TECHNICAL EVALUATION OF A REVERSE OSMOSIS DESALINATION PLANT IN THE CARIBBEAN: A CASE STUDY

I. C. Ramdhanie and C. Riverol*

Chemical Engineering Department, University of West Indies, Trinidad, Republic of Trinidad and Tobago.

Abstract: The aim of this paper is to determine the recovery rate and other performance parameters using a numerical model. The results are presented for a two-stage seawater reverse osmosis desalination unit with spiral-wound modules. The model, which is based on the mass and momentum transport equations, takes into consideration the longitudinal variation of the velocity, the pressure and the salt concentration in the membrane modules. Data given by plant authorities reveal that the plant is currently operating at a recovery rate of 67.53%. This project has shown that for the Desalination Company of Trinidad and Tobago, the recovery rate currently achieved by the plant (67.53%) might not be the most economical. Slightly reducing the recovery rate drastically reduces the energy cost, resulting in an overall reduced cost per cubic meter of desalinated drinking water.

Keywords: desalination plant; reverse osmosis; mathematical modelling; operating conditions.

**Correspondence to:*
Dr. C. Riverol, Chemical Engineering Department, University of West Indies, St. Augustine Campus, Trinidad, Republic of Trinidad and Tobago.
E-mail: criverol@eng.uwi.tt

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INTRODUCTION

In the past decade, seawater desalination plants have found several applications for the production of drinking water. Currently over 15 000 industrial scale units are operating worldwide. Continuous progress in desalination succeed in competitive operating costs when compared with other plants in the production of drinking water, making it the prime although reverse osmosis is not the only technology actually used.

Several optimization models using different techniques have been developed for optimizing desalination plants. Maskan *et al.* (2000). performed an analysis of dual-stage reverse osmosis system. This analysis was restricted to tubular modules. These results are not adequate for the majority of RO plants because they use mainly spiral-wound modules. Other studies (Van Dijk *et al.*, 1984; Voros *et al.*, 1997; Watada, 1997; Wilf and Klinko, 2001) optimized operating conditions of individual RO modules and did not optimize the RO plant as global system. The 90% of them pay more attention to the overall design aspect. They assured that the optimum rate is generally the maximum possible as limited by the brine osmotic pressure and brine flow considerations; nevertheless it may be not be true in all cases. On the other hand, few papers have illustrated a deep study of the seasonal influence giving by variations of environmental conditions (salinity, TDS, temperature, and so on) on the optimal operation of the RO plant along the year. Moreover, any reference about optimization of RO seawater plant in the Caribbean and South America did not have been found. The most important papers are focus over Mediterranean Sea and Arabian Gulf. In resume, the previous literature review shows that not acceptable models for RO plant using spiral-wound modules with application on the Caribbean Sea have not been published.

The objective of this work is to develop a mathematical model for this system and use it to optimize the operating conditions and the module configurations of a medium sized, two stage spiral-wound SWRO system (see Figures 1 and 2). The mathematical model has been calibrated with field data of 136 000 m^3 day^{-1} SWRO unit of the desalination plant of Trinidad and Tobago which has two SWRO units currently operating. The impact of the performance parameters: feed pressure, recovery, temperature and salt concentration will be examined individually. In practice however, there is usually an overlap of two or more parameters.

DESCRIPTION OF THE PLANT

The increasing demand for fresh, potable water supplies in Trinidad and Tobago due to factors such as rapid urbanization, increasing

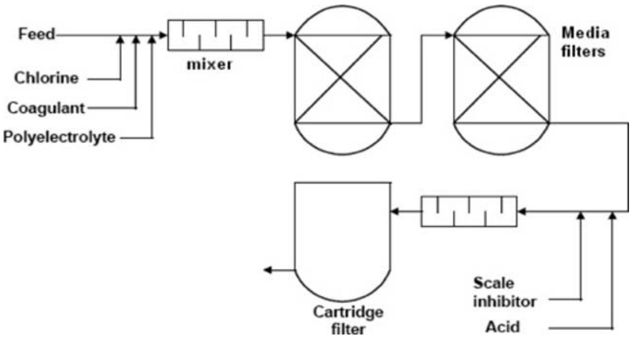

Figure 1. Schematic flow diagram of pre-treatment processes.

agricultural and industrial demands for water has contributed to the need for alternative source water supplies other than dams and other catchments areas. The salinity of the seawater entering the plant is 35 000 mg L^{-1} TDS; the finished water quality is less than 85 mg L^{-1} TDS. The common indicators of suspended particles used in the RO industry are turbidity and Silt Density Index (SDI). The maximum limits are: turbidity of 1 NTU and SDI of 4. Continuous operation of a RO system with feed water which has turbidity or SDI values near the limits of these values may result in significant membrane fouling. The turbidity of the incoming seawater from the Gulf-of-Paria to the plant is normally between 5–10 NTU. However, this is subject to fluctuations due to tide and seasonal changes (due to seasonal discharge into the Gulf-of-Paria from the nearby Orinoco River).

