# EXERGY AND THERMO-ECONOMIC ANALYSIS OF MODIFIED MSF DESALINATION PLANTS CONFIGURATIONS

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## ABSTRACT

This paper presents the exergy and thermo-economic analysis of a Modified MSF thermal Desalination Plant Configurations. The modified configuration is based on the filed patent of Fath, [1] for MSF with inter-stage brine re-heater(s). The brine re-heaters, placed at different inter-stages, are introduced to increase the unit flashing range. The Visual Desalination and Simulation (VDS) package, developed by authors [2], is used as a tool of analysis. The results are compared with the basic 5000 m3/day MSF configuration of Eoun Mousa (Egypt), [3].

An MSF process flow-sheet is developed of basic MSF desalination plant with inter-stage re-heater(s). The results showed that the use of reheating in the MSF desalination configuration reduces the unit water cost by 5.8 % and increases the distillate product by 3.7 % than that of the conventional MSF desalination plant. Using two re-heaters in the MSF flow-sheet cause a reduction in the unit cost of 6 % and increase in the distillate product of 5.2 % at the expense, of the performance ratio. Using re-heater in by pass of cooling stream (MSF_RH_CS) configuration shows 12.5 % increase in the distillate water product over that of the conventional MSF however, the performance ratio decreased. As a result, the water cost becomes higher than the conventional MSF by 3 %. The use of the re-heater in the MSF_M flow-sheet reduces the unit water cost by 9 % than that of the conventional MSF. The distillate product of MSF_M_RH is 4 % higher than that of the conventional MSF. Also the salt concentration is lowered by 20 % for the same brine recirculation.

**Keywords:** Desalination, VDSP package, MSF, unit water cost.

### Nomenclature

$\dot{C}$ : cost flow rate, \$/hr
$\overline{C}_p$ : Molar specific heat, *J/kmol.k*
$e$ : Specific exergy, kJ/kg
$h$ : Specific enthalpy , kJ/kg
$\dot{M}$ : Mass flow rate, kg/s
$s$ : Specific entropy , kJ/kg

$c$ : cost per unit exergy, \$/GJ
$\dot{E}$ : Exergy flow rate, MW
$f$ : Exergo-economic factor
$P$ : Pressure, kPa
$\dot{N}_m$ : Molar flow rate of saline water
$T$ : Temperature, K

$R_u$ : Universal gas constant, *J/kmol.k*
$x$ : Mole fractions
$\dot{Z}$ : Rate of the capital cost
$\bar{\rho}$ : Molar density, kmol/m$^3$
$r$ : Relative cost difference
$\dot{W}$ : Power, MW
$\rho$ : Density, kg/m$^3$
$\eta_{II}$ : Exergetic second law efficiency

**Superscripts:**
*CI* : Capital investment
*OM* : Operating & Maintenance

**Subscripts:**
0 : Dead state
*cw*: cooling water
*d* : Distillate
*L* : Loss
*p* : Product
*v* : Vapor
*b* : Brine water
*D* : Destruction
*F* : Fuel
*m* : Mixer of pure and salt water
s : salt water
*w* : Pure water

## INTRODUCTION

The previous exergy and thermo-economic analysis of the MSF plants, carried out by the authors [3], indicated that more investigations in the process configuration are important. For example, the important of the recovering of the bleeding cost which associated with the blow down brine stream in the MSF. Exergy and thermo-economic analysis puts the hand where the exergy is deteriorated as well as gives an insight to the important of the flow pattern and process flow-sheeting changes that can reduce the unit product cost.

