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Evaluation of sodium acetate and glucose as minor additives with calcium chloride as optimum mixed draw solutes for fruit juice concentration via forward osmosis

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Abstract−The selection of an appropriate draw solution is decisive to augment the performance of the forward osmosis (FO) process with maximal permeate flux and minimal reverse solute flux. Inorganic salts provide higher permeate flux in FO, but high reverse salt flux (RSF) associated with greater diffusivity limits their potential application. Herein, the incorporation of organic compounds including sodium acetate (NaAce) and glucose in $CaCl_2$ provides draw solutions with constant osmotic pressure for boosting FO performance. The PRO mode (active layer facing draw solution) is examined with 0.18 m/s of cross-flow velocity using a polyamide membrane associated with a polyethyleneimine (PEI) interlayer on a NaOH treated polyacrylonitrile substrate. The 5% NaAce with $CaCl_2$ as a draw solution (DS) delivers better performance against deionized water compared to glucose, resulting in lower RSF (6.64 g/m^2 h) and higher water flux (23.9 L/m^2 h). The NaAce with $CaCl_2$ suppresses RSF up to 41% without a significant reduction in permeate flux compared to single salt DS. The optimized draw solution concentrates the orange juice, resulting in 2.13 L/m^2 h of average water flux and 3.6 g/m^2 h of RSF for 72 h, thus concentrating the orange juice from the initial concentration of 13 °Brix to 24 °Brix.

Keywords: Forward Osmosis, Coupled Draw Solutions, Fruit Juice Concentration, Permeate Flux, Reverse Solute Flux, Osmotic Pressure

INTRODUCTION

Forward osmosis involves developing membrane-based technology using osmotic pressure as a driving force between feed solution and draw solution [1]. Forward osmosis (FO) possesses a low membrane-fouling tendency and low energy requirement compared to traditional nanofiltration and reverse osmosis processes driven by external hydraulic pressure [2,3]. Hence, FO has gotten tremendous attention recently and demonstrated huge potential for various applications including wastewater treatment [4,5], food processing [6,7], desalination [8,9], and power generation [10,11].

The selection of an appropriate draw solution (DS) demonstrates a vital role as osmotic pressure drives the process. The research regarding the development of draw solution relatively lags behind due to the operating challenges of draw solution that need to be fulfilled [12,13]. These challenges for the draw solution include reasonable molecular size to minimize the reverse salt/solute flux (RSF), high osmotic pressure to deliver higher water flux, nontoxicity, the low operational cost during recovery, and FO membrane compatibility [14-16]. The different types of compounds were investigated for the DS solution including inorganic and organic salts [17,18], hydrophilic magnetic nanoparticles [19], volatile compounds (dimethyl ether) [20], neutral compounds (i.e., ethylene glycol and urea) [21], and hydroacid magnetic nanoparticles [22]. However, these compounds exhibited limitations up to some extent considering the prerequisites of the draw solution to be fulfilled. The commonly used inorganic salts for draw solution consist of sodium chloride (NaCl), and magnesium chloride ($MgCl_2$) [23,24]. Although those salts produce high osmotic pressure via complete ionization in aqueous solution and deliver high permeate flux, they face extremely severe salt leakage and need high energy during the draw solution recovery. Moreover, magnetic nanoparticles, thermally responsive hydrogels, and thermosensitive polyelectrolytes as draw solutes [25,

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26] exhibit smaller solute leakage and easy recovery, but the lower water fluxes limit their potential application. To overcome this issue of low water flux, the thermolytic salts (i.e., ammonium bicarbonate) were developed [27,28] to deliver high permeate flux, which can be simply recovered via disintegration with industrial waste heat, but the harmful, as well as corrosive ammonia gas, can adversely affect product water quality with even a minute residue of draw solution [29,30]. Considering the inorganic class of DS, the $CaCl_2$ has more advantages considering the performance [23], although it exhibits greater RSF. The nutrient compounds including NaAce and glucose deliver low RSF compared to the inorganic class [31]. Moreover, NaAce can be used for the preservation of food, pH, and taste control. Even, if the glucose and sodium acetate diffuse toward the feed side, the influence will not be as adverse as inorganic $CaCl_2$ DS. The organic salts are considered as potential draw solutes with decent FO performance due to their chemical structure in an aqueous solution where the reasonable molecular size could provide low viscosity, high water flux, and ease recovery of the draw solution [32,33].

