A review of membrane fouling in forward osmosis

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Abstract. Over the past several decades, the forward osmosis (FO) has attracted growing attention in many water and wastewater treatment processing. The main obstacles for forward osmosis developing are membrane fouling, concentration polarization (CP) and reverse solute diffusion. In this study, we reviewed these three challenges in FO in order to consider FO process fully.

Introduction

With the rapid development of industrial and the exponentially growing population, the shortage of water resources has become a global problem. 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 [1]. Membrane technology has been widely used in water purification process, and obtained a better application. Reverse osmosis (RO) is currently the most mature and widely used water purification technology. However, RO requires higher osmotic pressure, which is energy intensive technology. Meanwhile, the process of RO has low recovery rate, concentrated water discharge, concentration polarization and membrane pollution and so on. It is need to develop a new energy saving water purification technology to resolve above questions.

Recent years, the forward osmosis (FO) has attracted more and more attention in drinking water purification [2], wastewater treatment [3], seawater/brackish desalination [4], food processing [5] and power generation [6].

FO is a transfer process referring to water penetration through a semipermeable membrane from high water chemical potential region (or low osmotic pressure) spontaneously to the low water chemical potential region (or high osmolality) [7]. The principle of FO, RO and pressure retarded osmosis (PRO) are show in Fig.1. the two different osmotic pressure solution water and brine are arranged on the two sides of the container respectively, which separated by a semipermeable membrane.

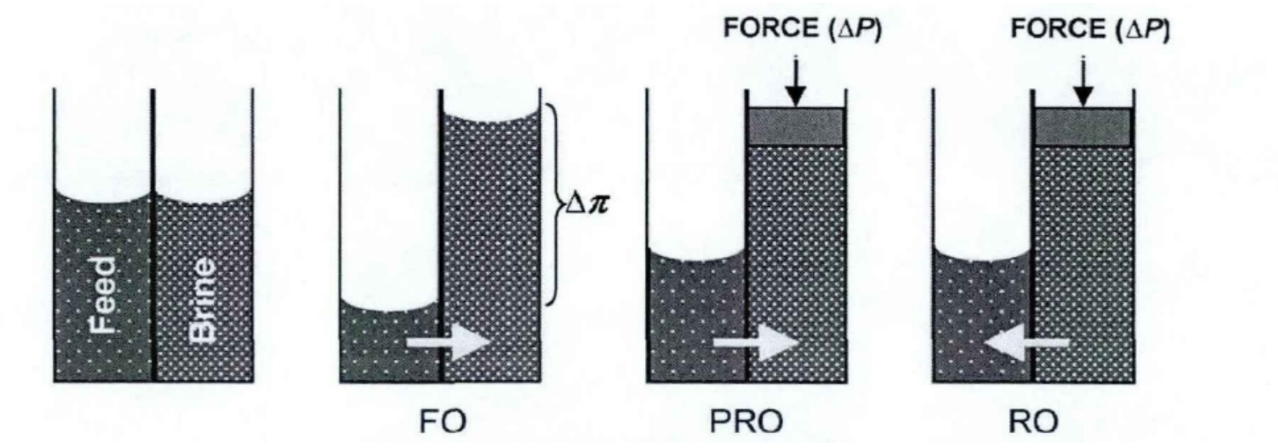

Fig.1 three solvent flows of FO, RO and PRO

In the absence of external pressure, the water spread through a semipermeable membrane spontaneously from the water side to the brine side. This will lead the liquid level rise in brine side, until stop penetration when the osmotic pressures are equal in both sides. This process is called FO. When an external pressure is applied on brine side, and this pressure is less than the osmotic pressure ($\Delta P < \Delta \Pi$), the water could still diffuse from the water side to brine side. This process is called

PRO process can convert osmotic pressure into energy and it is a practical form of the FO process. On the contrary, when the external pressure is larger than the osmotic pressure ($\Delta P > \Delta \Pi$) in brine side, the water will spread from the brine side to water side, and this is reverse osmosis (RO).

Membrane fouling, concentration polarization (CP) and reverse solute diffusion are key factors affecting the forward osmosis membrane characteristics, leading low water flux.

Concentration polarization

Both pressure driven (just like microfiltration, ultrafiltration and reverse osmosis) and osmotically driven membrane processes have a common and inevitable phenomenon named concentration polarization [8]. In osmotically driven membrane processes, external concentration polarization (ECP) and internal concentration polarization (ICP) can take place in FO processes. It is the major factor of ECP for membrane characteristics in RO. Unlike this, the ICP is the main factor for the water flux decline. The ICP and ECP in FO are shown in Fig. 2.

