MSF ENGINEERING

M.A. Darwish

Department of Mechanical and Industrial Engineering, Kuwait University, Kuwait

Keywords: Once-through, MSF System, Recirculation, Performance Ratio, Heat Transfer,Stages, Condenser, Flow Sheet Development, Maintenance Design Features, Component Design, Material, Energy Comparison, Cost Estimation,Steam Supply, Desalting Plant, Co-generation Turbine

Contents

Process Description

1. Introduction

In a multieffect (ME) desalination system the vapor forming the product is generated by (a) boiling in the effects and (b) flashing between the effects due to the pressure drops between these effects.

The percentages of vapor produced in a typical ME system by boiling (m_b) and by

flashing (m_f) are 80 per cent and 20 per cent, respectively. The increase of feed to distillate ratio F/D increases the flashing to boiling ratio m_f/m_b and this requires an increase of feed pre-heaters and decreases the effects of boiling heat transfer areas. The limit to this procedure is to increase F/D to the extent that the required vapor is produced by flashing only, the boiling heat transfer surface in each effect is completely eliminated, and the feed heaters type condenser surface areas are increased to condense all vapor released. The first large desalting unit using this limiting case, called a multistage flash (MSF) system, was built in Kuwait by Westinghouse Company in 1957 to desalt 0.5 mgal day^{-1} with four effects (called stages here) and 3.3 performance ratio (PR). The design of the unit was based on ME system analysis (presented earlier) with a PR close to but smaller than the number of effects (stages here).

Silver filed a patent (British Patent Application No. 829820, September 1957) for a MSF process with different analysis than the ME analysis in some respects.

The PR does not explicitly depend on the number of stages n.

The number of stages n in an integer number greater than at least twice the required PR. (In practice, the number of stages n is in the range of three times the PR). In 1958 Silver designed the first two units based on his patent. One unit was installed in Kuwait to produce 4550 m^3 day^{-1} (1 mgal day^{-1}) and has 24 stages and a PR of 5.8. The second unit has 40 stages producing 2775 m^3 day^{-1} (0.5 mgal day^{-1}) and has a PR of 10.5. Both units were commissioned with success in 1960. The dramatic increase in PR (compared to ME systems at that time) and the simplicity of the structure over the ME system have made MSF desalting systems the most used method for desalting seawater in large quantities since 1960. Since that time, individual units and plant capacities have continued to increase. Examples of the units and plant capacities in Kuwait are given in Table 1. In 1985, more than 80 per cent of the desalted seawater was produced by MSF plants.

	Brine heater	Heat recover stage		Heat rejection stage
		First and second	All other stages	
Clean heat transfer coefficient (kW m^{-2} C^{-1})	4.57	3.58	4.92	4
Design heat transfer Fouling factor (kW m^{-2} C^{-1})	2.07	2.33	2.83	2.25
LMTD	0.000263	0.000149	0.000149	0.000194
When clean	4.23	2.21	1.82	1.8
At design point	12.05	3.41	3.16	3.99
Velocity (m s^{-1})	2.13	1.98	1.98	2.08
Material	70/30 Cu-Ni	70/30 Cu-Ni	Al-brass	70/30 Cu-Ni
n (efficiency)				
Area (m^2 per stage)	0.99	0.99	0.99	0.98
Number in stage	3594	3676.5	3676	3148
Tube dimensions	1367	1451	1451	1588
OD (mm)	43.8	43.8	43.8	3.42
length (m)	18.84	18.84	18.84	18.84

Table 1. Data on typical 6 mgal day^{-1} plants operating at $T_O = 90.54°C$

There are two possible types of MSF system: the once-through and recirculation MSF systems. The recirculation MSF system is the most widely used and appears superior to the once-through system in energy consumption. The once through system loses too much heat with brine rejection. The next sections consider both MSF systems.

