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Long-term performance decline in a brackish water reverse osmosis desalination plant. Predictive model for the water permeability coefficient

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HIGHLIGHTS

- New model for the estimation of the water permeability coefficient
- Membrane performance decline in long-term
- Operating data of a BWRO desalination plant along 10 years

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ABSTRACT

Transport models in reverse osmosis (RO) desalination have been extensively studied taking into account various factors such as temperature, fouling, etc. However, there are not many models that describe the behavior of a desalination plant over long time periods. These models depend on operating time and empirical parameters to estimate the flux or the average water permeability coefficient (A) decline. The proposed model separates the decline of A in two stages, the first stage refers to a more pronounced decline due to initial compaction and irreversible fouling and the second stage describes a more stable period with less slope. The model is based on the superposition of two exponential functions, which depends on operating time, empirical parameters and fouling potential of the feedwater (k_{fp}). Ten years operating data of a brackish water reverse osmosis (BWRO) desalination plant were used. The obtained results with the proposed model showed a slightly better fit than previous models, but giving meaning to two different behaviors separated in two stages.

1. Introduction

The reverse osmosis (RO) is currently the undisputed leading desalination method [1–3]. Despite the progress made in this field [4,5], there is a continuing need for improvement and expansion. The understanding of the mechanisms at play in RO membrane separation is crucial to improve and raise this technology. Transport models are the tools used to understand membrane transport.

Different models have been proposed to give explanation to solvent and solute transport through dense or "nonporous" membranes [6]. Perhaps the more popular are the Spiegler-Kedem [7] and solution-diffusion [8] models, Eqs. (1) and (2) respectively.

$$J_w = \frac{1}{R_m \mu}(\Delta p - \sigma \Delta \pi) \tag{1}$$

$$J_w = A(\Delta p - \Delta \pi) \tag{2}$$

where J_w is the water flow (solvent), R_m is the membrane resistance, μ is the viscosity, Δp is the trans-membrane pressure, σ is the reflection coefficient ($\sigma < 1$ indicates a semi-permeable solute, while $\sigma = 1$ indicates an impermeable solute, complete rejection [9]), $\Delta\pi$ is the osmotic pressure difference across the membrane, and A is the membrane water permeability coefficient. The value of R_m and A are characteristic of the membrane in both cases and they are key in optimal design and operation of RO processes. The above mentioned coefficients depend (among other things) on the operating conditions and fouling potential of

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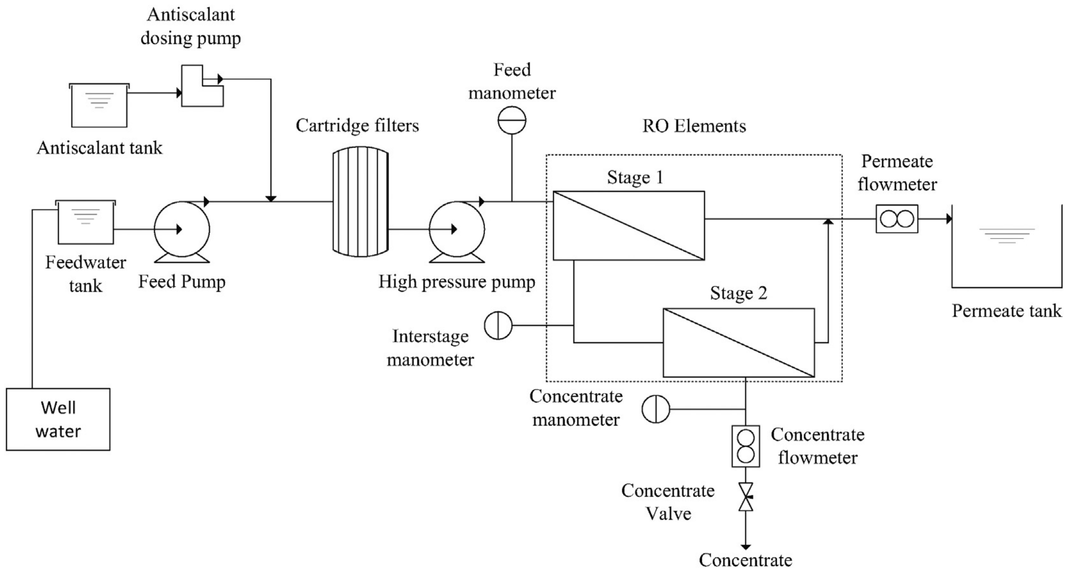

Fig. 1. Desalination plant flow diagram.

feedwater (k_{fp}) [10] becoming a permeate flow decline in time. A few coefficients have been added to *A* in order to fit the model to real behavior of desalination plants, *TCF* (temperature correction factor), *FF* (fouling factor), etc. Maybe the most relevant coefficient due to operational, environmental and economic implications is the *FF*.

