ENHANCING THE PART LOAD OPERATIONAL PERFORMANCE OF MSF DESALINATION PLANTS

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ABSTRACT

This paper proposes a scenario that enhances the performance of Multi Stage Flash (MSF) desalination plants at part loads. More emphases are given to large capacity plants, and those connected to electric power generation plants. The motivation for the present study arises from the fact that in many part load periods of power plants forces the desalination plants to reduce its production loads or shutdowns (due to product water full tanks). These conditions cause a thermal stresses to the MSF system and a deterioration of its overall performance. These problems could be mitigated and the performance could be maintained through the present proposed scenario.

The proposed operational scenario includes the simultaneous increase in both make-up flow rate and blow down rate. Under this operational scenario, the performance of MSF system could be maintained with improved operational parameters that have a direct effect in controlling the scale potential during part load periods. These parameters include; reduction in brine Total Dissolved Solids (TDS), Concentration Factor (C.F.) and the frequency of the acid cleaning interval.

The proposed operational scenario realizes the balance between the costs of additional rejected heat and chemicals in blow down against the positive gain results from decreasing input heat, increasing distillate and maintaining the plant normal operational performance. Economical and technical assessment and comparisons between the present and proposed operational scenarios are high lighted. Sidi krir 2*5000 m^3/day desalination plant supplies make-up treated boiler feed water to 2*325 MW power plants, is taken as the case study.

INTRODUCTION

Multi Stage Flash (MSF) is the used widely used distillation process for seawater desalination. Distillated water produced by MSF may represents about 50% of the water produced in the world. In Egypt, the only two MSF plants, Sidi krir and Auon

Mosa (2*5000 m^3/day each) are connected to 2*325 MW power plants. Each MSF unit serves only one power plant unit.

These and similar MSF desalination plants, particularly those connected to power generation plants, are usually exposed to multi- shut downs or part load operation, due to the un-availability of distillate storage tank (storage tanks are full, connecting header maintenance, …etc) or other operational scenarios for the power or desalination plants. Plants multi- shut downs or part load operation, exposes them to several thermal stresses. If such condition are considered as a prevailing operation mode for a long term, all operation parameters, especially the performance ratio (PR), would be deteriorated giving rise a degrading in efficiency of the system.

An operational scenario is proposed in order to optimize several parameters includes; performance ratio (PR), concentration factor x_c, flash range and Gain output ratio (GOR). The proposal assumes an increase in a make up feed water to the MSF system using up the useless rejected water in the rejection loop. Make up heat balances the equal increasing of heat rejection in the additional blow down flow (due to the make up increasing in order to maintain the level of brine water at last stage). Such proposed process decreases the total dissolved salts (TDS) in recovery loop and minimizes, therefore, the tendency for tubes scaling process in the system. Sidi krir Desalination Plant (MSF) 2 * 5000 m^3/day was the case study in this paper. Specification and details were demonstrated in Table (1).

Table (1) Technical Specifications of Sidi Krir
2 x 5000 m^3/day MSF Desalination Plant

Parameter	Value (Remark)
No. of Units	**2**
Unit Capacity	**5000 m^3/day**
No. of Stages	**20 (17 + 3)**
Designed PR	**8 kg (PW) / kg (steam)**
TBT	**110°C**
Seawater Temp.	**27°C**
Heating Steam Temp.	**117°C**
Cooling Water Flow Rate	**1570 m^3/hr**
Brine Recirculation Flow Rate	**1850 m^3/hr**
Seawater Concentration	**43900 ppm**
Brine Concentration	**63000 ppm**
PW Quality	**25 ppm**
Method of Scale Control	**High Temp. Additives (Belgard EV)**
Tube Sheet Material (BH + Condensers)	**90 / 10 Cooper Nickel**
Condensers Tubes	**90 / 10 Cooper Nickel**
Brine Heater Tubes	**70 / 30 Cooper Nickel**
Water Box (BH + Condensers)	**90 / 10 Cooper Nickel**

