Forward Osmosis Application in Treatment of Wastewater

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Abstract: *Forward Osmosis is a new membrane separation technology, which is gaining widespread attention since the last few years. Recently, forward osmosis (FO) has attracted growing attention in many potential applications such as power generation, desalination, wastewater treatment and food processing. Drinking water is becoming an increasingly marginal resource. Substituting drinking water for alternate water sources, specifically for use in industrial processes, may alleviate the global water stress. FO has the potential to sustainably treat wastewater sources and produce high quality water. Forward Osmosis is a process which makes use of the osmotic pressure difference across a semi permeable membrane. Water flows from low concentration to high concentration. In this study, a laboratory scale model is prepared, which explained the process of Forward Osmosis. Further, a sample of synthetic wastewater is tested by using two different Draw Solutions, in varying concentrations of 1M, 2M etc. Each test is performed by keeping a constant duration of 4 days, as the FO process is a time consuming process. All the results are based on the tests carried out for duration of 4 days each.*

The results indicate that Forward Osmosis is a time consuming process. After conducting each test for a fixed duration of 4 days, it was found that the volume of the feed solution decreases by a considerable amount, and the draw solution gets diluted. The flux had a direct relationship with the concentration of the draw solution. As the concentration of the draw solution was increased, the flux is also found to increase.

Keywords: *Forward Osmosis, Draw Solution, Membrane, Wastewater treatment.*

1. INTRODUCTION

Water shortages have plagued many communities, and humans have long searched for a solution to Earth's limited freshwater supplies. Less than 1% of the total water available on the earth is considered freshwater. Almost 96.5% of Earth's water is located in the seas and oceans; 1.7% is present in icebergs and the remaining percentage is made up of brackish water. The population explosion and the expansion of cities have made the production of potable water undependable and have led to an increase in demand compared with availability. Today, the production of potable water has become a worldwide concern; for many communities, the projected population growth and demand exceed available conventional water resources.

Worldwide, access to safe drinking water is decreasing. The future outlook remains bleak when considering that the earth is rapidly running out of clean, fresh water. At present, developed countries are using increasing amounts of energy (usually from non-renewable sources) in order to cope with the increasing demand for high quality water. However, global warming and the depletion of oil reserves together with its fluctuating price on an already volatile market are increasing the need for more efficient techniques to recover drinking water. It is therefore startling to realise that only a small proportion of this drinking quality water is actually used for sustenance. For example, several industrial processes can, in fact, utilise high quality reclaimed water. Thus it is not surprising that many have turned their interest to an alternative, low cost solution: water recovery from wastewater.

Drinking water is produced mainly from safe water sources i.e. groundwater, but due to population growth and economic development, exploitation of aquifers and declining groundwater levels have diminished fresh water sources. With the exponentially growing population and the depletion of fossil fuels, water and energy have become two of the most important resources on the earth. Both water shortages and energy crisis have plagued many communities around the world. It is reported that more than 1.2 billion people in the world lack access to clean and safe drinking water, and 2.6 billion lack adequate sanitation. Although most of the planet is surrounded by oceans, only approximately 0.8% of the world's total water is considered potable water. Further, according to the most recent world energy outlook report, world marketed energy consumption is projected to increase by 49% from 2007 to 2035.

Water and energy are inextricably linked to each other. Making freshwater available is an energy-intensive process, and generating power often requires a large amount of water. The unsustainable use of drinking water for purposes other than sustenance, i.e. industrial processes, is therefore of great concern. A possible alternative source is wastewater. Via microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) or reverse osmosis (RO), high quality water can be produced. Osmosis is the diffusion of water through a partially permeable barrier from a solution of low solute concentration (high water potential) to a solution with high solute concentration (low water potential). The inherent energy of this natural process is known as the chemical potential, or specifically the water potential, due to the difference in concentration of the two solutions. Forward Osmosis is an osmotically driven membrane process that takes advantage of the osmotic pressure gradient to drive water across the semipermeable membrane from the feed solution (low osmotic pressure) side to the draw solution (high osmotic pressure) side. The Forward Osmosis process simply makes use of a highly concentrated salt solution (known as the draw solution, osmotic agent, osmotic media, or osmotic engine) with low water chemical potential (high osmotic pressure) to draw the water molecules from a feed solution (brackish or seawater) with higher water chemical potential (lower osmotic pressure) compared to the draw solution. This is in agreement with the 2nd law of thermodynamics, since transport of water molecules will bring chemical potentials in the feed and the draw solution to equilibrium.

