Design of MSF type brine circulation system for steam power plant

S Wuryanti[1]

[1] Department of Energy Conversion Engineering, Politeknik Negeri Bandung, Jalan Gegerkalong Hilir, Bandung, Indonesia

E-mail: sriwuryanti.lamda@gmail.com

Abstract. Multi-Stage Flash Desalination type Brine Circulation (MSF-BC) is one of the desalination technology that utilises thermal heat in water treatment systems, which is used as a pre-treatment by purifying seawater into freshwater. In this design, MSF-BC design criteria are discussed that can meet the water needs of the 3 × 315 MW steam power plant generator with a water requirement of 130 m^3/hour. MSF-BC works with the principle of evaporation of seawater, and then the water vapour is condensed and produces distillate products. The design starts by determining the initial parameters of the design that is seawater data. Then do mass and energy balance calculations, heat transfer, and performance parameters using Performance Ratio (PR). The calculation shows that the temperature difference for each stage is 4.50 degree Celcius with a heat transfer area of 5154.2 square meter and the resulting distillate product is 131.42 tons/hour. The specifications of the pipe used are Copper-Nickel 90-10 with an outer diameter of 25.4 mm, pipe length of 2.22 m, and the number of pipes in the heat recovery stage are 2240 pieces with nine stages while in the heat rejection stage as many as 3060 pieces with three stages and performance ratio is 4.4.

1. Introduction

Water treatment systems or desalination plants function to reduce the levels of salt and minerals in seawater. Desalination systems commonly used are Reverse Osmosis (RO), Multi-Effect Desalination (MED), and Multi-Stage Flash (MSF). Strengths and weaknesses of each tool that is RO have advantages to meet the needs of public services, both small and large. Product capacities from 5-24000 tons/day require high electric power, making it difficult to maintain and cannot be used if the input water changes conditions [1]. MED has the advantages of low energy consumption, and high GOR value can be used for electricity generation and public services, easy to maintain. The shortage of MED is that it requires a large area of land for installation; the resulting capacity is not too large around 40-9000 tons/hr [2].

2. Methodology

They are designing a Multi-Stage Flash system, the amount of water used for the generator at start-up conditions and at the time of operation. The design stage in the Multi-Stage Flash-type brine circulation system is to determine the initial parameters such as the temperature of the incoming seawater, top brine temperature, mass flow rate of distilled water, seawater concentration, steam temperature, and stream velocity at the last stage. All of the initial parameters are based on standards in the design of desalination units so that the results of the Multi-Stage Flash brine circulation-type design can meet the design requirements. Design calculations include calculating the temperature difference at each stage, analysis of total mass balance, heat transfer analysis, area of heat transfer area. The next stage is calculating the performance of the Multi-Stage Flash-type brine circulation that has been designed which is called the performance parameter, including specific heat consumption (including specific heat consumption), specific heat transfer area and calculate system performance through Performance Ratio (PR). Moreover, determining the dimensions of Multi-Stage Flash-type brine circulation. The design stages are as follows:

- *Mass and energy balance in each stage*. The total mass balance and total salt concentrate can be calculated using Equation (1).

$$\dot{M}_f = \dot{M}_d + \dot{M}_b \tag{1}$$

- *Equilibrium Total Salt Concentration.* This was computed using Equation (2).

$$X_f . \dot{M}_f = X_b . \dot{M}_b \tag{2}$$

- *Distillation flow rates.* Calculation of feed flow rate in terms of distillation flow rates is as follows Equation (3).

$$\dot{M}_f = X_b \,/ (X_b \, - X_f). \dot{M}_d \tag{3}$$

  Where Mf is feed mass flow rate (kg/s), Md is distillate mass flow rate (kg/s), Mb is mass flow rate of brine blowdown (kg/s), and X is salt concentration (ppm).