In this work, the addition of organic compounds (glucose and sodium acetate) with calcium chloride was investigated as mixed draw solution to cope with the problem of reverse solute flux while maintaining the high solvent permeate flux. The FO performance of sodium acetate and glucose of various chemical compositions and different solution concentrations was investigated and compared with the reference calcium chloride solution. Herein, the NaAce was employed first time as a solute with $CaCl_2$ in DS. The acetate ion has a low diffusing tendency that significantly decreases the RSF of $CaCl_2$ and associated chloride ion. Moreover, few studies have been reported till now considering the FO performance using the organic salt draw solute. Those studies have investigated the FO performance via single solute salt as DS. The current research aimed to analyze the multiple-solute salts composed of various combinations of sodium acetate and glucose with calcium chloride as potential DS and their performance on FO considering the permeate flux and RSF simultaneously. The optimized draw solution significantly reduces the RSF while maintaining the high permeate flux and concentrates the orange juice via FO, exhibiting great potential for usage in FO in the future.

MATERIALS AND METHODS

1. Materials

Several experiments were performed on bench-scale FO apparatus to evaluate the cross membrane flux and reverse salt/solute flux (RSF). A combination of draw solutions of $CaCl_2$ as a major component and glucose and sodium acetate as minor components were used during the experiments. The osmotic pressure was kept equivalent to 1 molar $CaCl_2$ for the prepared draw solutions (DSs). Deionized water was used throughout the experiments. The chemical reagents used during experiments were calcium chloride dihydrated ($CaCl_2$ $2H_2O$) (Sigma-Aldrich, UK Purity: >99%), glucose monohydrated ($C_6H_{12}O_6$ H_2O) (Merck Co., Germany, Purity: >99%), sodium acetate anhydrous (CH_3COONa) (Sigma-Aldrich, UK, Purity: >99%), and methanol (CH_3OH) (Merck, Co., Germany, Purity: >99%).

2. Fabrication of Polyamide Membrane

The polyamide membrane with a polyethyleneimine (PEI) interlayer was fabricated via a typical interfacial polymerization, according to our previous work [34]. Specifically, the commercial polyacrylonitrile (PAN) ultrafiltration membrane was pretreated using 2 mol/L of NaOH solution at 65 °C for 1 h. The resultant PAN substrate was rinsed with DI water until neutral and denoted as HPAN. Subsequently, the HPAN was immersed in 1.5 g/L of PEI solution for 30 min to form a PEI interlayer on a porous substrate and then rinsed with DI water. Afterward, a m-phenylenediamine (MPD) aqueous solution (2.0 wt% MPD and 0.15 wt% SDS) and a trimesoyl chloride (TMC) n-hexane solution (0.1 w/v% TMC) were used to immerse the PEI-HAPN substrate successively for 2 min and 1 min, respectively. Note that the PEI-HPAN substrate needed air-drying at room temperature before being treated by TMC solution. After the interfacial polymerization reaction of MPD and TMC on the substrate, the polyamide membrane with PEI interlayer was obtained. To increase the density, the primary membrane was usually subjected to heat treatment at 80 °C for 5 min in an oven. The membrane used for the experimentation was provided by our Chinese collaborative research group. The scope of this study was to conclude the performance of draw solutions in terms of permeation, i.e., cross membrane water flux and reverse salt flux. The

Fig. 1. FO bench-scale apparatus.