DISTILLATION PROCESS & SCALE DEPOSITS

Distillation is the process in which a portion of the saline liquid is evaporated and subsequently condensed to form the product. In the particular case of distillation of sea water, it is assumed that the dissolved salts in solution are completely nonvolatile, in the operation range of temperatures and pressures. Thus, in principle pure H_2O is evaporated alone as a vapor and by condensing this, get pure H_2O liquid (distillate) as an end product. So, the concentration of salts increases in brine water due to evaporation of part of the pure water. Concentration increase must be controlled, in order to avoid the scale formation, through controlling a factor termed as concentration factor x_c (defined as the factor by which the initial sea water salts (feed water) concentration is multiplied to give the concentration of salts in the rejection stream (brine)).

In MSF system feed sea water supplied at rate M_f and the produced distillate at rate M_d, a rate of (M_f –M_d) is rejected from that system as rejected brine. If the original concentration of all salts in the sea water is represented by C_f , the original rate of total salts fed to the system is C_f M_f , the reject brine will have a concentration equal C_f M_f / (M_f-M_d) by a quantity equal (M_f -M_d), denoted as M_b. The concentration factor x_c = M_f/M_b . So, the x_c has a inverse relation with M_b, i.e., the x_c decreases as M_b increases, consequently the liquid being processed in that system may vary in concentration at different location in the plant between C_f -----> x_c C_f .

This last conclusion is considerable to get the main concept of the proposed scenario, where the variation in M_f (+ve value) may improve the level of x_c during the process. This factor has a direct effect in the tendency of scale deposit in the system. So, the operation modification scenario proposes an increasing in make-up flow rate as it is available during all operation periods of part loads to improve the x_c value, reduce the TDS in the recovery loop, and consequently minimize the advance of scale formation.

Three simultaneous factors are required in the initial crystallization from solution (Brine Water) at the of scale formation sites. These are; (i) super-saturation of the solution locally, (ii) nucleation sites, and (iii) adequate contact time of the solution and nucleus. All three factors must be present for scale to form initially and prevention of scaling requires elimination of any one or more of three factors. The first factor as it is mentioned above should be eliminated by reducing the x_c value through increasing the make up flow rate (M_f).

Scaling, as well known, is a function of a number of initial crystal sites resulting from the nucleation step, adequate contact time and degree of super-saturation of solution. Decreasing of flowing brine TDS gets the deposition of scale fails and diminishes the probability of super-saturation occurrence. In addition the input heat which is required to heat the brine water in brine heater, will decreases too to reach the same temperatures at the same different loads (lower fouling factor value and higher overall coefficient of heat transfer). Considerable values of heating steam and distillate may be saved by this modification, and could balance the costs of the excess chemical injection rate to both of the additional make up sea water to the system and the rejected heat in blow down stream. Further positive effect is the decrease in an acid cleaning frequency.

TECHNICAL ASSESSMENT

The performance ratio PR of the plant is defined precisely as the number of pounds of distillate produced per 1000 Btu of heat input. Therefore;

$$PR = 1000M_d/\text{heat input}$$
$$PR = 1000M_d/H$$
$$H = 1000M_d/PR$$

The total heat input H to the plant is calculated as follows, Figure (1),

$$H = (M_c - M_f)\, C_p\, (t_{fj} - t_{fo}) + M_d\, C_p\, (t_d - t_{fo}) + M_b\, C_p\, (t_b - t_{fo}) \tag{1}$$

or

$$H = M_r\, C_p\, (t_{bo} - t_r) \tag{1*}$$

The total heat which is rejected through blow down stream is,

$$H_b = M_b\, C_p\, (t_b - t_{fo}) \tag{2}$$

After application the t_r decreases and logically the input heating steam must increases as in Eq. (1`). From the relation between TDS and Input heat, Figure (2), physically, the input heat which is required to maintain the optimum value of TBT should decrease.