- *Average temperature*. Calculation of average process temperature (Tav) that occurs in a desalination system uses the following Equation (4).

$$T_{av} = \frac{(T_o + T_n)}{2} \tag{4}$$

  Where, Tv is average temperature (^oC), T_o is top brine temperature (^oC), T_n is brine temperature at the last stage (^oC).

- *Specific Ratio of Sensible Heat and Latent Heat.* The ratio of sensible heat and latent heat (y) can be determined using Equation (5).

$$y = \frac{Cp.\Delta t}{\lambda av} \tag{5}$$

  Where, y is a specific ratio; Cp is specific heat (kJ/kg^{o}C), λav is average latent heat (kJ/kg).

- *Distillate water generated each stage.* The amount of distillate water produced per stage can be calculated using Equation (6).

$$D_i = \dot{M}_r . y(1 - y)^{(i-y)} \tag{6}$$

  Where D_i is the amount of distilled water per stage (kg/s), MR $\dot{}$ is recycled seawater flow rate (kg/s), y is a specific ratio.

- *Cooling water flow rate.* Cooling water flow rate is needed to obtain the specific cooling water flow rate. This flow rate is obtained from Equation (7).

$$M_{cw} = \frac{(\dot{M}_s \, \lambda_s - \dot{M}_f C_p (T_n \; - \; T_{cw})}{(C_p (T_n - \; T_{cw}))} \tag{7}$$

  Where, Ms ̈is steam mass flow rate (kg/s), λs is latent heat (kJ/kg).

- *Steam Mass Flow Rate.* The amount of steam used to heat the seawater temperature of the feed [Tr] until it reaches, this was computed using Equation (8).

$$\dot{M}_s = \frac{\dot{M}_r . C_p (T_0 - T_{ri})}{\lambda s} \tag{8}$$

Where Ms is the steam mass flow rate (kg/s), λs is latent heat (kJ/kg).

- *LMTD Brine Heater*. LMTD brine heater is defined through by Equation (9).

$$LMTD_b = \frac{(T_s - T_o) - (T_s - T_f)}{\ln\left(\frac{T_s - T_o}{T_s - T_f}\right)} \tag{9}$$

Where, $LMTD_b$ is *log mean temperature difference* (°C), T_s is temperatur *steam* (°C).

- *Overall Heat Transfer Coefficient of the Brine Heater*. The Overall Heat Transfer Coefficient on the Brine Heater can be calculated by Equation (10).

$$U_b = 1.7194 + 3.2063x10^{-3} . T_s + 1.5971x10^{-5} (T_s)^2 - 1.9918x10^{-7} . (T_s)^3 \tag{10}$$

Where Ub is the heat transfer coefficient (kW/m^2 °C).

- *Brine Heater area*. The area of heat transfer that occurs in the brine heater unit can be calculated using Equation (11).

$$A_b = \frac{\dot{M}_s . \lambda_s}{U_b . LMTD_b} \tag{11}$$

Where Ab is an area of heat transfer of the brine heater (m^2).

- *Area of Condenser Heat Transfer.* An increase in boiling point that is affected by pressure to reduce the salt content in water is called a BPE (Boiling Point Elevation). Calculation of the BPE value, it is necessary first to calculate the values of constants B and C showed by Equation (12).

$$BPE = X_i . [B + (X_i)(C)] . 10^{-3} \tag{12}$$

With $B = [6{,}71 + 6{,}34x10^{-2} (T_i) + (9.74x10^{-5} (T_i)^2] . 10^{-3}$
$C = [22{,}238 + 9{,}59x10^{-3} (T_i) + 9{,}42x10^{-5} (T_i)^2] 10^{-8}$

Where BPE is Boiling Point Elevation (°C), Xi is a salt concentration in the brine flow (ppm), B & C is Constants.

