Modeling and Investigation of Multistage Flash-Mixing Brine in Benghazi City, Libya

Wael A. Abujazyah

College of Mechanical Engineering Technology, Benghazi, Libya

E-mail: waelbogazea@ceb.edu.ly

Abstract:
Desalination processes are considered an essential solution to meet the water scarcity in Libya. Among the desalination techniques, the multistage flash (MSF) desalination technique has a significant contribution to water budget in many regions around the world. This study aims with modeling and simulation of novel configuration of MSF process to reduce the production cost by increasing the performance ratio using the software constructed by author. The process is based on the modification of existing multi stage flash desalination plant with brine recycles MSF-BR, north Benghazi plant was used as case study. The modification involves removal of the heat rejection section and the addition of a mixing tank for the feed stream and the unevaporated brine recycle. This eliminates the amount of energy rejected in the cooling seawater stream and reduces the amount of energy rejected in the brine blowdown stream. Analysis of the MSF-M process shows an increase in the thermal performance ratio by a factor of 2-3 over conventional MSF.
Keywords: Desalination processes, water scarcity, the multistage flash (MSF), Benghazi-Libya.

الخلاصة :
تعتبر عمليات التحلية حلاً أساسياً لمواجهة ندرة المياه في ليبيا. من بين تقنيات تحلية المياه ، فإن تقنية تحلية المياه الوميضية متعددة المراحل (MSF) لها مساهمة كبيرة في ميزانية المياه في العديد من المناطق حول العالم, تهدف هذه الدراسة إلى نمذجة ومحاكاة التكوين الجديد لعملية MSF لتقليل تكلفة الإنتاج عن طريق زيادة نسبة الأداء باستخدام البرنامج الذي أنشأه المؤلف. تعتمد العملية على تعديل محطة تحلية المياه الومضية

الحالية متعددة المراحل مع إعادة تدوير المحلول الملحي MSF–BR و تحويلها الى MSF–M، تم استخدام محطة شمال بنغازي كدراسة حالة. يتضمن التعديل إزالة قسم طرد الحرارة وإضافة خزان خلط لتيار التغذية وإعادة تدوير المحلول الملحي غير المتبخر. هذا يلغي كمية الطاقة المرفوضة في تيار مياه البحر المبرد ويقلل من كمية الطاقة المرفوضة في تيار تفريغ المحلول الملحي. يُظهر تحليل عملية MSF–M زيادة في نسبة الأداء الحراري بمعامل 2 –3 مقارنة بـ MSF–BR التقليدي.

1. Introduction

Simulating MSF plants provides the ability to optimize designs and predict a plant's performance under the intended operating conditions. It can save much time and money when operating policies have to be altered. Almost all MSF simulations are based on solving the numerous, nonlinear and complex mass and heat balance equations stage to stage calculations. Wael A.Abujazyah.[1] describes the mathematical model developed for evaluating the performance of multistage flash (MSF-BR) desalination plants at steady state operation. The governing equations are linearized and arranged in a tridiagonal matrix form. The solutions of these equations are obtained by a computer code developed for this purpose. This code can predict the plant's productivity with profiles of temperatures and flow rates for all stages in the unit. Wael A. Abujazyah et al [2] they evaluate the various operating conditions of the north Benghazi MSF -BR desalination plant under its design constraints to determine the optimal operational conditions. The researchers begin with a discussion of the most important process variables that directly affect the production and performance ratio of the plant such as seawater flow rate, brine recirculating flow rate, make-up feed flow rate, and the temperature of the steam to brine heater. Thus, they constructed a computer code specially developed to simulate the plant's steady state and study the effects of operational variables on the system output. The results showed that the brine recirculation flow rate and temperature of steam introduced to the brine heater are of the most important operation variables which have a significant effect on the distillate product and performance ratio of the system. After that, the optimal operating conditions for achieving a stable plant operation were valuated, and the operation envelope could be constructed.

