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# Effect of changing cross flow velocity on water fluxes in Forward Osmosis

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**ملخص البحث**

أصبح التناضح الأمامي (FO) أحد أكثر التقنيات الجديدة إثارة للاهتمام. له العديد من المزايا على التناضح العكسي (RO) وهو أنه يسمح بشكل أساسي بتخلل الماء عن طريق الانتشار الطبيعي من خلال غشاء نصف نافذ من محلول ذي ضغط تناضحي عالٍي إلى واحد منخفض. على عكس RO حيث يجب استخدام ضغط خارجي يزيد عن الضغط الاسموزي من أجل أن تتخلل المياه من الضغط الأسموزي الأصغر إلى الضغط الأعلي وبالتالي يتطلب طاقة عالية للتشغيل. أيضا يحدث تلف سريع للغشاء المستخدم في عماية التناضح العكسي نتيجة ان الملوثات تكون مضغوطة على الغشاء وتتطلب تنظيفًا ميكانيكيًا وكيميائيًا لعكس تأثير تراكم الملوثات مما يفرض تكلفة إضافية على الأداء الكلي. التحدي الرئيسي مع FO هو تدفقات المياه الصغيرة نسبيا مما يجعل العملية برمتها ليست جذابة للغاية. تساهم العديد من العوامل في تدفقات منخفضة مثل خصائص الغشاء ، والخصائص الهيدروليكية ومحاليل السحب المستخدمة. واحدة من الخصائص الهيدروليكية الهامة التي يجب أخذها في الاعتبار هي سرعات المياه المتدفقة على جانبي الغشاء. تركز هذه الدراسة على دراسة تأثير سرعات التدفق على تدفقات المياه من خلال الغشاء.

## Abstract

Forward osmosis (FO) is becoming one of the most interesting new technologies. It has many advantages over reverse osmosis (RO) which is that it basically allows the water to permeate by natural diffusion through a semipermeable membrane from a solution with high osmotic pressure to a lower one. Unlike RO where an external pressure that is in excess of the osmotic pressure has to be applied in order for water to permeate from the lower osmotic pressure to the higher one and thus requiring high energy for operation. Also RO has a higher fouling potential than FO because the foulants are being compressed against the membrane and require mechanical and chemical cleaning in order to reverse the effect of fouling which poses an extra cost on the overall performance. The main challenge with FO is the relatively small water fluxes making the whole process not so appealing. Many factors contribute to the low fluxes such as the membrane properties, hydraulic properties and the used draw solutions. One of the important hydraulic properties to be considered is the cross flow velocities of the feed and draw solutions flowing on the two sides of the membrane. This study focuses on investigating the effect of the cross flow velocities on the water fluxes.

# 1. Introduction

Forward osmosis (FO) is becoming one of the most interesting new technologies. It has many advantages over reverse osmosis (RO) which is that it basically allows the water to permeate by natural diffusion through a semipermeable membrane from a solution with high osmotic pressure to a lower one. Unlike RO where an external pressure that is in excess of the osmotic pressure has to be applied in order for water to permeate from the lower osmotic pressure to the higher one and thus requiring high energy for operation. Also RO has a higher fouling potential than FO because the foulants are being compressed against the membrane and require mechanical and chemical cleaning in order to reverse the effect of fouling which poses an extra cost on the overall performance[1]. The main challenge with FO is the relatively small water fluxes making the whole process not so appealing. Many factors contribute to the low fluxes such as the membrane properties, hydraulic properties and the used draw solutions. One of the important hydraulic properties to be considered is the cross flow velocities of the feed and draw solutions flowing on the two sides of the membrane. This study focuses on investigating the effect of the cross flow velocities on the water fluxes.

# 2. What is forward osmosis

## 2.1. Definition

The concept of osmosis is that when two liquids of different salt concentrations are placed with a selectively permeable membrane in between, two drag forces occur. The first one would be that of water flowing from the lower concentration solution -feed solution (FS) to the higher concentration solution- Draw Solution (DS) trying to reach equilibriun, i.e. a state where both solution would have equal salt concentrations. The rate at which water crosses the membrane is the water flux. The second force would be that of the salt particles, flowing from the DS to the FS aiming to reach equilibrium. The rate at which the salt flows is the reverse salt flux (RSF). Many parameters affect the water flux and the RSF but the two major ones are the salt concentrations of both solutions and the membrane type. A higher salt concentration gradient results in higher fluxes. Many parameters affect the membrane type. A good membrane is one that provides high water permeability and high salt rejection i.e. low RSF, however higher water permeability is usually accompanied with higher salt fluxes and thus new membranes are being developped each day to better meet both criteria.