If the additional blow down rate after application equal "x", then the total rejected heat in blow down stream will be:

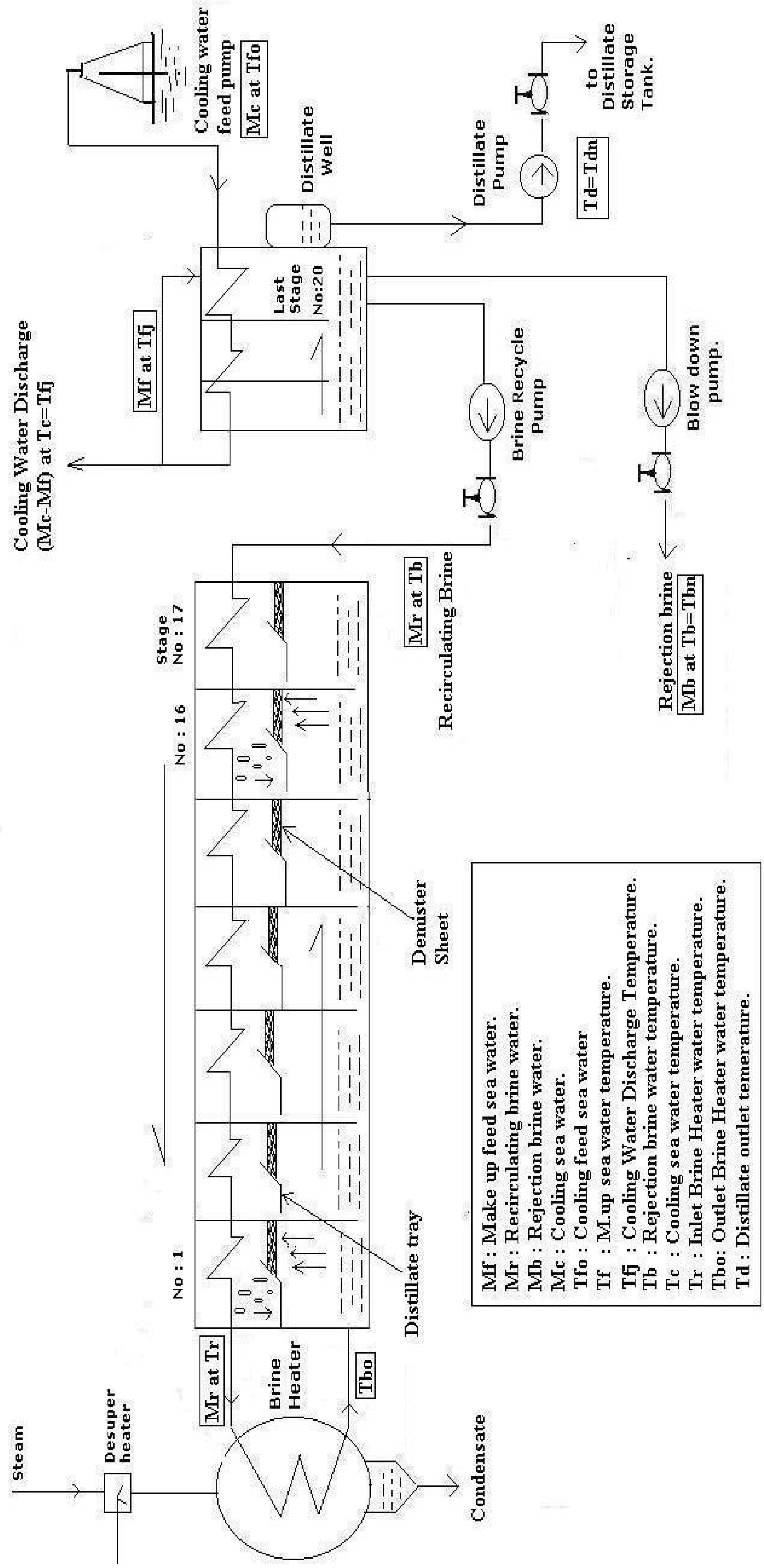
$$H_{b`} = M_{b+x}\, C_p\, (t_b - t_{fo}) \tag{3}$$

