

Gateway and Barriers of Forward Osmosis – A Mini Review

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ABSTRACT

Forward Osmosis (FO) is a technique that requires less power consumption compared to other membrane techniques. FO is significant for its fouling resistance rate, energy consumption, high recovery rate, water flux and scourable. The FO membrane is fabricated by successive steps namely phase inversion via immersion precipitation followed by interfacial polymerization under suitable parameters. The application of FO in various fields can be enhanced by overcoming the limitations. This study shows the approaches of membrane fabrication for FO technique, applications, advancement in the current industries with limitations and overcoming solutions.

Keywords: Forward osmosis, nanoparticles, antifouling

INTRODUCTION

The underground freshwater level has diminished up to 70% due to the rapid urbanization and excessive demand for freshwater [1]. Wastewater recycling is the most effective way to meet the demand for freshwater [2, 3]. Membrane technology serves as an effective and economical method of wastewater purification [4]. Wastewater can be purified by employing various techniques of membrane technology [5]. The membrane technology has attained enormous attention towards the water reclamation in seawater desalination and brackish water treatment [6].

Reverse osmosis, nano-filtration and membrane bio-reactor require hydraulic pressure to carry out the purification process with the concern of high cost and maintenance requirements [7]. FO is the superior method of membrane separation for its superior features like less tendency towards fouling, high water recovery

potential and selectivity. FO technology is based on the osmotic pressure gradient between the feed and draws solution to extract clean water from a feed solution using a semi-permeable membrane [8].

FO has been excellent in the action of complete removal of the extensive variety of contaminant and organic matter [9]. FO provides effective results in the desalination and brackish water treatment [10]. The resistance to biofouling propensity of FO is far better than reverse osmosis [11]. FO process was limited due to its water fluxes and internal concentration polarization (ICP) which can be counterbalanced by the exclusive additions in the membrane system and alteration of parameters.

MEMBRANE SYNTHESIS

The choice of membrane selection is key to the effective FO technique. Membranes with a high mass transfer

coefficient are preferred due to their high steady-state flux [9]. Membrane possesses high porosity and low ICP are the key factors for the choice of membrane selection. An asymmetric membrane comprising a selective active layer and the highly porous layer was preferred for commercial use. A flat plate FO membrane made up of polyester sheet coated with cellulose triacetate was used as commercial FO membranes. In the process of FO water is driven out through the membrane by chemical potential difference thus FO is independent of hydraulic pressure gradient and self-initiating, so membrane strength is not a concern [12]. Generally, there are two FO membrane categories: (i) thin-film composite (TFC) membrane and (ii) cellulose membrane (CA). CA has dominated the TFC membrane due to its higher hydrophilicity but they are impoverished chemical resistance [13].

The TFC membrane is a skewed structure composed of a thick selective layer and porous support layer which act as a hurdle for salt to pass through and have high chemical resistance [14]. The TFC membrane was synthesized via (i) phase inversion via immersion precipitation technique and (ii) interfacial polymerization. The casting solution was formed by mixing the polymer as a pore-forming agent in the solvent [15]. Then the casting solution was mixed continuously till the solution attains homogeneity. The concern of removing gas trapped inside the homogeneous casting solution was the main focus so the casting solution is degassed for 24 hours. The phase inversion process is executed after the support layer was spread over the glass plate uniformly to a thickness of 50 μ m with the help of a casting knife [16, 17].

The polyamide layer of TFC membrane was synthesized by the interfacial polymerization technique. Interfacial polymerization was

instigated by soaking the substrate layer in 2 wt% of m-phenylenediamine monomer embodying aqueous solution. The impregnated membrane is taken out from the aqueous solution after 2 minutes steadily, the droplets of an aqueous solution over the membrane surface were eliminated with the help of the air knife. The polyamide layer was developed by surging the organic solvent containing 0.15 wt% of trimesoyl chloride (TMC) only on the top face of the membrane and excess TMC solution is removed after 1 minute of contact. Interfacial polymerization was carried out in the oven for 3 minutes under the constant temperature of 60°C. The monomer solution was influenced only on the top surface of the membrane in all processes of polyamide layer synthesis [5,18]. The membrane was soaked with distilled water to remove the surplus solvent in case of the chemically cross-linked membranes. Membranes are made to be liable for the acid solution to acquire chemical cross-linking nature [16].

PRECEDENCE OF FORWARD OSMOSIS (FO) MEMBRANE

FO membrane exhibits a low fouling index when compared with other pressure-driven membrane filtration techniques which use hydraulic pressure for the filtration process, whereas FO works on an osmotic pressure gradient [2]. The power and cost consumption of FO was comparatively very lower than that of the pressure-driven membrane filtration techniques since it makes use of an osmotic pressure gradient. FO provides an advantage of high recovery rate, water flux, low-pressure performance, low fouling tendency and trouble-free cleaning [19]. FO is capable of removing contaminants like

surface pollutants, dye residual and heavy metals. Thus FO can be employed for wastewater reclamation, power engendering and food handling, etc [2, 3, 20].