The use of multi brine heater in multi stage flash desalination plant (MB-MSF) was investigated by Awerbuch *et al.* [4]. The author shows that an improvement process flowsheet was brought by subdividing the MSF plant into a three of interacting modules with individual brine heater. Each brine heater is individually fed by steam from a bleed port of a conventional power plant turbine. The heating steam properties of three intakes are (2.758 bar, 130 $^{0}$C), (0.5 bar, 98.88 $^{0}$C), (0.365 bar, 74 $^{0}$C) respectively. The MB-MSF cycle operated at top brine temperature of 121, 89, 65.6 $^{0}$C for three modules respectively. The calculations analyses are based on a combined power-water plant of 5 (mgd). The sea water fed to the plant contains 50000 ppm of total dissolved solids and the rejected brine contains 10000 ppm. The results of MB-MSF configuration showed that the heat transfer surface can be 15 % less and the acid consumption can be 30 % less than its value in single brine heater MSF plant with TBT of 110 $^{0}$C. However, exergy and thermoeconomic analyses are required to fully realize the advantage of MB-MSF configuration.

The concept of reheating the flashed brine after certain stage, MSF-RH proposed by Fath [1] in his field patent. The MSF_RH is developed for a new generation of Jumbo-

Giant MSF desalination plants. MSF_RH is claimed to improve the plant productivity, exergetic efficiency and reduce the final cost of the desalinated product water. The proposed MSF_RH configurations of Fath [1], will be investigated in the present work and compared with the conventional of 5000 $m^3$ / day MSF desalination plant (Eoun Mousa, Egypt) [5]. Visual Synthesis Desalination Program (VSDP) package developed by the authors [2] & [3] is used as a tool of analysis. The main feature of VSDP is to use thermoeconomic approach (with Energy, Exergy and Cost) and use the exergetic efficiency as base of energy consumption comparison. This will avoid the misleading of using only performance ratio. The use of performance ratio does not differentiate between the used steam quality and do not consider the auxiliary energy like pumping power Darwish *et al.* [6].

## MSF_RH PROCESS DESCRIPTION

Fig. 1 shows the proposed configuration of MSF_RH with interstage rehaeater. The reheater divides the heat recovery section in two groups of flash chambers. The first group operates at relatively higher temperature **(High Temperature Recovery Section) HTRS,** the second group operates at a lower temperature **(Lower Temperature Recovery Section) LTRS.**

The intake sea water is introduced to the condenser tubes of the heat rejection section as a coolant. Part of the cooling sea water leaves the heat rejection section towards to the last stage as make up and the other part is rejected. The recycled brine leaves the heat recovery sections and enters the brine heater to gain energy at a high temperature. The heated brine enters the **HTRS** group of flash chambers where it is partially flashes into vapor and the reminder leaves as a brine. The unflashed brine is then **reheated** in the reheater to its maximum temperature and is introduced to the second heat recovery group (**LTRS**). In each stage, the flashed off vapor flows through the demister, which removes entrained droplets of unevaporated brine. The vapor then condenses on the outside surface of the preheating condenser tubes. The condensed vapor is collected, over the distillate trays, and passed to the successive trays to form the final product. Both brine heater and reheater take their heating steam from either steam turbine or auxiliary boiler. Desuperheater unit is employed to maintain heating steam at the saturation conditions.

## RESULTS AND DISCUSSION

Four cases of MSF flowsheets are considered. The first case covers the MSF with one re-heater. The second case covers two re-heaters impeded in the MSF train. The third case involves the bypass cold stream with MSF_RH. The forth case involves the re-heater with the MSF_M configuration which developed by Eldessouky *et al.* [6]. The thermo-economic analysis of these cases is presented as follows:-

## 1. MSF flowsheet with one reheater

The re-heater area is taken equal to the brine heater and their total area is equal to the area of brine heater of the conventional MSF desalination plant. The relative positions of the reheater (bleeding point) to the main brine heater affect both the **HTR** and **LTRS** stages number. The effects of the reheater positions on the performance ratio, exergetic efficiency, product cost, distillate productivity and the brine circulation ratio **BCR** are shown in Fig.2. The steam temperature after desuperheater is controlled to fix the top brine temperature at 110 $^0$C.

