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ScienceDirect
Desalination 204 (2007) 148–154
DESALINATION
www.elsevier.com/locate/desal

Fouling in reverse osmosis: Detection by non-invasive techniques

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Received 2 February 2006; accepted 16 February 2006

Abstract

Two non-invasive techniques were demonstrated to detect silica fouling in reverse osmosis. The first technique, the sodium chloride tracer test, enabled the estimation of concentration polarisation (CP) level during the fouling process, where the polarisation was greatly enhanced by the formation of an unstirred layer. Using colloidal silica at a concentration of 200 ppm as model foulant and 2000 ppm NaCl as background ionic solution, and operation at a constant flux of 30 L/m^{2}h, it was found that the CP level increased by 75% whereas only 22% increase in the fouling resistance (R_f) was observed. The second method, ultrasonic time domain reflectometry, was used to monitor the growth of the fouling layer. The change in amplitude of the reflected signal was correlated to the amount of silica deposited on the membrane layer. Both techniques are valuable in the study of fouling or can be applied as early warning systems to provide critical information such as the level of concentration polarisation and the extent of the fouling layer.

Keywords: Concentration polarisation; Fouling; Reverse osmosis; Tracer test; Ultrasonic time domain reflectometry

1. Introduction

Reverse osmosis (RO) is widely used in desalination and water reclamation to convert seawater or wastewater to potable quality water. However membrane fouling is still a bottleneck in RO technology, which greatly reduces the filtration flux in constant pressure filtration or increases the trans-membrane pressure (TMP) in constant flux

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Presented at EuroMed 2006 conference on Desalination Strategies in South Mediterranean Countries: Cooperation between Mediterranean Countries of Europe and the Southern Rim of the Mediterranean. Sponsored by the European Desalination Society and the University of Montpellier II, Montpellier, France, 21–25 May 2006.

doi:10.1016/j.desal.2006.02.031

filtration. Many precautionary and preventative steps have been developed to combat fouling, however their success depends on how much we know about the fouling process. Current methods to monitor the fouling process are via flux decline or pressure rise data; while membrane autopsy is performed on a fouled membrane to gain details of the deposits present on the membrane. These methods have limitations as the measurement of TMP or flux is an average reading that reflects the overall changes in the membrane system; it does not recognise the actual location of the fouling deposits. Moreover, membrane autopsy is an undesirable method if the membrane has to be sacrificed. So, it is important to develop non-invasive, in-situ and real time tools to monitor fouling to enable an accurate determination of the fouling process. In this study, we show how two non-invasive techniques, namely the step tracer response test and the ultrasonic time domain reflectometry (UTDR), can be applied simultaneously to monitor the progress of fouling at constant flux operation. Colloidal silica was used as a model fouling species in the RO study.

2. Theory

Inevitably, fouling in RO is linked to concentration polarization (CP), a phenomena that arises when the rejected solutes accumulate at the surface of the membrane. Various attempts have been made to develop mathematical models for predicting the CP level in a clean membrane system. However, in the event of formation of a fouling layer, which can be considered as an unstirred layer, the back diffusion of salt ions from the membrane surface to the bulk solution is hindered. As a consequence, the concentration at the membrane surface is significantly increased and so is the osmotic pressure. The increase in osmotic pressure means a decrease in the effective trans-membrane pressure. This 'cake enhanced osmotic pressure' effect, defined by Hoek et al. [1] was often neglected, but instead the drop in performance was attributed solely to the build up of a high resistance fouling layer of particles. This assumption leads to an over estimation of the actual amount of fouling layer. Conversely, it means that a relatively low load of particles on the membrane can produce a greater impact on performance than anticipated from "cake resistance" considerations alone. In this study, a simple NaCl tracer response technique was used to study the 'cake enhanced osmotic effect' in an RO system under constant flux operation. This technique makes use of the unique property of an RO membrane to reject NaCl salts. Before the NaCl spike, flux can be expressed as

$$J_V = \frac{\left(\mathrm{TMP} - \mathrm{CP}\cdot\Delta\Pi_b\right)}{\eta\left(R_m + R_f\right)} \tag{1}$$

where CP is the concentration polarization modulus $(C_w - C_p)/(C_b - C_p)$. When a spike of NaCl is injected into the system, this causes an increase in the osmotic pressure. In order to maintain constant flux operation, the TMP of the system has to be raised. Therefore,

$$J_V = \frac{\left(\mathrm{TMP}_s - \mathrm{CP}\cdot\Delta\Pi_{bs}\right)}{\eta\left(R_m + R_f\right)} \tag{2}$$

where $\Delta\Pi_{bs}$ is the osmotic pressure and TMP_s is the trans-membrane pressure of the system during the spike. Combining the above two equations, yields

$$\mathrm{CP} = \frac{\mathrm{TMP}_s - \mathrm{TMP}}{\Delta\Pi_{bs} - \Delta\Pi_b} \tag{3}$$

Therefore, by knowing the trans-membrane pressure of the system as well as the conductivity of feed and permeate (conductivity can be easily converted to osmotic pressure) before and during the NaCl spike, CP can be determined.

Another approach that can be applied to monitor the formation of a colloidal silica layer is the