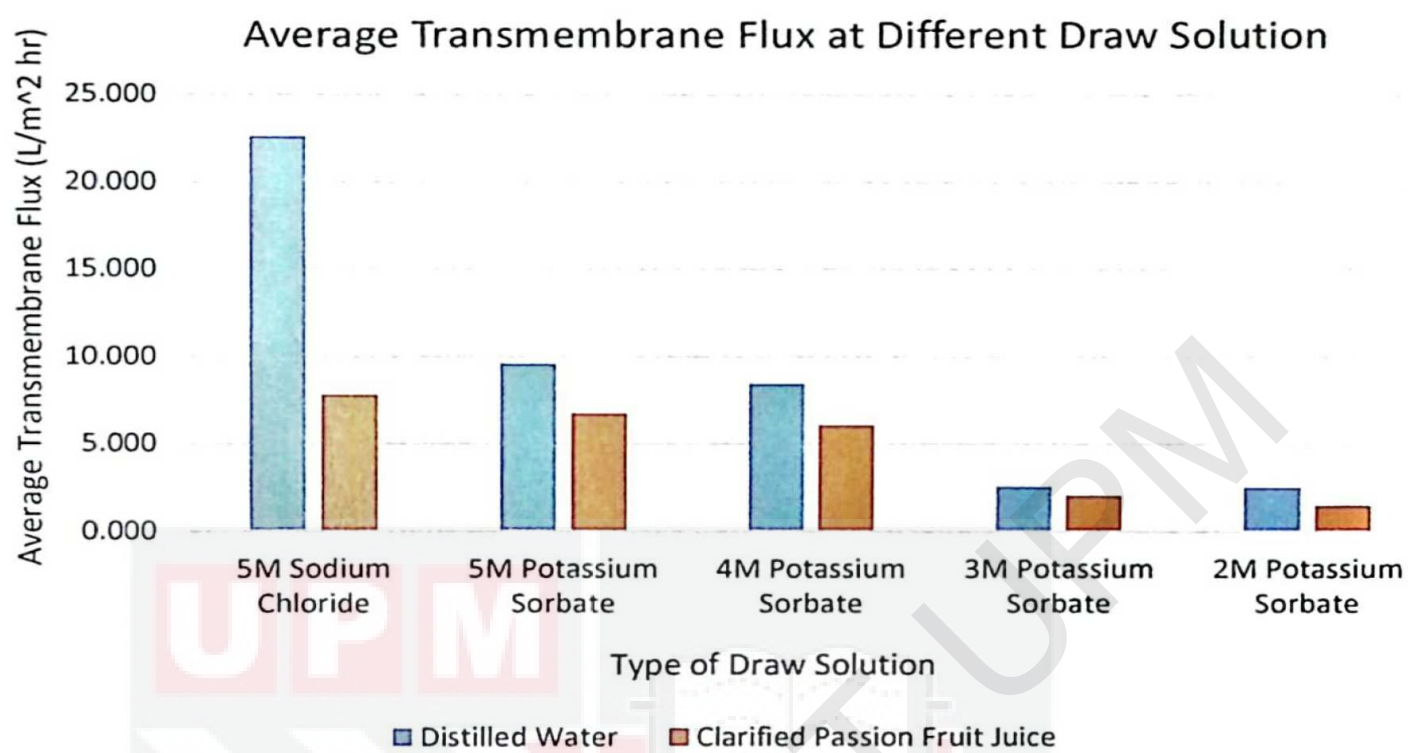


Figure 4-3: Average transmembrane flux of distilled water and clarified passion fruit juice at different concentration draw solution.

4.2 Effect of Concentration of Draw Solution on Brix Value of Clarified Passion Fruit Juice

This section discussed about the effect of concentration of DS on Brix value of clarified passion fruit juice and comparison of two different DS on Brix increment. Table 4-1 showed average increment of Brix value at different concentration of draw solution. Clarified passion fruit juice was concentrated by different concentrations of potassium sorbate solution (2M, 3M, 4M, 5M) and sodium chloride solution (5M). Brix value was recorded before conducting FO process and after the process, the data was tabulated in Table 4-1. From the data in Table 4-1 below, the trend showed a general increased when concentration of potassium sorbate solution increased from 2M to 5M. Among 2M to 5M, the highest average Brix increment was observed when clarified passion fruit juice was treated with 5M potassium sorbate solution. Meanwhile, the average brix increment of 5M sodium chloride solution, $0.77^{\circ} \pm 0.07$ or 7.68% as higher than 5M potassium sorbate, $0.57^{\circ} \pm 0.03$ or 5.88%. The reason why potassium sorbate solution showed lower Brix increment was related to factors that affected transmembrane flux that had been discussed in detail in section 4.1

Due to different concentration of DS was the only changing variables, the flow rate of was remained the same. In this case, the increment of Brix in the experiment using potassium sorbate solution and sodium chloride solution was considered low. Increasing flow rate will improve water flux performance by creating higher drag force on permeates to diffuse to bulk DS and reduce ECP. It was suggested to extend the duration of FO system and increase the flow rate for FS and DS to obtain greater increment in Brix.

Table 4-1: Average increment of Brix value at different concentration of draw solution.

Type of Draw Solution	Concentration of Draw Solution (M)	Average Initial Brix Value (°)	Average Final Brix Value (°)	Average Brix Increment (°)	Average Brix Increment (%)
Potassium Sorbate	2	9.90 ± 0.05	10.23 ± 0.02	0.33 ± 0	3.33
	3	9.83 ± 0.33	10.28 ± 0.48	0.45 ± 0.15	4.58
	4	9.40 ± 0.06	9.93 ± 0.09	0.53 ± 0.09	5.64
	5	9.70 ± 0.12	10.27 ± 0.03	0.57 ± 0.03	5.88
Sodium Chloride	5	9.50 ± 0	10.27 ± 0.07	0.73 ± 0.07	7.68

4.3 Analysis of Fourier Transform Infrared (FTIR)

The purpose of doing FTIR analysis was to trace potassium sorbate and sodium chloride in the clarified passion fruit juice after FO process. Trace of DS particles was found in FS, was due to RSD. Occurrence of RSD will lead to reduction in concentration gradient and water flux, membrane fouling and increment of CP (L. Li et al., 2020). Table

5M sodium chloride solution, 5M potassium sorbate solution, clarified passion fruit juice, clarified passion fruit juice which was concentrated with 5M sodium chloride solution and 5M potassium sorbate solution were analysed. The images of clarified passion fruit juice before being concentrated was shown in Figure 4-4 as reference. Images of clarified passion fruit juice before conducting FO, clarified passion fruit juice concentrated by 5M sodium chloride solution and 5M potassium sorbate were superimposed with the spectrum of it's chemicals used respectively in Figures 4-5 and Figures 4-6.

From Figure 4-4 below, it can be seen that the peak values were 3402.63, 2123.90, 1642.59, 1464.67, 1233.33, 1077.52, 964.55 and 739.84 cm^{-1} , which each of the absorption peak referring to a functional group. The absorption peaks were identified and tabulated in Table 4-2. For spectrum in Figure 4-5 and Figure 4-6, both figures showed similar trend from wavenumber 4000 to 1650 cm^{-1} with clarified passion fruit juice before concentrated (Figure 4-4).

Fingerprint region, which was started from 1400-650 cm^{-1} , this region was specific, unique, complex and hard to differentiate each peak. By comparing the trend in fingerprint region of Figure 4-5 and 4.7, it can be differentiated and determined that traces

of potassium sorbate (highlighted peak 1354 and 1392 cm^{-1} , 1535.98 and 1540.75 cm^{-1}) was found in clarified passion fruit juice after FO process. Therefore, it can be concluded that concentrated clarified passion fruit had traces of sodium chloride and potassium sorbate, this was due to RSD. However, from aspect of peaks and trend, for Figure 4.5, the three spectrums are quite similar. Thus, it was hard to differentiate or distinguish the trace of sodium chloride.

Due to time constraints and unexpected situations, only qualitative analysis, FTIR was managed to do to determine traces of potassium sorbate and sodium chloride in FS. It was expected to use UV-spectrophotometer to determine trace concentration of potassium sorbate and sodium chloride. In this case, potassium sorbate with a bigger molecular size, 150.22 g/mol was expected to have lower salt reflux in FS compared to sodium chloride, 58.44 g/mol. This was due to bigger molecule will be obstructed by CTA membrane (An et al., 2019).

Table 4-2: Absorption peak and functional group of clarified passion fruit juice before being concentrated.