- *Non-Equilibrium Allowance (NEA)*. The steam condensation temperature for each stage is necessary to know the value of NEA with Equation (13).

$$NEA = (0.9784)^{To} (15.7378)^{H} (1.3777)^{Vb . 10^{-6}} \tag{13}$$

Where, T_o is top brine temperature (°C), His high brine pool (m), Vb is brine mass per stage width (kg/ms).

- *Steam Condensation Temperature*. The temperature of the vapour produced by the 1st stage (Tv_1) can be calculated using Equation (14).

$$Tv_1 = T_1 - BPE_1 - NEA_1 - \Delta Td_1 \tag{14}$$

Where T is a steam temperature at stage 1 (C), ΔTd_1 is temperature drop on demister (°C).

- *Overall Condenser Heat Transfer Coefficient*. The Overall Heat Transfer Coefficient on the Condenser can be calculated by Equation (15).

$$Ur = 1.7194 + 3.2063x10^{-3} (Tv_1) + 1.5971x10^{-5} (Tv_1)^2 - 1.9918x10^{-7} (Tv_1)^3 \tag{15}$$

Where Ur is coefficient of overall heat transfer condenser (kW/m^2 °C).

- *Stage Dimensions.* Calculation of stage dimensions includes gate height, brine pool height, stage width, and stage length. Gate height seawater that enters the Flashing stage through a hole or also called a gate. The height of the gate (GH) can be calculated using Equation (16).

$$GH = \frac{M_r(2.\rho_b.\Delta P)^{(-0.5)}}{Cd.W} \tag{16}$$

Where GH is Gate Height (m), ρb is brine density (kg/m^3]), ΔP is a pressure difference between stages (bar).

- *The value of the brine pool height (H_l).* The height of the brine pool must be higher than the gate height can be used Equation (17).

$$H_l = 0.2 + GH \tag{17}$$

Where H_l is an excellent brine pool (m).

- *Stage Width.* The stage width is determined using Equation (18).

$$W = \frac{M_r}{V_b} \tag{18}$$

Where W is stage width (m), Vb is brine mass flow rate per stage width (kg/ms)

- *Stage Length (L).* The dimensions of the stage length are determined using Equation (19).

$$L = \frac{D_n}{\rho_{vn.}V_{vn}.W} \tag{19}$$

Where L is stage length (m), Dn is distillate flow rate at the last stage (kg/s), V_{an} is the steam velocity at the last stage (ms), ρ_{vn} is water vapour density (kg/m^3).

- *The area of each stage*. Cross-section area for each stage can be calculated with Equation (20).

$$A_s = L\, W \tag{20}$$

Whereas is the cross-section area [m^2]

- *Performance Parameters*. It is a ratio of the total rate of steam consumed to the product of water distillate produced and can be calculated using Equation (21).

$$R = \frac{\dot{M}_d}{\dot{M}_s} \tag{21}$$

Where Md is distillate mass flow rate (kg/s), Ms is a steam mass flow rate (kg/s).

3. Results and discussion

In this MSF-BC design a cross tube type configuration is used, where the tubes are arranged in a direction perpendicular to the saltwater flow. Design result is a standard configuration used in most MSF plants.

3.1. Main specifications design results

Table 1 shows the results of the calculation of the Multi-Stage Flash-type Brine Circulation design, where this unit uses a total of 12 stages, consisting of 9 heat recovery stages and three heat rejection stages. All stages in the heat recovery section have an identical construction. From the calculation results of this unit, design can produce product water with a capacity of 3154.1 m^3/hr and has a Performance Ratio of 4.4 [4].

Table 1. Design result.

MSF Parameter	Value
Total licked capacity, ton/hr	131.42
Heat recovery area, m²	393.72
Heat rejection, m²	536.97
The total area of heat transfer, m²	5154.414
Specific heat transfer area, m²/(kg/s)	148.2
Brine heater, m²	197.36
Performance ratio	4.4
Heat, kJ/kg	506.38

Whereas based on a journal with the same number of stages as calculation, 12 stages with nine heat recovery stages and three heat rejection stages produce product water with a capacity of 2400 m³/hr [5 -7]. Moreover, other design results show that using a total of 24 stages with a configuration of 12 heat recovery stages and three heat rejection stages produce 2479.2 m³/hr of product water [8,9].