Schippers et al. [11] studied the permeate flow (J_w) decline (based on Modified Fouling Index (MFI)) because of fouling and two terms were added to R_m (Eq. (1)) coefficient, the first related to concentration polarization and the second one to a resistance of the cake. Although the fouling phenomena, as well as the development of new fouling-resistant membranes, has been extensively studied [10,12–30], only a few authors [31–33] have proposed equations to estimate the decline of J_w in time due to variation of *A* in long-term. These correlations are applicable for the respective membrane type and for specific operating conditions. To obtain a model rigorous enough, it would be necessary to have long-term operating data in a wide range of operating conditions and different types of membrane. The mentioned model would depend not only on time, but on the characteristics of the membrane and the k_{fp}.

A previously proposed model to predict the decline of J_w, due to membrane compaction (short-time periods), was used by M. Wilf et al. [31] to estimate the J_w decline in long-term. Three years of experimental data from different sea water reverse osmosis (SWRO) desalination plants were used to identify the parameter of the model. They calculated the parameter for permeate flow decrements of 25 and 20%. R.A. Mohamed et al. [34] used four years' data from a SWRO desalination plant with the TFC 2822 Fluid system, initial feed pressure of 6.70 MPa and the flux recovery about 26–33%. Abbas et al. [32] proposed a model to determine the variation of the normalized average water permeability coefficient $A_n = A/A_0$, where A_0 is the initial average water permeability coefficient. It was an exponential equation depending on three parameters and time, the utilized membrane was the BW30–400 Filmtec . Five years of operating data were used for the parameter identification. The feedwater temperature was between 28 and 30 °C, the concentration in a range of 2540 to 2870 mg/L, and the feed pressure was around 1200 kPa. Zhu et al. [33] also proposed a model to predict the coefficient *A*, it was an exponential equation, but in this case a hollow fiber membrane was utilized (Dupont™ B-10) during one year of operating time. This correlation is not based on experiments but on model-based simulation: variable feed pressure (6.28–7.09 MPa), constant feedwater concentration and temperature (35,000 mg/L and 27 °C respectively). Belkacem et al. [35] used the Zhu model in terms of membrane resistance increase. The membrane used was the BW30LE-440 Filmtec™ in a two stage desalination plant with re-circulation during one year of operation. This model was not taken into account in this work since a proper fit was not achieved.

Two stages were differentiated in the decline of *A*. Stage I shows a more pronounced decline than stage II, mainly due to membrane compaction, irreversible fouling (strongly adherent films) and k_{fp}. The stage II is related to a gradual decrease mostly due to irreversible fouling, and frequency and efficiency of the chemical cleaning (CC). The operating

Table 1
Feed water inorganic composition.

Ion	Concentration range (mg/L)
Ca^{2+}	68.14–336.47
Mg^{2+}	79.40–467.43
Na^{+}	635.90–2,319.92
K^{+}	17.99–79.37
HCO_3^{-}	505.25–1,041.61
$SO_4^{=}$	254.11–1,177.82
NO_3^{-}	30.38–423.46
Cl^{-}	1,017.35–3,344.94
SiO_2	27.50–46.00
T DS	3,144.70–7,790.76

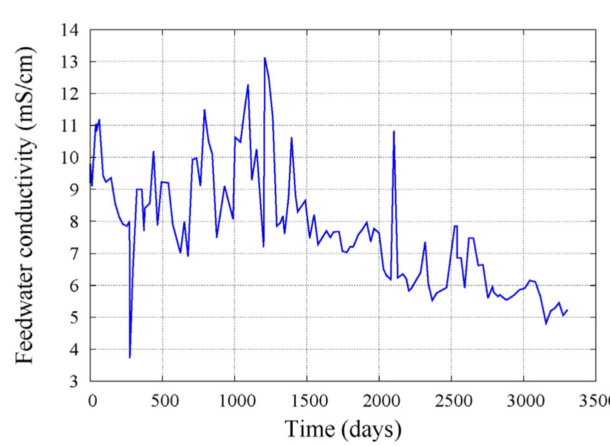

Fig. 2. Feedwater conductivity.