Absorption peak (cm ⁻¹)	Functional group
3402.63	Alcohol (O-H)
2123.90	Alkyne
1642.59	Amide
1464.67	-C-H bending
1233.33	O-H
1077.52	C-O stretch
964.55	O-H
739.84	-C-H

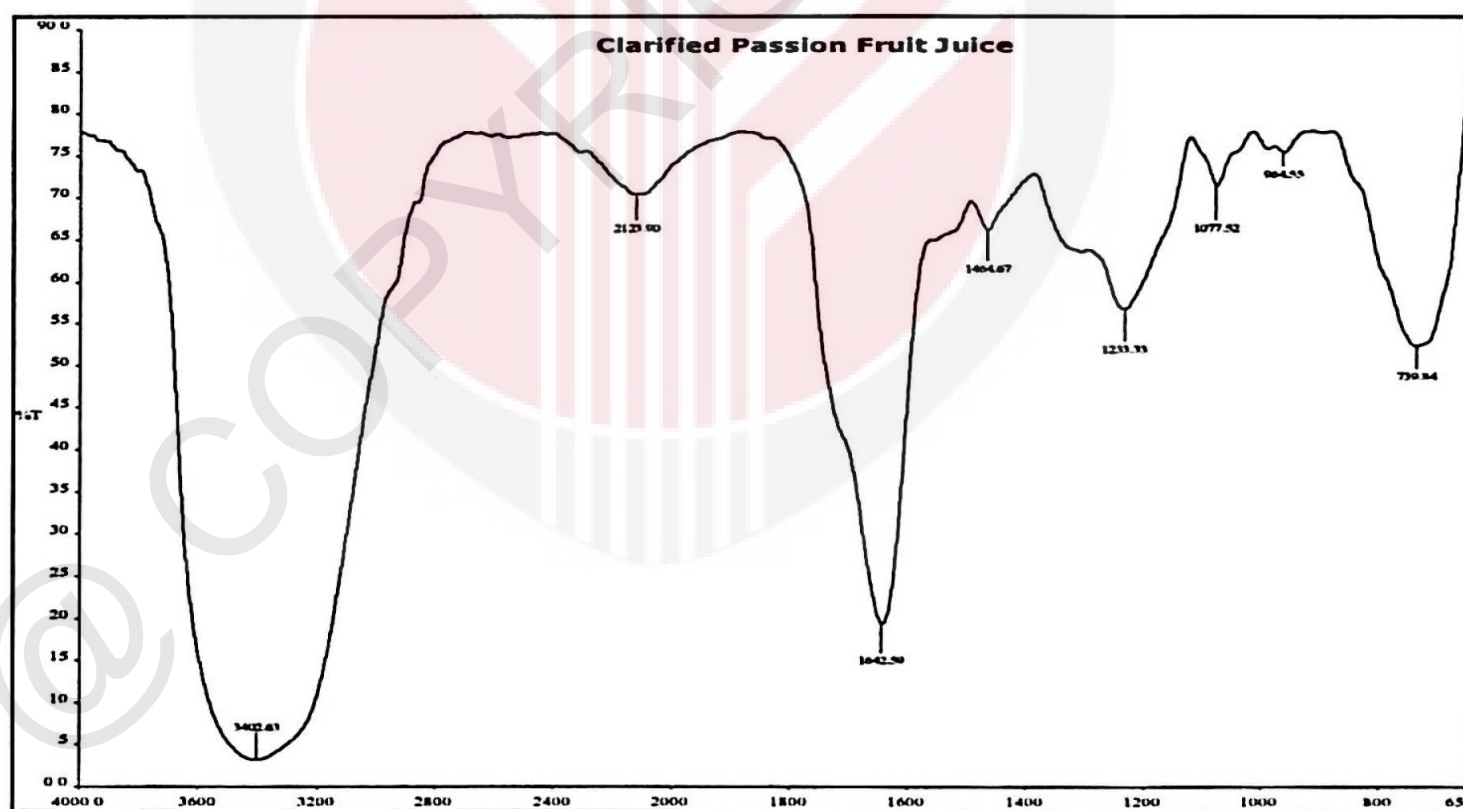


Figure 4-4: Clarified passion fruit juice before conducting forward osmosis.

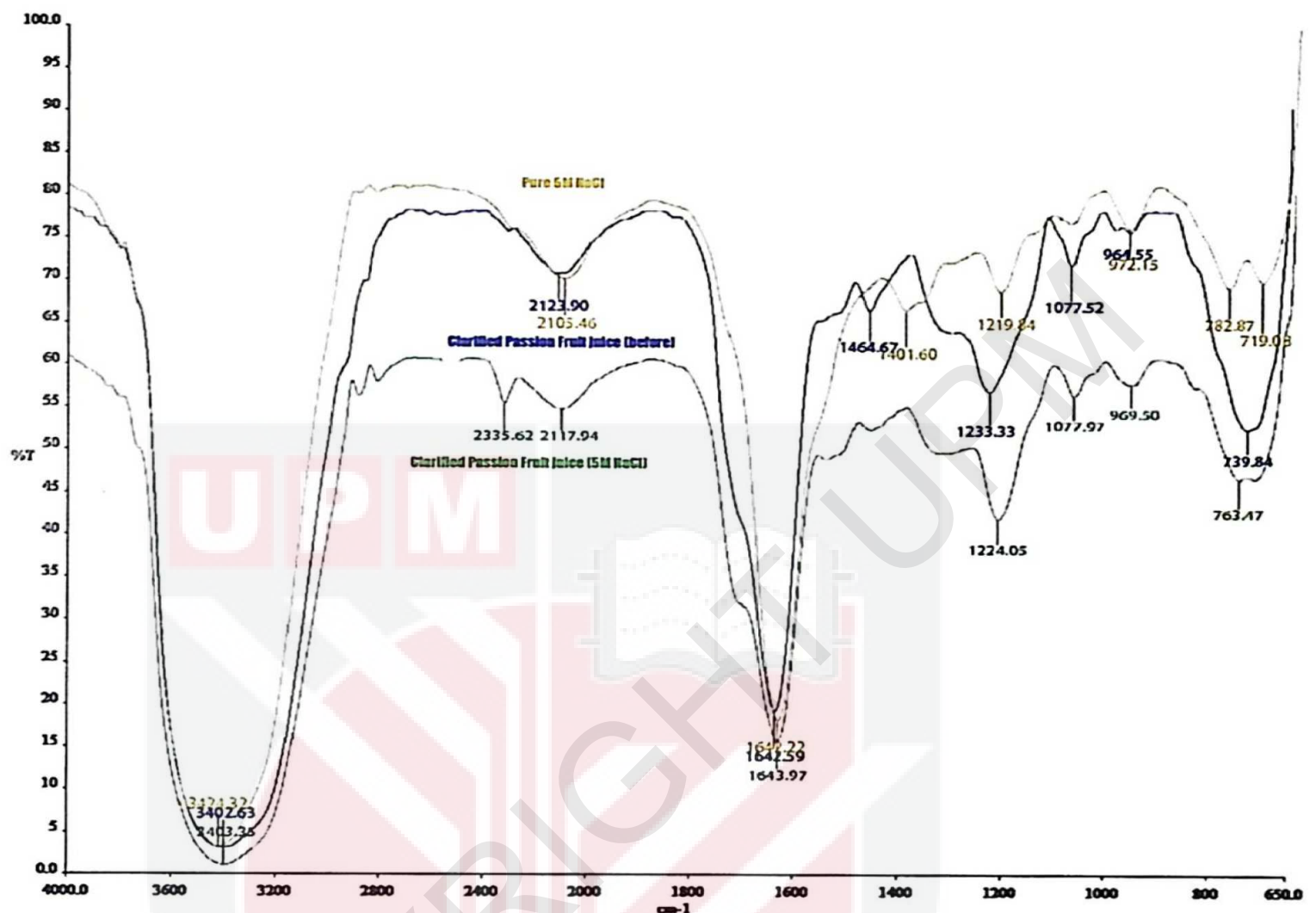


Figure 4-5: Spectrum of 5M sodium chloride solution, clarified passion fruit juice before conducting forward osmosis and clarified passion fruit juice concentrated by 5M sodium chloride solution.