2. Once-through MSF system

2.1 Single-stage Flash System

The once-through MSF represents the limiting case of the ME system when the feed flow rate is increased to the extent that the vapor is generated by flashing only and the boiling heat transfer surface is entirely omitted. The flash vapor is condensed on the feed heater-type condensers.
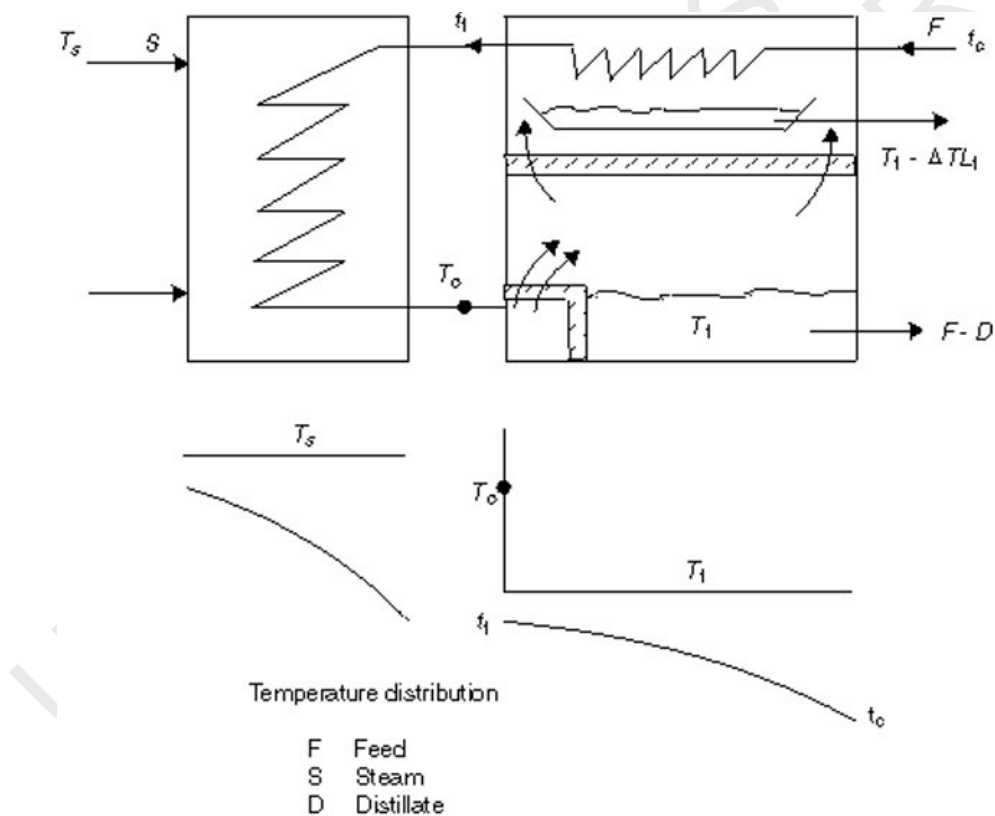
Figure 1. Single-stage flashing desalting system.

In a single-stage flash desalting system (Figure 1), the feed F, after pre-treatment, is pre-heated from t_c to t_1 in the condenser tubes. It is then heated in the brine heater (called heat input section, HIS) to temperature T_o by condensing the supply steam S (main energy source). The feed, leaving the brine heater at temperature T_o and pressure P_o, enters the first flashing chamber (or stage) kept at P_1 of saturation temperature $T_1 < T_o$. The feed becomes unstable and part of it is spontaneously vaporized (i.e. flashed in order to reach stability by dropping its temperature to T_1). The vapor released by

flashing flows upward through demisters (to separate entrained liquid brine) to the condenser tubes in the upper portion of the chamber. The vapor condenses there and forms the product. The heat released by vapor condensation is gained (or recovered) by the heated feed. The temperature of the flashed vapor (from brine at T_1) suffers some losses ΔTL due to non-equilibrium, boiling point elevation, and pressure drops through the demister and condenser tubes. The following energy balances can be carried out by assuming the following.

(a) Constant and average specific heat C for the feed F, distillate D, and brine B, streams and constant and average latent heat value L for condensing   apour and supply steam.
(b) A completely insulated stage.

(i)   For the condenser tubes

$$FC(t_1 - t_c) = DL \tag{1}$$

(ii)   For flashing brine

$$FC(T_o - T_1) = DL \tag{2}$$

(iii)   For the brine heater

$$Q = SL = FC(T_o - t_1) \tag{3}$$

where Q is the heat input rate (kJ s^{-1}) and S is the steam flow rate assumed to be supplied at saturated vapor condition and leaves at saturated liquid condition.

For the whole desalting unit

$$FCt_c + SL \cong BCT_1 + DCT_{V1} \tag{4}$$

Since

$$F = B + D$$

and

$$T_{V1} = T_1 - \Delta TL$$

then

$$SL \cong FC(T_1 - t_c)$$

Equations (1), (2), and (4) give

$$t_1 - t_c = T_o - T_1$$

$$\frac{D}{S} = \frac{t_1 - t_c}{T_1 - t_c} < 1 \tag{5}$$

$$PR = \frac{2330D}{SL} < 1 \tag{6}$$

$$\frac{F}{D} = \frac{L}{C(T_o - T_1)} = \frac{L}{C(t_1 - t_c)} \tag{7}$$

A typical example of a single-stage MSF system where $T_o = 90°C$ (top brine temperature, TBT), $t_c = 30°C$ (seawater temperature), and temperature approach of the condenser $T_1 - t_1 = 4.2°C$ would give $T_o - t_c = 60°C$, $t_1 = 57.9°C$, $T_1 = 62.1°C$, $D/S = 0.875$, and $F/D = 19.9$ (L is assumed equal to 2330 kJ kg^{-1}).