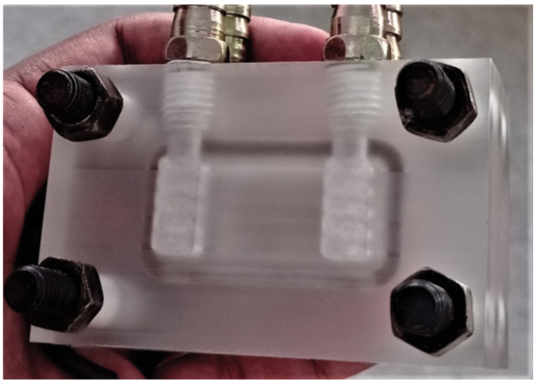

Fig. 2. Locally fabricated FO module for inorganic membrane testing.

membrane was used for the long-term operation and no significant deposition was observed on the surface of the membrane for the draw solutes.

3. Bench-scale FO Apparatus

The FO apparatus consisted of two reservoir tanks (i.e., one tank for draw solution (DS) and another tank for feed solution (FS)), two peristaltic pumps with built-in flow measurement, an online conductivity probe, heater and chiller, analytical balance, and magnetic stirrers as shown in Fig. 1. The concentration and weight were recorded for feed solution to evaluate cross membrane flux and RSF using an effective membrane area of 6.8 cm^2 via the FO module (Fig. 2). Draw solution was continuously stirred using a magnetic stirrer. Both solutions (draw and feed) had a constant temperature of 25±1 °C and were circulated through separate loops of food-grade connecting pipes with a flow rate of 600 mL/min.

4. Composition of Draw Solutions

With $CaCl_2$ as a major component, glucose combinations of 5 and 10% osmotic pressure and sodium acetate (NaAce), 3%, 5%, 7%, and 10% osmotic pressure combinations were tested. To get a better understanding of how the osmotic pressure is evaluated for the 10% glucose combination, the data used in the OLI Stream analyzer was as follows:

- Temperature: 28 °C
- Pressure: 1 atm
- Amount of calcium chloride: 135.1 grams=70.389 atm (90% of the reference osmotic pressure)
- Amount of glucose: 54 grams=7.821 atm (10% of the reference osmotic pressure)
- Total osmotic pressure=70.389+7.821=78.21 atm

OLI stream analyzer uses the below van't Hoff equation (Eq. (1)) for the evaluation of osmotic pressure.

$$\pi = -\frac{RT}{V_M} \ln a_W \tag{1}$$

where V_m is the molar volume of water and a_w is the activity of the solution. For multicomponent system, activity values can be calculated using the Ross equation (Eq. (2)), which is equivalent to the product of standard binary activity of each component used.

$$a_w \sim \Pi_{i=1}^{N} a_i^o \tag{2}$$

The concentration and amount of each used salt for every experimental run are shown in Table 1.

The first column of Table 1 specifies the percentage of total osmotic pressure (equivalent to 78.21 atm) that would be offered by the minor or major salt. For instance, in the first column of Table 1, 10% glucose combination, the amount of glucose added to the draw solution will be such that it offers only 10% of the total osmotic pressure. In the fourth column, the values of osmotic pressure were calculated using OLI Stream Analyzer. The tool only required the amount of each specie, temperature, and pressure for the calculation of the osmotic pressure. For instance, the 10% glucose combination of the data used in the OLI Stream analyzer was as follows:

- Temperature: 28 °C
- Pressure: 1 atm
- Amount of calcium chloride: 135.1 grams=70.389 atm (90% of the reference osmotic pressure)
- Amount of glucose: 54 grams=78.21 atm (10% of the reference osmotic pressure)

The calcium chloride ($CaCl_2$), glucose ($C_6H_{12}O_6$), and sodium acetate (CH_3COONa) are used for the preparation of draw solutions. The diffusivities and hydrated radius of these ions (i.e., Cl^-, Na^+, CH_3COO^-, and Ca^{2+}) and non-electrolytic molecule (glucose) are represented in Table 2. The chlorine ion exhibits the greater diffusivity among these ions and promotes the back diffusion of draw solution that adversely affected the performance of the process.