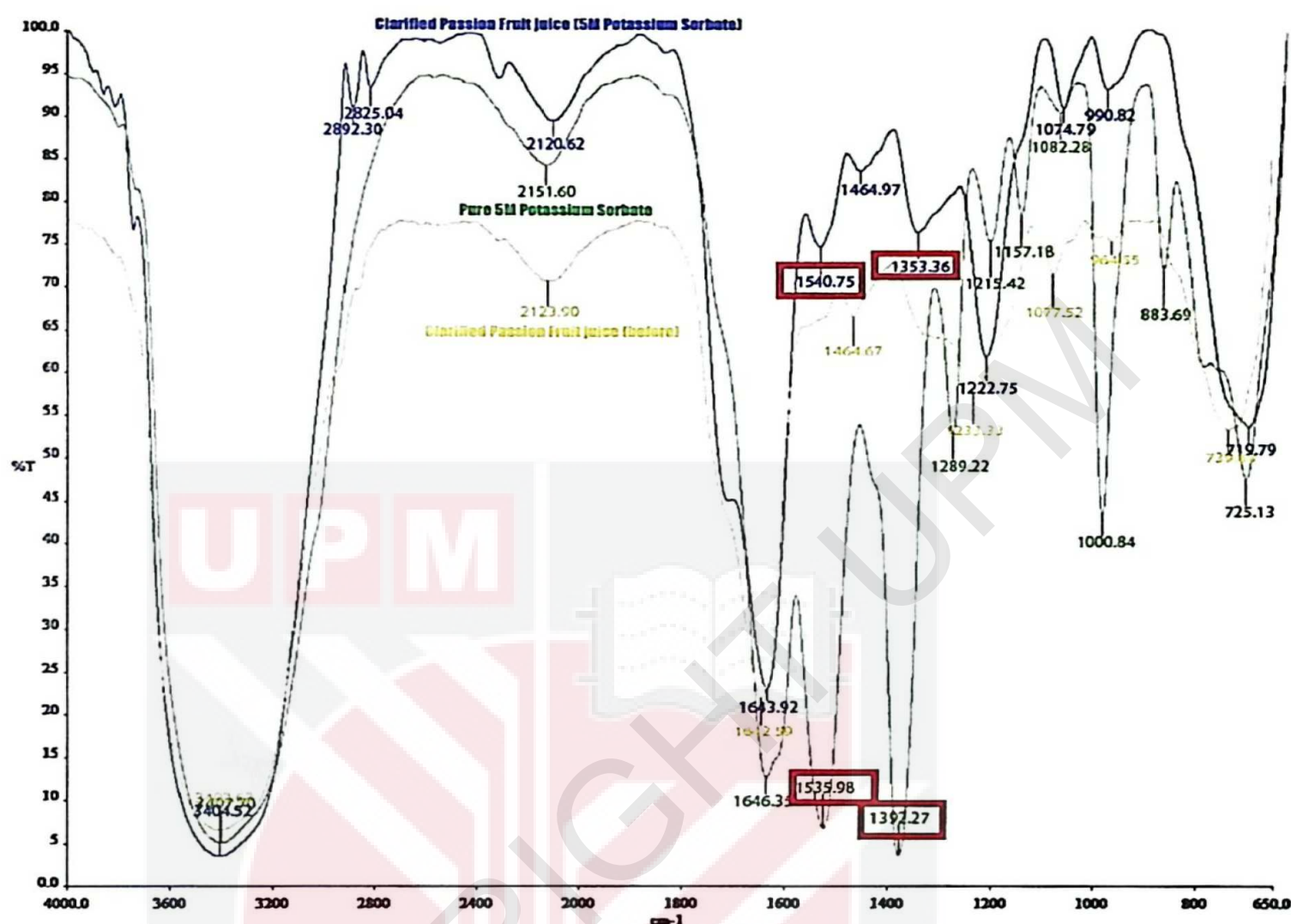


Figure 4-6: Spectrum of clarified passion fruit juice concentrated by 5M potassium sorbate solution, 5M potassium sorbate solution and clarified passion fruit juice before conducting forward osmosis.

4.4 Analysis of Field Emission Scanning Electron Microscopy (FESEM)

Analysis of field emission scanning electron microscopy (FESEM) was done on CTA membrane after FO process. Fresh CTA membrane, CTA membrane under FO with 2M and 5M potassium sorbate solution were sent to Institute of Advanced Technology (ITMA) to observe and analyse fouling on the membrane. In this analysis, active layer of CTA membrane will be observed. Fouling occurred at active layer was called external fouling, which was reversible and able to clean (Eyvaz et al., 2018). All the images observed by FESEM were under 300x magnification.

Fresh membrane in Figure 4-7 below showed no fouling as no particulates were accumulated on it. Since it was clean and no fouling, it was used as control to compare with other membranes to observe fouling condition. Membranes in Figure 4-8 and Figure 4-9 conducted FO process at 1.5L/min, using 2M and 5M potassium sorbate solution as DS respectively. It showed less deposition of particles on the surface when clarified passion fruit juice was treated with 2M potassium sorbate solution compared with 5M. Permeating flux was increasing with concentration of DS, thus more foulants were possible to accumulate on the membrane surface (Zou et al., 2011). Hydrodynamic condition which affected by concentration of DS, was a dominant factor that promoted fouling. Water flux due to high concentration of DS will contribute to higher hydraulic drag force, this led to more accumulation of foulants on the membrane (She et al., 2016). Thus, to prevent severe fouling on active layer, it is suggested to use lower concentration of draw solution during FO process.

Generally, foulants that can be found in fruit juice were polysaccharides and proteins. From the studies conducted by Wenten et al. (2021), they found that the majority of organic foulants in orange juice that accumulated on FO membrane from FTIR spectrum were proteins (1635 cm^{-1} and 1545 cm^{-1}) and polysaccharides (3279 cm^{-1} and 2923 cm^{-1}). In this case, clarified passion fruit juice treated by pectinase was used as FS, therefore, there should be less pectin accumulated on active layer. From the previous results that had been discussed in section 4.3, the results showed in FTIR, there was presence of amide functional group (1642.59 cm^{-1}). Therefore, the deposited particles on the membrane in Figure 4-8 and Figure 4-9 may be proteins found in passion fruit juice.

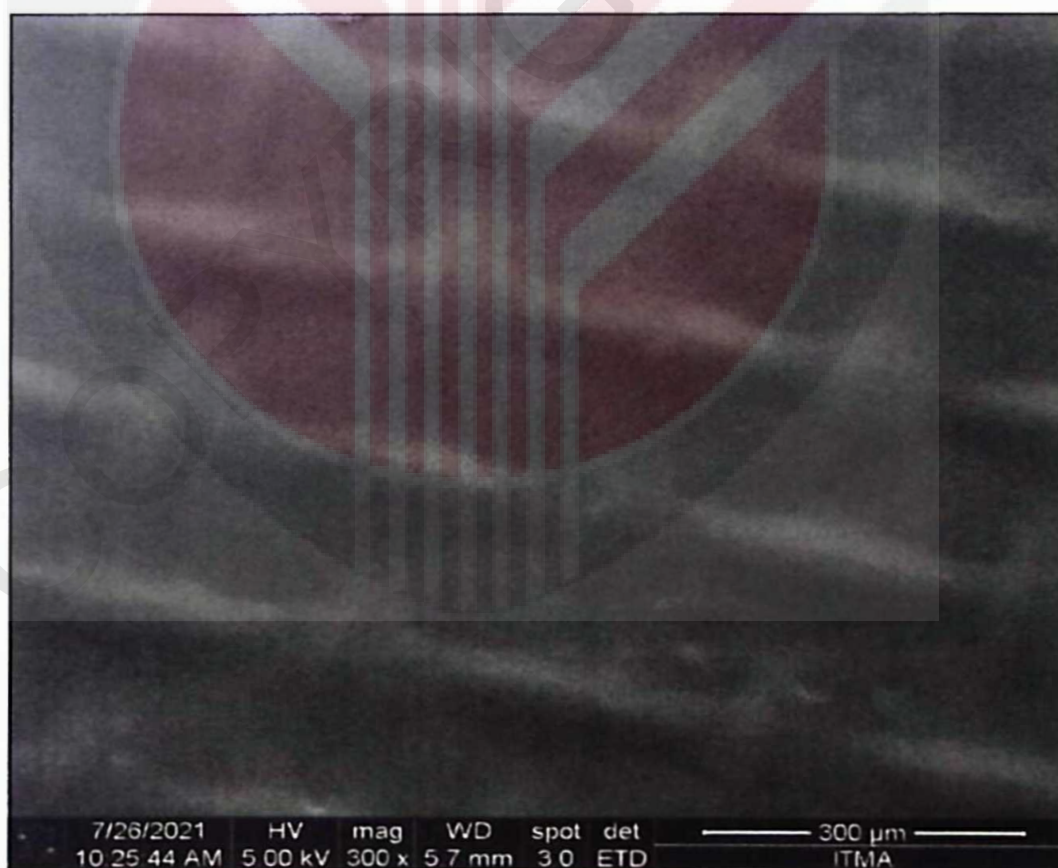


Figure 4-7: Fresh CTA membrane.