Water purification using forward osmosis includes the use of a high salinity solution (DS) which would draw clean water from an impaired water source through a semipermeable membrane, leaving behind all foulants, followed be the separation of the draw solution and pure water. Many challenges stand in the way of implementing this technology on a full scale like the very low water fluxes that occur which results in very low recovery rates, extraction of the draw solution can be quite costly making the whole process more expensive than the traditional RO, and an ideal membrane that allows for high water permeability ,high salt rejection and minimizes the internal concentration polarization is still being developed.

## 2.2 water extraction using forward osmosis

The process of water extraction using FO involves two steps as illustrated in figure (1). The first step is the FO process where water migrates from an impaired water source to the draw solution causing continuous concentration of the feed solution and dilution of the draw solution. The second step involves the extraction of the draw solutes from the diluted draw solution in order to give the permeate water and the concentrated draw solutes which can be recycled into the system once more.

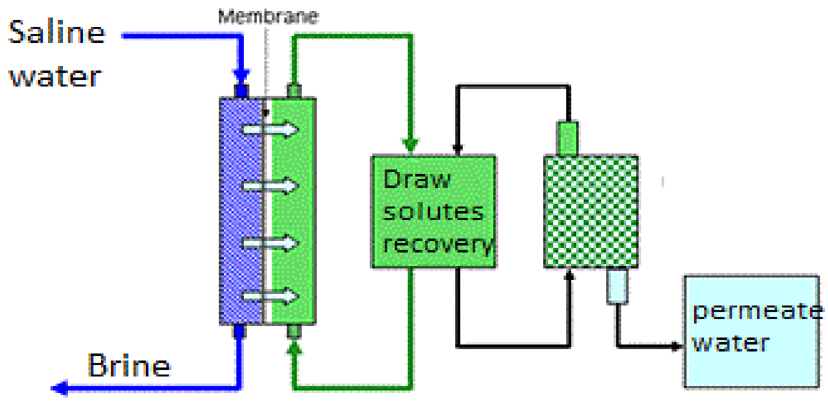


**Figure 1:water extraction process**

## 2.3 Membranes

Membranes are usually asymmetric and consist of two layers: a high density active layer which is responsible for the salt rejection and a porous support layer which is to protect the active layer from breaking[3]. A good membrane should be able to reject the feed and draw molecules and provide high water fluxes.

There are two modes of orientation for the membrane. The FO mode where the active layer is facing the feed solution and the PRO mode where the support layer is facing the feed solution. The choice of membrane orientation mainly depends on the application.

New membranes are being developed everyday trying to reach an ideal membrane minimizes internal concentration polarization and minimizes reverse solute flux and has a high resistance to fouling.

## 2 2.4 Draw Solution

The draw solution is the source of the driving force in the forward osmosis process. The higher the concentration of the draw solution, the higher the flux is. A good draw solution should be able to generate high osmotic pressure at a low viscosity, should have a molecular size that is small enough to minimize ICP yet large enough to minimize the reverse solute flux[2]. It should be inexpensive, highly soluble and could be extracted using efficient techniques [1]. There are many possible draw solutions available that could be used, but the selection of the draw solution mainly depends on the application. Possible draw solutions include: $CaCl_2$, $KHCO_3$, $MgCl_2$, $MgSO_4$,$NaHCO_3$, $KHCO_3$, $MgSO_4$, NaCl, $NaHCO_3$ and $Na_2SO_4$.

There are many possible ways for the draw solution extraction which includes: Reverse osmosis (RO), membrane distillation (MD), thermal separation, Nano filtration, and ultra-filtration.