5. Experimental Procedure

The sodium acetate anhydrous (CH_3COONa) and glucose monohydrate/dextrose ($C_6H_{12}O_6{\cdot}H_2O$) are used in a smaller quantity compared to calcium chloride dihydrate ($CaCl_2{\cdot}2H_2O$) for the prepara-

Table 1. Draw solution combinations for experiments

Osmotic pressure by minor salt (%)	Calcium chloride (g)	Sodium acetate (g)	Total osmotic pressure (atm)	Viscosity
3	143.4	11.6	78.21	1.07
5	141.0	17.5	78.21	1.10
7	138.7	22.6	78.21	1.33
10	135.1	29.9	78.21	1.17

Osmotic pressure by minor salt (%)	Calcium chloride (g)	Sodium acetate (g)	Total osmotic pressure (atm)	Viscosity
5	141.0	27.7	78.21	1.16
10	135.1	54.0	78.21	1.32

Table 2. The diffusion coefficients and hydrated radius of the selective ions and non-electrolytic molecule

Specie	Diffusion coefficient ($\times 10^{-10}$ m^2/sec)	Ionic radius in water/ hydrated radius (nm)
Cl^-	20.3	0.318
Na^+	13.34	0.235
CH_3COO^-	10.89	0.27
Ca^{2+}	7.69	0.242
Glucose	6.7	0.4

tion of draw solutions that are used for the performance evaluation. Methanol (CH_3OH) was used for membrane wetting. Deionized water with 3 to 5 ppm concentration was used for rinsing, and solution preparation. Each draw solution was stirred for 1 hour before the start of the experiment. The polyamide membrane was placed in 50% methanol solution for 5 minutes to confirm its appropriate wetting and then rinsed with deionized water for 10 minutes to remove any traces of the alcohol. The rinsing time was adjusted according to the variation of feed and draw solutions conductivity until no significant change happened in the conductivity for 5 minutes. The peristaltic pumps used for the feed and draw solutions were properly primed and calibrated prior to the initiation of the experimental runs. At constant temperature and flow velocity, volume decline and conductivity of the feed were recorded at intervals of 10 minutes to evaluate the cross membrane flux and RSF using Eqs. (3) and (4), respectively. For water flux, mass/volume decline was used. For RSF, conductivity was converted to concentration, and volume decline was used as in a previous study [8].

$$J_w=\frac{V_t-V_o}{A\Delta t} \tag{3}$$

$$J_s(RSF)=\frac{C_tV_t-C_oV_o}{A\Delta t} \tag{4}$$

Change in mass/volume was translated into flux by using the area of 6.8 cm^2 and a time interval of 10 minutes (Eq. (3)). For RSF, conductivity was converted to concentration using conversion factor 1 ppm$=10^{-6}$ g/ml, area of 6.8 cm^2, and time interval of 10 minutes (Eq. (4)). For simplification changes in density were considered negligible and mass decline was generally taken as volume decline. The initial concentration (C_o) was based on the amount of osmotic pressure, the draw solution would offer for which OLI Stream analyzer was utilized. For the operational phase, conductivity values were utilized to evaluate the C_t and later on reverse solute flux.

The reverse solute flux is primarily calculated using the conductivity of the feed solution rather than that of the draw solution. This has remained the most appropriate way for the evaluation as observed by the previous study [8]. In the absence of a dosing solution, the conductivity of the draw solution will reduce mostly because of water flux from the feed side. The reverse salt flux will have a negligible effect on the conductivity of the draw solution due to which conductivity of feed solution was used to evaluate the RSF. The performance of each DS was evaluated for three hours and each experiment was repeated three times for precise results. The overall FO operation was considered for three hours with the reading interval of ten minutes for all the draw solution combinations after which the equipment was prepared for another run. The whole run considering the preparation of equipment and draw solution needs four to five hours.

RESULTS AND DISCUSSION

1. Performance Evaluation of Reference Solution

The calcium chloride solution (1.0 M) was prepared and analyzed as a reference and used for the comparison as a standard for the other draw solutions. The average flux and reverse salt flux (RSF) obtained for the prepared $CaCl_2$ reference solution are 24.13 L/m^2h and 11.33 g/m^2h, respectively. The PRO mode (polyamide active layer facing draw solution) of the FO process was examined through concentrative internal concentration polarization inside the support layer. The active side toward the feed side in the FO mode where the water flux is rigorously influenced via dilutive internal concentration polarization [35], the PRO mode delivers greater water fluxes; nevertheless, the higher RSF limits its application.