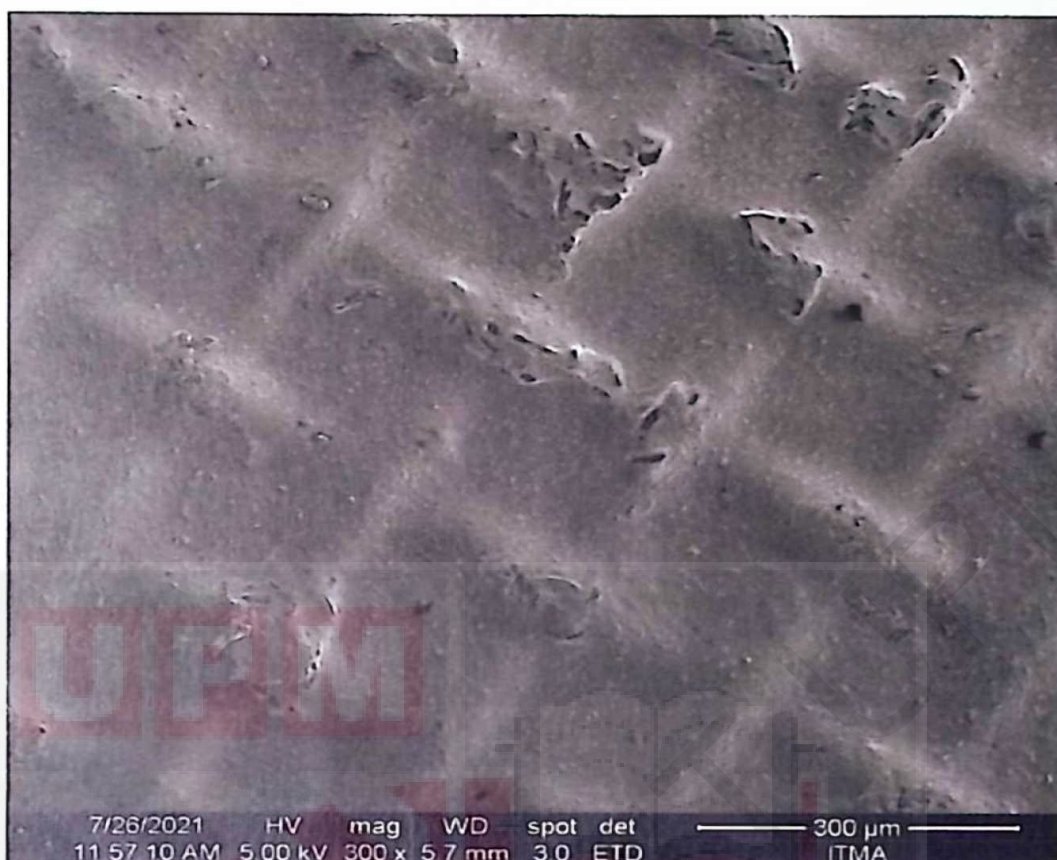


Figure 4-8: 2M of potassium sorbate solution at 1.5 L/min.

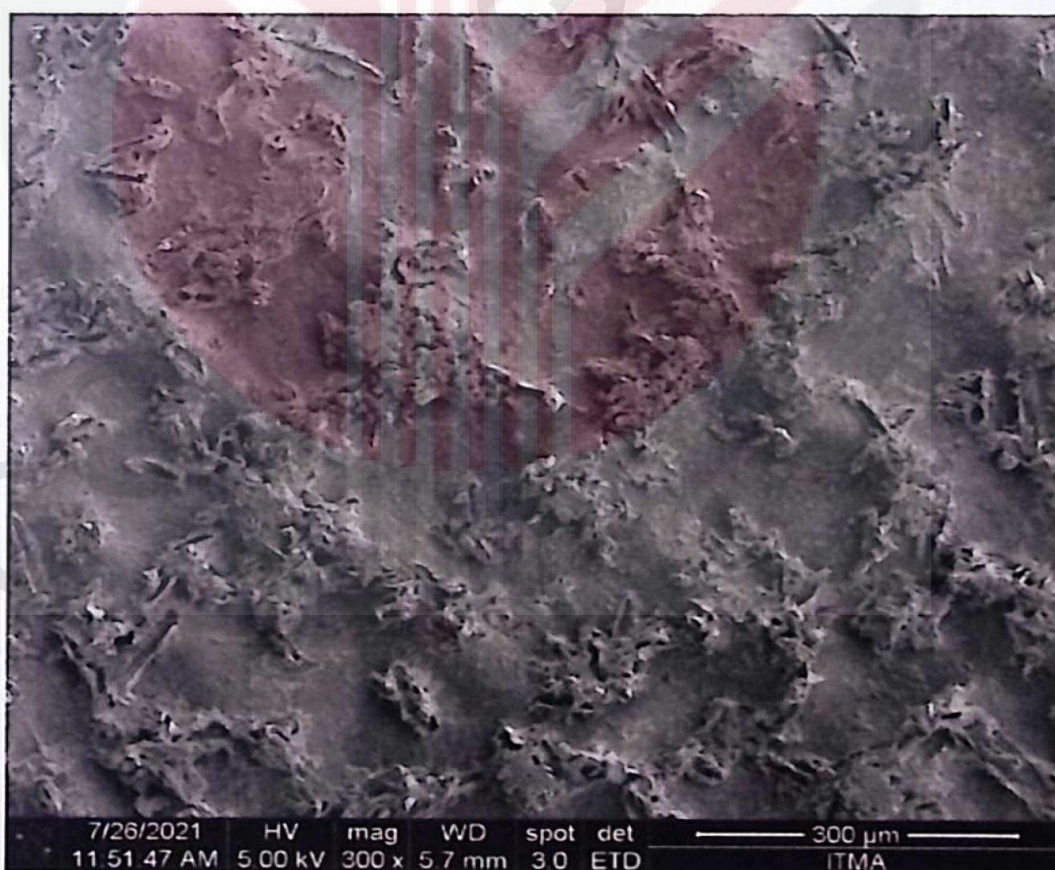


Figure 4-9: 5M of potassium sorbate solution at 1.5 L/min

4.5 Effect of Forward Osmosis Membrane Treatment on Clarified Passion Fruit Juice Quality

This section discussed about the effect of FO membrane treatment on clarified passion fruit juice, each data tabulated in Table 4-3 was taken from average value of experiment using potassium sorbate solution and sodium chloride solution as DS. Figure 4-10 and Figure 4-11 showed concentrated clarified passion fruit juice and unclarified passion fruit juice. According to research done by An et al. (2019), apple juice concentrated by 2M potassium sorbate solution at 5 L/m² hr for as long as 240 hours achieved soluble solids content increment from 10.6° to 45.1°. The soluble solids content in this research increased averagely from 10.01° to 10.26°, 10.01° to 10.27° for potassium sorbate and sodium chloride solution as DS respectively. The increment within 3 hours was not obvious as FO process for the experiment was short.

The content of ascorbic acid of clarified passion fruit juice after concentrated was lower than fresh fruit juice and clarified fruit juice before being concentrated. During clarification, passion fruit juice was incubated at 50 °C and heated to 80°C to deactivate the enzyme. While during FO process, clarified fruit juice was exposed to oxygen for a long time. Loss of ascorbic acid may due to degradation during the heating process and exposing to oxygen for a long time (Arsad et al., 2015). However, the ascorbic acid content was higher than commercial fruit juice which used evaporation to concentrate fruit juice. Thus, FO was a better method to preserve the ascorbic acid content than evaporation.

From the aspect of colour, clarified passion fruit juice after and before conducting FO had little differences. Compared to commercial and fresh passion fruit juice,

concentrated clarified passion fruit juice had lower L^* and b^* values which represented lightness and yellowness respectively. Concentrated clarified passion fruit juice in Figure 4-10 was in pale yellow coloured and more transparent. Comparing with studies of Swat Yin (2020), the colour of passion fruit juice after being concentrated, it stated higher L^* (47.85 ± 0.48), a^* (2.48 ± 0.38), b^* (29.15 ± 0.27) values than clarified passion fruit juice. Thus, unclarified passion fruit juice in Figure 4-12 indicated higher yellow intensity and a brighter colour than clarified passion fruit juice. According to Phung et al. (2019) research, passion fruit juice clarified by pectinase showed lower absorbance value as it was more transparent compared to unclarified juice. This was due to pectin was easier to deposit and be removed by centrifugation after being treated by pectinase. Hence, removal of pectin resulted in clearer and more transparent juice.

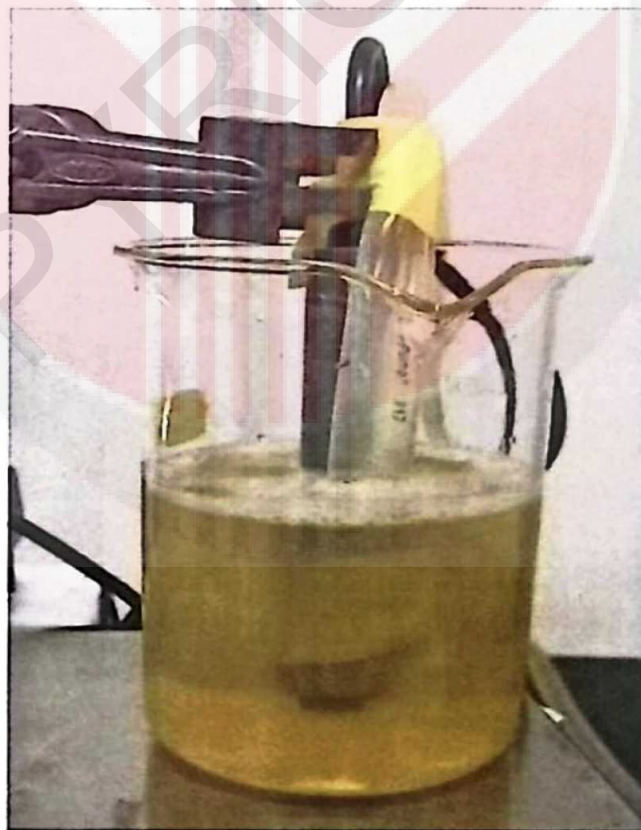


Figure 4-10: Concentrated clarified passion fruit juice.

