STUDY TO SELECT MALTODEXTRIN CONCENTRATION IN THE DRAW SOLUTION IN THE FORWARD OSMOSIS MEMBRANE TECHNOLOGY FOR DESALINATION

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Nguyen Quang Trung[1], Bui Quang Minh[1], Hoang Minh Tao[1,3], Le Van Nhan[1*],
Nguyen Thi Thuy[2,3], Nguyen Thanh Thao[4]
1. Center for Research and Technology Transfer, Vietnam Academy of Sciences and Technology
2. Institute of Environmental Science and Public Health, Hanoi 10072, Vietnam
3. Graduated University of Science and Technology
Vietnam Academy of Sciences and Technology, Hanoi 10072, Vietnam
4. Vietnam Academy of Sciences and Technology, Hanoi 10072, Vietnam
Email: levannhan.na@gmail.com

TÓM TẮT

NGHIÊN CỨU LỰA CHỌN NỒNG ĐỘ MALTODEXTRIN TRONG DUNG DỊCH LÔI CUỐN CỦA CÔNG NGHỆ KHỬ MẶN SỬ DỤNG MÀNG THẨM THẤU XUÔI

Thẩm thấu chuyển tiếp (FO) được coi là một trong những công nghệ hứa hẹn nhất để khử muối với nhiều ưu điểm như: chi phí năng lượng thấp, loại bỏ được nhiều chất ô nhiễm và ít tắc nghẽn màng so với các quá trình màng khác. Trong nghiên cứu này, chúng tôi khảo sát lựa chọn nồng độ maltodextrin cho dung dịch lôi cuốn sử dụng trong hệ thống FO, trong đó nước khử ion và nước muối 10 – 30‰ được sử dụng làm dung dịch đầu vào. Màng FO-TFC (thin film composite) và màng FO-CTA (cellulose triacetate) được sử dụng trong các thí nghiệm. Thông lượng nước và thông lượng thẩm thấu ngược của dung dịch lôi cuốn qua màng FO đã được đánh giá và màng NF được sử dụng để thu hồi dung dịch lôi cuốn. Kết quả nghiên cứu, dung dịch lôi cuốn với nồng độ maltodextrin 20% là phù hợp nhất cho hệ thống FO dùng để khử mặn nước đầu vào có độ mặn dưới 10‰. Như vậy, có thể sử dụng maltodextrin như dung dịch lôi cuốn trong hệ thống màng lọc thẩm thấu chuyển tiếp dùng để khử mặn nước mặn/lợ thành nước sinh hoạt.

Từ khóa: *khử mặn, maltodextrin, FO*

1. INTRODUCTION

From ancient times, water has always been considered an important resource that played crucial roles in the rise and fall of human civilizations [1]. For its essential and irreplaceable parts on the health, dignity, and prosperity of people, the access to water has been recognized by the United Nations as an important human right, and could significantly affect the realization of other fundamental human rights [2,3]. In modern times, with the challenges caused by rapid growth of human population and climate change, it has become increasingly clear that we must strive to ensure sufficient, safe, acceptable, physically accessible, and affordable water for personal and domestic use in order to avoid armed conflicts and minimizing human sufferings [4,5].

Desalination is considered as a solution producing fresh water from seawater, brackish water, and inland water, which increase the availability of fresh water in the coastal areas [6, 7]. There were two main categories of the desalination process, obtaining both thermal process and membrane process with different types, in which Reverse Osmosis (RO), Multi-stage Flash (MSF) and Multi-Effect Distillation (MED) were the most applied desalination technologies with the installed desalination capacity over the world was 65%; 22% and 8%, respectively [6, 8]. In addition, the other desalination processes were also used including Electro Dialysis (ED) and Electro Dialysis Reversal (EDR) [8]. However, these processes require a high cost of capacity as well as a large amount of energy for operation, whereas the future trends are priority applied and developed technologies that use less energy [9, 10].