Other researchers focused on MSF with brine mixing system (MSF-M), El-Dessouky et al. [3] proposed this system to reduce the energy losses. The PR was analyzed as a function of the TBT, the temperature of the unevaporated brine recycle, and the number of stages. Then El-Dessouky et al. [4] provided an overview of the MSF process that aimed to reduce the production cost. Also, a summary of the novel MSF-M system was presented. They reported that the MSF-M system showed higher thermal performance ratios compared with conventional MSF. Also, Alhazmy [5] presented a modified MSF- M plant. Part of the leaving brine was mixed with fresh seawater feed and before entering the bottom stage feed heater; it was cooled to low temperature. The results show that distillate yield was improved by 1.18%-1.4% for every 1℃ reductions in the temperature of the plant bottom and the modified MSF-MC demonstrated an expanded evaporation range and preserved the basic advantages of low chemical treatment and feed pumping compared to the conventional MSF plant.

In subsequent research, Khalideh Al Bkoor Alrawashdeh et al [6] presented a proposal for a medium scale MSF-M desalination plant to provide freshwater and serve the residents of Aqaba city. Mathematical model was applied to evaluate the technical characteristics of the plant. The performance ratio, heating load, temperature profile, streams flow rate, stage dimensions and distillated capacity were evaluated and obtained.

2. Objective

This study describes the mathematical model developed for evaluating the performance of novel configuration of multistage flash (MSF) desalination plants at steady state operation this configuration called multistage flash with brine mixing (MSF-M), which is based on the modification of existing MSF units to improve their thermal performance. Firstly, the modeled desalination plant was divided into module of brine heater, modules of flash stage modules, and module of mixer, with equations created and put together to represent the entire process model based on energy and mass conservation principles. Then, it is based on the fundamental rules of mass balance, energy balance, and heat transfer equations, as well as physical property correlations. The performance ratio, heating load, temperature profile, streams flow rate and distillated capacity were evaluated and obtained. North Benghazi desalination plant used as case study.

3. Description of the MSF-BR process.

Figure1 shows a schematic diagram of the MSF system. The system involves six main streams: intake seawater rejected cooling seawater, distillate product, rejected brine, brine recycle and heating steam. The system contains flashing stages, a brine heater, pumping units, venting system, and cooling water control loop. The flashing stages are divided into two sections: heat recovery and heat rejection. The intake seawater is introduced into the inside of the condenser tubes of the last flashing stage in the heat rejection section. Similarly, the brine recycle stream is introduced into the inside of the condenser tubes of the last flashing stage in the heat recovery section. The flashing brine flows counters to the brine recycle from the first to the last flashing stage [1].

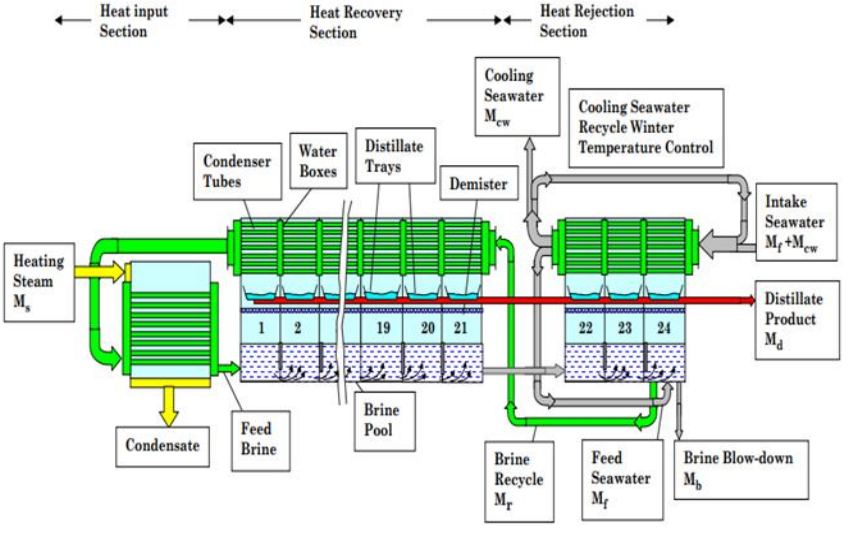

Fig. 1. Multi-stage flash with brine recycles (MSF-BR) desalination process

4. MSF with brine mixing (MSF-M)

The MSF-M system is a novel process proposed by ElDessouky et al. [4]. The main objective of this process is to reduce the energy losses in the cooling seawater stream, found in conventional MSF, or in the large brine blowdown stream, found in MSF-OT. The recovered energy will result in an improvement of the system overall performance. The process layout, shown in Fig. 2, includes a brine heater; a heat recovery section and a brine recycle mixing tank.