## 2.5 concentration polarization

This phenomenon and its impact on the net driving osmotic pressure is one of the most significant factors in osmotically driven processes, primarily because of the membrane support layer[4]. There are two types of concentration polarization (CP) according to where they occur, if the CP occurs inside the support layer of the membrane then it is called internal concentration polarization (ICP), but if the CP occurs outside the support layer then it is called external concentration polarization. Figure 3 shows the two membrane orientations that can be used. For the FO mode, the membrane active layer faces the feed solution while in PRO mode the membrane active layer faces the draw solution.

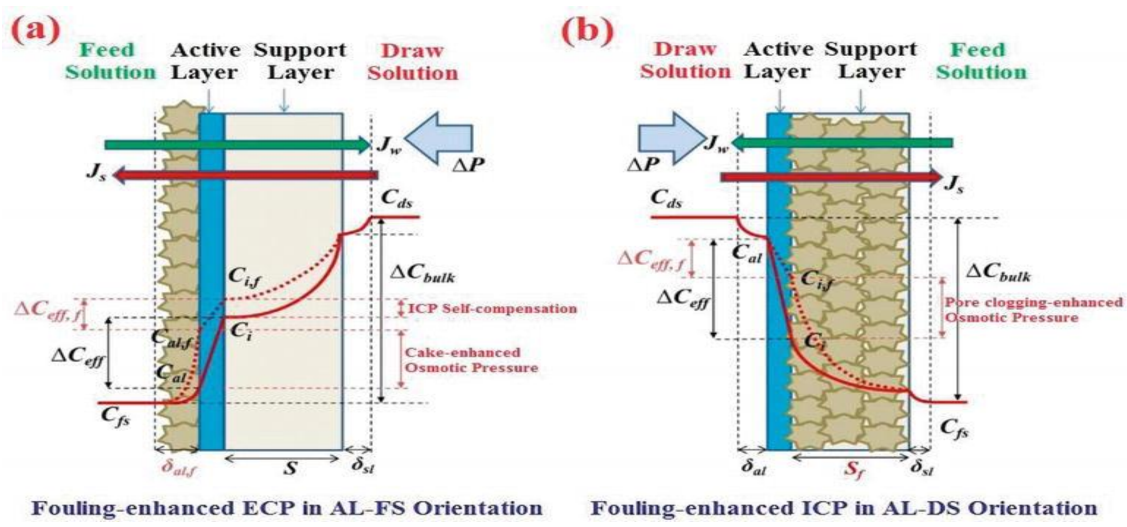


**Figure 2: concentration polarization in the FO mode and PRO mode**

### 2.5.1 Internal concentration polarization (ICP)

In FO mode, as the water permeates from the FS to the draw solution, dilution of the draw solution occurs inside the support layer thus decreasing the effective osmotic pressure across the membrane active layer, this is called dilutive ICP. While in PRO mode the solutes moving due to RSF from the DS to the FS get concentrated in the support layer, increasing the feed concentration thus increasing the effective osmotic pressure of the feed solution. This is called concentrative ICP. Both internal concentration polarization decrease the difference in effective osmotic pressure between the feed and draw solutions and thus decreasing the overall water flux across the membrane. Usually ICP is irreversible and cannot be mitigated by changing the hydraulic parameters of the flowing liquid.

### 2.5.2 External concentration polarization (ECP)

In FO mode, as the solutes move from the DS to the FS, the concentration of the FS increases and the effective osmotic pressure increases, while in PRO mode, as water permeates from the FS to the DS, dilution of the DS occurs and thus decreasing the effective osmotic pressure on the draw side. Both external concentration polarization decrease the difference in effective osmotic pressure between the feed and draw solutions and thus decreasing the overall water flux across the membrane, but the effect of the ECP is usually less severe than the ICP and can be mitigated by changing the flow hydraulic parameters.

## 3. Potential applications

Many possible applications are being considered nowadays which may include: wastewater treatment and water purification coupled with sea water desalination. In this application waste water is used as a feed solution and a high saline source of water like sea water is used as a draw solution[3]. Water permeated from the feed solution to the sea water resulting in diluted sea water and concentrated waste water. Another possible application is fertigation where a concentrated fertilizer is use as a draw solution and brackish ground water as a feed solution. As water permeates, the concentrated fertilizer becomes diluted and can be used directly in irrigation.