The value of F/D (=19.9) is large compared to F/D (=2.5) for a single-effect or ME system when the feed total dissolved solids (TDS) = 42000 p.p.m. and brine blowdown $TDS = 70\,000$ p.p.m.

The areas of heat transfer surface for both the brine heater and condenser heat exchangers can be determined by equating the thermal load of each exchanger with the overall heat transfer coefficient U, multiplied by the surface area multiplied by the effective temperature (LMTD). For the brine heater (with subscript b for the parameters involved)

$$SL = U_b A_b (\text{LMTD})_b \tag{8}$$

where

$$(\text{LMTD})_b = \frac{(T_s - t_1) - (T_s - T_o)}{\ell n\,(T_s - t_1)/(T_s - T_o)} \tag{9}$$

For the condenser (with subscript c)

$$DL = U_c A_c (\text{LMTD}) \tag{10}$$

$$(\text{LMTD})_c = \frac{(T_{v1} - t_c) - (T_{v1} - t_1)}{\ell n\,\dfrac{T_{v1} - t_c}{T_{v1} - t_1}} \tag{11}$$

Recalling $D/S = (t_1 - t_c)/(T_1 - t_c)$ and $T_{v1} = T_1 - \Delta TL$, the total specific area $A_t/D = (A_b + A_c)/D$ is expressed by

$$\frac{A_t}{D} = \frac{T_1 - t_c}{t_1 - t_c} \frac{L}{U_b(T_o - t_1)} \ell n \frac{T_s - t_1}{T_s - T_o} + \frac{L}{U_c(t_1 - t_c)} \ell n \frac{T_1 - \Delta T_L - t_c}{T_1 - \Delta T_L - t_1} \qquad (12)$$

The typical example mentioned earlier, with $T_s = 100°C$, $T_o = 90°C$, $T_1 = 62°C$, $t_c = 30°C$, $t_1 = 58°C$, $\Delta TL = 1.2°C$ and by assuming $U_b = 3$ kW m^{-2} C^{-1} and $U_c = 2.5$ kW m^{-2} C^{-1} has a specific total area $A_t/D = 108.74$ m^2 kg^{-1} s^{-1}.

2.2 Two-stage Flash System

Now a two-stage flash desalting system can be considered, as shown in Figure 2. The feed F entering the second stage condenser tubes at t_c is successively pre-heated to t_2 and to t_1 in the second and first stage condensers, respectively, before it enters the brine heater. The supply steam S raises the temperature of the feed in the brine heater from t_1 to T_o before it enters the first stage as flashing brine which is kept at pressure P_1 (of saturation temperature $T_1 < T_o$).
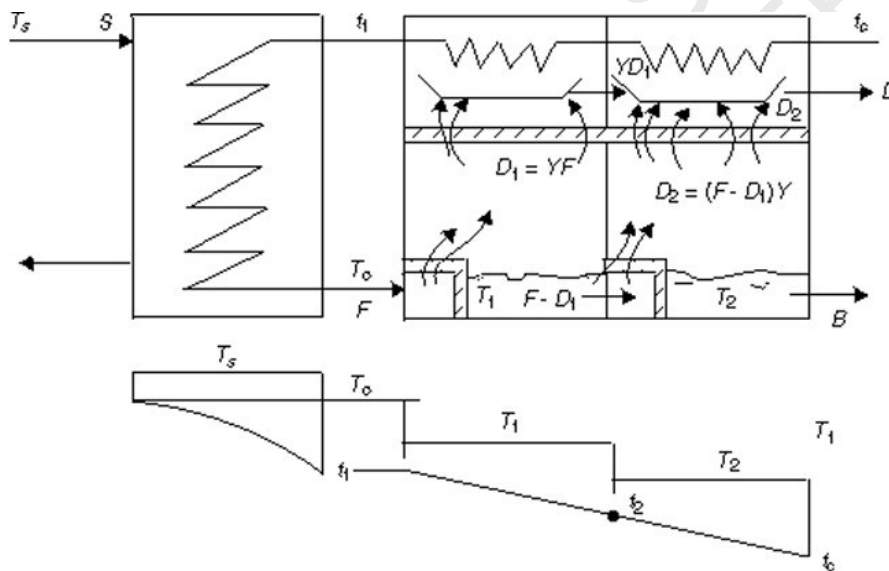

Figure 2. Two-stage once through MSF system.