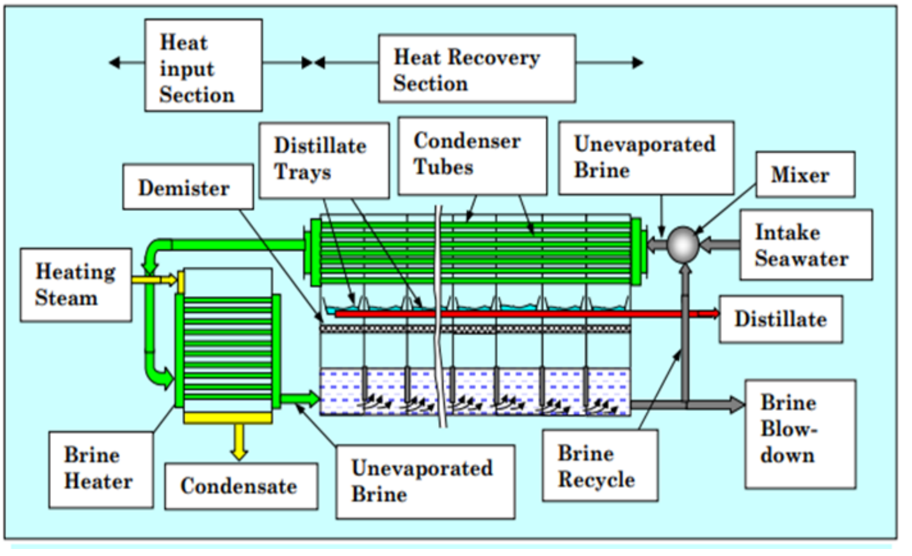

Fig. 2. Schematic of Multi-stage flash with brine mixing MSF-M desalination plant

5. Modification of existing MSF plants to MSF-M

Conversion of the MSF system with brine recirculation to the MSF-M configuration is simple and primarily involves elimination of the brine circulation and cooling seawater streams. The conversion includes the following:

1. removal of the cooling seawater loop as well as the temperature control loop on the feed seawater temperature;
2. modification of the brine circulation loop to recycle the brine to the storage tank instead of to the last stage;

3. addition of the accumulation tank for the recycled brine stream;
4. connection of the preheater tubes of the first stage in the heat rejection section and the last stage in the heat recovery section;
5. Replacement of the intake seawater pump with a smaller capacity pump; this is necessary because the cooling seawater stream in the MSF-M system is eliminated.

5. Mathematical model of MSF-M

The steady state mathematical model of the multi stage flash desalination process generally is developed under following simplifying assumptions:

- The product leaving any stage is salt free;
- The heat of mixing for brine solutions are negligible;
- No heat lost in system;
- No subcooling of condensate leaving the brine heater.

The model equations are constituted of a set of mass and energy balances with their final form are given in the following. A detailed description of these equations is presented in reference [1].