As compared with that of the conventional MSF configuration, Fig. 2 shows that as the **HTR** stages increase, the distillate productivity and the distillate cost increase however, the performance ratio, exergetic ratio and **BCR** decrease. The minimum cost is obtained when the reheater is positioned on stage after brine heater (one stage of the **HTRS** and 16 stages of **LTRS).** The MSF_RH at its minimum cost of the distillate is evaluated and compared against the conventional MSF and the results are shown in Table (1). This table shows that the performance ratio of MSF_RH configuration is 1.5 % less than that of the conventional MSF, however the exergetic efficiency of MSF_RH is 5.3 % higher than that of the conventional MSF. The brine circulation ratio in the MSF_RH is 2.8 % less than that of the MSF, this in turn reduce the pumping power by 21.5 % as shown. The distillate product of the MSF_RH is 3.7 % higher than that of the conventional MSF as a result the cost of distillate product in the MSF_RH is 6 % less than that of the conventional MSF. This means that the configuration MSF_RH will save 125,000 $/yr of the distillate cost.

## 2. MSF with two interstage reheaters

Fig. 3 shows MSF flowsheet with two reheaters (MSF_2RH). The area of the main brine heater and the two reheaters are also taken equal and their total area is equal to the brine heater of the conventional MSF configuration. The relative positions of the two reheaters are investigated and the results are summarized in Table (2). The sea water feed rate and the brine recirculation are adjusted at 1370 Ton/hr and 1845 Ton/hr respectively. The top brine temperature after the brine heater and the two reheaters are also fixed by 110 $^0$C. Table (2) shows that the best MSF_2RH configuration is (**1-$RH_1$-1-$RH_2$-15-3**) with unit water cost of 1.138 $/m$^3$, Fig. 3. The MSF_2RH configuration gives a higher performance ratio, lower distillate product and lower exergetic efficiency than MSF_RH. This best configuration for MSF_2RH is compared against MSF_RH and the conventional MSF under the same operating conditions. Table (3) shows that MSF_2RH gives the lower water cost of 1.138 $/m$^3$ due to the higher distillate product of 219 m$^3$/hr, however the conventional MSF gives the higher performance ratio.

## 3. MSF_RH with bypass cold stream

Fig. 4 shows the MSF_RH_CS configuration in which the blended cold stream of the recirculated partially is bypassed the LTRS. The re-circulated brine $M_r$ is divided in two streams; the first stream ($M_r$-y) flows through the condenser/preheater of the LTRS; and the second stream (y) is mixed with the first stream at a point just before the entrance of the condenser/preheater of HTRS. The mixed stream recovered energy from HTRS and heated in the brine heater to 110 $^0$C. The unflashed brine out of HTRS is heated again in the reheater to 110 $^0$C. The MSF_RH_CS lowers the temperature of the mixed stream and therefore, increase the temperature difference between the vapor and condenser cooling water in the HTRS. As result the heat transfer rate would be enhanced.

The effect of mass ratio ( $y/M_r$) on the entire system performance and water cost is shown in Table (4); where the brine circulated in the LTRS is fixed at 1845 T/hr. Table (4) shows that as the brine bypass mass flow rate y increases, the performance ratio decreases due to the increase in the heating steam consumption. The steam consumption increased due to the increase of the brine flow rate (at relatively lower temperature at the inlet of the brine heater). This table also indicates that the water cost, the distillate product and the exergetic efficiency are proportional to the y variations.

Fig. 5 and Fig. 6 show the mass and temperature distribution in both MSF_RH_CS and MSF_RH flowsheets respectively at the same operating conditions. These figures show that distillate of the HTRS of the MSF_RH_CS is higher than that of the MSF_RH. This enhancement in the condensation process is due to the mix of colder brine stream. Comparison between the MSF_RH_CS and MSF_RH is shown in Table (5). This table shows that the water cost in the MSF_RH is lower than that of MSF_RH_CS, due to the higher performance ratio in the first. The higher distillate product is, however, obtained by the MSF_RH_CS configuration. The distillate product of the MSF_RH_CS flowsheet is 12.5% higher than that of the conventional MSF at the expense of the performance ratio. As a result the water cost becomes higher than that of the conventional MSF by 3 %.