2. The Effect of Glucose on Draw Solution

The glucose with 5% and 10% as an additive in the $CaCl_2$ were examined as mixed draw solutions. This combination of the draw solution resulted in the lessening of cross membrane permeate flux and RSF. The 5% glucose solution delivered 22.74 L/m^2h water flux and 9.36 g/m^2 h RSF. This combination decreases the flux by 6%, while considerably decreasing the RSF by 17% compared to the performance of the single DS reference solution. The flux and RSF observed for the 10% glucose were 19.55 L/m^2h and 7.33 g/m^2h, respectively. This DS significantly decreased the RSF by 33.5%; however, the water flux also decreased by 19%. The flux decline for the deionized feed and the associated RSF are shown in Fig. 3. The observations demonstrate that the incorporation of glucose as an additive in $CaCl_2$ draw solution influentially minimized the RSF, but also adversely affected the cross membrane permeate flux. Nevertheless, the decline in RSF was much greater than the permeate flux, which affects FO performance.

The significant decrease in both RSF and permeate flux could be attributed to the larger hydrated radius of a glucose molecule.

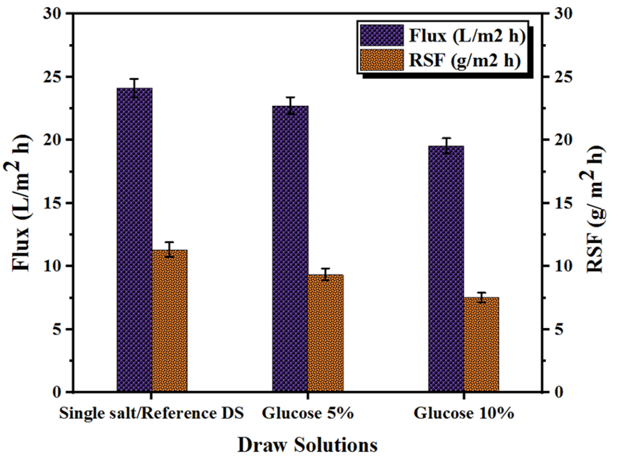

Fig. 3. The influence of glucose combination on flux and RSF in comparison with reference DS.

The non-electrolyte nature and low diffusivity of the glucose are reducing the diffusion of glucose molecules inside the membrane matrix, thus delivering interference to the chloride ions. Moreover, the glucose molecules possessing the slow diffusion block the inside pores of the membrane structure during its passage, hence abruptly hindering the water flux and reverse flux of draw solutes [8]. The introduction of glucose in the reference solution also enhances the solution viscosity, hence increasing the velocity and concentration boundary layer thickness. Thus, the water flux and RSF are significantly decreased by increasing the effectiveness of internal and external concentration polarization [36]. Glucose has larger sizes due to which the process is prone to fouling from the draw solution side. Complexes are also formed in the ionic salt solutions by the nutrient molecules, including glucose and sucrose [37], which also affects the performance of the reference DS.

3. The Effect of Sodium Acetate on Draw Solution

NaAce has Na^+ cation that exhibits high diffusivity, while CH_3COO^- anion delivers lower diffusivity and has a greater hydrated radius to boost performance and can provide a stable water flux [23]. NaAce is associated with sodium chloride and sodium formate [31]. The acetate ion demonstrates low RSF considering the other ions available in the draw solution because of its smaller diffusion coefficient and bigger size while the chloride ions possess the greater RSF. Herein, the NaAce was first time used with $CaCl_2$ as an additive to formulate the draw solution. The incorporation of low diffusing CH_3COO^- anion influentially decreased the RSF compared to reference draw solution especially the RSF of Cl^- ions. Organic salts like glucose and sodium acetate exhibit fouling properties due to their low diffusivity compared to the inorganic salts. The proposed mixed draw solution contains only a very small proportion of the organic salts for reduction in the RSF due to which the cross membrane water flux was reduced slightly. This reduction can be attributed partially to the negligible fouling of organic salts being utilized.

