CHANGE OF DISTILLER PERFORMANCE WITH FOULING

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Summary

The performance of an MSF distiller is affected by several factors, the most important of these being the fouling of the heat exchange surfaces. Fouling occurs in the heat exchanger tubes in all parts of the MSF plant. This will considerably affect the performance ratio and the production rate of the distiller.

The effects of various fouling factors within each stage in the evaporator performance of the MSF plant, the change in the overall heat transfer coefficient, the stage temperature distributions, the effect of the distillate purity, and further hydraulic and thermal effects on the MSF plant will be shown in the following article.

1. Introduction

The performance of a multistage flash (MSF) distiller is affected by several factors, the most important of these being fouling on the heat exchange surfaces. This will considerably affect the performance ratio and the production rate of the distiller. Other factors which influence the performance of the distiller, for example the salinity and alkalinity of seawater, will only have a marginal effect on the evaporator.

The term fouling refers to the deposition of material on a heat transfer surface, usually resulting in an increase in the resistance to the heat transfer and a subsequent loss of thermal exchange capacity of the heat transfer equipment. Fouling occurs in the heat exchanger tubes in all parts of the MSF plant: brine heater, heat recovery section, and heat reject section.

The rejection section suffers from macrofouling (e.g. algae and mussels), slimy microfouling, water borne particles, and corrosion products from the tubes. Debris filter, chlorination, and on-load ball cleaning have proved to be successful countermeasures. The brine heater and recovery section mainly suffer from scaling by calcium carbonate and magnesium hydroxide formation when seawater is heated. This kind of fouling increases with increasing temperatures in the MSF plant and is often at a maximum in the brine heater. Possible countermeasures are the use of acid treatment with decarbonization, additives, acid shots, off-load acid cleaning, and on-load sponge ball cleaning.

Tube fouling in the brine heater and in the recovery section causes a higher steam consumption and influences the product flow rate.

2. Relationship Between Fouling and Steam Consumption

When a completely clean MSF plant becomes fouled, the steam consumption will rise and the plant performance will change. Figure 1 shows the steam consumption and product flow of a 4500 m^3 day^{-1} MSF plant as a function of the plant fouling.

A fall in the heat transfer coefficient due to fouling will increase the heat input to the plant and, hence, increase steam consumption in the brine heater. The brine heater fouling is compensated for by increasing the steam temperature and pressure. Increased steam consumption also means increased heat input to the reject section, which then has to be compensated for by an increased cooling water flow. Somewhere above the design point, the fouling effects cannot be compensated for any further. Any additional fouling will then result in a decreased product flow with constant heat consumption.

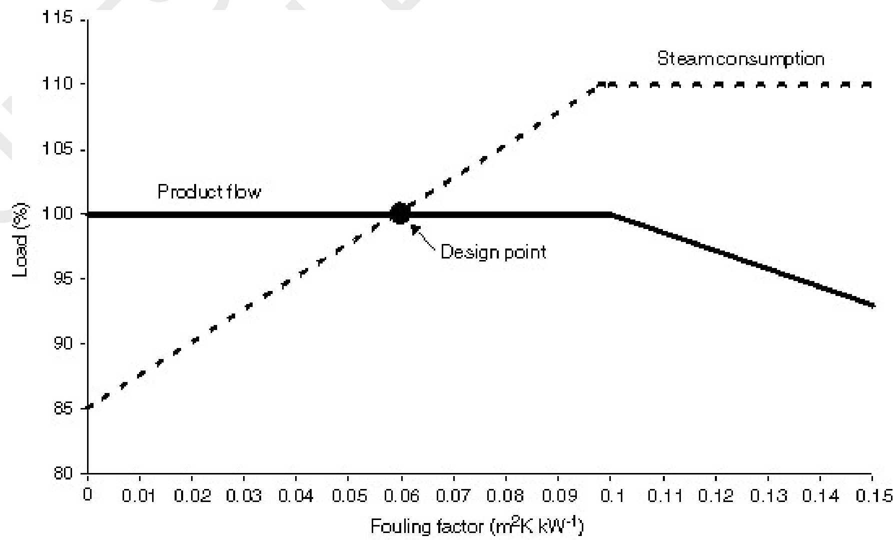

Figure 1. Relationship between steam consumption and fouling factor (Wade 1978).

