

# STUDIES ON REVERSE OSMOSIS MEMBRANE TRANSPORT MODELS

BY

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*THESIS SUBMITTED TO THE  
INDIAN INSTITUTE OF TECHNOLOGY, DELHI  
FOR THE AWARD OF THE DEGREE OF  
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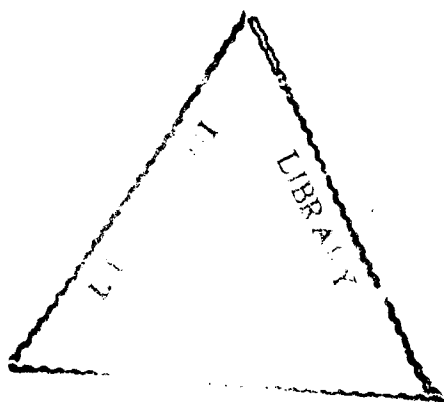
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Dedicated to  
my grandmother late Smt Bhadramma,  
and my parents  
Sri Z.V.Subba Rao and Smt Panchakshari Devi

## CERTIFICATE

This is to certify that the thesis entitled "STUDIES ON REVERSE OSMOSIS MEMBRANE TRANSPORT MODELS" submitted by Z.V.Panchakshari Murthy, for the award of the degree of Doctor of Philosophy, has been prepared under my supervision in conformity with the rules and regulations of the Indian Institute Of Technology, Delhi. The research report and results presented in the thesis have not been submitted for any degree in any other University.

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I am extremely grateful to Dr. Nivedita Datta and all my friends for their help and cooperation during the research period.

I would like to express my gratitude to M/S. Permionics, Baroda, India, for providing thin film composite polyamide membranes "Perma-TFC" for my research work.

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## ABSTRACT

The objective of the present work is to conduct reverse osmosis experiments under different operating conditions for a number of solute-water systems and use this experimental data for evaluating various membrane transport models available in the literature.

The separation data are obtained with four binary aqueous solutions, i.e. sodium chloride-water, sodium sulfate-water, phenol-water and sodium cyanide-water under widely varying operating conditions using cellulose acetate and commercial thin film composite amide membranes.

For the analysis of the experimental data, it is essential to know the mass transfer coefficient in the membrane test cell to account for the effect of concentration polarization. When the methods available in the literature for estimating the mass transfer coefficients are used for this purpose, it is found that the estimated parameters of a given membrane transport model vary with the operating conditions. Similar conclusions have been reached by other researchers in the literature. Further analysis of the experimental data proved that the reason for this erroneous conclusion may be due to the incorrect values of the mass transfer coefficient used in the analysis.

To estimate more consistent values of the membrane transport parameters and the mass transfer coefficients, two new methods are developed by combining the concentration polarization

model with the solution-diffusion (CFSD) model, and the Spiegler-Kedem (CFSK) model. A simple graphical method to estimate the solute transport parameter and the mass transfer coefficient is proposed. The working equation of the graphical method is a rearranged form of the CFSD model. The CFSK model parameters are estimated from a nonlinear parameter estimation program following the Box-Kanemasu method which is superior to the Marquardt method. Both the methods are capable of providing estimates of the mass transfer coefficient as well as the parameters of the given membrane transport model.

The parameters estimated from the graphical method show little variation with operating conditions, but the parameters from Kimura-Sourirajan Analysis (KSA), one of the methods available for analyzing the reverse osmosis data, show wide variation over the same operating conditions. On the other hand, the variation in the solute transport parameter obtained from the graphical method is small; the mass transfer coefficient is unpredictably low and varied little with flow rate. However, when the same data is analyzed by the CFSK model, the values change with flow rate in the expected manner, but the membrane parameters show little variation with the operating conditions. Therefore, one might conclude that the "simple graphical method" is too "simple", i.e. does not provide valid results.

In the present work, a new phenomenon is observed that there exists a maximum in the observed rejection ( $R_o$ ) when it is plotted against the product flux ( $J_v$ ) through the membrane. This

is the case with phenol-water and sodium cyanide-water systems using thin film composite polyamide membranes. This behavior is explained with the help of the CFSK and the CFSD models. An equation for  $J_{v,min}$ , which is the value of product flux  $J_v$  for which  $(1-R_o)/R_o$  vs.  $J_v$  plot shows a minimum or the observed rejection reaches a maximum when plotted against  $J_v$ , is derived from both the models. Such type of trend was not observed previously in the literature with reverse osmosis membranes. The reason for this may be due to the fact that this maximum rejection for a number of other solute systems occurs at very large values of product flux  $J_v$ , which may be beyond the working limits of the experimental setup. In the present work, this is found to be true in the case of sodium chloride-water and sodium sulfate-water systems using cellulose acetate membranes. Though both the models predict the  $J_{v,min}$ , it is found that the values from the CFSK model are more accurate.

For all four solute-water systems tested in the present investigation, the Spiegler-Kedem model is found to predict the rejection data more accurately and its parameters are independent of the operating conditions studied. On the other hand, the values of the parameters of the solution-diffusion model also remain constant, but the model fails to predict the rejection data accurately.

Since a large number of membrane transport models are available in the literature which can be rewritten in the same mathematical form as the Spiegler-Kedem model, though their

assumed mechanism of mass transport in the reverse osmosis membrane may be different, it may be assumed that the parameters of these models will also show little variation with the operating conditions. These models may then be used for interpreting the parameters of the Spiegler-Kedem model which is based on the theory of irreversible thermodynamics.

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