Exploration of concentration polarisation and fouling in Forward Osmosis using high resolution impedance spectroscopy technique

W.C.L. Lay\(^1\)\(^*\), J. Cen\(^1\), J.M. Kavanagh\(^1\), T.C. Chilcott\(^1\), P. Le-Clech\(^2\), C.Y. Tang\(^1\), Y. Liu\(^1\), A.G. Fane\(^1\)\(^2\), H.G.L. Coster\(^1\)\(^*\)

\(^1\)Singapore Membrane Technology Centre, Nanyang Technological University, Singapore 637723, Singapore;
\(^2\)UNESCO Centre for Membrane Science and Technology, University of New South Wales, NSW 2052, Australia
\(^3\)School of Chemical and Biomolecular Engineering, The University of Sydney, NSW 2006, Australia

(*) Corresponding author : Tel: +61 2 9351 2256, Fax: +61 2 9351 2854, Email: hcoster@usyd.edu.au

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Introduction

The forward osmosis (FO) has been viewed as a promising membrane process in meeting global challenges in energy and water supply (McGinnis and Elimelech, 2008). It has been speculated that FO may have lower fouling propensity compared to the pressure-driven reverse osmosis (RO) process based on flux decline observation. The hypothesis postulated here is that FO may have lower fouling cake compaction, as it does not entail the use of hydraulic pressure in the separation process (Holloway et al. 2007). However, Lay et al. (2009) showed through experiment and modelling analysis that the slower flux decline commonly observed in FO experiments did not prove lesser fouling cake compaction as compared to RO. There could be other contributing factors, such as the use of hydrophilic and smooth membranes, and the counteracting effect of the internal concentration polarisation (ICP) that is inherent of FO. Therefore, more effective monitoring methods are desirable for fouling characterisation in FO. The electrical impedance spectroscopy (EIS) has been recognised as a feasible non-invasive analytical technique for membrane processes (Chen et al. 2004). Kavanagh et al. (2009) demonstrated the potential of this technique and obtained information on fouling of RO membranes in a four-terminal electrical cell using CaCO\(_3\) as the model foulant. The aim of this study is to experimentally explore the phenomena of concentration polarisation and fouling in FO using high resolution EIS technique.

Materials and methods

The EIS experiments were conducted using the spectrometer system supplied by INPHAZE Pty Ltd. The system allowed the membrane to be held in place in a four terminal chamber and obtained impedance information as frequency varied. The feed solution was 1 g L\(^{-1}\) of BSA with 10 m\(\text{m}\) NaCl as background electrolyte. The draw solution was 1 m MgSO\(_4\) that provided bulk osmotic driving force of about 24 bar. Each solution was supplied from a reservoir volume of around 2 L, and recirculated via a
peristaltic pump with separate connections into the EIS chamber. Water flux was measured by a weighing balance. Conductivity measurement of both solutions typically gave a difference less than or around 0.2 mS/cm by the end of each experiment, indicating that dilution and concentration effects were small, and transmission of the draw solute was negligible.

**Results and discussion**

The analysis of the EIS measurement was performed based on the Maxwell-Wagner model, which relates the total impedance \( Z \) to the elements of the system as follows:

\[
Z = \sum_{k=1}^{K} Z_k = \sum_{k=1}^{K} \frac{1}{G_k + j\omega C_k}
\]

Here, \( G_k \) and \( C_k \) represent the conductance and capacitance of a particular element \( k \), respectively, and \( \omega \) is the angular frequency of the alternating current (a.c.) electrical field.

The EIS measurement picked up BSA fouling sensitively and provided a distinct response with more elements detected (Figure 1). Interestingly, the EIS also observed flux-dependent conductance response for different draw and feed solutions (Figure 2), which corroborated with the capacitance measurement that revealed a dip in the lower frequency range (< 1 Hz). The implication here is that interfacial phenomena were observed, and the shift in the conductance response was associated with the dilutive or concentrative nature of the concentration polarisation occurring.
Preliminary conclusion

The EIS technique is able to reveal the effects of fouling and concentration polarisation in FO. Ongoing work focuses to quantitatively relate the impedance response to its physical interpretation.

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References