3. Performance of the Evaporator Under Different Tube Fouling Conditions

Current practice in MSF distiller design is to assign constant fouling factors to the brine heater, the heat recovery section condensers, and to the rejection section pre-heaters. However, this is not in conformity with the actual fouling situation for several reasons.

(a) Alkaline fouling depends largely on the tube-side wall temperature. Thus, fouling will rapidly decrease with falling stage temperatures.
(b) Sponge ball cleaning removes soft scale, thus producing an asymptotic fouling resistance, which probably reaches the design values only in the top temperature stages.
(c) Non-condensable gases can produce, by blanketing the tube sections, a heat transfer resistance of the same order as the design fouling resistance.

With the ball cleaning system in operation, the performance ratios and, hence, the MSF evaporater performance in continuous operation are normally higher than the design specification.

3.1. Design Specifications and Heat Balances of an MSF Plant

Generally, only the overall heat transfer coefficients and fouling factors of the brine heater, heat recovery section, and heat rejection section are considered for the design of the desalination distiller. In reality the fouling factors vary within the different stages of a plant. The consideration of the varying fouling factors within the stages is very important for the determination of an optimum operation point. A desalination unit designed according to this aspect could be operated more efficiently, because the scale-inhibiting tools such as additive dosing and ball cleaning could be designed and operated to suit the plant specifications.

The effects of various fouling factors on the MSF evaporator performance within the stages of a typical MSF plant will be shown in the following sections. Table 1 shows the essential design data of the typical MSF recycle plant.

Thermal and hydraulic data	Nominal operation: summer	Nominal operation: winter
Seawater temperature (°C)	32.0	18.0
Top brine temperature (°C)	105.0	98.0
Capacity (m^3 day^{-1})	30 000	30 000
Brine recycle flow (t h^{-1})	11 945	11 163
Maximum weir load (t h^{-1} m^{-1})	948	886
Concentration of seawater (g kg^{-1})	45	45
Concentration factor	1.4	1.4
Performance ratio	8.3	8.2
Mechanical design data	Recovery	Rejection
Number of stages	17	3
Number of tubes per stage	2832	2580
Tube internal diameter/thickness (mm)	27.8/1.1	29/1.1

Tube length (m)	≈13.9	≈13.9
Heat transfer area (m^2)	63 120	10 582
Chamber length (m)	St. 1-11: 3.80 St. 12-17: 4.70	4.70
Chamber width (m)	14.0	14.0
Tube material	CuNi 70/30	Titanium
Design fouling factor ($m^2K\,W^{-1}$)	0.00012	0.00015