## 4. MSF_RH on the MSF_M configuration

The Multi Stage Flash – Mixed brine (MSF_M) configuration, proposed by Eldessouky *et al.* [4], is investigated with impeded re-heater, Fig.7. The effect of the relative position of the reheater is shown in Table (6); which shows that the lower water cost and higher performance ratio are occurred at 1-RH-19 configuration as shown in Fig.7. In this configuration the flashing brine is bled after the first stage and reheated to 110 $^0$C before being introduced to the reminder nine-teen successive flash chambers.

Comparison between MSF_M and MSF_M_RH configuration under the same operating conditions is shown in Table (7). Table (7) shows that MSF_M_RH configuration gives a lower water cost of 1.1 $/m$^3$ and higher distillate product of 217 Ton/hr. The comparison shows also that the salt concentration in the recirculation brine of the MSF_M_RH configuration is lower than that of the MSF_M configuration. When comparing the obtained results of Table (7) and that of Table (1), the following points could be concluded:

- The use of the reheater in the MSF_M flowsheet reduces the unit water cost by 9 % lower than that of the conventional MSF.
- The distillate production rate of MSF_M_RH is 4 % higher than that of the conventional MSF.
- The salt concentration of MSF_M_RH is lowered by 20 % than the conventional MSF configuration for the same brine recirculation.

## CONCLUSIONS

1. The use of one additional interstage reheater in the MSF desalination configuration reduces the unit water cost by 5.8 % and increases the distillate product by 3.7 % than that of the conventional MSF desalination plant.
2. Using two reheaters in the MSF flowsheet cause a further 6 % reduction in the distillate unit water cost and 5.2 % further increase in the distillate product, however, at the expense of the performance ratio.
3. Using reheater with bypass of cooling stream MSF_RH_CS shows 12.5 % increase in the distillate product than that of the conventional MSF at the expense of the performance ratio and as a result the water cost become higher than that of the conventional MSF by 3 %.
4. The use of the reheater in the MSF_M system reduces the distillate unit water cost by 9 % than that of the conventional MSF. In addition, the distillate product of MSF_M_RH is 4 % higher than that of the conventional MSF and the salt concentration is lowered by 20 % for the same brine recirculation rate.

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**Table (1): Comparison between MSF and MSF_RH configurations**

| Variables | MSF | MSF_RH | % diff. |
|---|---|---|---|
| Performance ratio | 7.98 | 7.86 | -1.5 |
| Exergetic efficiency | 5.93 | 6.24 | 5.3 |
| Distillate | 208 | 215 | 3.7 |
| Area of brine heater, m$^2$ | 780 | 390 | -50 |
| Area of reheater, m$^2$ | - | 390 | 100 |
| TBT1, after brine heater, $^0$C | 110 | 110 | - |
| TBT2, after reheater, $^0$C | - | 110 | |
| Total heating surface area, m$^2$ | 10147 | 10147 | - |
| BCR | 8.82 | 8.57 | -2.8 |
| Pumping power, MW | 0.65 | 0.51 | -21.5 |
| Stages number | 17+3 | 1+16+3 | |
| Cost of distillate, \$/m$^3$ | 1.21 | 1.14 | -6 |