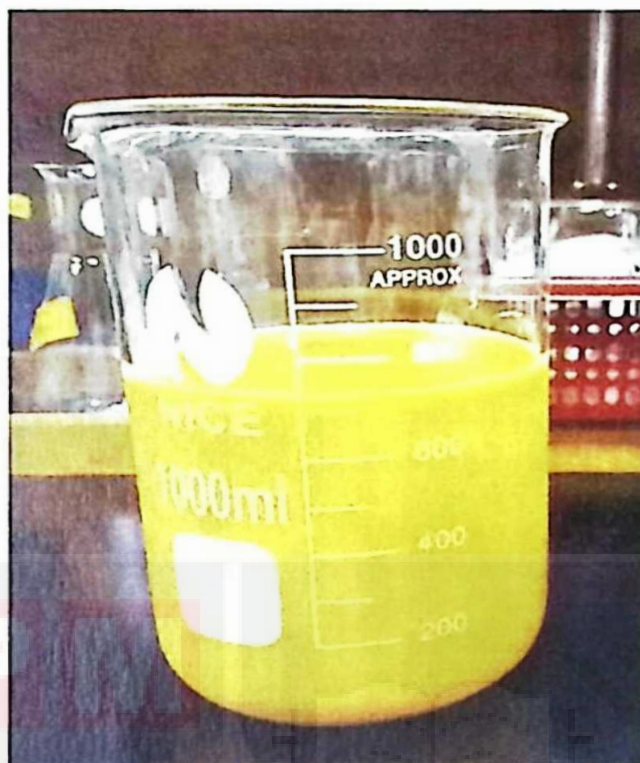


Figure 4-11: Passion fruit juice without clarification.

Table 4-3: Characteristics of concentrated clarified passion fruit juice obtained by forward osmosis and evaporation.

Analysis	Clarified Passion Fruit Juice	Clarified Passion Fruit Juice that undergoes FO treatment (Potassium Sorbate)	Clarified Passion Fruit Juice that undergoes FO treatment (Sodium Chloride)	Commercial Passion Fruit Juice
pH	3.16 ± 0.03	3.09 ± 0.05	2.99 ± 0.01	3.55 ± 0.05
Soluble solids content (°)	10.01 ± 0.14	10.26 ± 0.02	10.27 ± 0.07	15.0 ± 0.13
L*	27.84 ± 1.46	23.60 ± 1.34	26.34 ± 1.17	42.35 ± 0.23
a*	1.77 ± 0.31	3.00 ± 0.37	0.89 ± 0.19	2.34 ± 0.43
b*	1.66 ± 0.17	4.28 ± 0.76	6.95 ± 0.35	25.15 ± 0.21
Content of Ascorbic Acid (mg/100mL)	16.29 ± 0.07	14.75 ± 0.10	14.53 ± 0.07	12.3 ± 0.47

CHAPTER 5 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In conclusion, FO system was developed by using food preservative that is potassium sorbate to concentrate clarified passion fruit juice. Potassium sorbate is a food preservative that designated as 'generally recognized as safe' (GRAS) by the US Food and Drug Administration (FDA). In this study, the effect of using different concentrations of potassium sorbate on the performance of FO was evaluated. It was found that transmembrane flux and Brix increased when higher concentration of DS was used. Also, the quality of clarified passion fruit juice was determined after FO process.

From the aspect of transmembrane flux and Brix increment, potassium sorbate solution showed greater effect when the concentration increased from 2M to 5M as osmotic pressure increased along with concentration of DS. However, when same concentration (5M) of potassium solution and sodium chloride were compared, sodium chloride showed a greater effect. This was due to potassium sorbate had lower osmotic pressure and higher viscosity. These characteristics concluded that potassium sorbate gave a lower effect than sodium chloride on permeate flux and Brix increment. The overall Brix increment was considered low, hence it is suggested to conduct in higher flow rate.

From the result of FTIR, the trace of DS was found in concentrated passion fruit juice due to RSD. Meanwhile, the fouling condition was severe when a higher concentration of DS was used. Possible foulant that deposited on the membrane was proteins instead of polysaccharides as most of the pectin in clarified passion fruit juice was removed. From the aspect of quality, clarified passion fruit juice concentrated by FO

was clearer than commercial passion fruit juice. Since the FO process was carried out at room temperature, there was less degradation of ascorbic acid in clarified passion fruit juice than commercial passion fruit juice which concentrated by evaporation.

Using FO and potassium sorbate as DS can preserves the quality of juice better. This was due to potassium sorbate has low RSD, minimal changes in quality was observed in clarified passion fruit concentrated using FO compared with clarified passion fruit before undergo FO and with commercial passion fruit juice. Finally, the use of FO system that employs low pressure could reduce the use of the amount of energy, which also could reduce help preserving the energy.

5.2 Recommendation

In future research, FO can be used in food industry for concentration purposes. For better performance and for further study, it is recommended to:

1. Varies the flow rate to obtain optimised performance. Use flow rate that will bring good performance and less or moderate fouling.
2. Use other type of food preservation as draw solution that has higher osmotic pressure.
3. Integrate FO with other technology such as membrane distillation.
4. Preserve the membrane system properly to maintain it's performance in FO process.

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Appendix

Calculation of mass of draw solution (potassium sorbate and sodium chloride) to different concentration

Potassium sorbate:

$$0.5 \text{ L} \times \frac{2 \text{ mole}}{1 \text{ L}} \times \frac{150.22 \text{ g}}{\text{mole}} = 150.22 \text{ g}$$

$$0.5 \text{ L} \times \frac{3 \text{ mole}}{1 \text{ L}} \times \frac{150.22 \text{ g}}{\text{mole}} = 225.33 \text{ g}$$

$$0.5 \text{ L} \times \frac{4 \text{ mole}}{1 \text{ L}} \times \frac{150.22 \text{ g}}{\text{mole}} = 300.44 \text{ g}$$

$$0.5 \text{ L} \times \frac{5 \text{ mole}}{1 \text{ L}} \times \frac{150.22 \text{ g}}{\text{mole}} = 375.55 \text{ g}$$

Sodium chloride

$$0.5 \text{ L} \times \frac{5 \text{ mole}}{1 \text{ L}} \times \frac{58.44 \text{ g}}{\text{mole}} = 146.1 \text{ g}$$

Calculation of Transmembrane Flux

Density of Passion Fruit Juice = 1043 kg/m^3

Change the weight change to unit of litre (L), if weight change is 0.00019 kg

$$\begin{aligned} \text{Volume} &= \frac{\text{weight change}}{\text{density of passion fruit juice}} \\ &= \frac{0.00019 \text{ kg}}{1043 \text{ kg/m}^3} \\ &= 1.822 \times 10^{-7} \text{ m}^3 \end{aligned}$$

$$\begin{aligned} \text{Contact area of membrane} &= \frac{\pi d^2}{4} \\ &= \frac{\pi (0.051 \text{ m})^2}{4} \end{aligned}$$

$$= 2.043 \times 10^{-3} \text{ m}^2$$

Time interval for reading weight change = 5/60 hr

$$\begin{aligned} \text{Transmembrane flux} &= \frac{\text{Volume of solution (l)}}{\text{Surface area of membrane (m}^2\text{)} \times \text{Duration of interval (hr)}} \\ &= \frac{\frac{0.00019 \text{ kg}}{1043 \text{ kg/m}^3} \times \frac{1000 \text{ L}}{\text{m}^3}}{0.002043 \text{ m}^2 \times \text{hr}} \\ &= 1.070 \text{ L/ m}^2 \text{ hr} \end{aligned}$$

Calculation of ascorbic acid content

Calculate ascorbic acid content for fresh passion fruit juice. First, calculate the number mole of iodine

n = concentration of iodine x volume titrated

$$= 0.005 \frac{\text{mole}}{\text{L}} \times 0.0022 \text{ L}$$

$$= 1.10 \times 10^{-5} \text{ mole}$$

The reactions occurred were showed in equations below:



A.1

Mole ratio of $\text{I}_2 = 2$

Calculate mole of ascorbic acid

$n_{\text{ascorbic acid}} = n \times \text{mole ratio}$

$$= 1.10 \times 10^{-5} \times 2$$

$$= 2.20 \times 10^{-5} \text{ mole}$$

Convert mole of ascorbic acid to mass

$m = n \times \text{molecular mass of ascorbic acid}$

$$= 2.20 \times 10^{-5} \times 176.12 \frac{\text{g}}{\text{mole}} \times 1000 \frac{\text{mg}}{\text{g}} \times \frac{100}{20 \text{ mL}}$$

$$= 19.37 \text{ mg/ 100 mL}$$

Proceed the calculation for clarified passion fruit juice and average concentrated clarified passion fruit juice by sodium chloride solution and potassium sorbate solution.

