تطوير برنامج كمبيوتر لتصميم محطات التحلية
بالتبخير الوميضي متعددة المراحل

أ- علي محمد راشد [1*] ، أ- عيسى فرج .المشرقي [1*] ، أ - خالد احمد الفرد [2*]
1 المعهد العالي لتقنيات شؤون المياه ، العجيلات ليبيا - 2 كلية الهندسة جامعة الزاوية

الملخص:

تعتبر تقنية التحلية بالتقطير الوميضي متعدد المراحل من التقنيات المهمة التي استخدمت في العقود الاخيرة في الشرق الاوسط وشمال افريقيا من أجل انتاج المياه المحلاة للأغراض الصناعية و مياه الشرب .

في هذه التقنية تختلف مساحة انتقال الحرارة من مرحلة إلى أخرى بسبب الاختلاف في نقطة الغليان وبعض الخواص الفيزيائية للمحلول الملحي ، وبالتالي فإن حسابات دقيقة يجب إجراؤها لتحقيق معايير التصميم الامثل .

في هذه الورقة ، سيتم تطوير برنامج كمبيوتر لتقدير جميع متغيرات التصميم باستخدام معادلات اتزان الحرارة والكتلة لكل مرحلة على حدة ، وسيؤدي ذلك إلى بيانات دقيقة عن مساحة انتقال الحرارة ، وتدفق المياه المالحة ، والبخار المنتج ، وعدد الأنابيب اللازمة لتكثيف البخار ، وهذا بدوره سوف يقلل من التكلفة الإجمالية لمحطة تحلية المياه.

أخيرًا ، سيتم مقارنة البيانات المستخرجة من برنامج الحاسوب المطور مع بيانات التصميم الحقيقية لوحدة تحلية مياه البحر تاجوراء بمعدل 1200 متر مكعب في اليوم.

الكلمات المفتاحية: تحلية المياه ، فلاش متعدد المراحل ، تكلفة رأس المال ، الكمبيوتر ، نقطة الغليان

Developing computer program for a Design a single and multi stage flash desalination plant

Ali M. Rashed [1*], Eisay .F.Almshraqi [1*] , Khalid Al Fared [2*]
[1] Higher institute of technical water affairs, Ajelat , Libya
[2]Engineering faculty University of Zawiya , Zawiya , Libya

Abstract

Multi stage flash desalination process one of the most techniques which is widely used for large scale drinking and industrial water production, for the last decades most of MSF desalination units were installed in the middle east and north Africa.

The heat transfer area is different from stage to stage due to the boiling point elevation in the brine solution, therefore the precise calculation is required to achieve optimum design parameters.

In this paper, a computer program will be developed to estimate all the variable using heat and mass balance equations for each stage separately, and this will result accurate data of heat transfer area, brine flow, produced steam, and accurate number of pipes, which will reduce the total capital cost of MSF desalination plant. Finally the output data will be assessed against real design data of a 1200 m3/day msf desalination unit.

Key words: desalination, Multistage flash, capital cost ,computer , boiling point

1. Introduction

A major problem that faces Middle Eastern and North African States is access to sufficient water for domestic, industrial and agricultural use. Libya is one of these countries where river systems do not exist and the main water source in the country is the underground fossil water, which contributes more than 98% of the total water consumption. Libya is classified as an arid or semi-arid area, receiving less than 150 mm of rainfall per year and high evaporation rates ranging between 1700 mm/year in the north to about 6000 mm/year in the south [1]. The rapid population growth rates and the ever increasing rate of urban drift that has led to serious pressure on urban water supply worsen the problem. Industrialization, particularly when it involved heavy industry, has made further demands on available water resources. As a result of the excessive water use, the water table has fallen markedly in many areas and has led to the intrusion of seawater into the aquifer. Recent studies on the water resources and water requirements for Libya have shown that there is an increase of more than 50% in the water demand between 2005 and 2025 [3]. this leads to the necessity of developing the water resources and increase the supply of water to sustain life in the country. For Libya, only two possibilities exist. One is the use of subterranean fossil water that may or may not be recharged by rainfall. This needs the use of modern methods of water extraction, which can easily endanger what is, in effect, a fragile resource. Either the water table sinks or water raised proves to be saline and brackish. The second alternative is to use a desalination system, whereby seawater is purified to make it potable or useable for agricultural purposes. The installation cost of MSF plants has dramatically decreased in the past years despite a normal inflation increase. The reason for such a trend can not be justified only by the competition but must be the result of a better plant design, larger unit size and also on a more realistic approach to the requirements by the owners. Desalination technologies have been well established since the mid-20th century and widely deployed in the Middle East and North Africa. The contracted capacity of desalination plants has increased steadily since 1965 and is now about 38 million cubic metres per day worldwide [4].