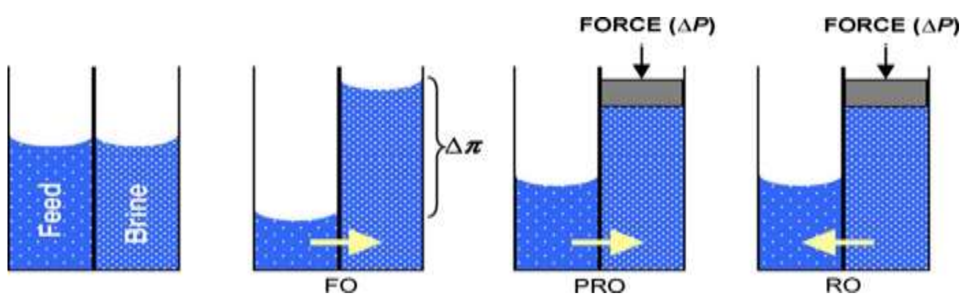

Fig 1: Principle of Forward Osmosis (**Figure adapted from Cath et. al, 2006**)

In order to oppose the movement of water, osmosis may be countered by increasing the pressure (ΔP) in the region of high solute concentration with respect to that in the low solute concentration region. This is equivalent to the osmotic pressure of the solution. The osmotic pressure difference (Δπ) or gradient is a measure of the driving force of water transported from a solution of low solute concentration across a membrane into a solution of high solute concentration. Hence by calculating Δπ, it is then possible to determine the driving force of the osmosis process. The general equation describing the water transport in FO, RO and PRO is given as:

$$Jw = A\,(\Delta\pi - \Delta P)$$

According to the above equation, the direction of water transport, i.e., from feed solution to draw solution or vice versa, is dependent on the direction given by Δπ- ΔP. When Δπ is larger than ΔP (or when ΔP is zero), water is transported from the feed solution side to the draw solution side (as in FO process). On the other hand, when ΔP is larger than Δπ, then water is transported in the same way as RO. Flux directions and driving forces for these three processes were first demonstrated in the 1980s by Lee et al. (1981).

Even though the basic principles of Forward Osmosis have been demonstrated by Lee et. al, in as early as 1981, not much emphasis was given to FO. This was probably because during the period from 1960's to 1990's, RO was the process which was more researched upon. This was based on two main advantages or assumptions in the RO process: obtaining high quality permeate from single process system and much lower energy consumption as compared to thermal processes. However, given the current global energy strain and the constantly growing water-energy nexus, a lot of research is being done on FO, given its lower energy consumption than RO process.

2. Previous works in osmotic pressure driven membrane filtration.

Osmotic pressure driven membrane process is commonly referred to as in literature as Direct osmosis, or Forward Osmosis. In this paper, the term Forward Osmosis (FO) is used hereafter. FO process has the ability to desalinate saline water at a reduced cost compared to other filtration processes which utilize the hydraulic pressure difference as the driving force .Depending on the type of osmotic agents, the driving forces that can be induced by osmotic pressure differences are very large compared to hydraulic pressures used in RO, since osmotic pressure is limited only by solubility and molecular weight, while hydraulic pressure is limited by high osmotic pressures and membrane fouling. This will potentially lead to higher water fluxes and recoveries.

FO is not a new process and research on this topic has been done as early as in the 1960's. Recently, this process is gaining widespread attention because of the numerous advantages it possesses. The selection of a draw solution which creates the osmotic pressure is important. The criteria for an ideal draw solution for FO process are; it should have high solubility, and low molecular weight resulting high osmotic pressures. Also it should be non toxic, chemically compatible with the membrane material, and easily and economically separable from the draw solution.