The vapor generated in the first stage D_1 (due to the pressure drop of the flashing brine) is condensed on the outer surface of this stage condenser tubes and, thus, raises the temperature of the feed circulating in this condenser from t_2 to t_1. The unflashed brine $(B_1 = F - D_1)$ and the formed distillate D_1 proceed to the second stage kept at pressure P_2 of saturation temperature $T_2 < T_1$. Again both flashing brine and distillate suffer a pressure drop, partially evaporated by flashing and their temperatures drop to the second stage saturation temperature. The vapor generated in the second stage is condensed on these stage condenser tubes and heats the feed flowing in the condenser from t_c to t_2. The unflashed brine $(B_2 = F - D_1 - D_2)$ leaves the second stage as brine blowdown at T_2. The term D_2 represents the vapor evaporated (flashed) from the flashing brine in the second stage only. The mass and energy balances for the two-stage flash desalting system give the following.

Brine heater

$$SL = FC(T_o - t_1)$$

Flashing brine entering the first stage

$$D_1L = FC(T_o - T_1)$$

First stage condenser tubes

$$D_1L = FC(t_1 - t_2) = FC\Delta t$$

where $\Delta t = t_1 - t_2$

Second stage flashing brine

$$D_2L = (F - D_1)C(T_1 - T_2)$$

or

$$D_2 = (F - D_1)C\Delta T / L$$

where $\Delta T = T_1 - T_2$ and D_2 is the vapor released from flashing brine. Vapor flashed from distillate D entering the second stage is equal to

$$D_1C(T_{v1} - T_{v2})/L = D_1C\Delta T / L$$

Accumulated vapor condensed on the second stage condenser tubes is equal to

$$D_2 + D_1C\Delta T / L = FC\Delta t / L$$

Second stage condenser

$$FC(t_2 - t_c) = FC(T_1 - T_2)$$

Overall system (assuming no heat losses)

$$SL = FC(T_2 - t_c)$$

The above equations give

$$T_o - t_1 = T_2 - t_c$$
$$T_o - T_1 = t_1 - t_2$$
$$T_1 - T_2 = t_2 - t_c = \Delta T$$

-
-
-

TO ACCESS ALL THE **98 PAGES** OF THIS CHAPTER,
Visit: http://www.desware.net/DESWARE-SampleAllChapter.aspx

Bibliography

AI-Zubaidi A A (1987) Seawater desalination in Kuwait - a report on 33 years experience. *Desalination* **63**, 1-55.

Barba D, Bogazzi D, German A and Tagliferri (1980) Analysis of large desalination plants. *Desalination* **33**, 1-10.

Birkett and Newton E H (1981) *Survey of Service Behavior of Large Evaporative Desalting Plants, PB82-1203 12*. Washington, DC: Office of Water Research and Technology.

Darwish M A (1986) On the thermodynamics of dual purpose power-desalting plants, part I: using steam turbines. *Desalination* **64**, 151-167.

Darwish M A (1987) Critical comparison between energy consumption in large capacity reverse osmosis (RO) and multistage flash (MSF) sea water desalting plants. *Desalination* **63**, 143-161.

Darwish M A (1988) Cogeneration power-desalination plants. *Desalination* **69**, 27-46.

Darwish M A (1991) Thermal analysis in MSF desalting systems. *Desalination* **85**, 59-79.

Darwish M A (1995) Fuel cost charged to desalters in cogeneration power-desalination plants. *Heat Recovery Systems and CHP* **15**(4), 357-368.

Darwish M A et al. (1987) Energy consumption and cost of different desalting systems. *Desalination* **64**, 83-96.

Genthner K, Wangnick K, Bodendick F and Al Gobaisi D (1997) The next size generation of MSF evaporators, 100,000 m³/d L. (Thermal and Hydraulic Design Recommendation IDA Conference, Madrid, 1997).

Hanbury T (1980) *A Short Course on Desalination Technology*. Jeddab, King Abdul Aziz University.

Khan A H (1986) Desalination processes and multistage flash distillation practice. Amsterdam: Elsevier.

Office of Saline Water report (OSW) , 1966 OSW N0.**214** , Washington DC

Office of Saline Water report (OSW) , 1967 OSW N0.**315** , Washington DC

Office of Saline Water report (OSW) , 1980 OSW N0.**108** , Washington DC