1.1 The MSF process description

The MSF process configuration is constituted by four main parts (see Fig. 1). These are the brine heater, the flashing chambers, feed pre-treatment, and venting line/system. The brine heater has a shell and tube configuration, where the feed seawater flows through the tube side and the heating steam on the shell side. In large plants, the heating steam is introduced through several ports along the length of the heater. This is to ensure uniform temperature distribution within the brine heater. Flashing stages (see Fig. 1) include a brine orifice, brine pool, demister, distillate tray, condenser tubes, and venting tubes. In the flashing stages brine undergoes a flashing process in which vapor is produced at the expenses of the brine sensible heat which is reduced along the stages (how can be seen by the temperature trend). In the upper part of the stage feed seawater flows inside the condenser tubes, where (on the external surface of condenser tubes) the vapor produced in the stages by brine flashing is condensed. As a result, the feed seawater temperature increases due to absorption of the latent heat of the flashed off vapor. On the other side, condensed vapor accumulates and flows in the distillate tray across the stages. The brine leaving the last flashing stage is rejected to the sea. Selected stages are vented to the ejector unit in order to continuously remove and prevent accumulation of the non-condensable gases found in the brine recycle (oxygen, nitrogen, and carbon dioxide). The feed seawater water passes through a coarse screen that removes suspended particles and small organisms. The stream is then treated with a mixture of antiscalent, anticorrosion, antifoaming, and chlorination compounds. Additional details on the MSF process as wells as its features and operating parameters can be found in most of the references cited in this study.

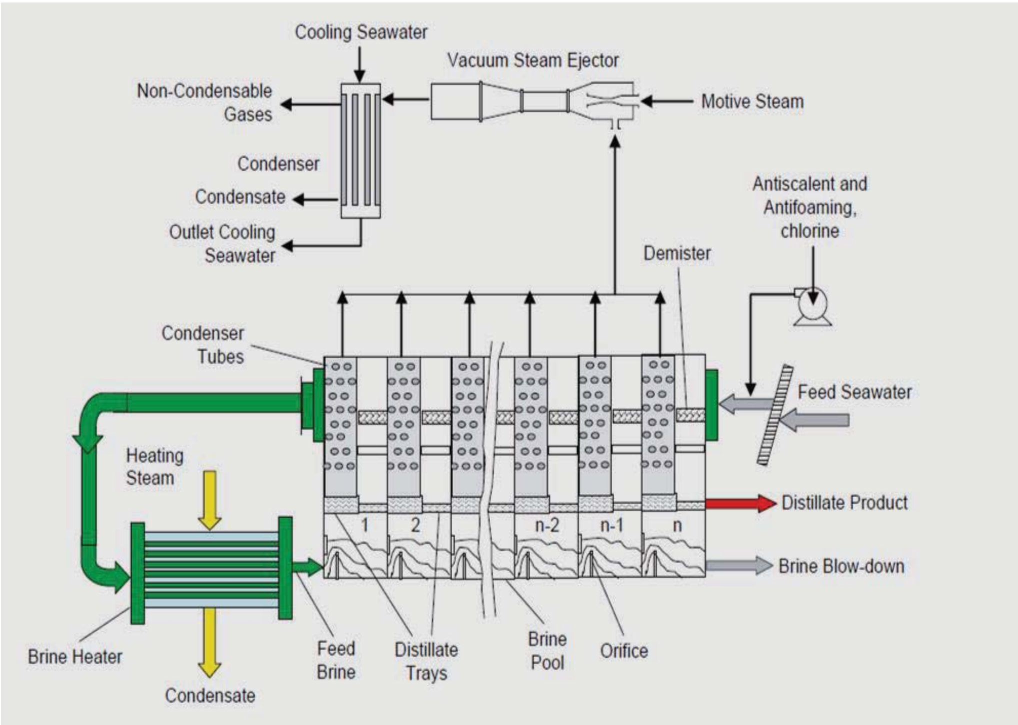


Fig. 1. Schematic of the once through MSF process

2. Material and methodology

2.1 Overview of the developed program

Thermodynamic calculations were performed in order to obtain design data for the various parameters of MSF desalination plant . All calculations were performed stage by stage with a very detailed steady-state computer program, which was developed by the author, the calculated parameters of each stage are illustrated in table 1a and 1b