3. Material and Methods

3.1 Membrane

Today, the most commonly used commercially available FO membrane is the cellulose tri-acetate membrane which is developed by Hydration Technology Innovations (USA). This FO membrane has a polyester mesh embedded between the cellulose triacetate (CTA) material for mechanical support, as opposed to a thick support layer typically found in RO. With a thickness of about 50μm, it was purported to reduce the effect of internal concentration polarization (ICP) effect due to the thick porous support layer of conventional RO membranes.

However, the commercially available FO membrane is not readily available and it is also very costly. For experiments such as this, it was not economically feasible to acquire the commercially available FO membrane. Hence, the membrane which I have used for the experiment is a residential Reverse Osmosis (RO) membrane. This membrane was acquired from the DOW chemical company.

Fig 1: RO membrane used in this study.

3.2 Feed water and draw solution

3.2.1 Feed water

The feed water refers to the water which is to be treated, which in this cases was the synthetic wastewater prepared in the laboratory. The composition of the feed water which was used in all the experiments is as follows:
5g/L Meat extract
1g/L Glucose (C6H12O6)
0.6g/L Ammonium Sulphate (NH4)2SO4
0.14g/L Potassium Phosphate K2HPO4
The Feed water had an initial TDS of 3000mg/L and a pH of 6.5

3.2.2 Draw solution

The Draw solution or osmotic agent is a concentrated solution, by the virtue of which, an osmotic pressure difference is created across the semi permeable membrane. Two Draw solutions; Sodium Chloride (NaCl) and Magnesium sulphate ($MgSO_4$) were used in the experiments in varying concentrations of 1M, 2M etc. There are many solutions/chemicals which can be used as draw solutions and there performance can be analysed by using these draw solutions in the experiments. However, the reason for choosing NaCl and $MgSO_4$ is that these are commonly available, and are also less costly.

4. Experimental set up for Forward osmosis

The Forward Osmosis set-up was a piped model which was made using acrylic pipes of 1" diameter. Two equal pieces of the pipe were cut and connected to two 90 degree PVC elbow of diameter 1". Two small pieces of pipe were cut and connected to other end of the elbow on either side. Both the ends were then connected to a PVC union which was placed in the centre as shown in figure. An outlet was provided at the top and a pipe was placed to collect the surplus water in a small container. The membrane is secured inside the PVC union by cutting into circular pieces of appropriate diameter. The entire assembly is positioned on a wooden platform for support.

As Forward Osmosis is a time consuming process, all the experiments are conducted for a fixed duration of 4 days. An initial experiment or trial run was carried out using tap water as the Feed solution and NaCl as the draw solution, to check whether the process is actually taking place or not. After the stipulated duration it was found that there is a considerable change in the volumes of both the Feed and Draw solutions. This meant that the process of Forward osmosis is successfully happening in this set up. Hereafter, experiments were conducted using the synthetic waste water as feed solution, and the draw solution and its concentration was varied in each experiment. Tests were conducted for 0.5M NaCl, 1M NaCl, 1.5M NaCl, 2M NaCl, 0.5M MgSO4, 1M MgSO4, 1.5M MgSO4 and 2M MgSO4. Flux was calculated after each test. The change in the volumes of the feed and draw solutions were noticed after each test.

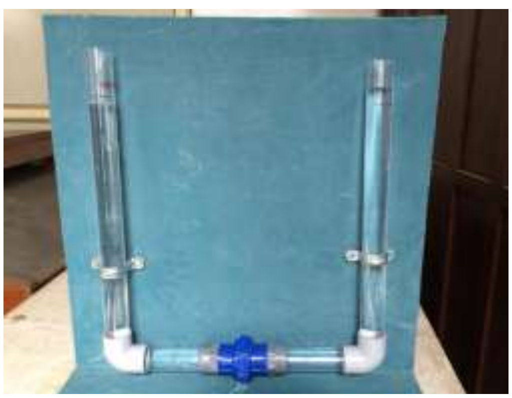

Fig 2: Experimental set up of Forward Osmosis

5. Results and Discussion

The Forward Osmosis process is not a complete treatment and it is perceived as a pre-treatment by which, the volume of the wastewater can be reduced and hence the load on the further treatment processes can be reduced, which will automatically lead to reduction in costs. If complete treatment is required, FO can be combined with other processes such as RO or MD.

