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Optimal design of hybrid RO/MSF desalination plants Part III: Sensitivity analysis

A.M. Helal, A.M. El-Nashar, E.S. Al-Katheeri, S.A. Al-Malek

Power and Desalination Research Center, Abu Dhabi Water and Electricity Authority (ADWEA), Abu Dhabi, UAE, P.O. Box 54111

Tel. +971 (2) 508-1504; Fax +971 (2) 508-1506; email: alya123@emirates.net.ae

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Abstract

This is the last paper in a series of three parts entitled "Optimal design of hybrid RO/MSF desalination plants". This research is concerned with exploring the feasibility of hybridization of multi-stage flash (MSF) and reverse osmosis (RO) technologies in order to improve the performance characteristics and process economics of the conventional MSF process. The research project involved an optimization study where the water cost per unit product is minimized subject to a number of constraints. In the first part, the design and cost models were presented, the optimization problem formulated and solutions for a number of cases were outlined. In the second part, results were presented and discussed. In this paper we discuss the sensitivity of water cost from the alternative plant designs to variations in some cost elements and operating conditions. In general, it is concluded that, for the same desalting capacity, hybrid RO/MSF plants can produce desalted water at a lower cost than brine recycle MSF plants, while hybrid plants are characterized, by lower specific capital costs and higher water recovery fractions. Reduction in steam cost allows MSF to compete more with hybrid RO/MSF plants. This result explains the advantage of coupling MSF plants and steam power plants where the exhaust steam from the back pressure turbine represents a relatively cheaper source of heat for the MSF process. Results showed that the RO technology exceeds all other designs over the whole range of energy, chemicals and membrane costs studied here. However, water cost of the RO process was the most sensitive to variations in membrane and electricity costs compared to other hybrid configurations.

Keywords: Hybridization; Optimization; Hybrid RO/MSF; Desalination economics; Sensitivity analysis

1. Introduction

In this sensitivity analysis, the following cost elements and operating variables were considered to study their impact on th minimum water cost:

- Steam cost
- Membrane cost
- Top brine temperature (TBT)
- Cost of chemicals
- Cost of electrical energy

*Corresponding author.

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The objective function, Ψ ($/m^3) in this optimization study is given by:

$$\Psi = \frac{\left[(C_{DR} + C_{IR} + C_{OR}) + (C_{DM} + C_{IM} + C_{OM})\right]}{W_Y} \frac{\$/y}{m^3/y}$$

where C_{DR} = RO direct capital cost including membrane cost, civil work and intake cost ($/y); C_{IR} = RO indirect capital cost ($/y); C_{OR} = RO operation and maintenance cost including labor, membrane replacement, parts, chemicals and energy costs ($/y); C_{DM} = MSF direct capital investment cost ($/y); C_{IM} = MSF indirect capital investment cost ($/y); C_{OM} = MSF operation and maintenance cost including labor, parts, steam, energy and chemicals costs ($/y); and W_Y = total production capacity per year (m^3/y).

In all the cases presented here, the plant capacity of desalted water is the same (3366 metric t/h; 21.37 mgd), and the final product quality is less than 500 ppm.

The plants presented in the following text are single purpose (water only). They receive electrical power and steam from an external source at specified costs. In the case of hybrid plants, the MSF to RO production ratio is 1:2. In all the cases including brine recycle MSF plants, the number of rejection stages was taken to be three. Calculations are based on a feed concentration of 42,000 ppm and a seawater temperature of 25°C.

The objective of the computations was to design the desalination plant for a given configuration so that the water cost is minimized while the following constraints are satisfied:

- The final product concentration should be less than 500 ppm.
- The brine velocities inside tubes in the heat recovery, heat rejection and the brine heater lie between 3 and 6 ft/s.
- The brine loading in the MSF plant section should be maintained between 1000 and 1200 m^3/h per meter of stage width.
- The maximum concentration of the flashing brine at the exit from the last rejection stage is limited to 80,000 ppm maximum.
- The reject brine concentration from the first stage in the two-stage RO plant should be less than 67,000 ppm. The maximum reject brine concentration off the second RO stage is 30,000 ppm.
- In all hybrid plants, the reject concentration from the RO (single-stage) plant section is limited to a maximum of 67,000 ppm.
- Operating pressure in the RO plant section in the hybrid designs should not exceed 80 atm. The same condition is imposed on the operating pressure in the first stage in the case of a two-stage RO plant. Pressure in the second stage is limited to 35 atm maximum.

In the cases including MSF plants, an amount of seawater which is equal to 145 metric t/h is considered to be used at the venting condenser. The overall plant recovery is defined as the percent of the total seawater intake, including the water to the vent condenser, converted to fresh water when an MSF plant is included.

2. Results and discussions

Figs. 1–9 represent the optimal designs obtained through computations based on the engineering and cost data given in Tables 1 and 2. The output plant characteristics corresponding to those flow sheets are given in Table 3.The output values reported in Table 4 are based on the cost data outlined in Table 2. These cost data are taken as reference where a cost multiplier equal to one is assigned to each cost item. In Tables 5–9, representing the results of the sensitivity study, the output values corresponding to a cost multiplier of 1 are emphasized in bold.

It was explained earlier in Part II of this work that the high capital investment cost of the MSF process represents a major economic disadvantage of that technology. According to the cost