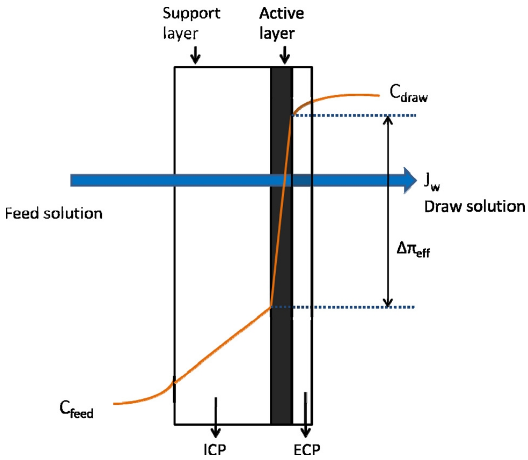

Fig.2 the ICP and ECP in FO

The ECP takes place in the surface of the membrane active layer in FO. It can increase membrane surface velocity to alleviate the impact of the ECP. Compared with ECP, the ICP always occurs at the inside of support layer which determined by the characteristics of support layer. It can not be mitigated by altering hydrodynamic conditions, resulting in reducing the water flux by more than 80%.

Membrane fouling

Like other pressure driven membrane process, the membrane fouling is also an important phenomenon in FO process. Because of osmotically driven membrane processes, that low hydraulic pressure being employed in FO process always makes the FO membrane fouling different from the pressure-driven membrane process [9].

Membrane fouling exists in all membrane separation processes. It is always divided into 4 types, such as dissolved inorganic fouling, organic fouling, biological fouling and colloidal fouling. The dissolved inorganic fouling always caused by soluble inorganic contaminants. These inorganic salts can precipitate on the surface of the membrane during the membrane separation process, resulting in the water flux decline.

Organic fouling involves a range of organic compounds, such as proteins, humic acid, polysaccharide, amino acid, nucleic acid and so on. These organic compounds can migrate to the membrane surface and formed cake layer, resulting in the decrease of the permeate flux and the reduction of the separation efficiency.

the colloidal fouling always caused by colloidal particles, including clay minerals, silica gel, oxides of iron, aluminum and manganese, organic colloids and suspensions, and calcium carbonate deposits. Colloids particles are tending to pile up on the surface and form cake layer. It not only leads to the decrease of membrane flux and the plugging of membrane pore, but also make it more difficult to remove the surface pollution of the membrane by physical cleaning.

Compared with inorganic, organic and colloidal fouling, it is more serious for biological fouling caused by biological pollution during the long operation time of membrane separation. In the membrane separation process, microorganisms in the water body adhere to the surface of the membrane and the extracellular polymeric substances produced by microorganisms can form viscous hydration gel. That these gels aggregated on the membrane surface is the main reason of biological fouling. Therefore, alleviating the biological fouling should be not only to removal microbial, but also to improve the membrane hydrophilicity in order to reduce the hydration gel adhesion and accumulation.

Reverse solute diffusion

In FO process, the concentration differences between the draw solution and feed solution bring about the reverse diffusion of the solute from the draw solution through the membrane to the feed solution and it is also inevitable [10]. The reverse diffusion of the draw solution might jeopardize the process.

After reverse diffusion, some multivalent ions (such as Ca^{2+} and Mg^{2+}) may be likely to aggravate membrane fouling because of the interfering with the foulants by these multivalent ions in the feed solution. Additionally, because of the larger ion sizes and lower solution diffusion coefficients, these multivalent ions solutions may also enhance the ICP. The ratio of the reverse solute flux to the forward water flux is defined as the specific reverse solute flux. This ratio could evaluate the FO performance. A higher ratio means a decrease in membrane selectivity and a lower FO efficiency. Although the draw solution using multivalent ion solutions could alleviate the membrane fouling, it can bring higher ICP which can increase the risk of fouling. Therefore, reverse solute diffusion should be fully considered and minimized in osmotically driven membrane processes.

Conclusions

Forward osmosis is a promising membrane process for water purification. The membrane fouling, concentration polarization and reverse solute diffusion are very important in membrane characteristics and FO performance. It should be fully considered and made efforts to overcome these questions.

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