The net additional latent heat blow down stream is found to be,

$$H_n = H_b - H_{b`} \tag{4}$$

If the additional make up water flow rate after application equal "y", then the total latent heat in feed water stream will be:

$$H_{f`} = M_{f+y}\, C_p\, (t_{fj}) \tag{5}$$


Steam
Desuper heater
Condensate
Brine Heater
Mr at Tr
Tbo
No : 1
No : 16
Stage No : 17
Distillate tray
Demister Sheet
Mr at Tb
Recirculating Brine
Cooling Water Discharge (Mc-Mf) at Tc=Tfj
Mf at Tfj
Last Stage No:20
Cooling water feed pump
Mc at Tfo
Distillate Well
Distillate Pump
Td=Tdn
to Distillate Storage Tank.
Brine Recycle Pump
Blow down pump.
Rejection brine
Mb at Tb=Tbn
Mf : Make up feed sea water.
Mr : Recirculating brine water.
Mb : Rejection brine water.
Mc : Cooling sea water.
Tfo : Cooling feed sea water
Tf : M.up sea water temperature.
Tfj : Cooling Water Discharge Temperature.
Tb : Rejection brine water temperature.
Tc : Cooling sea water temperature.
Tr : Inlet Brine Heater water temperature.
Tbo: Outlet Brine Heater water temperature.
Td : Distillate outlet temerature.

Then the additional latent heat intruded to the system as a feed water is:

$$H_{n`} = H_f - H_{f`} \quad (6)$$

Then the actual amount of heat which is loosed after application equal,

$$H = H_n - \Delta H_{n`} \quad (7)$$

Practically the difference in temperatures between the rejection loop and the blow down stream, Eq. (7), is usually about two degrees centigrade. Eventually, this small amount of lost heat could be restored depending on the decreasing of the input heat to the system at the same loads. Further, the excess of distillate gained in the test could be restored in the additional chemicals costs in feed water to the system.

All variables, operation parameters readings and chemicals cost estimation in the MSF system of Sidi Krir Desalination plant (2*5000 m^3/h) were recorded in Tables (2), (3), (4) and (5). Comparison between the two operational cases, before and after proposal modification, resulting observations ate described as following:

1- Decreasing of bottom temperature could be considered as a positive effect to increase the efficiency of recovery loop as a cooling element.

2- Due to the decreasing in TDS value in recovery loop, as the increasing of make up flow rate (M_f); the input heating steam to the system decreased, as shown in Figure (2).

3- The decreasing in TDS leads to increasing in flashing rate which gave rise an increase in distillate water production, as shown in Figure (3).

4- The blow down flow rate M_b progressively increases to maintain the level at the last stage due to the additional make up water into the system. So, this additional rejected water leads to a more loses in chemicals and latent heat. Consequently such changes mathematically affects directly in performance ratio PR, of the system. However, the gained excess in production rate and the saved input heating steam those are obtained after the application could equalize this loses and maintain the performance ratio PR, which may increases too, Figure (4).

Table (2) Readings recording before proposal application

Item Load%	Steam Flow Tons/h	Inlet BH. Temp °C`	Outlet BH Temp. °C`	Conc. Factor	Brine Recirc. Temp. °C`	Make up Flow Tons/h	Blow Down Temp. °C`	Make up Temp. °C`	Distillate Outlet Flow Tons/h	Blow Down Flow Tons/h	Sea Water Temp. °C`
60%	**16.4**	**87.4**	**93.6**	**1.59**	**31.9**	**360**	**33.2**	**31.9**	**142**	**218**	**24.2**
70%	**18.0**	**92.1**	**98.3**	**1.60**	**32.5**	**400**	**34.0**	**32.7**	**155**	**245**	**24.2**
80%	**20.6**	**95.2**	**101.9**	**1.61**	**34.6**	**450**	**36.2**	**34.4**	**170**	**280**	**24.2**