5.1 Brine heater model.

Referring to Fig 3.a the performance of the brine heater can be described in terms of the following equations**.**

Energy balance

$$M_r \; C_{P\,RH} \;(T_{B0} - T_{F1}) = W_S \;\; \lambda_S \qquad (1)$$

Mass balance

$$B_0 \;\; = M_r \qquad (2)$$

$$X_{B0} \;\; = X_R \qquad (3)$$

Heat transfer equation

$$W \; C_{P\,RH}\,(T_{B0} - T_{F1}) = \frac{U_H \;\; A_H \;(T_{B0} - T_{F1})}{Ln\left[\frac{(T_S - T_{F1})}{(T_S - T_{B0})}\right]} \qquad (4)$$

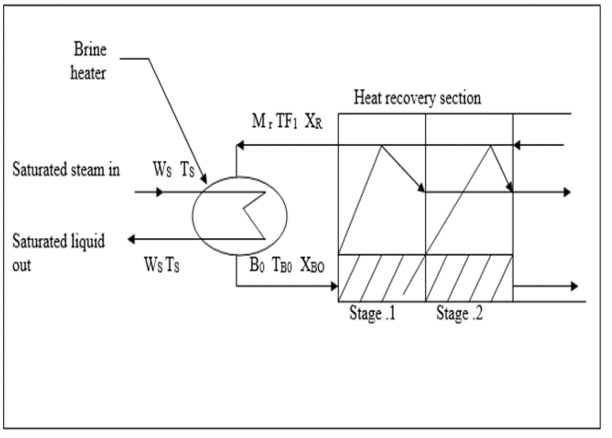

Fig. 3.a. Heat input section

5.2 Mixing tank model.

Mass balance (see figure to 3.b)

$$M_C + M_f = M_r \quad (5)$$

$$M_C \; X_n + M_f \; X_f = M_r \; X_r \quad (6)$$

Energy balance

$$M_C \, C_{Pn} \, (T_n - T^*) + M_f \, C_{PF} \, (T_f - T^*) = M_r \, C_{Pr} (T_f - T^*)$$
(7)

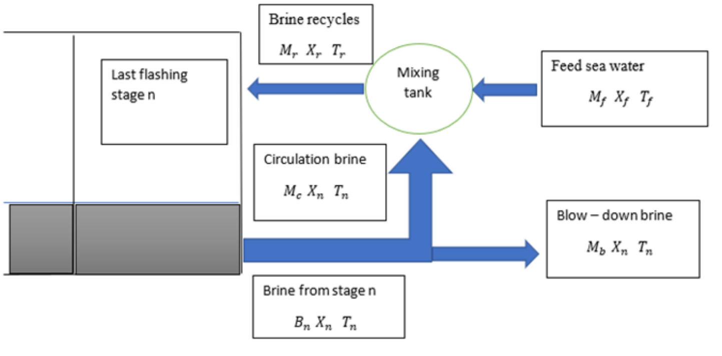

Fig 3.b mixing tank

6. System performance

The performance of the plant can be defined as the ratio of the distillate product rate to the rate of steam supplied to the plant. Another way to define the performance is to estimate how much kg of water can be produced by the input of 540 k Cal to brine heater or to the first effect.

$PR = (D_N / Ws);$ This ratio is dimensionless (8)

The specific heat consumption (q) is defined as being the ratio between the heat flux injected to the brine through brine heater and the distillate output.

$q = Ws * \lambda s / D_{N};$ (9)

7. Problem algorithm;

The mathematical model for a steady state simulation, as described above, is used to build computer code for performance analysis of MSF desalination systems**.**

In this code, all the temperature profiles T_{Fj}, T_{Bj}, and T_{Dj}, j =1, N are initialized so the various properties, heat transfer coefficients and temperature losses can be calculated and, as a result, all the model equations become linear. A TDM is developed consisting of linear equations correlating each combination of three successive temperatures T_{Fj}, T_{Fj-1}, and T_{Fj+1}. By solving these equations simultaneously, an updated profile of T_{Fj} is obtained which is used through the heat transfer equation to update the T_{Dj} profile. The convergence criterion used is:

$$\sum_{J=1}^{N}[T^{i+1} B_J - T^{i} B_J]^2 \leq 0.00001 \times N$$

Where i is the iteration index.

