

Executive Summary

1 INTRODUCTION

Membrane fouling is the single most critical problem limiting the wider application of separation by membrane filtration. The flux decline that accompanies fouling affects the operational efficiency and economics of many membrane separation processes such as microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), electrodialysis (ED), and reverse osmosis (RO). In efforts to develop methods by which to reduce or prevent fouling, much research has been conducted. The development of a non-invasive technique to monitor the presence and growth of a fouling layer in real time, under realistic operating conditions, is potentially of great importance - to optimize plant operation and minimize operating costs.

In this project an ultrasonic time-domain reflectometry (UTDR) technique was developed as a non-invasive technique to investigate fouling layer formation and growth on membrane surfaces in MF, UF, RO. The ultrasonic testing technique provides a method for the early detection and monitoring of fouling in progress.

This preliminary investigation has formed the basis for a second project (1166) on the visualisation of the effects of electro-magnetic turbulence defouling techniques in membrane units. This project is currently in progress.

2 OBJECTIVES

The original aims of the proposed project were:

- To understand and measure the effectiveness of electrical defouling in spiral wrap desalination elements.
- To extend this process where possible to ultrafiltration and microfiltration membranes.
- If possible, to extend the process to cross-flow capillary for tubular design.
- To see if the process has other possibilities.
- To ensure effective patenting of all innovations.

Early on in the project the above objectives were modified to encompass the following.

It was considered more advantageous to move to the modified objectives in order to utilise the potential of the technology.

The revised objectives of this study were to:

- Investigate the use of ultrasonic time-domain reflectometry (UTDR) as a possible visualization technique for the detection fouling on membrane surfaces.
- Design a suitable desalination cell for ultrasonic testing in RO modules.
- Design a flat-bed-type device for the detection and monitoring of membrane fouling in MF and UF.
- Evaluate the efficiency of various cleaning techniques by UTDR.
- Correlate the UTDR response with membrane performance and corroborate the results via morphological characterization of the fouling layer.

The original objectives had to be modified during project execution because of problems encountered with co-operation and commitment from a local membrane company who were to supply the Project Team with, and give the team access to, fouled spiral modules. The Steering Committee subsequently agreed that the Project Team should continue the fundamental work being done on flat sheet cells and to characterise the technique and to attempt to perfect it as far as possible by the end of the project

3 EXPERIMENTAL APPROACH

Rectangular flat-sheet cells, built from Perspex and aluminium, and tubular and capillary membrane cells, were designed and used in this study. Systems for UTDR measurements and ultrasonic cleaning were set up and used. A focal transducer was designed and built. Various liquid separation systems such as MF, UF and RO, were set up. Different types of foulants were used: paper mill effluent, calcium carbonate and calcium sulphate. Various cleaning techniques such as forward flushing, ultrasonic cleaning and ultrasound with flushing were used and evaluated by UTDR in this study.

4 RESULTS

4.1 Ultrasonic measurement of fouling and cleaning of MF membranes

The UTDR technique was first applied to the non-invasive, in-situ, continuous visualization of fouling and defouling in flat-sheet MF nylon membranes. Results showed that the UTDR technique could effectively detect fouling-layer initiation and growth on, and its removal from, the membrane in real-time. The acoustic signal response had a good correspondence with flux-decline behavior during fouling.

The UTDR technique was also capable of detecting subtle changes, such as the presence and/or absence of a cake layer on the membrane surface, and distinguishing between two modes of growth at axial velocities of 1.0 and 4.2 cm/s. More specifically, the formation of a second echo in the time domain demonstrated that the UTDR technique could be used to quantify the thickness of a fouling layer on a membrane surface.

The fact that the UTDR technique monitors changes on the membrane surface makes it very suitable to study membrane cleaning and to determine the effectiveness of various cleaning techniques. Results of cleaning experiments showed that ultrasound associated with crossflushing was the most effective cleaning method; it was better than either the flushing or ultrasonic cleaning (without flow) methods. Cleaning by the former method resulted in a 40 x increase in permeate flux.

Results of SEM analyses of fouled and cleaned membrane surfaces supported UTDR visualization.

4.2 Ultrasonic measurement of fouling and cleaning of UF membranes

The UTDR technique could effectively detect fouling-layer initiation and growth on, and its removal from, a UF membrane in real-time. The structure of an asymmetric composite PS membrane was detected by UTDR.

The UTDR technique was also capable of detecting subtle changes in cake layer formation on the membrane surface, and the stop and recommencement of ultrafiltration.

The formation of a second (fouling layer) echo signal in the time domain demonstrated that the UTDR technique could be used to quantify the thickness of a fouling layer on the membrane surface.

In cleaning experiments, results showed that ultrasound associated with forward flushing was an effective cleaning method. The fact that the UTDR technique monitors changes on a UF membrane surface makes it very suitable to study membrane cleaning.

Results of SEM analyses of fouled and cleaned membrane surfaces again supported UTDR visualization.

4.3 UTDR measurement of inorganic fouling and cleaning of RO membranes

The results of this study showed that an ultrasonic testing technique was able to visualize inorganic fouling of RO membranes non-destructively, in situ, and under actual operating conditions in a flat-sheet, high-pressure test cell.

The ultrasonic technique could monitor subtle changes on a membrane surface due to the growth of calcium carbonate fouling. More specifically, a fouling echo obtained in the time domain indicated the actual state of the fouling layer on the membrane surface.

An increase in the amplitude of the fouling echo resulted from the build-up of the fouling layer. Moreover, the movement of the fouling echo in the time-domain was seen, due to an increase in the thickness of the fouling layer. The ultrasonic testing technique was capable of distinguishing between dead-end and crossflow modes of fouling growth.

The fact that the UTDR technique can monitor the removal of a fouling layer and membrane cleaning makes it a very suitable tool to study the effectiveness of various cleaning techniques.

5 CONCLUSIONS

- The ultrasonic signals of fouling processes provide a good measurement of fouling-layer growth in membrane separation test cells.
- The ultrasonic technique effectively detected fouling-layer initiation, its growth on and removal from the membrane in real-time. Data also showed the formation and growth of a fouling layer echo as fouling proceeded. Therefore, the UTDR technique can be used to quantify the thickness of a fouling layer on the membrane surface.
- The UTDR technique was successfully applied to, and fouling monitored in: MF, UF and RO; and with feeds that included: paper industry effluent, kaolin, calcium sulphate and calcium carbonate.
- The UTDR technique can be used to monitor cleaning and evaluating the cleaning effectiveness of various cleaning methods. Results of cleaning experiments show that ultrasound associated with flushing is the most effective cleaning method of those tested.
- Results of SEM analyses of fouled and cleaned membrane surfaces supported UTDR visualization.

Numerous publications have emanated from this work and consideration is currently being given to patenting a surveillance apparatus for monitoring membrane fouling. These achievements will be expanded on in the following project #1166.

RECOMMENDATIONS

This preliminary investigation has formed the sound basis for a second project (#1166) on the visualisation of the effects of electro-magnetic turbulence defouling techniques in different membrane units. (This project is currently in progress.)

Membrane units should include the following: UF tubular and capillary membrane modules and also spiral-wound modules.

Ultrasonic reflection modelling should also be developed, to understand the signal reflection of a fouling layer on the membrane surface.

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