Table 1 MSF plant design data

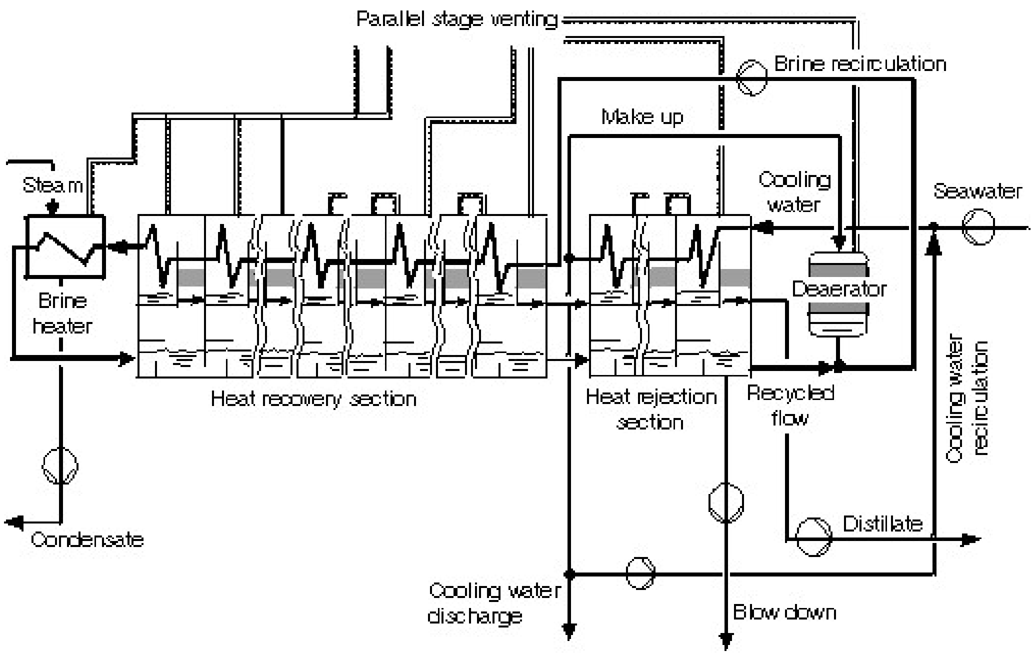

Figure 2. Simplified flow diagram of an MSF recycle plant.

The design data are typical for large MSF plants in operation today in the Middle East, except that here a single tier design was considered. The design of an MSF distiller requires detailed analysis of heat and mass balances, as well as plant cost factors. Figure 2 shows the flow diagram of an MSF recycle process. In general the whole MSF plant can be described by the following energy balances. The specific enthalpy *h* is a function of the temperature *T* and the salt concentration ξ of the corresponding mass flow.

(a) Overall heat balance for an MSF recycle plant:

$$\dot{m}_{\mathrm{C}}\ h\left(T_{\mathrm{S}},\xi_{\mathrm{S}}\right)+\dot{Q}_{\mathrm{BH}} = \left(\dot{m}_{\mathrm{C}}-\dot{m}_{\mathrm{MU}}\right) h\left(T_{\mathrm{MU}},\xi_{\mathrm{S}}\right)+\dot{m}_{\mathrm{D}}\ h\left(T_{\mathrm{D}},\xi_{\mathrm{D}}\right)+\dot{m}_{\mathrm{BD}}\cdot h\left(T_{\mathrm{BD}},\xi_{\mathrm{BD}}\right) \qquad (1)$$

Heat balance for the rejection section of the MSF plant:

$$\dot{m}_{D_{NREC}}\ h\left(T_{D_{NREC}},\xi_{D_{NREC}}\right)+\dot{m}_{NREC}\ h\left(T_{NREC},\xi_{NREC}\right)+\dot{m}_{C}\ h\left(T_{S},\xi_{S}\right)= \dot{m}_{C}\ h\left(T_{MU},\xi_{S}\right)+\dot{m}_{D}\ h\left(T_{D},\xi_{D}\right)+\left(\dot{m}_{BD}+\dot{m}_{R}\right)h\left(T_{BD},\xi_{BD}\right) \quad (2)$$

Heat balance for the recovery section of the MSF plant:

$$\dot{Q}_{BH}+\dot{m}_{BR}h\left(T_{BR},\xi_{BR}\right)= \dot{m}_{D_{NREC}}h\left(T_{D_{NREC}},\xi_{D_{NREC}}\right)+\dot{m}_{NREC}\ h\left(T_{NREC},\xi_{NREC}\right) \quad (3)$$

Heat balance for the mixing point:

$$\dot{m}_{R}\ h\left(T_{BD},\xi_{BD}\right)+\dot{m}_{MU}\ h\left(T_{MU},\xi_{S}\right)=\dot{m}_{BR}\ h\left(T_{BR},\xi_{BR}\right) \quad (4)$$

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