Table (3) Readings recording after proposal application

Item Load%	Steam Flow Tons/h	Inlet BH. Temp °C	Outlet BH Temp. °C	Conc. Factor	Brine Recirc. Temp. °C	Make up Flow Tons/h	Blow Down Flow °C	Make up Temp. °C	Distillate Outlet Flow Tons/h	Blow Down Flow Tons/h	Sea Water Temp. °C
60%	**15.0**	**86.8**	**93.4**	**1.42**	**30.8**	**470**	**33.2**	**31.9**	**144.5**	**325.5**	**24.2**
70%	**16.6**	**91.3**	**98.3**	**1.42**	**31.5**	**520**	**34.0**	**32.7**	**158.0**	**244.5**	**24.2**
80%	**19.0**	**94.0**	**101.7**	**1.44**	**33.7**	**585**	**36.2**	**34.4**	**173.5**	**411.5**	**24.2**

Table (4) Chemical Injection System

Item Chemicals	Injection point	Dosing Rate	Chemical Consumption rate		The Excess Dosing Rate	Additional Cost
			Before Application	**After Application**		
Anti-Scale **(20000LE/ Ton)**	**Recirculating Discharge pump**	**4.0ppm**	**45.6 kg/day**	**55.2 kg/day**	**0.96 kg/day**	**192LE**
Na_2SO_3 **(2350LE /Ton)**	**Recirculating Discharge pump**	**1.0ppm**	**13.2 kg/day**	**15.6 kg/day**	**2.4 kg/day**	**5.64 LE**
Anti-Foam **(23000LE/ Ton)**	**Make up Sea water**	**0.1ppm**	**0.24 kg/day**	**1.56 kg/day**	**0.24 kg/day**	**5.65 LE**
Total Cost						**203.3LE/day 74204.5/year**

Table (5) The Positive income costs after proposal application

Item	Distillate production Tons/day	Heating Steam Tons/day	Chemical Cleaning Per year	Total Income Costs
Income **Cost(L.E)**	**72** **720**	**36** **1080**	**Once/year** **18000**	 **676440/year**