Forward osmosis (FO) has been considered as one of the most promising technologies for desalination with the advantages of low energy cost, high rejection of many pollutants and low membrane fouling in comparison with the other membrane processes such as RO, nanofiltration (NF), ultrafiltration (UF), and microfiltration (MF) [11, 12]. This technology utilizes the natural phenomenon of osmosis which was generated by different pressures between feed solution and draw solution in two sides of the semi-permeable membrane to produce fresh water. A followed process was conducted to reconcentrate the diluted draw solution and produce clean water. In the FO process, the draw solution plays a pivotal role to attract water from the feed solution. A numerous of draw solutions was studied for FO process such as ammonium bicarbonate [13], fertilizer [14], and magnetic nanoparticles [15], EDTA sodium salts [12], 2-methylimidazole-based compounds [16], polyacrylic acid sodium salts (PSA) [17], sodium lignin sulfonate (NaLS) [18], etc. The study and select a suitable draw solute can greatly influence the efficiency and sustainability of FO operations. According to Huayong et al. [11] and Enling et al. [19], the properties of an ideal draw solute in FO were high osmotic pressure, minimal reverse solute diffusion, easy to recover from the diluted draw solution, nontoxic, low cost, reusability, and compatibility with FO membranes.

Maltodextrin (MX) is a polysaccharide produced from the enzymatic hydrolysis or the acidic of starch, which is considered as a polymer of D-glucose chains linked by glycosidic α-(1-4) and α-(1-6) bonds, and is formed by linear (amylase) and branched (amylopectin) carbohydrates with different equivalents of dextrose [20]. Maltodextrin was a nontoxic material which used widely in the cosmetic domain [21], food industries [20, 22], and the pharmaceutical industry [23]. However, no reports were studied maltodextrin as a draw solution in the FO process.

In this study, we investigated to select maltodextrin concentration for the draw solution using in FO system, wherein deionized water and NaCl 10 – 30 ‰ were used as feed solutions. FO-TFC and FO-CTA were used in the experiments. Water flux and reverse osmosis flux of draw solution through the FO membrane were evaluated, and NF membrane was used to recover draw solution.

2. MATERIALS AND METHODS

2.1. Materials

Maltodextrin ($C_{6n}H_{(10n+2)}O_{(5n+1)}$) (> 98%) was purchased from Sigma-Aldrich Corporation (Germany). The commercial thin-film composite (TFC) forward osmosis membrane (305 x 305 mm) was bought from Sterlitech Corporation (USA). An ultrapure water system (Purelabflex-3, ELGA, UK) was used to produce de-ionized water, which was utilized to prepare the different concentrations of all solutions for experiments. Deionized water and NaCl 10 – 30 ‰ were used as feed solutions in the FO system.

2.2. Forward osmosis setup

The experiments were conducted in three replications. A rectangular cross-flow permeation cell (8 cm in length, 4 cm in width and 0.5 cm in height) was designed in a plate and frame configuration to hold the flat FO membrane for experiments (Figure 1). The experiment was set up with the active layer of FO membrane oriented to face the feed solution, whereas the support layer of the membrane facing the draw solution. The pumps with a flow rate of 1.2 L/min, maximum outlet pressure of 125 psi, voltage of 24 VDC and an amp of 0.24 A were separate used to re-circulate the feed and draw solutions on both sides of the FO membrane. DI water was used as feed solution, whereas draw solutions were prepared from maltodextrin in DI water. An amount of 500 mL and 300 mL was the initial volumes of feed solutions and draw solutions, respectively. A digital scale balance (Sartorius, Goettingen, Germany) was used to determine the changes in the weight and volume of feed solution while the Laqua F-74 sensor was utilized to monitor any changes in TDS, EC and salt concentration of the feed solutions and draw solutions periodically 15 min during experiments. Different concentrations of draw solution (5%, 10%, 15%, 20%, 25% and 30%) were investigated to find the optimized concentration use for the complete FO membrane system in the next stage of the experiments.