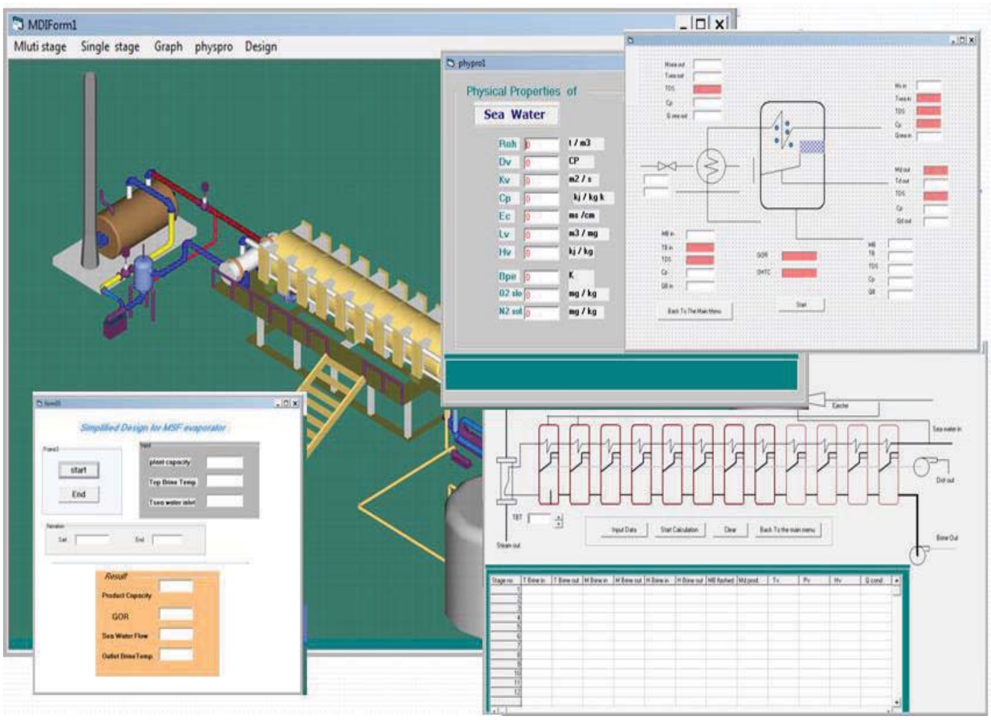


Figure (2). Developed program user interface

2.2 Design procedure

1. Fixed the Production Capacity
2. Choose the GOR (6- 8) State of the Art
3. Mass Balance calculation
4. Energy Balance calculation
5. Heat Transfer Area calculation
6. Sizing of MSF stages
7. Sizing the condenser and brine heater
8. Cost estimation

2.3 Calculation procedure

Calculate output brine temperature

$T_{brine\ out} = \mathrm{BTT} - (\mathrm{BTT} - \mathrm{T}_{\mathrm{sea\ in}}) * \mathrm{GOR} / \mathrm{GOR} + 1$
(1)

Over All Mass Balance

$Bav = D\ \Delta hV / Cp * To$
(2)

Where

$\mathbf{Bav} = (\mathbf{Mfeed} + \mathbf{B\ out}) / \mathbf{2}$
(3)

Δhv at Average Evaporation Temperature (Tv)

Initial Evaporation temperature calculated as

$T\mathrm{v} = (\mathrm{BTT} + \mathrm{Tbrine\ out}) / 2$
(4)

Salt balance is calculated as

$X\ F * M\ feed = MD * XD + M\ BR\ out\ \ XB$
(5)

Terminal temperature difference is calculated as

$\Delta\mathrm{T\ ttd} = \mathrm{BTT} - \mathrm{T\ sea\ out} - \Delta\mathrm{T\ stage} - \Delta\mathrm{T\ loss}$
(6)

Delta T stage can be calculated as

$\Delta\mathrm{T\ stage} = \Delta\mathrm{To} / \mathrm{n}$
(7)