First, the influence of NaAce on the $CaCl_2$ was investigated using 5% and 10% solutions of sodium acetate after which the effect of 3% and 7% of NaAce additive was further analyzed to examine the performance evaluation. The average flux and RSF for 3%, 5%, 7% and 10% addition of NaAce with $CaCl_2$ were 24.059 L/m^2 h, 9.28 g/m^2 h; 23.90 L/m^2 h, 6.64 g/m^2 h; 23.08 L/m^2 h, 10.23 g/m^2 h; and 22.69 L/m^2 h, 15.56 g/m^2 h, respectively. The comparison of flux and RSF of each combination of NaAce is shown in Fig. 4.

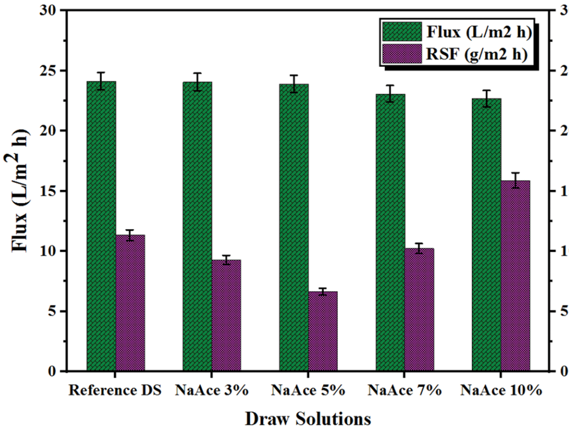

Fig. 4. The effect of NaAce on flux and RSF compared to reference DS.

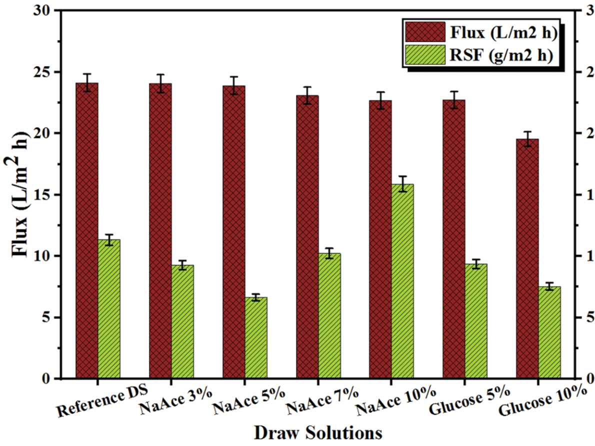

Fig. 5. The effect of sodium acetate and glucose as additives in DS on flux and RSF.

NaAce composed of Na^+ cation has greater diffusivity and is capable of providing a proper water flux, while CH_3COO^- with a greater hydrated radius and smaller diffusivity reduces the RSF. The permeate flux is not significantly influenced by the incorporation of the NaAce in $CaCl_2$. This is attributed to the larger size of CH_3COO^- which affects the Cl^-. The high RSF slightly reduces the water passage inside the membrane. The 3 and 5% NaAce significantly decrease the RSF and are attributed to a greater hydrated radius, slow diffusing, and anionic nature of CH_3COO^-. The reverse flux of Cl^- ions inside the membrane matrix is not only reduced by the steric hindrance of larger CH_3COO^- anion, but also by electrostatic repulsion by anionic nature. Nevertheless, above the 5% of NaAce, the capability of CH_3COO^- anions to hinder the RSF of Cl^- anion is to be reduced for the 7% and 10% of NaAce (Fig. 5). The 10% NaAce DS provides a greater RSF than the single DS reference solution. This increase in the performance is attributed to the Na^+ ions availability. The greater concentration of Na^+ anions across a membrane augments the RSF by combining the Na^+ with Cl^- due to the electrical neutrality. Despite its low diffusivity, higher RSF of Na^+ was observed compared to Cl^- previously [38]. The enhancement of Na^+ ions in DS dragged the Cl^- anion across the membrane to develop the electroneutrality originated by H^+ diffusing towards the DS [39]. There may be also some other factors, but the electroneutrality and enhancement in concentration gradient for Na^+ have a major contribution to enhancing the RSF of the reference draw solution.