3.2. *Top brine temperature against performance ratio*

The distillate that is desired to meet the needs of the generator water, Top Brine Temperature is as minimum as possible so that the Performance ratio gets big. The performance ratio is the sum of the rate of distillate product produced per unit of steam heating mass rate PR = Md/Ms.

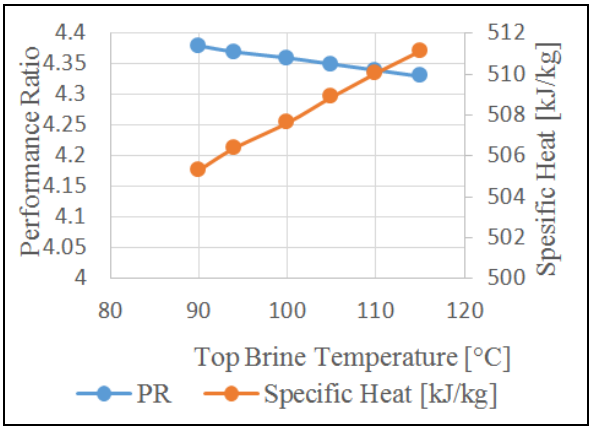

Figure 1. Graph of changes in top brine temperature to PR and specific heat consumption.

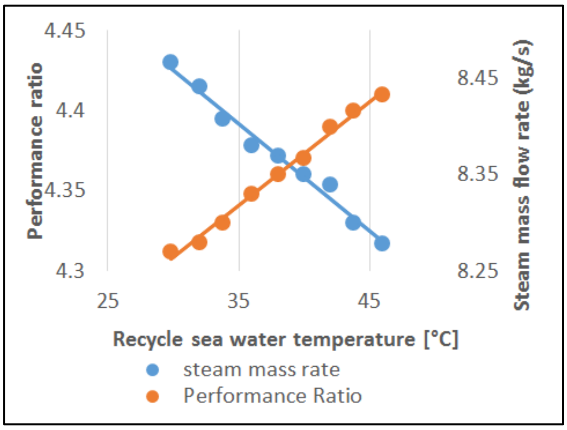

Figure 2. Graph of changing seawater recycle temperature on PR and steam mass rate.

Figure 1 shows that the higher the temperature of the saltwater, the higher the specific heat consumption and affects the value of the rate of the mass of steam to heat the brine which will enter the first stage. Processes that require a higher vapour rate will result in a lower total distillate product rate, so the performance ratio decreases. To meet the needs of the plant, Top Brine Temperature is as minimal as possible so that the performance ratio is even higher; this is by the statement that to optimize the performance of the multi-effect evaporator system by using as little steam as possible [10].

3.3. *Changes in sea water temperature recycle to performance ratio*

With the higher value of the recycle seawater temperature, the required steam rate will decrease, and this is a bit caused because if the recycle seawater temperature is high, the seawater temperature value that passes through the first stage will also increase thus the value of the mass steam rate used to heat seawater, in order to reach the top brine temperature point, will be a little, this is in accordance with the equation Ms = (Mr x Cp (T_o-Tri)/ λs, with a constant value of T_o while 3 changes due to changes in seawater recycle value then the rate steam mass M_s will decrease with increasing sea recycle temperature and λs is latent heat of vaporization [10].

4. Conclusions

The MSF-BC design produces the following conclusions. The amount of product water produced under the MSF-BC design is 131.42 tons/hour, the capacity of the MSF-BC unit can meet the water needs of the 3 × 315 MW generator. The design MSF-BC can work at the recycled seawater temperature of 30 °C - 45 °C with a performance ratio value of 4.4.

5. References

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