Sensitivity of Brine Heater Fouling on Optimization of Operation Parameters of MSF Desalination Process using gPROMS

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Abstract

For fixed water demand, this paper studies the effect of brine heater fouling factor with seasonal variation of seawater temperatures on the plant performance ( in terms of Gained Output Ratio (GOR) and the operating cost) using a steady state MSF process model. Based on actual plant data, a simple linear dynamic fouling factor profile is developed which allows calculation of fouling factor at different operation time (season). January is considered to be the starting time (when the fouling factor is minimum) of the process after yearly overhauling. The total monthly operation cost of the MSF process is selected to minimize, while optimizing the operating parameters such as make up, brine recycle flow rate and steam temperature and a seasonal optimal operation policy is developed for the whole year. The software gPROMS models builder 2.3.4 is used for model development and optimization.

**Keywords:** MSF desalination process, brine heater fouling, fixed water demand, annual operating cost, optimization

1. ****Introduction****

Currently about 40% of the world’s population suffer from a shortage of fresh water and this is expected to increase in the future (Tanvir and Mujtaba, 2008). Multistage flash (MSF) desalination process is a major source of fresh water around the world. The process consists of a steam source, water/steam circuit (brine heater), pumping units, flashing stages and mixer (Fig.1).

Most MSF units usually operate at Top Brine Temperature (TBT) of 90-120°C. Although operating at higher TBT increases the efficiency, it increases scale ( fouling) formation (Aly and El-Fiqi, 2003) which can reduce the heat transfer efficiency by plugging the heat exchangers leading to frequent shutdowns of the heat exchangers for cleaning and will increase specific energy consumption and operating costs. Scale formation is mainly caused by crystallization of calcium carbonate e.g. CaCO3 and magnesium hydroxide Mg(OH)2. Non–alkaline scales e.g. CaSO4 are perhaps the most common scales found in MSF (AL-Sofi, 1999). The fouling tendency requires about 20 to 25% excess design allowance and the design of the heat transfer area constitutes about 30% of the total cost (Gill, 1999).

Scaling leads to dynamic adjustment of operating parameters if certain freshwater demand is to be met. Rather than playing with an operating plant to determine the new set points it is always economical to determine the optimal set points based on accurate process model and optimization techniques before the operating set-point are applied in the actual plant (Mussati et al., 2004). A typical MSF process model includes mass and energy balance, heat transfer equations and physical property correlations, the temperature losses due to boiling point elevation, non-equilibrium allowance and temperature losses in the demisters. The accurate calculation of the overall heat transfer coefficient (which is also a function fouling factor) is of substantial importance in MSF processes. However, in the past several modelling, simulation and optimisation studies of MSF process have been carried out using fixed fouling factor for the brine heater (Tanvir and Mujtaba, 2008; Mussati et al., 2004; EL–Dessouky and Ettouney, 2002).

In this work, a time dependent fouling factor (to represent dynamic scaling effect) is developed and a series of optimal operation snap shots are taken at discreet time intervals. An optimisation problem is formulated by incorporating steady state process model (Fig. 3) where operating cost is minimized while the operation parameters (such as make up, brine recycle flow rate and steam temperature) are optimized for a given configuration of the MSF process and a given fresh water demand. All physical properties correlations are taken from (Rosso et al., 1996) except temperature elevation due to salinity is taken from (EL–Dessouky and Ettouney, 2002).

Fig.1 A typical MSF Process

### 2. Estimation of Dynamic Brine Heater Fouling Profile

Fig. 2 shows the variation of actual fouling factor (m2K/kw)with time (hr) of the brine heater section (Hamed et al., 1999, 2000). Using regression analysis, the following linear relationship is obtained for (a) and (b):

 (1)

Fig.2 Brine Heater Fouling  Profile: (a) 0.8 ppm polyphosphate and TBT =90˚C (b) 3 ppm polyphosphate and TBT =108˚C

The constant in equation 1 represents the initial fouling of the brine heater section (, m2hK/kcal) at t = 0 (say January, at the beginning of the operation after plant overhauling).

