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Forecasting the effect of seasonal parameters on fouling deposition: a single effect thermal-vapor compression desalination unit as study case

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ABSTRACT

The aim of this paper is to apply a new approach focus in the context of the desalination process in the Caribbean. A practical procedure based on in the combination of a nonlinear function and sequential annealing (SA) algorithm allowed predicting the fouled deposit thickness. The methodology is based on the fact that values of these parameters are target values along the year rather than fixed real numbers. The results of this paper indicate that the fouling deposition can change up to 0.4 mm according to the season.

Keywords: Sequential annealing (SA) algorithm; Salinity; Thermo vapor compressor unit; Desalination; Fouling; Cleaning; Optimization; Caribbean

1. Introduction

The quality of the seawater is very important in the design of the desalination plant. It is worth noting, that the operational parameters (salinity, TDS) depend on the seasons (dry and rainy) such that they are not constants along the year (*see* Table 1). Several models using different techniques have been developed for different types of desalination plants, however the seasonal influence cannot be considered [1]. Maska performed an analysis of dual-stage reverse osmosis system [2]. This analysis was restricted to tubular modules. Other studies optimized operating conditions of individual reverse osmosis (RO) modules and did not optimize the RO plant as global system [3,4]. The 90% of them pay more attention to the overall design aspect. On the other hand, few papers have illustrated a deep study of the seasonal influence and 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.

The aim of the investigation is to evaluate the seasonal influence on the fouling deposition of the environmental conditions (salinity, TDS) on cleaning schedule of Thermo-vapour compression unit using an Sequential Annealing (SA) method. The simulated annealing method simulates the process of slow deposition of fouling on the pipe such that to achieve the minimum function value in a minimization problem. The minimum deposition was obtained in November (rainy season) and March in the dry season. The similar results were obtained in [5].

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Table 1
Field data: Salinity (ppm) and TDS

Month	Salinity (ppm)	TDS (ppm)
January	26,100	36,000
February	26,100	36,000
March	25,800	36,000
April	25,500	36,006
May	25,100	37,700
June	24,400	38,000
July	24,000	38,500
August	23,900	38,500
September	23,800	38,700
October	23,800	38,800
November	23,800	38,800
December	23,800	38,800

2. Problem definition and algorithm

The probability model was made using a set of random discrete data during 4 y. The data were used for creating the probability mass function where the function assigns probability of each value of X. A discrete probability function was not necessary for different operating conditions; however the function has a little different when the data are coming from dry or hurricane season. In consequence, sequential annealing (SA) is designed without constraints. A nonlinear regression approximates the discrete values of the following function:

For Rainy season:

$$f\left(x_1, x_2\right) - \frac{\sin\sqrt{0.1+\left(x_1-r\right)^2+\left(x_2-TA\right)^2}}{\sqrt{0.1+\left(x_1-r\right)^2+\left(x_2-TA\right)^2}} \tag{1}$$

For dry season:

$$f\left(x_1, x_2\right) - \frac{\sin\sqrt{0.13+\left(1.1 * x_1-r\right)^2+\left(x_2-TA\right)^2}}{\sqrt{0.15+\left(1.1 * x_1-r\right)^2+\left(x_2-TA\right)^2}} \tag{2}$$

where r is average fouling value, *TA is* the average TDS value taking from the sensors and x_1 and x_2 are any values for TDS respectively. The values were obtained using the average of fifteen different positions along the evaporator in the TVC unit. Later, this function with the SA algorithm was used for reproducing the results. The algorithm has to execute for a reasonably large number of iterations for a solution to drift to a global minimum. For the algorithm to be effective, it is recommended that $e^{-\Delta f}$ be in the range $0.5 \le e^{-\Delta f} \le 0.9$. The function predicts the behaviour of the fouled deposit with an accuracy of 93.1%.