**Table (2) : Effect of reheater positions in MSF_2RH configuration**

| Reheater, R$_1$&R$_2$ positions | Pr | ε | Water cost, \$/m$^3$ | Distillate, T/hr |
|---|---|---|---|---|
| 1-RH$_1$-1-RH$_2$-15-3 | 7.7 | 6.5 | 1.138 | 219 |
| 1- RH$_1$-3- RH$_2$13-3 | 7.12 | 9.79 | 1.159 | 223 |
| 1- RH$_1$-5- RH$_2$-11-3 | 6.42 | 12.14 | 1.2 | 224.5 |
| 1- RH$_1$-7- RH$_2$-9-3 | 5.63 | 14.9 | 1.27 | 225 |
| 2- RH$_1$-1- RH$_2$-14-3 | 7.4 | 6.78 | 1.146 | 222 |
| 2- RH$_1$-3- RH$_2$-12-3 | 6.8 | 9.11 | 1.175 | 224.8 |
| 2- RH$_1$-5- RH$_2$-10-3 | 6 | 11.3 | 1.23 | 225.3 |
| 2- RH$_1$-7- RH$_2$-8-3 | 5.27 | 14 | 1.3 | 225.6 |
| 3- RH$_1$-1- RH$_2$-13-3 | 7.11 | 6.19 | 1.16 | 223 |
| 3- RH$_1$-3- RH$_2$-11-3 | 6.45 | 8.61 | 1.2 | 224.5 |
| 3- RH$_1$-5- RH$_2$-9-3 | 5.7 | 10.93 | 1.26 | 225.3 |
| 3- RH$_1$-7- RH$_2$-7-3 | 4.87 | 13.75 | 1.36 | 225.2 |
| 4- RH$_1$-1- RH$_2$-12-3 | 6.77 | 5.97 | 1.18 | 223.7 |
| 4- RH$_1$-3- RH$_2$-10-3 | 6.1 | 8.56 | 1.23 | 225.1 |
| 4- RH$_1$-5- RH$_2$-8-3 | 5.29 | 11 | 1.3 | 225.3 |
| 4- RH$_1$-7- RH$_2$-6-3 | 4.48 | 13.74 | 1.42 | 225.5 |

**Table (3): Comparison between MSF, MSF_RH and MSF_2RH configurations**

| Variables | MSF | MSF_RH | MSF_2RH |
|---|---|---|---|
| Performance ratio | 7.98 | 7.86 | 7.7 |
| Exergetic efficiency, E | 5.93 | 6.24 | 6.5 |
| Water cost, $\$/m^3$ | 1.21 | 1.143 | 1.138 |
| Brine re-circulate, T/hr | 1845 | 1845 | 1845 |
| Make up, T/hr | 660 | 660 | 660 |
| Distillate product, T/hr | 208 | 215 | 219 |
| Rejected temperature, $^oC$ | 39.27 | 39.7 | 40.13 |
| Rejected salt concentration, gm/Kg | 70 | 71.22 | 71.6 |
| Salt concentration in recycle brine, gm/ Kg | 62.2 | 62.9 | 63.13 |
| Feed flow rate, T/hr | 1370 | 1370 | 1370 |

**Table (4): Effect of mass flow rate ratio of (y) variations**

| y % | PR | Cost, $\$/m^3$ | Distillate,T/hr | Make up, T/hr | $M_r$,HTRS, T/hr | E |
|---|---|---|---|---|---|---|
| 0.01 | 7.17 | 1.16 | 221.4 | 663 | 1862 | 6.17 |
| 0.03 | 6.79 | 1.18 | 224.7 | 685 | 1904 | 6.3 |
| 0.05 | 6.44 | 1.2 | 227.8 | 699 | 1945 | 6.3 |
| 0.1 | 5.7 | 1.24 | 234.2 | 723 | 2045 | 6.4 |
| 0.18 | 4.62 | 1.36 | 244 | 785 | 2245 | 6.8 |