The most suitable concentration of draw solution was used in the complete system of the FO process in combination with the nanofiltration using DOW FILMTEC NF90-400 membrane to produce fresh water and recover the draw solution.

Experiments were conducted on a laboratory scale in the Center for Research and Transfer of Technology – Vietnam Academy of Science and Technology, Hanoi, Vietnam. FO membrane was immersed into the DI for 24h before use to ensure the porous support layer of the membrane is fully saturated with water.

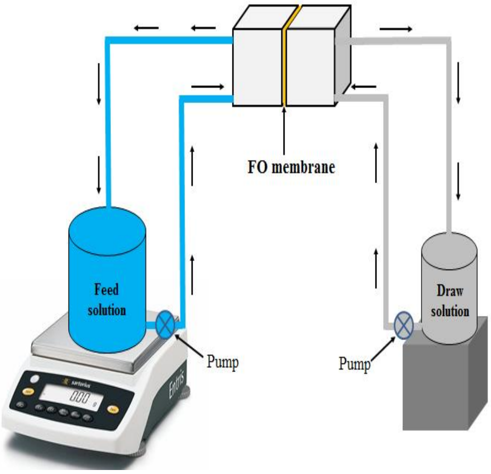

Figure 1. Schematic diagram of FO system to test the efficiency of draw solution

2.3. Measurement of water flux and reserve salt flux

The water flux and reserve salt flux across the FO membrane were determined via the volume exchange of feed solution using the equations as below:

$$F = \frac{V_i - V_o}{A(T_i - T_o)} \quad (*) \qquad RF = \frac{C_iV_i - C_oV_o}{A(V_i - V_o)} \quad (**)$$

Where:

F: is the water flux across the FO membrane (LMH)

RF is the reserve salt flux across the FO membrane (LMH)

A is the surface area of the FO membrane (cm^2)

C_o is the initial concentrations of the feed solution (g/L)

C_i is the concentration of the feed solution measured at a time of T_i (g/L)

V_o is the initial volume of feed solution used for experiments (mL)

V_i is the volume of feed solution determined at a time of T_i (mL)

3. RESULTS

The properties of Maltodextrin draw solution was evaluated in the forward osmosis system and recovery by nanomembrane filtration under the specific conditions listed in Table 1, and maltodextrin concentration in the draw solution changed in the range of 5 to 30%. Data results of the experiments were showed in Figure 1 and 2.

Table 1. Operation conditions of the forward osmosis syste

Operation parameters		**Values**
The initial solutions	The feed solution side	NaCl 10 – 30 ‰ or deionized water
	The draw solution side	Change depends on the group of the specific experiments
Flow rate	The feed solution side	25 L/h
	The draw solution side	15 L/h
Other parameters (FO)	Temperature	$30^{o}C$
	Flow rate direction	Opposite direction
	Different pressure	0,2 bar
	Time of the experiments	150 minutes
Other parameters (separate by magnetic)	Magnetic source	Rare earth magnet
	Settling time	180 seconds
Other parameter (NF)	Inlet flow pressure	10 bar
	Waste flow rate	90%
The test is repeated at least 5 times, with a maximum allowable error of 10%.		

Research results show that, the highest water flux through the membrane was reported in 10,67 LMH in maltodextrin draw solution with operation conditions of (1) deionized water as feed solution, (2) draw solution with 30% maltodextrin, (3) FO-TFC membrane. However, the value of membrane water flux increased significantly when the concentration of maltodextrin in the draw solution raised from 10% to 20%, however, the higher concentration of maltodextrin, the water flux through the membrane continued to increase slightly. This phenomenon is especially evident when the input water source is saline water, and can be explained by the fact that after the threshold of Maltodextrin concentration of 20%, the draw solution has begun to form an ICP effect on the membrane, which resistance to water permeation through the membrane, leading to a decrease in the water flux through the membrane.