A total of 8 experiments were conducted using two different draw solutions NaCl and MgSO4 in concentrations of 0.5M, 1M, 1.5M, and 2M each. After the stipulated duration of each experiment which was set as 4 days, the change in volume of the feed and draw solutions was observed and noted down. The flux was calculated after each experiment.

Draw Solution	**Change in volume (ml)**	**Flux ($l/m^2 h$)**
0.5 M NaCl	**10**	**0.05**
1 M NaCl	**20**	**0.13**
1.5 M NaCl	**20**	**0.13**
2 M NaCl	**25**	**0.16**
0.5 M $MgSO_4$	**5**	**0.03**
1 M $MgSO_4$	**15**	**0.09**
1.5 M $MgSO_4$	**18**	**0.11**
2 M $MgSO_4$	**20**	**0.13**

Fig 3: Changes in volume of Feed solution and draw solution after a period of 4 days

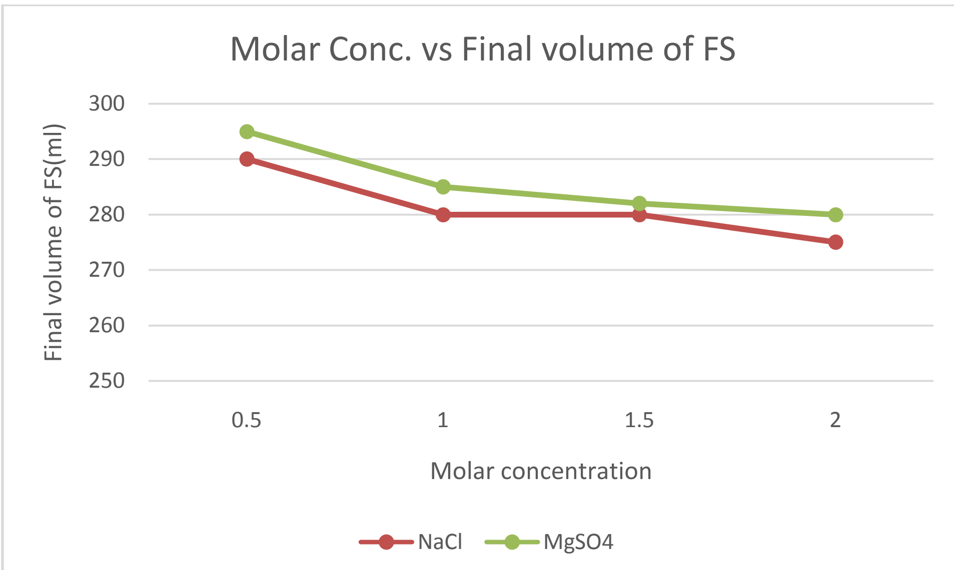

Fig 4: Graph showing variation in final volume of Feed solution with the molar concentration for NaCl and $MgSO_4$