Q of brine heater can be calculated as

$\mathrm{Q\ BH} = \mathrm{M\ feed} * \mathrm{Cp} * (\mathrm{BTT} - \mathrm{T\ sea\ out})$
(8)

Q of condensation can be calculated as

$$Q\ cond = M\ feed * Cp * (T\ sea\ out - T\ sea\ in)$$
(9)

$$A\ cond = Q\ cond / (K * \Delta T\ l\ n)$$
(10)

Due to, the temperature difference along the length of the condenser tubes is not uniform. In reality the temperature change is logarithmic, therefore, LMTD is introduced
and is evaluated by the following equation:

$$\Delta T_{ln} = \Delta T_{in} - \Delta T_{out} / ln\,(T_{in} / T_{out})$$
(11)

Once $\dot{Q}$, A, and T_{ln} have been calculated, the overall heat transfer coefficient, U,

is determined from the following equation:

$$Q = UAF\Delta Tln$$
(12)

2.4 Stage to stage calculation

Mass Balance in the flash chamber:

$$B_{i-1} = B_i + V_i$$
(13)

Mass Balance for the distillate tray:

$$D_i = D_{i-1} + V_i$$
(14)

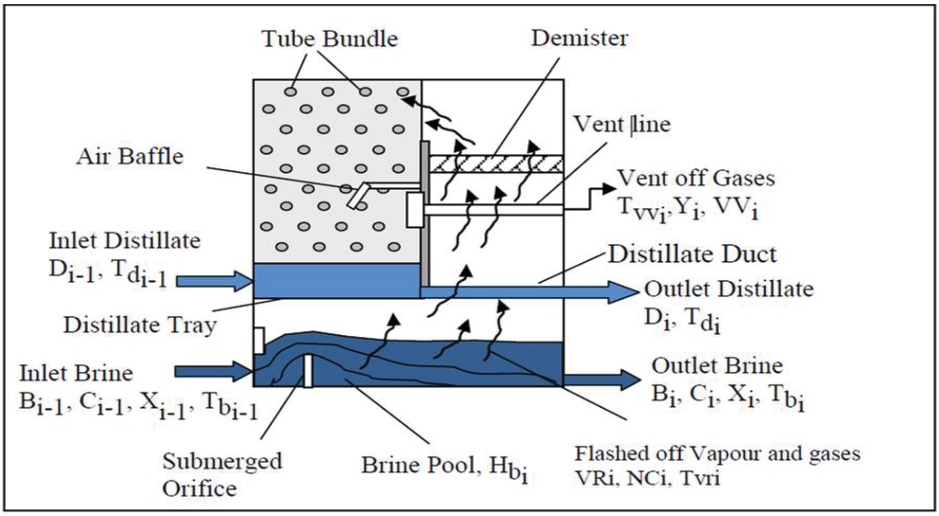


Figure (2). variables in MSF process (between stages (i) and (i+1))

All other variables are calculated with the same procedure for each stage and physical and thermodynamic properties are calculated with the correlation which obtained from Tajuora desalination plant

2.5 Developed program validation

Technical design data of tajura MSF desalination plant which was used to validate the results of developed program

Technical design data of 1200 ton / day Tajuora MSF desalination plant

GOR = 6.944 BTT = 108 C No of stages = 12

K = 3065 W/ m ΔT_{BPE} = 0.5 C ΔT_{NE} = 0.1 C

ΔT_{DEM} = 0 .1 C T sea in = 28 C Cp = 3.98 TDS = 38,000 ppm

Do =16 mm Di = 14 mm L= 2800 mm

3. Result and discussion

Different plant variables. As shown in figures (3,4,5,6) , the steam flow rate is 439 ton/hr while the total distillate capacity of the MSF system is 50 ton/hr, this distillate quantity depends on the plant produced steam, its flow rate, temperature and pressure (latent heat of vaporization). In addition, calculated heat transfer area for the last sections of the MSF plant shows that the heat rejection section has less heat transfer area compared to the other two sections.

Table 1 a and table 1 b shows the calculated design parameters of each stage , the result shows that the maximum value of sea water flow , produced distillate were in the first stage and the minimum value were in the last stage , this because of the decreeing in evaporation temperature and increasing in boiling point elevation . While the log mean temperature has the minimum value in the first sage and maximum value in the last stage

this is due to decreasing in condensation temperature and latent heat of evaporization.