REVERSE OSMOSIS PROCESS

The RO process in the plant utilizes polyamide membranes, namely cellulose acetate membranes. This material is cast on a fabric support. The plant employs in the plant is a spiral configuration (see Figure 3). This configuration gives a good membrane area to operating volume ratio. The membranes must have high water permeability and a high degree of semi-permeability i.e., the rate of transport of water must be higher than the rate of transport of dissolved ions. They should also be stable over a wide range of pH and temperature and have good mechanical integrity. The RO system utilizes a two pass process. Each pass contains two distinct stages which operate at different pressures.

Pass 1

The filtered water is pressurized to about 1000 psi and pure water is forced through the RO membranes. The salts

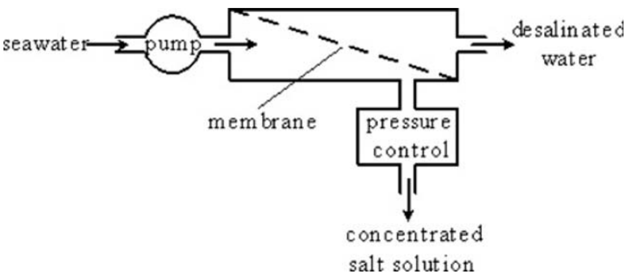

Figure 2. Basic scheme of desalination by reverse osmosis.

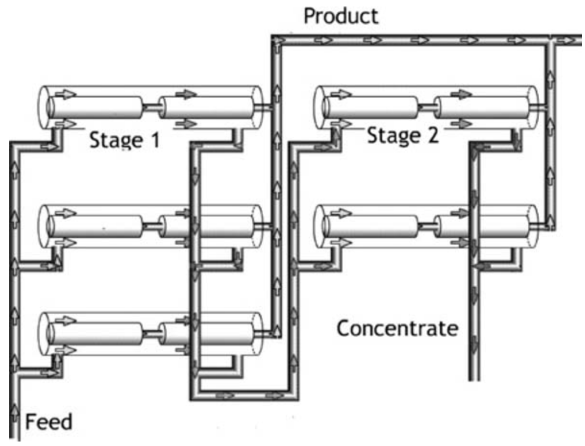

Figure 3. Seawater RO modular skids.

that are left behind are flushed away in the high-pressure concentrate that drives an energy recovery turbine (ERT) that reduces the electrical energy required for the process. It should be noted that only one third of the incoming feed water is purified/recovered in the first pass and this permeate (product water) goes to the product tank. The remaining unpurified feed water is boosted back up to 1000 psi to be processed once again.

Pass 2

The pure water from the first pass is re-pressurized to about 250 psi and is passed through a second set of RO membranes to reduce the salt level from about 400 ppm to about 60 ppm. The energy of the water exiting the second pass is used to power the turbine.

The permeate (product water) from the RO process requires treatment prior to storage and delivery to consumers. Therefore a treatment process must be conducted following the RO process.

TRANSPORT MODEL AS APPLIED TO THE PLANT

The productivity and permeate quality of a spiral-wound module was simulated numerically by a simplified mathematical model based on the one described by Alvonitis (1993) and Geraldes *et al*. (2005). The basic assumptions of this model are as follows:

- the feed channels are flat;
- assume plug flow;
- the pressure decrease in the permeate channels is negligible;
- the flow in the porous substructure of the asymmetric membrane is unhindered;
- the concentration polarization is quantified by the film theory.

The overall and TDS mass balances to the infinitesimal control volume are given by:

$$\frac{dV}{dz} = -\frac{-2V_p}{h} \tag{1}$$

$$\frac{dC_{sf}}{dz} = \frac{2V_p}{hV}\left(c_{sf} - c_{sp}\right) \tag{2}$$

where z is the distance to the channel inlet, V_p is the local permeate flux, and c_{sf} and c_{sp} are the TDS concentration in