## 4. Objective

Many parameters other than membrane properties and salt concentrations of the feed and draw solutions affect the water fluxes. In this study it is required to experimentally investigate the effect of changing the cross flow velocities of the feed and draw solutions on the water fluxes.

## 5. Methodology

An experimental setup was prepared in order to measure the water fluxes for different salt concentrations. Figure (3) illustrates a schematic for the setup. It includes a custom made FO cell made up of plexi glass. It has an upper section where the FS flows and a lower section where the draw solution flows separated by the membrane. Flat sheet membranes from porifera were used in all experiments. Two diaphragm pumps were used to pump the feed and draw solutions. Two pressure gauges and two flow meters were used to measure and monitor the pressure and discharge respectively. Needle valves were used to accurately adjust the pressure and flow values. A conductivity meter was used to measure the increase in feed water salinity in order to calculate the RSF. A digital balance that was connected to a computer via a digital data logger was used to measure the increase in draw solution volume to be translated into water fluxes. Each experiment was replicated at least three times to ensure the consistency of the results. Pressure was adjusted such that both pressure gauges had a reading of 0.5 bars such that the transmembrane pressure was equal to zero. The experiment was left to run for at least one hour before taking any flux measurements to ensure that a steady state has been reached. The membrane was backwashed between any two experiments by flushing deionized water at a flow rate of 1 LPM. Deionized water was used as feed solutions and a 0.5M of NaCl solution was used as a draw solution. The cross flow of the draw solution was first kept constant at 0.3 LPM which corresponds to a cross flow velocity of 5cm/sec while varying the flow rate of the feed solution, then the flow rate of the feed solution was kept constant at 0.3 LPM which also corresponds to a cross flow velocity of 5cm/sec while varying the flow rate of the draw solution.Cross flow rates were increased at 30 minutes interval and water fluxes were measured for the corresponding flow rate

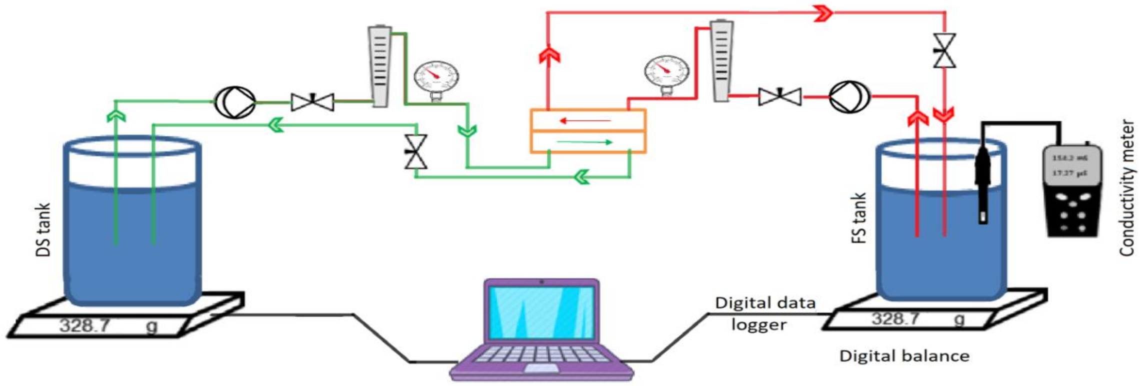


Figure 3: experimental setup

## 6. Results and discussions

Water flux is given as the volume of water that permeates through a unit area of the membrane in a unit time and usually expressed in LMH(liters per square meter per hour). Figure (4) shows the variation of the water fluxes with time for the experiment described above. Water fluxes reached as steady state after the first hour of the experiment. Reading were only taken from the point where a steady state has been reached.