Besides, when the salinity of the input water increases, the value of water osmotic flux through the membrane also decreases, due to the difference in natural osmotic pressure between the feed solution and the draw solution reduced. In the case with the FO-CTA membrane, even at the salinity threshold of the feed solution of 10‰, the water flux through the membrane was reduced to less than 5 LMH at all concentrations of the draw solution, showing that FO-CTA membrane combined with Maltodextrin draw solution is not very effective in desalination application for saline water. In contrast, there was a suitable range of desalination conditions exists when using FO-TFC membrane as (1) the salinity of the input water does not exceed 10‰ and (2) the concentration of Maltodextrin in the draw solution higher than 20%. Then, the water flux through the membrane can be achieved above 5.11 LMH. It is in agreement with the previous studies of Nguyen et al [24] that the higher water flux might generate the higher osmotic driven force in the transportation of water through the membrane. In addition, NH_4HCO_3 was used as a draw solution in the forward osmosis process [25, 26]. This indicated that the potential application of maltodextrin as the draw solution of the FO process in desalination.

In addition, the extent of the draw solute loss during the operation of the FO system as well as the reconstitution of the attractant solution should be considered. As shown in Figure 1, it can be seen that low reverse osmosis flux through the membrane was reported in high concentration of maltodextrin in draw solution in comparison with NaCl. It could be explained by the fact that Maltodextrin has a relatively high molecular weight and does not dissociate into ions with small sizes, therefore, it is more difficult to move through the membrane than NaCl. However, as the concentration of Maltodextrin in the draw solution increased, the reverse osmosis flux of Maltodextrin also increased, especially, the higher concentration than 15%. And, it can also be found that the permeable efficiency of FO-TFC is higher than that of the FO-CTA.

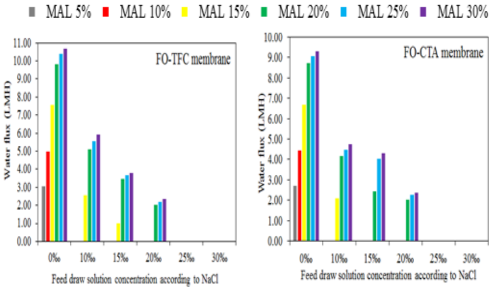

Figure 1. The specific water flux using maltodextrin draw solution (MAL)

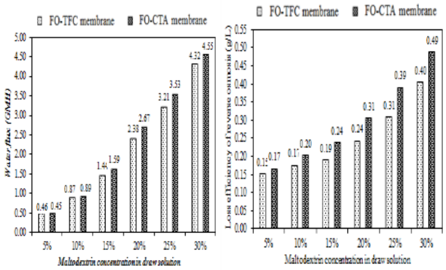

Figure 2. The specific reserve flux of maltodextrin draw solution with de-ionized water feed solution

Figure 2 shows the reverse osmosis loss efficiency is evaluated based on the ratio between the reverse osmosis draw flux and the membrane permeable water flux. It can be seen that, FO-TFC membrane was more effective at preventing reverse osmosis for Maltodextrin compared to FO-CTA membrane. The reverse osmosis loss efficiency of Maltodextrin reached its lowest value when the draw solution concentration did not exceed 15%, and increased sharply when the draw solution concentration increased above 15%. This is the combined effect of the continued increase in reverse osmotic draw flux as the concentration of Maltodextrin in the draw solution increases, and the "sleep gap" in osmotic flux caused by the ICP phenomenon.

From the above results, the draw solution with a concentration of 20% Maltodextrin on the FO system using the FO-TFC membrane was selected for the next experiments. At the stage of recovery by low-pressure NF filtration, the resulting clean water has a TDS index of about 350 mg/L, lower than the maximum threshold according to WHO guidelines for domestic water of 500 mg/L. The average loss factor of the draw solute in the NF filter stage was determined to be 2.39%. The draw solution can then be used for desalination of water sources with a NaCl concentration not exceeding 10‰.

4. CONCLUSION

An draw solution with a concentration of 20% maltodextrin is most suitable for the FO system used for desalination of inlet water with a salinity in NaCl below 10%.

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