# Simulation of tubular reverse osmosis"*

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## Abstract

The rational design of reverse osmosis systems is made difficult because the engineering variables of pressure, flow rate, solute rejection and permeate flux are interrelated in a complex way, even before such effects as membrane fouling and degradation are taken into account. Where pilot-plant data may be available, unless they cover a very comprehensive range of operating conditions, it will still be difficult to estimate the consequences of varying the parameters in the process of seeking the most economic design. A similar situation applies to an existing plant which has to be adapted to changing circumstances.

Although complex, the underlying mechanisms of reverse osmosis are quite well understood, and are readily amenable to computer simulation. A computer package is being developed to serve as a tool for the analysis or design of reverse osmosis plants. Its use is demonstrated by means of a hypothetical case study based on pilot-plant data gathered at the Lethabo Power Station near Sasolburg.

## Introduction

Reverse osmosis (RO) first became a commercially viable desalination process in the late 1960s, and rapidly established itself in the field of potable water production from brackish water, and later also from sea water. Today it is the preferred technology for these applications.

Almost from the beginning, the potential of RO for the treatment of industrial effluents and pollution control was recognised, since it provides a means for effecting a pure separation of solutes from water, with minimal or no addition of treatment chemicals, and with no phase change. Progress in this field has, however, not matched the spectacular achievements of the natural water desalination applications. Part of the reason for this is the sensitivity of RO membranes to fouling and chemical damage, together with the variability of industrial effluents, both from location to location, and with respect to time at a single location, so that the accumulation of relevant expertise is a relatively arduous process.

Commercial RO membranes are generally packaged in one of three major configurations: tubular, spiral-wrapped and hollow-fine-fibre modules. The latter two are very efficient in terms of providing a large surface area per unit volume, but are very sensitive to fouling, since mechanical cleaning of any sort is impossible. Tubular membranes typically have a 12,5 mm tube diameter, and are relatively tolerant of particulates in the feed, and can be cleaned by passing sponge-balls through them in addition to chemical cleaning methods. Thus, they may be the only practical choice for some effluents, in spite of their low capacity.

A computer model of tubular reverse osmosis (TRO) is being developed by the Pollution Research Group of the University of Natal, under the sponsorship of the Water Research Commission, as a tool to be used in the investigation, design and evaluation of aqueous effluent treatment plants, with special reference to the TRO modules manufactured by Membratek of Paarl.

In 1987 Eskom built a TRO plant to separate salts from the cooling tower blow-down at the Lethabo Power Station near Sasolburg. The motivation was to reduce the volume of saline effluent to that required for the conditioning of the station's ash dumps, thus achieving a zero aqueous effluent discharge to the environment. In the previous year, a pilot investigation was carried out using a plant consisting of 30 Membratek TRO modules, each containing 1,72 $m^2$ of cellulose-acetate membrane in 12,5 mm diameter tubes (Schutte et al., 1987). Eskom has made some of the data gathered from the pilot plant available to provide a realistic test of the modelling procedures.

This paper explores, through simulation, some aspects of the relationship between the pilot plant and the full-scale plant that was designed from it, to illustrate the use of computer modelling in conjunction with pilot-plant investigations.

**Nomenclature**

*A* = RO membrane pure water permeability coefficient, $kg/m^2$
*c* = Solute concentration, $kg/m^3$
*d* = Tube diameter, m
*D* = RO membrane solute transport coefficient, m/s
D = Molecular diffusivity of solute in water, $m^2/s$
*k* = Turbulent diffusion mass transfer coefficient, m/s
*L* = Equivalent length of RO tube per module to account for pressure drops through fittings, m
*N* = Flux, $kg/m^2s$
*P* = Pressure, Pa
*Q* = Flow rate through RO tubes, mVs
*v* = Flow velocity, m/s
M = Incremental membrane area in numerical integration, $m^2$
AL = Incremental tube length in numerical integration, m
AP = Incremental pressure drop in numerical integration, Pa
u. = Viscosity of water, Pa-s
*II* = Osmotic pressure, Pa
p = Density of fluid, $kg/m^3$
*Sh* = Sherwood number *kd*
*Re* = Reynolds number *put*

Sc = Schmidt number $\frac{u}{pD}$

**Subscripts**

*b* = In the bulk solution within an RO tube
*m* = In the solution at the membrane surface

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