Table A-1: Volume of Iodine Used in Titration to Determine Ascorbic Acid Content

Type of solution	Volume of iodine titrated (mL)				Ascorbic Acid Content (mg/100 mL)
	1st	2nd	Average	Average with standard value	
Fresh passion fruit juice	2.1	2.30	2.20	2.20 ± 0.14	19.37 ± 0.14
Clarified passion fruit juice	1.80	1.90	1.85	1.85 ± 0.07	16.30 ± 0.07
5M sodium chloride (1st run)	1.60	1.70	1.65	1.65 ± 0.07	14.53 ± 0.07
5M potassium sorbate (1st run)	1.50	1.70	1.60	1.68 ± 0.10	14.75 ± 0.10
4M potassium sorbate (1st run)	1.80	1.60	1.70		
3M potassium sorbate (1st run)	1.70	1.60	1.65		
3M potassium sorbate (2nd run)	1.80	1.80	1.80		
2M potassium sorbate (1st run)	1.60	1.50	1.55		
2M potassium sorbate (2nd run)	1.80	1.70	1.75		

Table A-2: L*, a*, b* of Fresh Passion Fruit Juice, Clarified Passion Fruit Juice, Concentrated Clarified Passion Fruit Juice by Sodium Chloride Solution and Potassium Sorbate Solution.

Type of passion fruit juice	Trial					
		1st	2nd	3rd	Average	Average with standard error
Fresh	L*	42.15	42.36	44.68	43.06	43.06 ± 0.81
	a*	4.66	5.00	4.33	4.66	4.66 ± 0.19
	b*	27.52	26.88	28.46	27.62	27.62 ± 0.46
Clarified	L*	25.54	30.55	27.44	27.84	27.84 ± 1.46
	a*	2.31	1.25	1.74	1.77	1.77 ± 0.31
	b*	1.38	1.66	1.94	1.66	1.66 ± 0.17
Clarified concentrated by 5M NaCl	L*	24.74	25.65	28.62	26.34	26.34 ± 1.17
	a*	0.91	0.55	1.22	0.89	0.89 ± 0.19
	b*	7.59	6.38	6.88	6.95	6.95 ± 0.35
Clarified concentrated by 5M potassium sorbate	L*	20.90	31.13	27.01	26.35	$L^* = 23.88 \pm 1.34$ $a^* = 2.38 \pm 0.68$ $b^* = 3.42 \pm 1.00$
	a*	7.82	2.11	1.28	3.74	
	b*	11.34	0.58	0.01	3.98	
Clarified concentrated by 4M potassium sorbate	L*	24.47	24.61	25.11	24.73	
	a*	0.08	0.90	0.55	0.51	
	b*	0.72	0.84	1.00	0.85	
Clarified concentrated by 3M potassium sorbate	L*	22.79	22.51	20.97	22.09	
	a*	2.08	2.89	2.64	2.54	
	b*	1.14	2.63	5.66	3.14	
Clarified concentrated by 2M potassium sorbate	L*	22.72	22.02	22.35	22.36	
	a*	2.20	1.91	4.04	2.72	
	b*	7.95	5.49	3.70	5.71	

Table A-3: pH of Fresh Passion Fruit Juice, Clarified Passion Fruit Juice, Concentrated Clarified Passion Fruit Juice by Sodium Chloride Solution and Potassium Sorbate Solution.

Type of passion fruit juice	pH				
	Trial				
	1st	2nd	3rd	Average	Average with standard error
Fresh	3.12	3.16	3.20	3.16	3.16 ± 0.02
Clarified	3.12	3.22	3.15	3.16	3.16 ± 0.03
Clarified concentrated by 5M NaCl (1st run)	3.00	2.98	2.98	2.99	2.99 ± 0.01
Clarified concentrated by 5M PS (1st run)	3.10	3.01	3.09	3.07	3.09 ± 0.05
Clarified concentrated by 4M PS (1st run)	3.10	2.99	2.92	3.00	
Clarified concentrated by 3M PS (1st run)	3.30	3.36	3.29	3.32	
Clarified concentrated by 3M PS (2nd run)	3.18	3.09	3.16	3.14	
Clarified concentrated by 2M PS (1st run)	2.99	3.04	3.02	3.02	
Clarified concentrated by 2M PS (2nd run)	2.97	3.04	3.01	3.01	

Table A-4: Average Transmembrane Flux of Distilled Water and Clarified Passion Fruit Juice at Different Concentration of Draw Solution.

Type of Draw Solution	Concentration of Draw Solution (M)	Average Transmembrane Flux (L/m ² hr)	
		Distilled Water	Clarified Passion Fruit Juice
Sodium Chloride	5	22.575	7.790
Potassium Sorbate	2	2.524	1.472
	3	2.547	2.054
	4	8.430	6.075
	5	9.568	6.705

Table A-5: Initial, Final and Increment of Brix for Clarified Passion Fruit Juice Concentrated by Sodium Chloride and Potassium Sorbate.

Type of Draw Solution	Brix (°)										
	Initial				Standard error	Final					Increment
	1st	2nd	3rd	Average		1st	2nd	3rd	Average	Standard error	
5M Sodium chloride (1st run)	9.5	9.5	9.5	9.50	9.5 ± 0	10.2	10.2	10.4	10.27	10.27 ± 0.07	0.77
5M Potassium sorbate (1st run)	9.7	9.5	9.9	9.70	9.70 ± 0.12	10.3	10.2	10.3	10.27	10.27 ± 0.03	0.57
4M Potassium sorbate (1st run)	9.4	9.5	9.3	9.40	9.40 ± 0.06	10.1	9.9	9.8	9.93	9.93 ± 0.09	0.53
3M Potassium sorbate (1st run)	10.1	10.2	10.2	10.17	9.83 ± 0.33	10.6	10.8	10.9	10.77	10.28 ± 0.48	0.60
3M Potassium sorbate (2nd run)	9.5	9.5	9.5	9.50		9.8	9.8	9.8	9.80		0.30
2M Potassium sorbate (1st run)	9.6	9.6	9.6	9.60	9.90 ± 0.30	9.9	9.9	10	9.93	10.23 ± 0.30	0.33
2M Potassium sorbate (2nd run)	10.2	10.2	10.2	10.20		10.5	10.6	10.5	10.53		0.33

Experimental data

Table A-6: Transmembrane flux of Distilled Water at Different Concentrations of Draw Solution.

Draw Solution: 5M sodium chloride							
Time (min)	Weight change (g)		Transmembrane flux (L/m ² hr)			Conductivity (mS/cm)	
	1 st Run	2 nd Run	1 st Run	2 nd Run	Average	1 st Run	2 nd Run
0	0	-	0.000	-	0.000	-	-
5	-4.62	-	27.221	-	27.221	-	-
10	-3.82	-	22.507	-	22.507	-	-
15	-4.13	-	24.334	-	24.334	-	-
20	-4.23	-	24.923	-	24.923	-	-
25	-4.11	-	24.216	-	24.216	-	-
30	-4.14	-	24.392	-	24.392	-	-
35	-4.05	-	23.862	-	23.862	-	-
40	-4.78	-	28.163	-	28.163	-	-
45	-3.77	-	22.212	-	22.212	-	-
50	-4.4	-	25.924	-	25.924	-	-
55	-3.91	-	23.037	-	23.037	-	-
60	-3.85	-	22.684	-	22.684	-	-
Average	-3.832	-	22.575	-	22.575	-	-

Draw Solution: 5M potassium sorbate								
Time (min)	Weight change (g)		Transmembrane flux (L/m ² hr)			Conductivity (mS/cm)		
	1 st Run	2 nd Run	1 st Run	2 nd Run	Average	1 st Run	2 nd Run	
0	0	-	0	-	0.000	140.2	-	
5	-1.39	-	8.190	-	8.190	142.7	-	
10	-1.88	-	11.077	-	11.077	145.1	-	
15	-1.67	-	9.839	-	9.839	146.1	-	
20	-1.87	-	11.018	-	11.018	147.5	-	
25	-1.82	-	10.723	-	10.723	148.3	-	
30	-1.73	-	10.193	-	10.193	149	-	
35	-2.03	-	11.961	-	11.961	149.7	-	
40	-1.69	-	9.957	-	9.957	150.5	-	
45	-1.96	-	11.548	-	11.548	150.9	-	
50	-1.5	-	8.838	-	8.838	151.5	-	
55	-1.74	-	10.252	-	10.252	151.7	-	
60	-1.83	-	10.782	-	10.782	152	-	
Average	-1.624	-	9.568	-	9.568		-	
Draw Solution: 4M potassium sorbate								
Time (min)	Weight change (g)		Transmembrane flux (L/m ² hr)			Conductivity (mS/cm)		
	1 st Run	2 nd Run	1 st Run	2 nd Run	Average	1 st Run	2 nd Run	
0	0	-	0.000	-	0.000	138.8	-	
5	-1.77	-	10.429	-	10.429	139.3	-	
10	-1.68	-	9.898	-	9.898	139.5	-	
15	-1.94	-	11.430	-	11.430	139.5	-	
20	-1.89	-	11.136	-	11.136	139.5	-	
25	-1.66	-	9.781	-	9.781	139.7	-	
30	-1.42	-	8.367	-	8.367	139.8	-	