Comparison of developed program data and plant design data include the flow rate, salinity, and temperature profiles of the brine stream across the stages. Results are shown in Figs. (7 – 10). As shown, good agreement is obtained between calculated data and the plant data, especially for the brine flow rate, where the errors did not exceed 0.73%. On the other hand, the relative error in calculated brine flow rate and salinity is limited to a maximum of 2.2% for produced distillate flow and 0.87% for the brine salinity.

This is because of un accuracy of stage brine temperature in the first stage and this erro was decreasing stepwise after the precise calculation of stage brine temperature of other stages was performed The calculated results gets closer to the design data at the two ends of the plant, this is two are closer to boundary conditions mainly seawater temperature and top brine temperature.

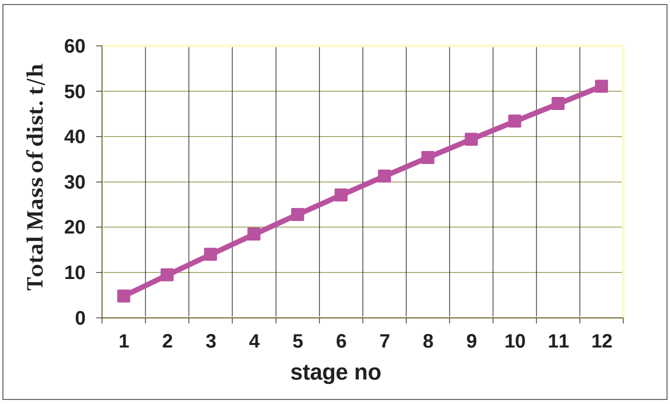
4. Tables and figures

Table (1)a calculated **Design parameters of 12 stages msf desalination plant .**

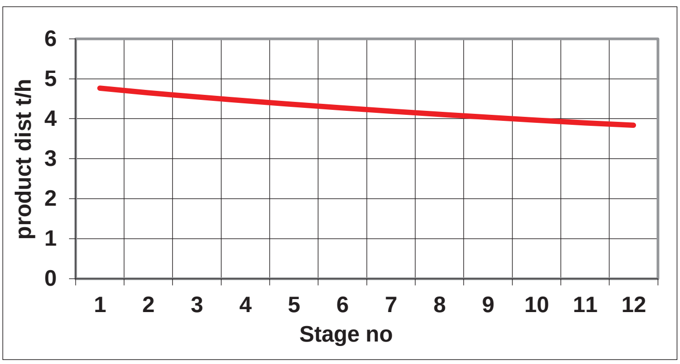
Stage no	Msea Tons/hr	Md Tons /hr	Mdtotal Tons /hr	Tv C	Hv Kj	Mbout Tons/hr	Tbin C	Tbout C
1	438.9	4.77	4.77	101.17	2676.26	434.13	108	102.08
2	434.13	4.65	9.42	95.28	2667.1	429.48	102.08	96.17
3	429.48	4.55	13.97	89.38	2657.77	424.93	96.16	90.25
4	424.93	4.45	18.42	83.48	2648.26	420.48	90.24	84.33
5	420.48	4.36	22.78	77.58	2638.58	416.12	84.32	78.41
6	416.12	4.27	27.05	71.68	2628.74	411.85	78.4	72.49
7	411.85	4.19	31.24	65.78	2618.75	407.66	72.48	66.57
8	407.66	4.11	35.35	59.88	2608.62	403.55	66.56	60.65
9	403.55	4.04	39.39	53.98	2598.35	399.5	60.64	54.73
10	399.5	3.97	43.36	48.07	2587.95	395.53	54.72	48.81
11	395.53	3.9	47.26	42.17	2577.45	391.63	48.8	42.89
12	391.63	3.84	51.1	36.27	2566.86	387.79	42.88	36.97

Table (1)b calculated **Design parameters of 12 stages msf desalination plant .**