**Table (5): Simulation results of comparison between MSF_RH and MSF_RH_CS**

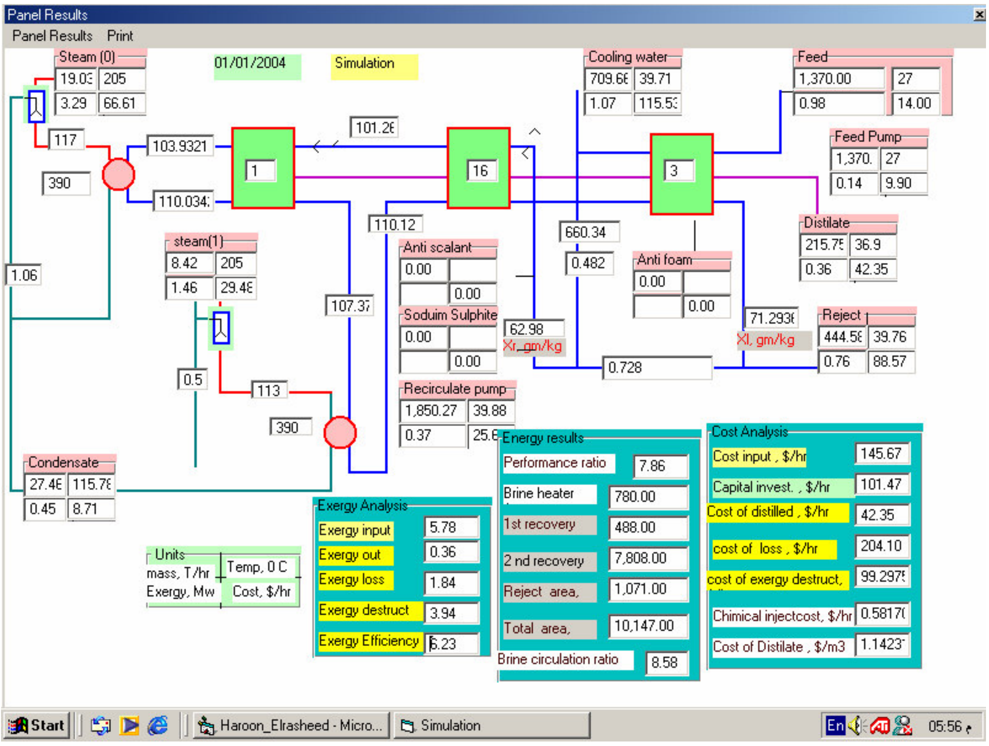
| Variables | MSF_RH | MSF_RH_CS |
|---|---|---|
| PR | 7.4 | 5.7 |
| Exergetic efficiency, E | 6.19 | 6.44 |
| Water cost, $\$/m^3$ | 1.15 | 1.25 |
| Cooling water in LTRS, T/hr | 1845 | 1845 |
| Cooling water in HTRS, T/hr | 1845 | 2045 |
| Make up, T/hr | 660 | 723 |
| Distillate product, T/hr | 219 | 234 |
| Rejected temperature, $^oC$ | 40.6 | 45.4 |
| Salt concentration in rejected brine, gm/ Kg | 71.9 | 70.97 |
| Salt concentration in recycle brine, gm/ Kg | 63.4 | 62.85 |
| Feed flow rate, T/hr | 1370 | 1370 |

**Table (6): Effect of reheater position on the MSF_M_RH**

| Reheater position | PR | $\varepsilon$ | Water cost, $\$/m^3$ |
|---|---|---|---|
| 1-R-119 | 7.87 | 6.28 | 1.109 |
| 3-R-17 | 7.4 | 6.38 | 1.115 |
| 5-R-15 | 6.75 | 6.38 | 1.154 |
| 7-R-13 | 6 | 6.28 | 1.211 |