35	-1.5	-	8.838	-	8.838	139.8	-
40	-1.51	-	8.897	-	8.897	139.8	-
45	-1.23	-	7.247	-	7.247	139.9	-
50	-1.22	-	7.188	-	7.188	140	-
55	-1.45	-	8.543	-	8.543	140.1	-
60	-1.33	-	7.836	-	7.836	140.1	-
Average	-1.431		8.430		8.430		-
Draw Solution: 3M potassium sorbate							
Time (min)	Weight change (g)		Transmembrane flux (L/m ² hr)		Conductivity (mS/cm)		
	1 st Run	2 nd Run	1 st Run	2 nd Run	Average	1 st Run	2 nd Run
0	0	0	0	0	0	118.5	123.7
5	-0.42	-0.51	2.475	3.005	2.740	120.6	125.1
10	-0.38	-0.45	2.239	2.651	2.445	121.5	125.6
15	-0.21	-0.54	1.237	3.182	2.209	121.9	125.8
20	-0.56	-0.4	3.299	2.357	2.828	122.3	126.1
25	-0.36	-0.39	2.121	2.298	2.209	122.7	126.3
30	-0.32	-0.48	1.885	2.828	2.357	122.9	126.9
35	-0.41	-0.51	2.416	3.005	2.710	123.2	127.1
40	-0.58	-0.43	3.417	2.534	2.975	123.6	127.3
45	-0.5	-0.68	2.946	4.006	3.476	123.9	127.5
50	-0.61	-0.51	3.594	3.005	3.299	124	127.6
55	-0.41	-0.48	2.416	2.828	2.622	124.3	127.8
60	-0.51	-0.59	3.005	3.476	3.241	124.5	127.9
Average	-0.405	-0.459	2.388	2.706	2.547	-	-

Draw Solution: 2M potassium sorbate						
Time (min)	Weight change (g)		Transmembrane flux (L/m ² hr)		Conductivity (mS/cm)	
	1 st Run	2 nd Run	1 st Run	2 nd Run	1 st Run	2 nd Run
0	0	0	0	0	101.6	86.1
5	-0.2	-0.63	1.178	3.712	103.2	88.9
10	-0.46	-0.7	2.710	4.124	103.8	89.1
15	-0.6	-0.52	3.535	3.064	104.0	89.2
20	-0.67	-0.24	3.948	1.414	104.2	89.4
25	-0.6	-0.33	3.535	1.944	104.6	89.6
30	-0.54	-0.45	3.182	2.651	104.8	89.8
35	-0.58	-0.41	3.417	2.416	105.2	90.1
40	-0.43	-0.51	2.534	3.005	105.6	90.3
45	-0.49	-0.4	2.887	2.357	105.8	90.4
50	-0.39	-0.41	2.298	2.416	105.9	90.5
55	-0.41	-0.39	2.416	2.298	106.2	90.6
60	-0.45	-0.33	2.651	1.944	106.3	90.7
Average	-0.448	-0.409	2.638	2.411	-	-

Table A-7: Transmembrane flux of Clarified Passion Fruit Juice at Different Concentrations of Draw Solution.

Draw Solution: 5M sodium chloride								
Time (min)	Weight change (g)		Transmembrane flux (L/m ² hr)			Conductivity (mS/cm)		
	1 st Run	2 nd Run	1 st Run	2 nd Run	Average	1 st Run	2 nd Run	
0	0.00	-	0.000	-	0.000	-	-	
5	-2.13	-	11.996	-	11.996	-	-	
10	-1.30	-	7.322	-	7.322	-	-	
15	-1.44	-	8.110	-	8.110	-	-	
20	-1.25	-	7.040	-	7.040	-	-	
25	-1.44	-	8.110	-	8.110	-	-	
30	-1.56	-	8.786	-	8.786	-	-	
35	-1.31	-	7.378	-	7.378	-	-	
40	-1.35	-	7.603	-	7.603	-	-	
45	-1.41	-	7.941	-	7.941	-	-	
50	-1.43	-	8.054	-	8.054	-	-	
55	-1.31	-	7.378	-	7.378	-	-	
60	-1.67	-	9.406	-	9.406	-	-	
65	-1.21	-	6.815	-	6.815	-	-	
70	-1.97	-	11.095	-	11.095	-	-	
75	-1.00	-	5.632	-	5.632	-	-	
80	-1.48	-	8.335	-	8.335	-	-	
85	-1.68	-	9.462	-	9.462	-	-	
90	-1.52	-	8.561	-	8.561	-	-	
95	-1.42	-	7.998	-	7.998	-	-	
100	-1.55	-	8.730	-	8.730	-	-	
105	-1.24	-	6.984	-	6.984	-	-	

110	-1.47	-	8.279	-	8.279	-	-
115	-1.70	-	9.574	-	9.574	-	-
120	-1.50	-	8.448	-	8.448	-	-
125	-1.20	-	6.758	-	6.758	-	-
130	-1.33	-	7.491	-	7.491	-	-
135	-1.41	-	7.941	-	7.941	-	-
140	-1.54	-	8.673	-	8.673	-	-
145	-1.41	-	7.941	-	7.941	-	-
150	-1.02	-	5.745	-	5.745	-	-
155	-1.30	-	7.322	-	7.322	-	-
160	-1.13	-	6.364	-	6.364	-	-
165	-1.30	-	7.322	-	7.322	-	-
170	-1.45	-	8.166	-	8.166	-	-
175	-1.36	-	7.660	-	7.660	-	-
180	-1.39	-	7.829	-	7.829	-	-
Average	-1.38	-	7.790	-	7.790	-	-

Draw Solution: 5M potassium sorbate

Time (min)	Weight change (g)		Transmembrane flux (L/m ² hr)		Conductivity (mS/cm)	
	1 st Run	2 nd Run	1 st Run	2 nd Run	1 st Run	2 nd Run
0	0.00	-	0.000	-	151.6	-
5	-1.02	-	5.745	-	151.2	-
10	-1.09	-	6.139	-	151.1	-
15	-1.23	-	6.927	-	151.2	-
20	-1.25	-	7.040	-	151.3	-
25	-1.20	-	6.758	-	151.7	-
30	-1.19	-	6.702	-	152.0	-
35	-1.18	-	6.646	-	152.4	-

40	-1.27	-	7.153	-	7.153	-	152.7	-
45	-1.26	-	7.096	-	7.096	-	153.0	-
50	-1.19	-	6.702	-	6.702	-	153.3	-
55	-1.39	-	7.829	-	7.829	-	153.7	-
60	-1.18	-	6.646	-	6.646	-	153.9	-
65	-1.43	-	8.054	-	8.054	-	154.0	-
70	-1.00	-	5.632	-	5.632	-	154.1	-
75	-1.19	-	6.702	-	6.702	-	154.2	-
80	-1.09	-	6.139	-	6.139	-	154.4	-
85	-1.23	-	6.927	-	6.927	-	154.5	-
90	-1.20	-	6.758	-	6.758	-	154.7	-
95	-1.07	-	6.026	-	6.026	-	154.9	-
100	-1.22	-	6.871	-	6.871	-	154.9	-
105	-1.11	-	6.252	-	6.252	-	155.1	-
110	-1.24	-	6.984	-	6.984	-	155.1	-
115	-1.23	-	6.927	-	6.927	-	155.3	-
120	-1.22	-	6.871	-	6.871	-	155.3	-
125	-1.11	-	6.252	-	6.252	-	155.3	-
130	-1.12	-	6.308	-	6.308	-	155.3	-
135	-1.35	-	7.603	-	7.603	-	155.5	-
140	-1.08	-	6.083	-	6.083	-	155.4	-
145	-1.47	-	8.279	-	8.279	-	155.5	-
150	-1.33	-	7.491	-	7.491	-	155.5	-
155	-1.28	-	7.209	-	7.209	-	155.5	-
160	-1.26	-	7.096	-	7.096	-	155.6	-
165	-1.42	-	7.998	-	7.998	-	155.6	-
170	-1.22	-	6.871	-	6.871	-	155.7	-