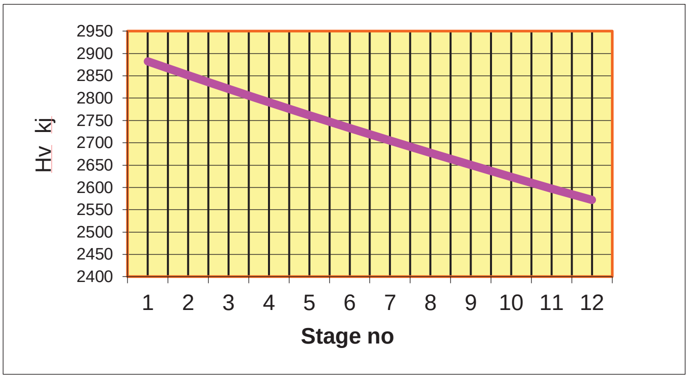
Stage no	Hbin Kj	Hbout Kj	Q Kw	Tcondout C	Tcondin C	Dtlog C	AREA m^2
1	436.15	411.56	2882.48	99	93.08	4.5	213.42
2	411.56	387.12	2851.18	93.08	87.17	4.53	209.9
3	387.11	362.8	2820.62	87.16	81.25	4.55	206.52
4	362.79	338.6	2790.75	81.24	75.33	4.58	203.25
5	338.58	314.49	2761.52	75.32	69.41	4.6	200.1
6	314.48	290.47	2732.89	69.4	63.49	4.62	197.06
7	290.45	266.52	2704.83	63.48	57.57	4.64	194.12
8	266.5	242.63	2677.3	57.56	51.65	4.67	191.28
9	242.61	218.79	2650.28	51.64	45.73	4.69	188.53
10	218.77	194.99	2623.75	45.72	39.81	4.71	185.87
11	194.98	171.23	2597.67	39.8	33.89	4.72	183.3
12	171.22	147.51	2572.04	33.88	27.97	4.74	180.8



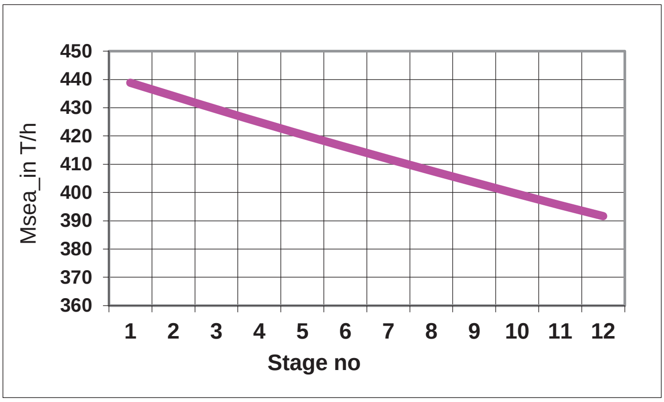
Figure(3) accumulated produced distillate



figure(4) produced distillate vs stage no



figure(5) enthalpy of evaporation vs stage no



figure(6) inlet sea water vs stage no

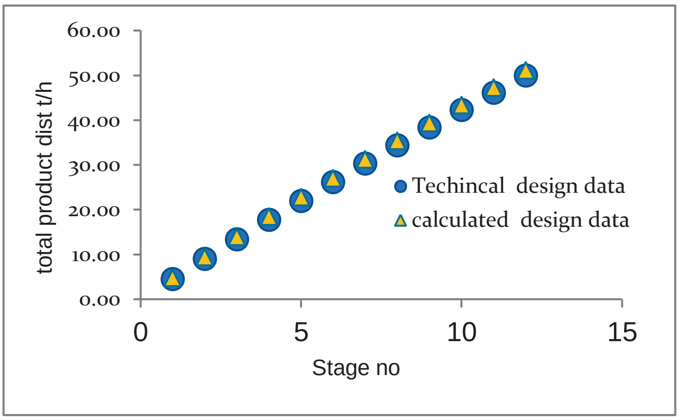


figure (7) A comparison between calculated

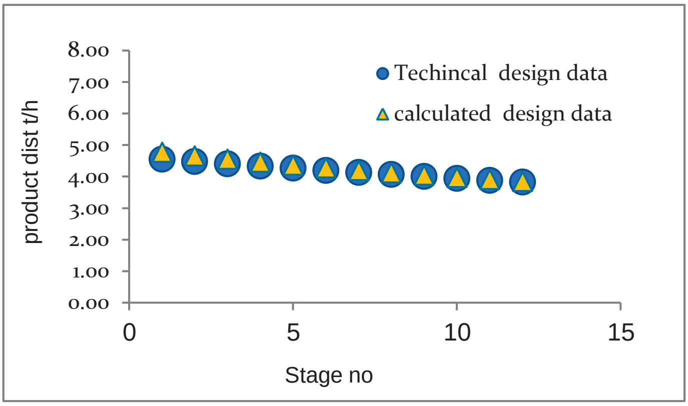


figure (8) A comparison between calculated results and technical design data of tajuora results and technical design data of tajuora plant of (total produced distillate) plant of (stage produced distillate)