The excision steps are as following:

1. Initialize all the variables, temperatures, flow rates and salinity
2. Solve enthalpy balance equations for flashing brine flow rate (Bj) 3. Solve overall mass balance equation for distillate

flow rate (Dj). 4. Balance the mass on mixing tank (relation between M_C, Mr, , Mf and B_n).
3. Balance the overall salt for recycle concentration (Xr).
4. Balance the salt on brine heater.
5. Calculation of the stage's temperature losses (BPEj, δj, Δj).
6. Solve the stage heat balance equations simultaneously (matrix equations) for the tube side temperatures and top brine temperature, T_{Fj}, T_{B0}.
7. Solve the heat transfer equations simultaneously for updating distillated temperature profiles (TDj).
8. Solve equilibrium equations iteratively for a new temperature profile of flashing brine (T_{Bj}).
9. Test for convergence.
10. Use the converged values to obtain the other variables (Ws, q, PR).

8. Case study

In this case study the performance characteristics have predicted by the developed computer code. The design data used for this purpose belong to the North Benghazi (Libya) MSF desalination plant [7]. The rules of modification presented in section 5 was used, the novel configuration can obtain.

9 .Results.

To demonstrate the capability of the developed code for predicting the performance parameters, the seawater intake flow rate (M_F), the recycle stream flow rate (M_R) and the steam temperature (Ts) are input to the code. On the basis of these information the code is run to calculate the plant productivity together with the profiles of temperatures and flow rates of in all the stages of the unit. The main parameter used to quantify the process performance is the ratio between the distillate product and the steam flow rate. The results of this calculation are reported in Table 1.

Table 1. Performance characteristic of modified MSF-M plant

Number of stages	T_{Bj} C°	T_{Dj} C°	T_{Fj} C°	D_j t/h	B_j t/h	XB_j %
0	91.04	0.00	0.00	0.00	2600	0.0473
1	88.29	87.50	87.59	14.22	2587.78	0.0475
2	85.22	84.73	82.62	27.34	2572.66	0.0477
3	82.97	81.94	80.07	40.51	2559.49	0.0479
4	79.84	79.07	76.94	53.12	2547.12	0.0481
5	76.96	76.18	74.06	67.04	2532.96	0.0483
6	74.16	73.38	71.26	80.22	2519.78	0.0485
7	71.26	70.50	68.36	93.15	2506.85	0.0487
8	68.36	67.59	65.36	106.02	2493.98	0.0489
9	65.45	64.67	62.41	119.31	2480.69	0.0491
10	62.55	61.77	59.45	132.27	2467.73	0.0493
11	59.65	58.87	56.61	144.76	2455.24	0.0495
12	56.82	56.05	53.81	159.10	2440.90	0.0497
13	53.99	53.22	50.94	170.12	2429.88	0.0499
14	51.22	50.44	48.17	182.44	2417.56	0.0501
15	48.52	47.76	45.80	195.59	2404.41	0.0503
16	46.84	46.06	43.88	207.97	2392.03	0.0505
17	44.13	43.34	41.17	219.35	2380.65	0.0507
18	41.43	40.34	38.44	230.16	2369.84	0.0509
19	38.75	37.96	35.79	243.32	2356.68	0.0511
20	36.05	35.42	33.11	255.87	2344.13	0.0513

10. Comparison of conventional MSF and MSF-M

Comparison of the two MSF configurations is performed for the design data for the north Benghazi MSF desalination plant, **[7]** as shown in Table 2. the presence of a control mechanism on the temperature of the intake seawater i.e., the heat rejection section in the conventional MSF system and the mixing tank in the novel MSF-M system, reduces its effect on system performance during operation in various seasons. The MSF-M system gives higher thermal performance ratio. This increase is caused, in part, by a reduction in the amount of energy rejected in the cooling seawater stream.

Table 2 Comparison between two configurations.