**Table (7): Comparison between MSF_M and MSF_M_RH configurations**

| Variables | MSF_M | MSF_M_RH |
|---|---|---|
| PR | 7.97 | 7.87 |
| Exergetic efficiency, E | 6 | 6.28 |
| Distillate product, T/hr | 211 | 217 |
| Area of brine heater, $m^2$ | 780 | 390 |
| Area of reheater, $m^2$ | - | 390 |
| TBT1 | 110 | 110 |
| TBT2 | - | 110 |
| Total heating surface area, $m^2$ | 10147 | 10147 |
| Recirculate brine, T/hr | 1845 | 1845 |
| Pumping power, MW | 0.64 | 0.42 |
| Water cost, $/$m^3$ | 1.18 | 1.1 |
| Make up, T/hr | 1370 | 1370 |
| Salt concentration in recirculate brine, gm/ Kg | 56 | 50 |
| Stage number | 20 | 1-19 |



Exergy Analysis

| | |
|---|---|
| Exergy input | 5.78 |
| Exergy out | 0.36 |
| Exergy loss | 1.84 |
| Exergy destruct | 3.94 |
| Exergy Efficiency | 6.23 |

Energy results

| | |
|---|---|
| Performance ratio | 7.86 |
| Brine heater | 780.00 |
| 1st recovery | 488.00 |
| 2 nd recovery | 7,808.00 |
| Reject area, | 1,071.00 |
| Total area, | 10,147.00 |
| Brine circulation ratio | 8.58 |

Cost Analysis

| | |
|---|---|
| Cost input , $/hr | 145.67 |
| Capital invest. , $/hr | 101.47 |
| Cost of distilled , $/hr | 42.35 |
| cost of loss , $/hr | 204.10 |
| cost of exergy destruct, | 99.2975 |
| Chimical injectcost, $/hr | 0.58170 |
| Cost of Distilate , $/m3 | 1.1423 |