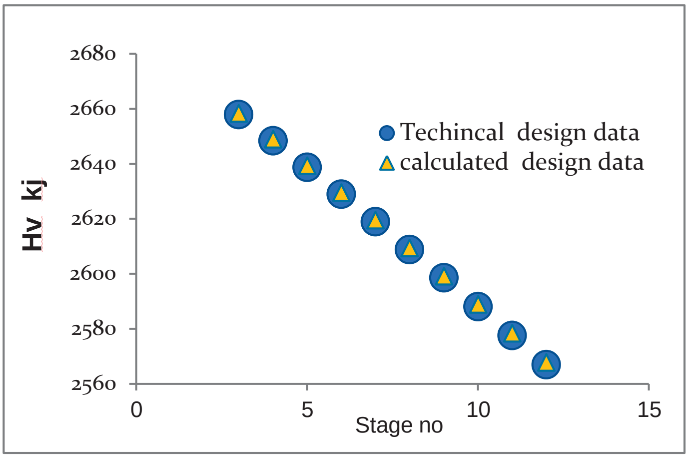


figure (9) A comparison between calculated

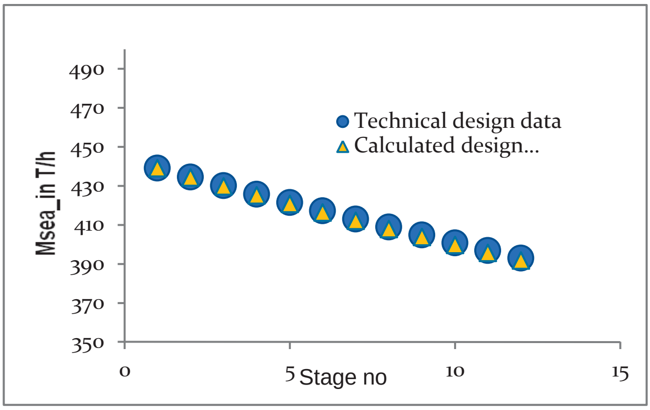


figure (10) A comparison between calculated results and technical design data of tajuora results and technical design data of tajuora plant of (stage enthalpy) plant of (sea water inlet)

5. Conclusion

1. Developed program is fully capable of calculation the design parameters for desalination plant.
2. Calculated results were validated by the technical design data for 1200 tons per day msf desalination plant, and most Figures shows a good agreement between the calculated results and technical design data.
3. The maximum error was about 2.2% and occurred in stages 1,2,3 for produced distillate.
4. Most of calculated results gets closer to the design data at the ends of the plant, this is attributed to the fact that the two are closer to a preset boundary conditions mainly inlet seawater temperature and top brine temperature.
5. The heat transfer area is decreasing stepwise from stage 1 to stage 12 ,where the decreasing percent between first stage 1 and last was 15.49 % , and the total reduction in heat transfer area was about 8 %(ie 205 m^2)

6. Recommendation

- Improving the ability of software for to involve the other desalination technologies such as (RO , MED , MSF brine recirculation).
- Developing this software to include simulation and optimization tools of desalination plants.
- Developing our own empirical equation of physical and thermodynamics properties for brackish and sea water.
- Building pilot plants for all desalination technology , to establish local data base involves real technical parameters for different available technology.

Nomenclature

A Heat transfer surface area, m2

B Brine flow rate, kg/s

Cp Specific heat at constant pressure, kJ/kg C

D Flow rate of distillate formed by evaporation, in the ith effect, kg/s

L Length, width or thickness, m

LMTD Logarithmic mean temperature difference, C

M Mass flow rate, kg/s

T Temperature, ◦C

U Overall heat transfer coefficient, kW/m2 C

X Salinity, ppm

H enthalpy kj

Subscripts

b Brine

s sea water

av average

cond Condenser or condensate

cw Cooling water or intake seawater

d Distillate

e Evaporator

f Feed seawater

HB Brine heater

i ith stage

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