A schematic representation of the two columns is given in Figure 1. For MVBRD process, the column is divided into rectifying and stripping sections by the feed vessel. Both columns are represented by detailed dynamic models in the form of Differential and Algebraic Equations system. The model assumes negligible vapour holdup, adiabatic plates, constant molar holdup on plates and in the condenser, perfect mixing on trays, fast energy dynamics, constant operating pressure and total condensation with no sub-cooling and assuming no azeotrope formation. The model includes mass and energy balances with constant molar holdup and rigorous thermodynamic properties. Dynamic model for feed tank and feed plate for MVBRD are shown in Figure 2. The kinetic model (Sanz et al., 2004) can be written as:

 (2)

Where *k1* = 1.65 × 105 mol. gm-1. min-1, *k2*= 1.16 × 106 , *E1* and *E2* = - 50.91 and - 48.52 J. mol-1 respectively and *a*i represent the activity of the component *i* (*ai* = i *x*i).

The vapor-liquid equilibrium are computed as:

 (3)

where γi is computed from UNIQUAC equation, the vapor pressure ()of pure components estimated by using Antoine’s equation.

### 3. Optimization Problem Formulation

The optimization problem is described below.

Given: Fixed number of stages, heat exchangers areas, design specification of each stages, seawater flow and fixed water demand.

Optimize: Steam temperature (), Recycled brine flow rate (*R*), Make-up seawater (*F*).

Minimize: The total annual operating cost (TOC).

Subject to: Any constraints.

The Optimization Problem (OP) can be described mathematically by:

OP 

s.t. 



  ; 

Where,  is the total amount of fresh water produced and  is the fixed water demand (9.45× kg/hr).  is the fixed top brine temperature (90 or 108˚C). Subscripts / superscripts L and U refer to lower and upper bounds of the parameters. The model equations presented in Fig. 3 can be described in a compact form by  where xrepresents non linear sets of all algebraic variables, *u* is the control variable, such as steam temperature, recycle flow rate, etc., *v* is a set of constant parameters. TOC is composed of many components are shown in Fig.4 (Helal et al., 2003).

TOC (Total Annual Operating Cost) = C1 + C2 + C3 + C4 + C5

Where,

C2 (Chemical cost) = 8000 × [∑ (Unit cost ($/gm) × Dosing rate (ppm))] × (F/Db)

Where Db = density of brine (kg/m3)

Chemical cost ($/kg) and dosing rate (ppm) (Nafey et al., 2006):

Sulphuric acid: 0.504, 24.2; Caustic Soda: 0.701, 14; Anti- scaling of polyphosphates: 1.9, (0.8 or 3); Chlorine, 0.482, 4.

Fig.4 Cost Functions (all costs are in $/year)

Table 1 Constant parameters and input data.

‘ Aj /AH IDj/IDH ODj/ODH  Fj/fbh wj/LH Hj

Brine heater 3530 0.022 0.0244 7.5×10-5 - 2.6×10-4 12.2 ----

Recovery stage 3995 0.022 0.0244 1.4×10 -4 12.2 0.457

Rejection stage 3530 0.024 0.0244 2.33×10 -5 10.7 0.457

# 4. Case Study

Here the effect of dynamic brine heater fouling on the performance of MSF process (in terms of  and operating costs) is studied for a fixed demand fresh water Dj = 945000 kg /hr. Two cases are considered. In case 1, TBT = 90°C with anti- scaling (polyphosphates) rate of 0.8 ppm is considered. In case 2, TBT =108˚C with anti- scaling rate of 3ppm is considered. Note, the concentration (ppm) of H2SO4, Caustic Soda and Chlorine are constant for both case studies.

The configuration investigated in this work refers to the case study reported by Rosso et al. (1996). The total number of stages is 16, with 3 stages in the rejection section and 13 in the recovery section. The specifications and constant parameters, which are used in this work, are shown in Table 1. Seawater flow rate () of 1.13×107 kg/hr with salinity 5.7 wt% is used for both cases. Seasonal variation of seawater temperature is shown in Tables 2 and 3 (based on Adel-Jawad and AL-Tabtabael, 1999). For different seawater temperatures corresponding brine heater fouling factors are calculated using equation (1). The optimization problem OP is then solved for each  and . Tables 2 and 3 show the optimal monthly operating cost, chemical required, steam consumption and the operating parameters such as make up, brine recycle flow rate, steam temperature and GOR throughout the year.