Parameter	MSF-BR	MSF-BM
Capacity (t / h)	254	254
Seawater temperature (° C)	27	27
Temperature of recirculated brine (° C)	40.3	36.1
Last stage brine temperature ((° C)	36.22	36.22
Product water temperature (° C)	35.42	35.27
Brine heater inlet temperature (° C)	84.52	88.96
Top brine temperature (° C)	91.04	91.04
Steam temperature (° C)	103	103
Cooling water flow rate (t / h)	1355	0
Brine recirculation rate (t / h)	2915	2600
Blowdown flow rate (t / h)	621	976.13
Make-up water flow rate (t /h)	875	1230.13
Heating steam flow rate (t / h)	35.67	15.36
Brine circulation ratio	11.48	10.24
Flashing range (° C)	54.82	54.82
Total temperature range (° C)	64	64
Performance ratio	7.12	16.54
Salt concentration in circulated brine (ppm)	54000	47300
Salt concentration of feed water (ppm	42000	42000
Salt concentration of rejected brine (ppm)	59600	51100

This reduces the amount of heating steam needed by the system, which, in turn, increases the system thermal performance ratio.

11. Conclusion.

The novel brine-mixing MSF process, MSF-M, presented in this study contains the main elements of the conventional MSF system. This allows for simple modification of operational MSF units to the newly proposed MSF-M system. The characteristics of the MSF-M system can be summarized as follows**.**

1. The thermal performance ratio of the MSF-M system is twofold higher than that of conventional MSF.
2. The salinity of the unevaporated brine recycles and brine blowdown has a lower value than that of conventional MSF.
3. Operation of the MSF-M system with no brine recycle reduces the system to the MSF-OT configuration, which has a much lower thermal performance ratio.

The important factor addressed in this study is the need to increase the thermal performance ratio beyond the value of eight. This is a must in order to face the challenges of other competitive thermal desalination processes. The proposed system, MSF-M, shows that innovative design can lead to the desired system performance.

References:

[1]. Abujazyah, W, 2017, Modelling and simulation of multistage flash desalination plants. Libyan Journal for Engineering Research (LyJER). Vol.1, ISSN 2522-6967.

[2]. Abujazyah, W, 2022, Evaluation Study of the Optimal Operational Conditions for Multistage Desalination Plants. International Science and Technology Journal (ISTJ). Vol.30.

[3]. El-Dessouky H.T., Ettouney H,1999, Multiple-effect evaporation desalination systems. Thermal Analysis, Desalination, 125(1-3): 259-276.

[4]. El-Dessouky, H.T., Ettouney, H.M., Al-Roumi, Y,1999, multi-stage flas desalination present and future outlook. Chemical Engineering Journal, 73(2): 173- 190.

[5]. Alhazmy, M.M. (2011). Multi stage flash desalination plant with brine–feed mixing and cooling. Energy, 36(8): 5225-5232.

[6]. Khalideh Al Bkoor Alrawashdeh and Kamel K. Al-Zboon , 2021 , Modeling and Investigation of Multistage Flash-Mixing Brine in Aqaba City, Jordan. Mathematical Modelling of Engineering Problems Vol. 8, No.6, pp. 905-914.

[7]. ELECTROBEL Consulting Engineers, 1972, Operating manual of MSF desalination plant at north-Benghazi station.

APPENDIX: Nomenclature

Symbols	Defined
A_H	Heat transfer area of brine heater.
B_D	Blowdown mass flow rate
B_J	Flashing brine mass flow rate leaving stage j
B_0	Flashing brine mass flow rate Leaving the brine heater
C_p	Specific heat at constant pressure
D_j	Distillate flow rate leaving stage j
D_N	Plant productivity.
Mc	Cycled brine flow rate
M_F	Feed seawater flow rate
Mr	Recycle brine flow rate
N	total number of stages
T^*	Reference temperature
T_{B0}	Temperature of flashing brine leaving the brine heater
T_{Dj}	Temperature of distillate leaving stage j
T_{Fj}	Temperature of cooling brine leaving stage j
T_{Bj}	Temperature of flashing brine leaving stage j
T_f	Intake seawater temperature
T_r	Recycled brine temperature
T_S	Steam temperature
U_H	Overall heat transfer coefficient at brine heater.
W_S	Steam mass flow rate
X_{B0}	Salt concentration in flashing brine leaving brine heater
X_F	Feed seawater salt concentration
Xr	Salt concentration in recycle brine
λ_s	Latent heat of steam to brine heater