MEMBRANE FOULING DURING FERTILISER DRAWN FORWARD OSMOSIS DESALINATION USING BRACKISH GROUNDWATER

By

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CERTIFICATE OF AUTHORSHIP/ORIGINALITY

I certify that this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledge within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Signature of candidate

Fezeh Lotfi

For my wonderful husband, Dr. Behnam Fatahi

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LIST OF ABBREVIATIONS

FO: Forward osmosis

FDFO: Fertiliser drawn forward osmosis

RO: Reverse osmosis

PRO: Pressure retarded osmosis

BGW: Brackish groundwater

DS: Draw solution

CP: Concentration polarisation

ICP: Internal concentration polarisation

ECP: External concentration polarisation

CTA: Cellulose triacetate

PA: Thin film composite polyamide

HTI: Hydration Technology Innovations

NF: Nanofiltration

TDS: Total dissolved solids

DI water: Deionised water

DAP: Diamminium phosphate or $(NH_4)_2HPO_4$

MAP: Monoammonium phosphate or $NH_4H_2PO_4$

SOA: Sulphate of ammonia or $(NH_4)_2SO_4$

CAN: Calcium nitrate tetra hydrate

MW: Molecular weight

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Abstract

Freshwater has become a scarce resource in many parts of the world and has been recognised as a critical global issue. By far, agriculture is the largest consumer of global freshwater, reaching a proportion that exceeds 70% of the total water consumption, mainly in the form of irrigation. In 2006, 54% of the total water use in Australia related to the irrigation of farms and pastures although the figure was much higher in previous years. Due to the rapid growth in the world's population, water demand for agriculture will keep increasing to meet the corresponding food demands. Creating new water sources can reduce pressure on the existing fresh water resources. Hence, desalination can play a key role in creating a new water sources because saline water sources exist in abundance. However, current desalination technologies are energy and cost intensive and this can have negative impacts on the environment and natural resources.

Forward osmosis (FO) has been recognised as one of the most promising low energy processes for desalination. The FO process, as an alternative to conventional desalination techniques, has attracted much attention in recent years. The driving force in the FO process is generated by the osmotic pressure difference between the feed water and the concentrated draw solution (DS).

Where a natural source of high concentration DS is available, FO can be highly attractive due to its significantly lower energy demand for pumping. Fertiliser drawn forward osmosis (FDFO) desalination has been recently studied as one of

the most practical applications of FO for irrigation. The study indicated that most commercially available fertilisers can be used as osmotic draw solutes. This led to the idea of applying FO technology in agriculture where the diluted fertiliser DS containing desalinated water can be used directly for fertigation (fertilised irrigation) instead of further subjecting it to a separation process.

Despite the many benefits of membrane technologies, the unavoidable issue of membrane fouling during membrane filtration remains a problem. Membrane fouling is a process where solute or particles deposit onto a membrane surface or into membrane pores. Membrane fouling causes a reduction in the permeate yield and a decrease in the quality of water produced, which leads to an increase in the operational and capital costs of the entire membrane filtration process.

It is generally accepted that fouling reduces the performance of membrane. When the fouling occurs, a thick gel layer and cake layer are formed on and in the membrane, causing the permeate flux to decline and increasing the operational costs due to the need for higher energy, cleaning frequency and/or the reduced life of the membrane. Mechanisms of fouling in pressure-driven membrane processes have been investigated extensively. By contrast, only a few studies have so far targeted membrane fouling during the FO process.

This study investigates the influence of various factors affecting the water flux behavior and membrane fouling during the desalination of brackish groundwater by FDFO process. The major factors responsible for the performance of FDFO water flux behavior are thoroughly investigated and their implications to the overall process were discussed. The major factors assessed include membrane properties, DS properties and FS properties. The influences of all these factors have been measured in terms of water flux decline. A membrane autopsy has also been conducted to identify the inorganic scaling that forms on the membrane surface. Foulants have been analysed using Scanning Electron Microscopy (SEM), energy dispersive spectroscopy (EDS) and X-Ray Diffraction (XRD).

Six commercially available fertilisers (Potassium chloride, potassium nitrate, ammonium sulphate, monoammonium phosphate or MAP, diammonium phosphate or DAP, calcium nitrate) have been selected as DS to observe the effects of different fertilisers in water flux behavior during the FDFO process. DAP, having one of the highest osmotic pressures amongst the six selected fertiliser solutions has been found to produce unexpected water flux behavior with severe flux decline during the FDFO desalination of brackish ground water (BGW).

The XRD results indicate that the scales formed on the membrane surface during FDFO process using DAP as DS are mainly composed of magnesium phosphate ($MgHPO_4$) and magnesium ammonium phosphate ($MgNH_4PO_4.6H_2O$) or struvite. These insoluble compounds are formed because of the reverse diffusion of DAP towards the feed during the osmotic process which then reacts with the magnesium ions present in the FS.

This study shows that, the selection of fertiliser as DS is important for several reasons. Fertilisers that generate higher water flux at lower concentrations are preferable as these can contribute to significant cost savings in terms of both capital and operational costs. The other important characteristic of DS is that, it should have lower membrane scaling and fouling potential. Fertilisers that produce steady water flux and lower membrane scaling and fouling during long-term operation are preferable for FDFO application.

This work also seeks to show that besides the selection of suitable fertiliser as DS during the long term FDFO process, the selection of an appropriate membrane for the selected fertiliser is also essential. The interaction between fertiliser properties and membrane characteristics has a significant influence in water flux behavior.

As in real situations, varied types of foulants always coexist in natural waters. In addition to inorganic scaling by super saturation of calcium and sulfate ions, which are common in brackish groundwater, organic fouling is also possible due to prevalent natural organic matters. Therefore, alginate, albumin (BSA), and humic acid (HA) have been chosen as model organic foulants to study the effect of combined fouling in water flux behavior during the long term operation of the FDFO desalination process. 60 mg/l alginate has been found to aggravate inorganic scaling leading to a decrease in water flux of more than 30%.

Physical cleaning with cross-flow rates similar to normal FDFO process has been adopted to evaluate the effectiveness of restoring the membrane flux after inorganic scaling. The flux recovery is about 80-97% depending on the type of the DS. However, when the cross-flow rate is increased, the water flux is restored almost in full, irrespective of the type of DS and DS concentration used.