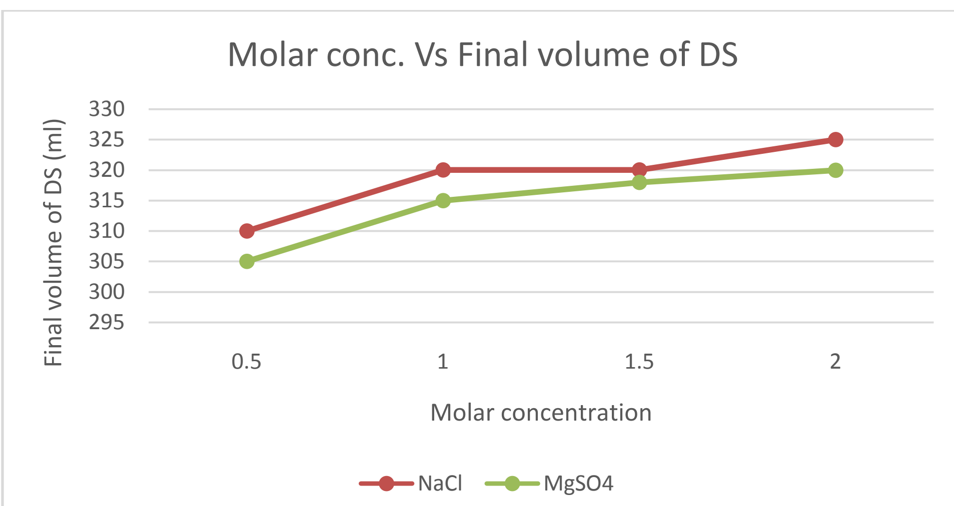

Fig 5: Graph showing variation in final volume of DS with molar concentration for NaCl and $MgSO_4$

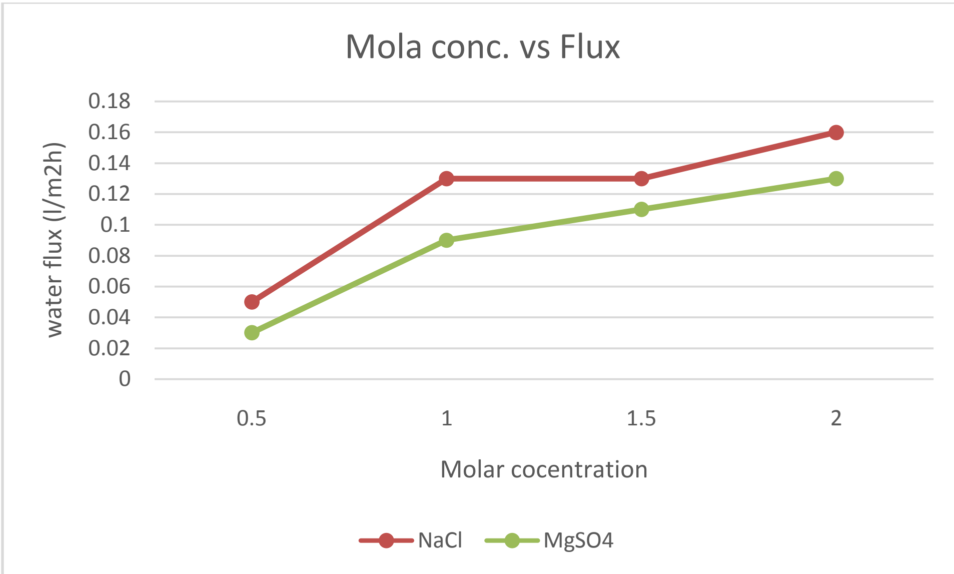

Fig 6: Graph showing variation in flux with molar concentration of NaCl and $MgSO_4$

In all the experiments, it can be seen that after a period of 4 days, there is a considerable change in the volumes of the feed and draw solution. The volume of the feed solution has decreased as water has permeated through the membrane to the draw solution side. The water flux is seen to be increasing as the molar concentration of the draw solution is increased.

6. Conclusion

From the test results, it is evident that Forward Osmosis leads to reduction in volume of waste streams. Forward Osmosis is essentially a pre-treatment and not a complete treatment. Forward Osmosis can be combined with other processes such as Reverse Osmosis, Membrane Distillation etc to provide a complete treatment. Therefore, reduction in the volume of the wastewater will greatly reduce the load on the further treatment processes. This will automatically reduce the cost of treatment. As discussed in detail in chapter 2, Forward Osmosis has many applications and is gaining widespread attention as it can be employed in many fields of science and engineering.

This study was a basic study which demonstrated Forward Osmosis as an alternative membrane technology which was carried out using an RO membrane, on a very small scale. However, good results can be obtained if a proper FO membrane is used. In order to make FO reach its full potential, more research is required on the development of new membranes. The membranes need to provide high water permeability, high rejection of solutes, substantially reduced internal CP, high chemical stability, and high mechanical strength. Also, selection of a suitable Draw solution for a specific application and its suitable regeneration method is important. In case of a fertilizer used as a draw solution, the diluted draw solution can directly be applied for fertigation without the need for recovery and regeneration of Draw solution.

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