175	-1.35	-	7.603	-	7.603	155.7	-
180	-1.38	-	7.772	-	7.772	155.7	-
Average	-1.19	-	6.705	-	6.705	154.1	-
Draw Solution: 4M potassium sorbate							
Time (min)	Weight change (g)		Transmembrane flux (L/m ² hr)		Conductivity (mS/cm)		
	1 st Run	2 nd Run	1 st Run	2 nd Run	Average	1 st Run	2 nd Run
0	0	-	0.000	-	0.000	139.2	-
5	-0.97	-	5.463	-	5.463	138.8	-
10	-1.22	-	6.871	-	6.871	138.6	-
15	-1.25	-	7.040	-	7.040	138.7	-
20	-1.2	-	6.758	-	6.758	138.5	-
25	-1.08	-	6.083	-	6.083	138.6	-
30	-1.22	-	6.871	-	6.871	138.6	-
35	-1.13	-	6.364	-	6.364	138.6	-
40	-1.16	-	6.533	-	6.533	138.6	-
45	-1.03	-	5.801	-	5.801	138.6	-
50	-1.2	-	6.758	-	6.758	138.5	-
55	-1.14	-	6.421	-	6.421	138.4	-
60	-1.14	-	6.421	-	6.421	138.6	-
65	-1.04	-	5.857	-	5.857	138.5	-
70	-1.14	-	6.421	-	6.421	138.6	-
75	-1.22	-	6.871	-	6.871	138.4	-
80	-1.04	-	5.857	-	5.857	138.5	-
85	-1.22	-	6.871	-	6.871	138.5	-
90	-0.97	-	5.463	-	5.463	138.3	-
95	-0.99	-	5.576	-	5.576	138.2	-
100	-1.29	-	7.265	-	7.265	138.0	-

105	-1.01	-	5.688	-	5.688	-	138.3	-
110	-1.06	-	5.970	-	5.970	-	138.0	-
115	-1.17	-	6.590	-	6.590	-	137.9	-
120	-0.97	-	5.463	-	5.463	-	137.5	-
125	-1.3	-	7.322	-	7.322	-	137.4	-
130	-1.12	-	6.308	-	6.308	-	137.3	-
135	-0.92	-	5.181	-	5.181	-	137.2	-
140	-1.11	-	6.252	-	6.252	-	137.3	-
145	-1.03	-	5.801	-	5.801	-	137.1	-
150	-1.09	-	6.139	-	6.139	-	137.1	-
155	-1.07	-	6.026	-	6.026	-	137.1	-
160	-1.19	-	6.702	-	6.702	-	137.0	-
165	-0.94	-	5.294	-	5.294	-	136.5	-
170	-1.01	-	5.688	-	5.688	-	136.6	-
175	-1.18	-	6.646	-	6.646	-	136.6	-
180	-1.09	-	6.139	-	6.139	-	136.5	-
Average	-1.08	-	6.075	-	6.075	-	-	-
Draw Solution: 3M potassium sorbate								
Time (min)	Weight change (g)		Transmembrane flux (L/m ² hr)			Conductivity (mS/cm)		
	1 st Run	2 nd Run	1 st Run	2 nd Run	Average	1 st Run	2 nd Run	
0	0	0	0	0	0	104.3	84.0	
5	-0.19	-0.34	1.070	1.915	1.492	105.1	84.9	
10	-0.41	-0.15	2.309	0.845	1.577	104.1	83.7	
15	-0.36	-0.26	2.028	1.464	1.746	103.9	83.5	
20	-0.42	-0.25	2.365	1.408	1.887	104.2	84.3	
25	-0.47	-0.25	2.647	1.408	2.028	104.6	84.9	
30	-0.42	-0.3	2.365	1.690	2.028	104.8	85.4	

35	-0.26	-0.26	1.464	1.464	1.464	105	86
40	-0.49	-0.26	2.760	1.464	2.112	105.4	86.1
45	-0.32	-0.33	1.802	1.859	1.830	106.2	86.7
50	-0.77	-0.28	4.337	1.577	2.957	106.3	87.3
55	-0.44	-0.36	2.478	2.028	2.253	106.4	87.1
60	-0.37	-0.98	2.084	5.519	3.802	106.8	88.1
65	-1.3	-0.16	7.322	0.901	4.111	106.9	88.5
70	-0.42	-0.26	2.365	1.464	1.915	107.0	88.9
75	-0.54	-0.16	3.041	0.901	1.971	107.2	89.1
80	-0.36	-0.23	2.028	1.295	1.661	107.5	89.5
85	-0.33	-0.23	1.859	1.295	1.577	107.6	89.4
90	-0.48	-0.54	2.703	3.041	2.872	108.0	90.3
95	-0.16	-0.28	0.901	1.577	1.239	108.3	90.5
100	-0.5	-0.28	2.816	1.577	2.197	108.3	90.5
105	-0.37	-0.18	2.084	1.014	1.549	108.1	90.6
110	-0.4	-0.27	2.253	1.521	1.887	108.2	91.2
115	-0.56	-0.1	3.154	0.563	1.859	108.2	91.1
120	-0.32	-0.25	1.802	1.408	1.605	108.2	91.1
125	-0.99	-0.21	5.576	1.183	3.379	108.3	90.9
130	-0.33	-0.24	1.859	1.352	1.605	108.3	91.3
135	-0.23	-0.18	1.295	1.014	1.155	108.2	91.1
140	-0.31	-0.31	1.746	1.746	1.746	109.6	91.1
145	-0.34	-0.22	1.915	1.239	1.577	109.4	91.1
150	-0.33	-0.46	1.859	2.591	2.225	109.2	91.2
155	-0.33	-0.42	1.859	2.365	2.112	109.3	91.2
160	-0.56	-0.39	3.154	2.197	2.675	109.5	91.3
165	-0.34	-0.38	1.915	2.140	2.028	109.8	91.3

170	-0.42	-0.62	2.365	3.492	2.929	110	91.4
175	-0.36	-0.41	2.028	2.309	2.168	110.1	91.5
180	-0.48	-0.51	2.703	2.872	2.788	110	91.5
Average	-0.424	-0.306	2.387	1.722	2.054	-	-

Draw Solution: 2M potassium sorbate

Time (min)	Weight change (g)		Transmembrane flux (L/m ² hr)			Conductivity (mS/cm)	
	1 st Run	2 nd Run	1 st Run	2 nd Run	Average	1 st Run	2 nd Run
0	0	0	0	0	0	125.5	123.6
5	-0.21	-0.1	1.183	0.563	0.873	126.0	124.0
10	-0.32	-0.12	1.802	0.676	1.239	126.4	124.8
15	-0.29	-0.29	1.633	1.633	1.633	126.7	125.2
20	-0.62	-0.11	3.492	0.620	2.056	127.2	125.6
25	-0.22	-0.17	1.239	0.957	1.098	127.8	125.9
30	-0.33	-0.18	1.859	1.014	1.436	128.4	126.1
35	-0.3	-0.12	1.690	0.676	1.183	128.9	126.4
40	-0.31	-0.2	1.746	1.126	1.436	129.4	126.5
45	-0.28	-0.16	1.577	0.901	1.239	129.7	127.1
50	-0.29	-0.15	1.633	0.845	1.239	130.2	127.0
55	-0.29	-0.28	1.633	1.577	1.605	130.7	127.5
60	-0.22	-0.2	1.239	1.126	1.183	130.6	127.4
65	-0.29	-0.27	1.633	1.521	1.577	131.1	128.4
70	-0.27	-0.15	1.521	0.845	1.183	132.1	127.6
75	-0.31	-0.14	1.746	0.788	1.267	132.5	129.2
80	-0.28	-0.22	1.577	1.239	1.408	132.9	129.6
85	-0.29	-0.14	1.633	0.788	1.211	133.0	130.0
90	-0.3	-0.14	1.690	0.788	1.239	133.3	130.6
95	-0.28	-0.16	1.577	0.901	1.239	133.4	130.9

100	-0.34	-0.21	1.915	1.183	1.549	133.6	128.4
105	-0.26	-0.09	1.464	0.507	0.986	133.7	130.4
110	-0.24	-0.22	1.352	1.239	1.295	134.4	128.0
115	-0.3	-0.24	1.690	1.352	1.521	134.5	128.2
120	-0.27	-0.31	1.521	1.746	1.633	134.8	128.4
125	-0.28	-0.25	1.577	1.408	1.492	135.0	128.5
130	-0.32	-0.31	1.802	1.746	1.774	135.2	129.5
135	-0.26	-0.42	1.464	2.365	1.915	135.5	128.2
140	-0.29	-0.38	1.633	2.140	1.887	135.7	128.4
145	-0.28	-0.41	1.577	2.309	1.943	135.9	128.9
150	-0.27	-0.36	1.521	2.028	1.774	135.8	129.2
155	-0.32	-0.34	1.802	1.915	1.859	135.9	129.5
160	-0.28	-0.35	1.577	1.971	1.774	140.1	129.7
165	-0.36	-0.26	2.028	1.464	1.746	140.2	129.9
170	-0.33	-0.37	1.859	2.084	1.971	140.3	130.2
175	-0.28	-0.34	1.577	1.915	1.746	140.4	130.7
180	-0.33	-0.47	1.859	2.647	2.253	140.6	131.2
Average	-0.289	-0.233	1.630	1.314	1.472	-	-