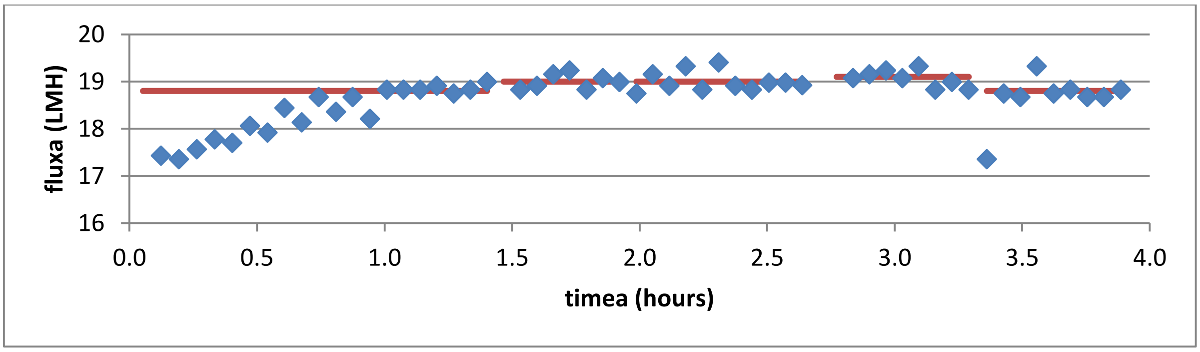


Figure 4: variation of water fluxes with the experiment time

It was found that the slight change in water fluxes due to changing the cross flow velocities of both the feed and draw solutions is within the experimental error and cannot be attributed to the increase in cross flow velocities. Figure (5) shows the variation in water flux due to an increase in the cross flow velocity of the feed solution, while figure (6) shows the variation in water flux due to an increase in the cross flow velocity of the draw solution.

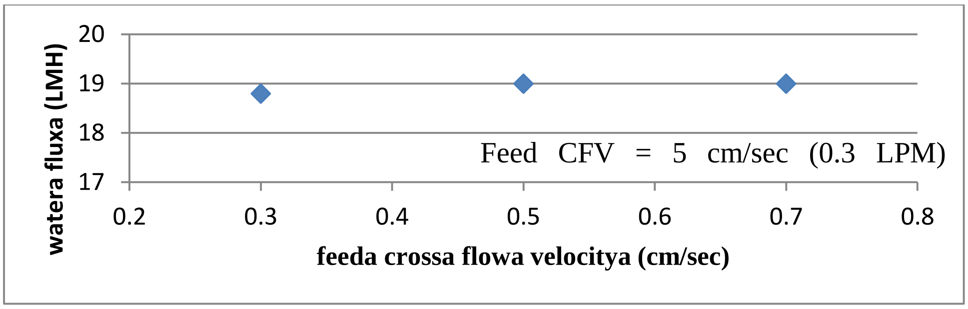


**Figure 5: variation of water flux with respect to the feed cross flow velocity**

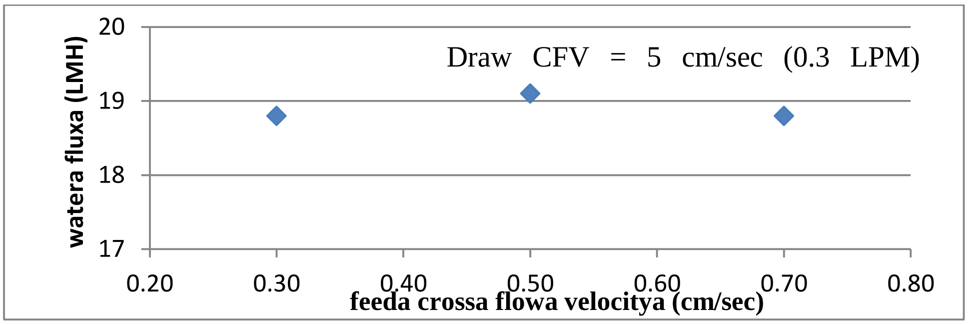


**Figure 6: variation of water flux with respect to draw cross flow velocity**

## 7. Conclusions

A bench scale experimental setup was performed to measure the water fluxes for variable cross flow velocities of the feed and draw solutions. Minimal change was found in the water fluxes and can only be attributed to experimental error.

## 8. Recommendations

Many other parameters like the differential pressure across the membrane, and water temperature affect the water flux, but the extent of their effect is unknown and should be considered. Also fouling was not studied in this research. Thus more studies should be performed to investigate the change in water flux taking into account the other parameters. Also in this study deionized water was used as feed solution in all experiments but the change in feed cross flow velocities might have a significant effect on water fluxes for higher salt concentrations as it mitigates the external CECP.

# 9. References


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