4. Comparison of the Influential Effect of Glucose and Sodium Acetate

Sodium acetate as an additive is observed to perform better compared to glucose. Better performance of the NaAce in terms of RSF as an additive can be attributed to ionic nature of the acetate ion. While steric hindrance is offered by both NaAce and glucose, glucose molecules are larger with no electrolytic nature. The glucose DS exhibits higher viscosity than the NaAce, could significantly reduce the RSF, however at the cost of permeate flux. Considering the case of NaAce, the decent performance of NaAce in terms of

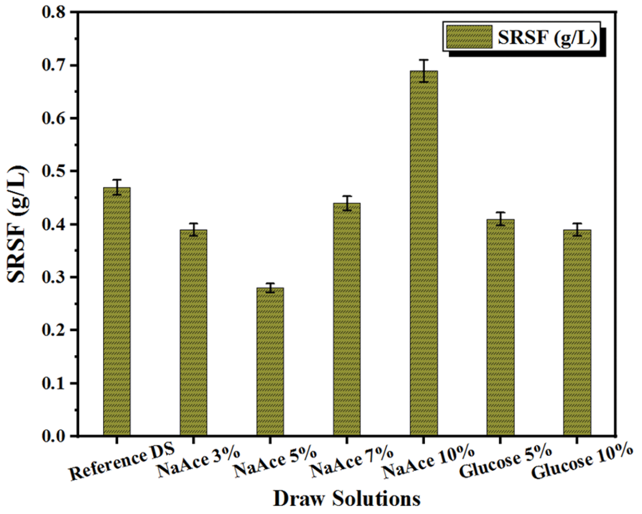

Fig. 6. Specific reverse salt flux for sodium acetate and glucose.

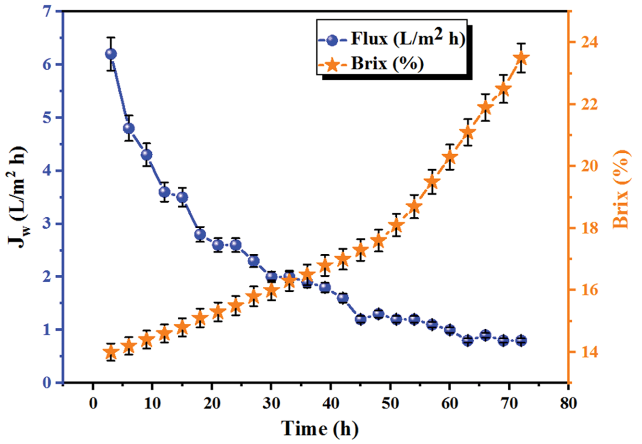

Fig. 7. The implementation of optimized draw solution for orange juice concentration in 72 h.

RSF is due to the negative charge of acetate ion, where the performance is not only contributed by the steric hindrance but electrostatic repulsion also plays a significant role in boosting the performance. The effect of sodium acetate and glucose on flux and RSF and their comparison is shown in Fig. 5.

Specific reverse salt flux (SRSF) is a crucial parameter that is obtained from the ratio of reverse solute flux to the permeate flux. The SRSF shows the grams of DS dissolved towards the feed per liter of water towards the DS. The 5% NaAce DS exhibits a significant reduction in SRSF compared to the other DSs, suggesting the best of the proposed combinations. The SRSF of the 3% sodium acetate is equal to the 10% glucose combinations. Although the 10% glucose also shows good permeate flux and lower RSF, the operating test needs more time to deliver the same performance as 5% NaAce (Fig. 6).