Table 2 Summary of optimization results (Case 1)

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Months |  |  |  |  |  | Ant-scale kg/month |  |  | GOR |
| Jan | 15 | 0.065 | 3.91 | 4.74 | 93.6 | 2252.2 | 4.48 | 116955 | 8.08 |
| Mar | 20 | 0.093 | 4.40 | 4.85 | 94.4 | 2539.9 | 4.65 | 120122 | 7.86 |
| May | 28 | 0.121 | 5.48 | 5.05 | 95.6 | 3159.0 | 5.01 | 127307 | 7.42 |
| Jul | 32 | 0.150 | 6.15 | 5.21 | 96.7 | 3542.0 | 5.25 | 132241 | 7.14 |
| Aug | 35 | 0.164 | 6.75 | 5.35 | 97.4 | 3891.4 | 5.47 | 136718 | 6.91 |
| Oct | 30 | 0.192 | 5.79 | 5.13 | 97.4 | 3340.0 | 5.18 | 129986 | 7.27 |
| Dec | 20 | 0.221 | 4.40 | 4.85 | 97.1 | 2538.6 | 4.71 | 120535 | 7.84 |

Table 3 Summary of optimization results (Case 2)

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Months |  |  |  |  |  | Anti-scale kg/month |  |  | GOR |
| Jan | 15 | 0.065 | 2.45 | 4.40 | 110.3 | 5309.1 | 4.52 | 98823 | 9.56 |
| Mar | 20 | 0.093 | 2.75 | 4.45 | 111.0 | 5952.9 | 4.64 | 100677 | 9.38 |
| May | 28 | 0.121 | 3.32 | 4.57 | 111.8 | 7177.2 | 4.87 | 104345 | 9.05 |
| Jul | 32 | 0.150 | 3.65 | 4.64 | 112.5 | 7902.8 | 5.01 | 106657 | 8.86 |
| Aug | 35 | 0.164 | 3.94 | 4.71 | 112.9 | 8520.5 | 5.13 | 108625 | 8.69 |
| Oct | 30 | 0.192 | 3.48 | 4.60 | 113.1 | 7529.6 | 4.97 | 105584 | 8.95 |
| Dec | 20 | 0.221 | 2.75 | 4.45 | 113.1 | 5955.2 | 4.72 | 100936 | 9.36 |

From January onward  increases and so does the . This consequently demands higher *F* and *R* and steam consumption () at higher , leading to higher TOC (monthly) for both cases. However, with decrease in  August onward, *F*, *R* and TOC decrease (even though  kept on increasing). Clearly, the effect of  on *F*, *R* and TOC is more pronounced compared to the effect of. Note, the highest total TOC is noted in August at the maximum yearly  (35˚C). For all cases, *F* and *R* vary significantly. Low TBT required higher *R* and *F* (compare the results in Table 2 with 3). Although there is a decrease (only slightly) in steam cost for case 1, the total chemical cost is higher due to higher requirement of *F*. The overall optimization results also show higher performance ratio () is achieved with higher TBT and chemical additives (see amount of anti-scale in Tables 2 and 3). Although the operating cost is slightly lower in case 2 (about 2.6%), the residual anti-scaling concentration present is higher in the brine blow down. It is expected that the impact on marine environment will be higher if this blow down is discharged to the sea without treatment.

Finally, note that at the same  of 20 C in March and December, although *F* and *R* remain the same, ,  and TOC increase due to increase in .

# 5. Conclusions

A linear dynamic brine heater fouling factor profile is developed based on actual MSF plant operation data. The sensitivity of the fouling factor on the optimal performance of MSF process is studied at discrete time zone corresponding to different seawater temperature using optimisation techniques in gPROMS. Two different operations in terms of TBT and anti scale dosing are considered. With freshwater demand fixed throughout the year, for each discrete time interval (season), the operating parameters such as make up flow rate, brine recycle flow rate and steam temperature are optimized while minimizing the total operation costs.

The results clearly show that as the scale builds up with time, there will be increase in the steam temperature, steam consumption, brine flow rates, total operating costs and decrease in GOR even though the seawater remains the same throughout the year. The variation in seawater temperature throughout the year together with changes in the brine heater fouling factor adds further changes in the operating parameters, costs and GOR. High TBT and anti-scaling dosing although preferable in terms of steam consumption and GOR this will lead to further environmental impact.

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