Since the FO membrane has shown more resistance to fouling, it can be enhanced further by the exclusive addition of nanoparticles to the surface of the membrane during the synthesis of the membrane. Nanoparticles with individual properties increase the resistance towards fouling produce antifouling membranes [3]. Water flux can be improved by increasing the porosity of the membrane. Fouling resistance and water flux of the FO membrane can be enhanced by employing Polydopamine coated with zeolitic imidazolate framework (PDA@ZIF-8) hybrid active layer with no effect on the selectivity. The bulging up of PDA@ZIF-8 leads to the development of interfacial voids which leads to the enhancement of water flux of membrane [4]. A controlled increase of tortuosity was performed while the membrane preparation process to reduce reverse solute flux without affecting the water flux rate [17]. The addition of anionic surfactant to the FO membrane can reduce the reverse solute flux [21]. Pressure assisted FO process can provide an excellent water flux rate and reduced reverse solute flux considerably [22].

Silica nanoparticles associated with nanocomposite membrane performance have observed to be having higher water flux, selectivity and salt rejection rate [16]. Water flux of the FO membrane can be enhanced by incorporating the aquaporin from E.coli with a selective layer of the membrane [14]. Aquaporin incorporated support layer results in the abatement of structural parameters to build up high water flux [23, 24]. The disinfected by-products were

eliminated by the application of an aquaporin-based membrane [25].

Silver nanoparticles associated with aquaporin membrane have high water flux and exhibit antifouling propensity [26]. TFC membrane fabricated with double skinned support layer synthesized from double skin layer technique has improved higher selectivity, reverse salt flux, permeability and mean pore radius [8]. FO was applied in the manure treatment to separate protein from the disposal water. The dairy processing industry meets their power demand with the aid of FO for congregation and dehydration of milk whereas the other pressure-driven methods demand high energy for processing [13].

LIMITATIONS OF FORWARD OSMOSIS (FO)

FO has provided numerous upper-hands than other membrane techniques in several aspects, but FO has some major concerns. Membranes of the pressure-driven processes were fabricated with a strong support layer to resist the effect of pressure [16]. As the FO works on an osmotic pressure gradient the membrane possesses low mechanical strength and concern for the choice of selection [19]. The mechanical strength of the TFC membrane can be improved by fabricating a thick support layer which affects the active surface layer and also filtration process. Moreover, the thick support layer can increase the ICP [20].

External concentration polarization (ECP) transpires on the outer side of the membrane and can be nullified by increasing the external turbulence at the membrane surface whereas ICP transpires inside the membrane [18]. ICP is the major drawback of FO [27]. ICP of the membrane was based on the porosity

of the support layer of the FO membrane. TFC comprising thick polymeric support layer exasperate the water flux and ICP [28]. The rate of driving force of the FO membrane was influenced by ICP. Tortuosity and porosity of the membrane have influenced the ICP and membrane fluxes of FO significantly [17]. Ultrasound-assisted FO membrane can be employed to reduce ICP and increase permeate flux as the ultrasound wave increases the turbulence by causing cavitation in water which increases the rate of diffusion of the draw solution [29]. The high reverse solute flux was a major drawback of the FO, nanoparticle comprising membranes have enhanced reverse solute flux [3]. The pressure-driven membrane process has low reverse solute flux due to the application of pressure.

CONCLUSION

FO finds its uniqueness in the membrane technology due to its power consumption, resistance to fouling, cost efficiency and effective salt removal rate. FO employed in the process of desalination, manure and dairy processing industry, etc. FO membrane can be employed in sewage wastewater treatment without any requirement of energy and also can obtain effective purification. Nanoparticles incorporated FO membrane can act as an antifouling membrane which can be beneficial in membrane technology. Enhancement of water flux rate of the FO membrane is achieved by high porosity which makes FO superlative to other pressure-driven processes. The major concern for reverse solute flux and ICP can be resolved by enhancing the porosity and tortuosity of a membrane and by the application of components

on the membrane surface. The improvement of permeate and reverse solute flux can have a huge deal for FO in the future, negotiating the limitations and advancement in FO can make it flawless and affluent.

NOMENCLATURE

CA	Cellulose acetate
ECP	External concentration polarization
FO	Forward Osmosis
ICP	Internal concentration polarization
PDA@ZIF-8	Polydopamine coated with zeolitic imidazolate framework
TFC	Thin-film composite
TMC	Trimesoyl chloride

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