Mixed draw solutions have been tested by other researchers as follows: Holloway et al. [40], studied the reduction in RSF of sodium chloride draw solution by addition of other agents. Their combination with sodium acetate resulted in reducing the RSF from 70 mmol/m^2 h to approximately 63 mmol/m^2 h (Table 3). Nguyen et al. combined aluminum sulfate in minor quantity with $MgCl_2$ and achieved a reduction in RSF from 1.55 g/m^2 h to 0.53 g/m^2 h [8]. Achilli et al. studied the inorganic salts individually and concluded that $CaCl_2$ is capable of producing high water flux but also high RSF. On the other hand, NaAce offers low water flux and RSF [23] (Table 3). The proposed combination in the current research work resulted in water flux of 23.9 L/m^2 h and RSF of 6.64 g/m^2 h which accounts for 41% reduction in RSF as compared to the parent $CaCl_2$ draw solution. The flux and RSF of the developed draw solute are compared with the previous studies as shown in Table 3.

5. Concentrating of Orange Juice and Permeation Analysis

The optimized draw solution (5% NaAce) was employed for concentrating the orange juice. The PRO mode was used for 72 hours, which produces 2.13 L/m^2 h average water flux and 3.6 g/m^{2}h RSF. Orange juice used for the experimental run was obtained locally (cappy pulpy orange juice). For the final concentration run of orange juice as feed, the juice was completely filtered through a cotton cloth to remove any visible suspended matter and was then subjected to permeation in FO. The orange juice of one liter was concentrated

Table 3. Comparison of the flux and RSF with the previous studies

Draw solute	Solution osmotic pressure (bar)	Flux	RSF	References
NaCl+NaAce (5%)	48	13.4 L/m^2 h Deionized water	63 mmol/m^2 h	[40]
(1 mol) $MgCl_2$+ (0.05 mol) $Al_2(SO_4)_3$	-	4.09 L/m^2 h Brackish water	0.53 g/m^2 h	[8]
$CaCl_2$	42	11.6 L/m^2 h Deionized water	9.5 g/m^2 h	[23]
Sodium Acetate (NaAce)	28	9.00 L/m^2 h Deionized water	2.73 g/m^2 h	[23]
Glucose	-	0.37 L/m^2 h Tomato juice	-	[41]
$CaCl_2$+NaAce (5%)	78.21	23.9 L/m^2 h Deionized water	6.64 g/m^2 h	This work

up to 23.6 °Brix from the initial concentration of about 13 °Brix as shown in Fig. 7. The low permeate flux and RSF are attributed to higher internal concentration polarization inside the membrane supporting layer because of available nutrient compounds in the feed of orange juice. Using a lower brix solution results in a higher concentration gradient as compared to using a higher brix solution. For instance, it will be easier to concentrate a solution from 10 to 20 brix rather than 30 to 40 brix because of the high driving force between feed and draw solutions. On the other hand, the feed solution used for the actual juice permeation was 1 liter of orange juice against a liter of draw solution. Taking a smaller volume of the feed solution would very well result in concentrating up to higher brix as observed in a previous study [42]. The performance of the draw solution is reasonable for concentrating the orange juice and opens new ways for future studies.

CONCLUSIONS

In this research, NaAce and glucose with parent draw solute, $CaCl_2$ for FO were investigated. The effects of various concentrations and combinations of the draw solutes in DS with constant osmotic pressure on the permeate flux, RSF, and SRSF for FO were systematically studied. The 5% combination of monovalent sodium acetate with divalent $CaCl_2$ significantly decreased the RSF by 41% with a trivial fall in permeate flux. The effect of glucose with $CaCl_2$ on FO performance has less significance compared to sodium acetate. The 3% sodium acetate DS and 10% glucose DS deliver almost the same SRSF of 0.39 g/L, but the 10% glucose DS needs a long time compared to the 3% sodium acetate DS to achieve the same outcome. The optimum concentration of sodium acetate (5%) DS imparts the 2.13 L/m^2 h average permeates flux, 3.6 g/m^2h RSF, and 0.39 g/L SRSF against the feed of orange juice.

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