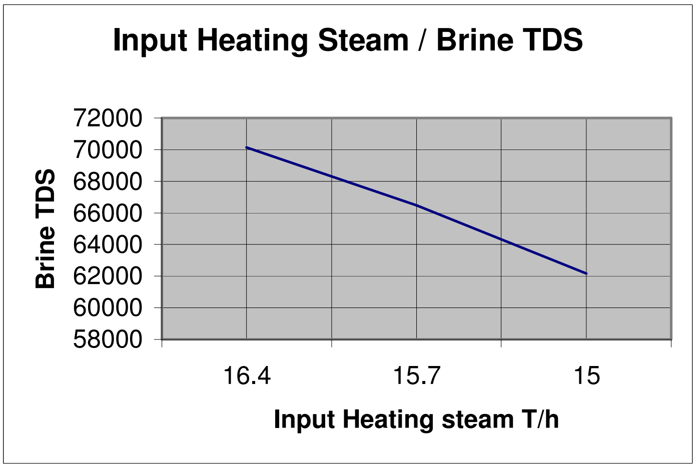


Figure (2) Input Heat/TDS

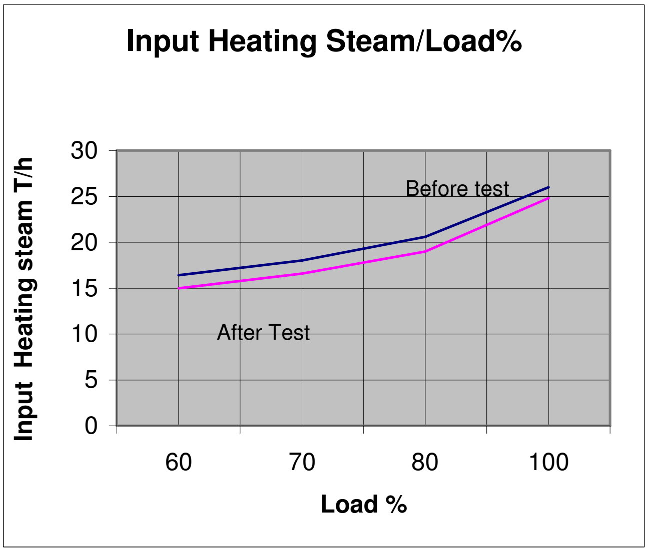


Figure (3) Input Heat/Load %

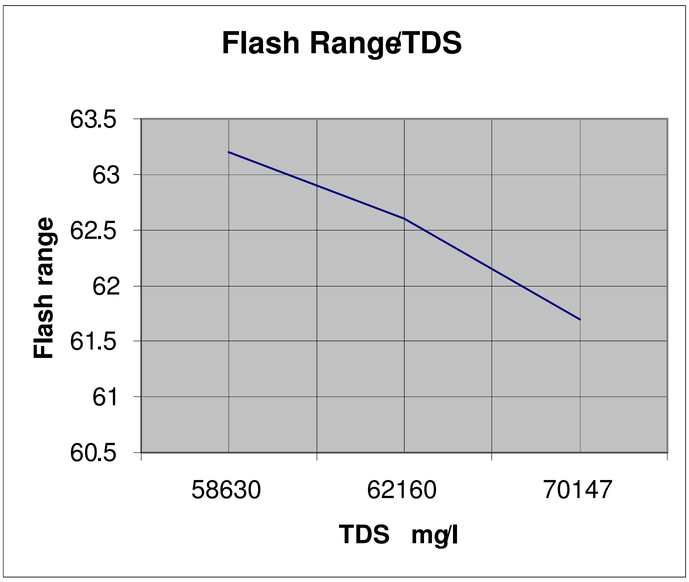


Figure (4) Flash Range/TDS Relationship

CONCLUDING REMARKS

- A proposed a scenario that enhances the performance of Multi Stage Flash (MSF) desalination plants at part loads has been presented. The proposed operational scenario includes the simultaneous increase in both make-up flow rate and blow down rate.

- Under this operational scenario, the performance of MSF system could be maintained with improved operational parameters that have a direct effect in controlling the scale potential during part load periods.

- The proposed operational scenario realizes the balance between the costs of additional rejected heat and chemicals in blow down against the positive gain results from decreasing input heat, increasing distillate and maintaining the plant normal operational performance.

- Economical and technical assessment and comparisons between the present and proposed operational scenarios are high lighted. Sidi krir 2*5000 m^3/day desalination plant supplies make-up treated boiler feed water to 2*325 MW power plants, is taken as the case study.

- The proposal will, therefore, have the following advantages:

1- Decrease the possibility of scaling deposit process.
2- Maintaining the performance ratio (PR) of the system and the target values of operation parameters.
3- Decrease the frequency of acid cleaning, and save, therefore, the costs of maintenance and chemicals of chemical cleaning processes.
4- Preventing the un-scheduled shut down of the system.

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NOTATION

The following symbols are used in this paper:

M_f : Mass flow rate of Make up feed sea water.
M_r : Mass flow rate of Recirculating brine water.
M_b : Mass flow rate of Rejection brine water.
M_c : Mass flow rate of Cooling sea water.
M_d : Mass flow rate of Outlet Distillate water.
T_{fo}: Cooling Feed sea water temperature.
T_f : Make up sea water temperature.
T_{fj} : Cooling water discharge temperature.
T_b : Rejection brine water temperature.
T_c : Cooling sea water temperature.
T_r : Inlet brine heater water temperature.
T_{bo} : Outlet brine heater water temperature.
T_d : Distillate outlet temperature.
R : Performance ration of plant, weight/energy.
Btu: British thermal unit.

Note. While the British units defined above have been used by the author, it will be observed that in general the equations given are not dependent on the system of units used. It will be recalled, however, that R was defined as the number of pounds of distillates produced per 1000 Btu of heat input, i.e.,

$$R = \frac{1000\, M_d}{Heat\ input}$$

Hence if another system is adopted, the value of the constant 1000 must be suitably where it occurs, so that the design parameter R will be invariant in the different systems of units.