The next step is to predict the inside tube surface area using SA algorithm. For a good mathematical prediction a good function can be selected. Several analyses have been done in previous work [6]. A non-linear function adjusted good to the data. Knowing the function, the basic algorithm for the prediction of fouling is the following:

1. Choose the starting point X_0
2. Using a step α_0, calculate $f_1 = f(X_0 + \alpha X)$
3. If $\Delta f = \left(f_n - f_{n-1}\right) = 0$ stop
4. If $\Delta f = \left(f_n - f_{n-1}\right) \neq 0$ then $\alpha = \alpha_0 + e^{-\Delta f}$
5. Go to step 2

It must be emphasized that the Sequential Annealing (SA) method was applied using data from Caribbean Sea such that we recommend this relationship applies only to Eastern Venezuelan Seawater; even those occasional exceptions are noted.

3. Results and discussion

Observing the Table 2, the values of the fouling deposition are quiet different; in fact, during the dry season, the values are higher than rainy season. The values can differ until 52% because of the fluctuations of the TDS and salinity along the year. We assume that the drastic changes in the salinity and TDS behaviour are due to global warming. The behaviour of TDS and salinity are

Table 2
Fouling deposition (mm) during 2005 (an example)

Month	Real thickness	AS-prediction (thickness)
January	0.84	0.86
February	0.77	0.77
March	0.71	0.72
April	0.92	0.90
May	1.20	1.21
June	1.18	1.18
July	1.21	1.20
August	1.20	1.21
September	1.21	1.21
October	0.90	0.91
November	0.82	0.81
December	0.87	0.87

Table 3
Comparison between real thickness and predicted thickness

mm (thickness)	Real (average)	Predicted (average)
January-June	1.18	1.20
July-December	0.83	0.81

seasonal instead of random. The fluctuations in the seasonal parameters affect the chemical pre-treatment in the plant. The supplier recommends cleaning the unit every four months however during the dry season the cleaning process has to be done every two months. The fluctuation of the fouling deposition was monitoring during last 5 y, recently, the dry season becomes longer than rainy thus that the cleaning process during 2005 was more frequently than 5 y ago.

The main components of the Thermo-vapour compression (TVC) desalination unit are the evaporator, steam injector and the feed heater or the condenser. Basically a mass of seawater at known temperature and salinity concentration is introduced into the tube side of the condenser where its temperature increases. The cooling water is dumped back to the Sea. The pipe in the condenser t was cleaning in several times along 5 y and the values were taken from the wall of the pipe. The filed data were compared with the predicted and the results are shown in the Table 3. The results indicated that the method of prediction using AS is close enough to the real values, such that the fouling can be predicted knowing quality of the seawater. The Fig. 1 shows an example of the TVC unit during a cleaning.

Nevertheless, an exact agreement between predicted and observed results is hardly to be expected; therefore, the sequential annealing (SA) treatment shown in this paper can help in the study of heat transfer and optimization of energy of a desalination plant in the Caribbean or another tropical place where the global warming problems around the planet can intensify the fluctuations of the parameters, especially in the hurricane season.

Fig. 1. Thermo-vapour compression unit during a cleaning section.

4. Conclusions

In this paper, we took advantage of to work under uncertainties for assessing the seasonal variables of a TVC desalination unit in the Caribbean. Although in such uncertain environments 100% success can be never reached, we decided to use sequential annealing (SA) method because it is easy to follow, see the algorithm and it does not need any previous knowledge in artificial intelligent as in the case of [5]. The following conclusions can be drawn of this study:

- The cleaning schedule has to be reviewed every year according to the seawater quality. During the dry season, the maintenance should be performed more frequent than rainy season.
- For design purposes, that a pre-treatment unit has to be added for decreasing the operational costs during the rainy season. The new pre-treatment unit will allow keeping the salinity, pH, temperature etc. constant using chemical additives. A specific treatment is not recommended in this article however to add carbonate compound to the Seawater allows to keep the pH around 8.8. The temperature does not use to increase over 22°C thus that any cooling system is not necessary. If these operating parameters are constants the accuracy in the fouled thickness calculation can increase and the uncertainties can be reduced significantly.

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