**Fig.1: MSF_RH configuration of desalination plant**

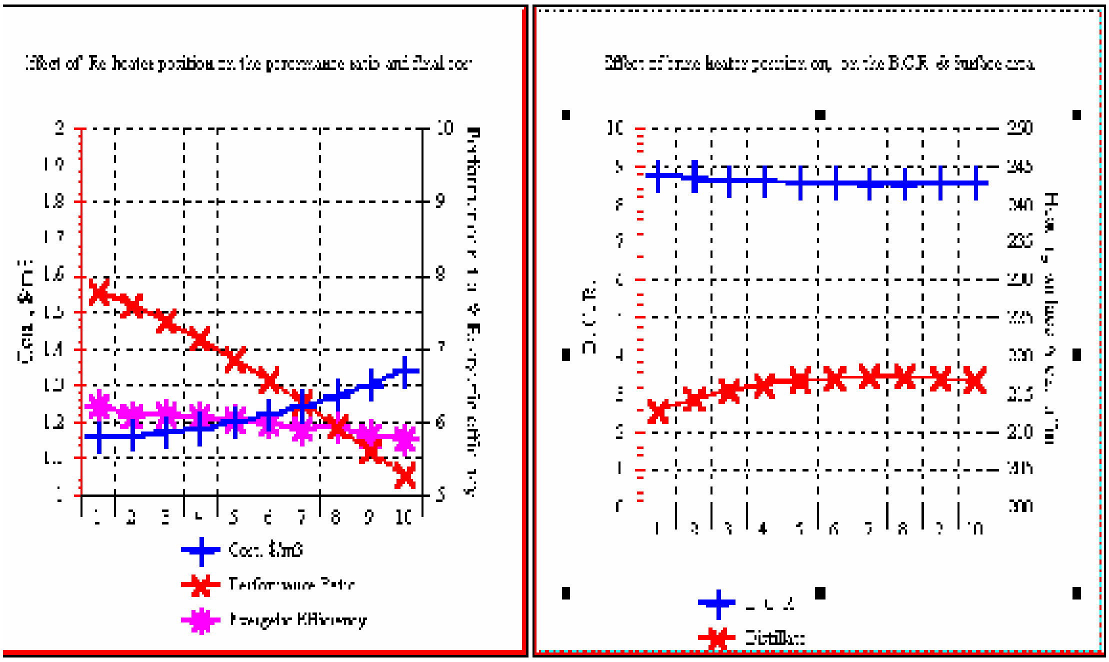
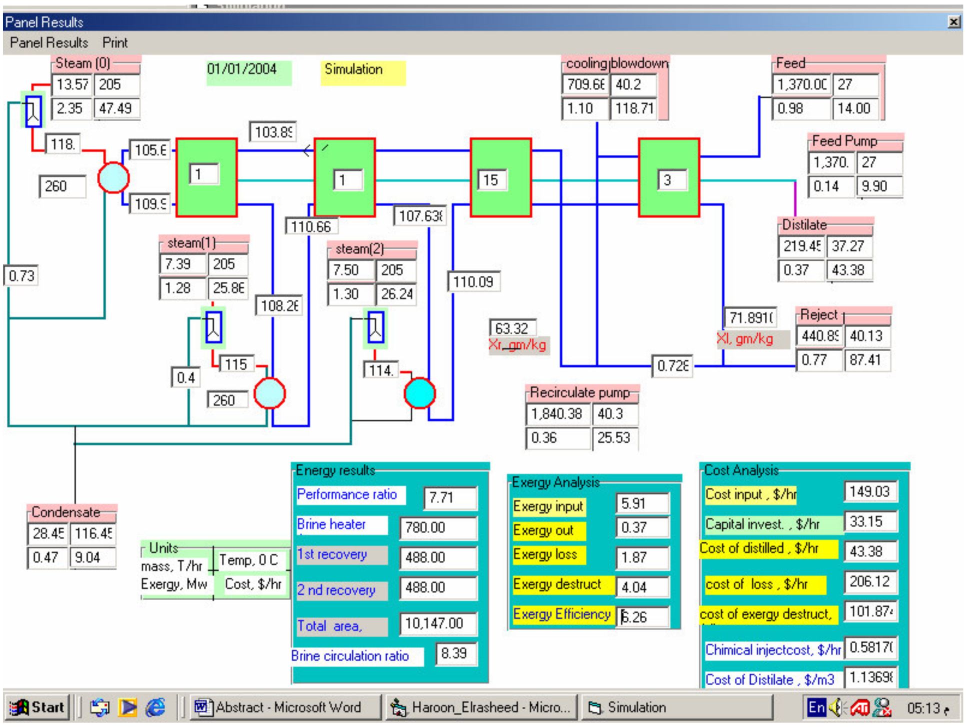


**Fig. 2: Influence of The Inter-Stage Brine Re-heater position on MSF_RH Plant Parameters**



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Simulation

| Steam (0) | |
|---|---|
| 13.57 | 205 |
| 2.35 | 47.49 |

| cooling | blowdown |
|---|---|
| 709.6€ | 40.2 |
| 1.10 | 118.71 |

| Feed | |
|---|---|
| 1,370.0C | 27 |
| 0.98 | 14.00 |

| Feed Pump | |
|---|---|
| 1,370. | 27 |
| 0.14 | 9.90 |

| steam(1) | |
|---|---|
| 7.39 | 205 |
| 1.28 | 25.8€ |

| steam(2) | |
|---|---|
| 7.50 | 205 |
| 1.30 | 26.24 |

| Distilate | |
|---|---|
| 219.4! | 37.27 |
| 0.37 | 43.38 |

| Reject | |
|---|---|
| 440.8! | 40.13 |
| 0.77 | 87.41 |

| Recirculate pump | |
|---|---|
| 1,840.38 | 40.3 |
| 0.36 | 25.53 |

| Condensate | |
|---|---|
| 28.4! | 116.4! |
| 0.47 | 9.04 |

118.
260
105.€
109.!
103.8!
1
1
15
3
110.66
107.63(
108.2€
110.09
0.73
0.4
115
260
114.
63.32
Xr_gm/kg
71.891(
Xl, gm/kg
0.72€

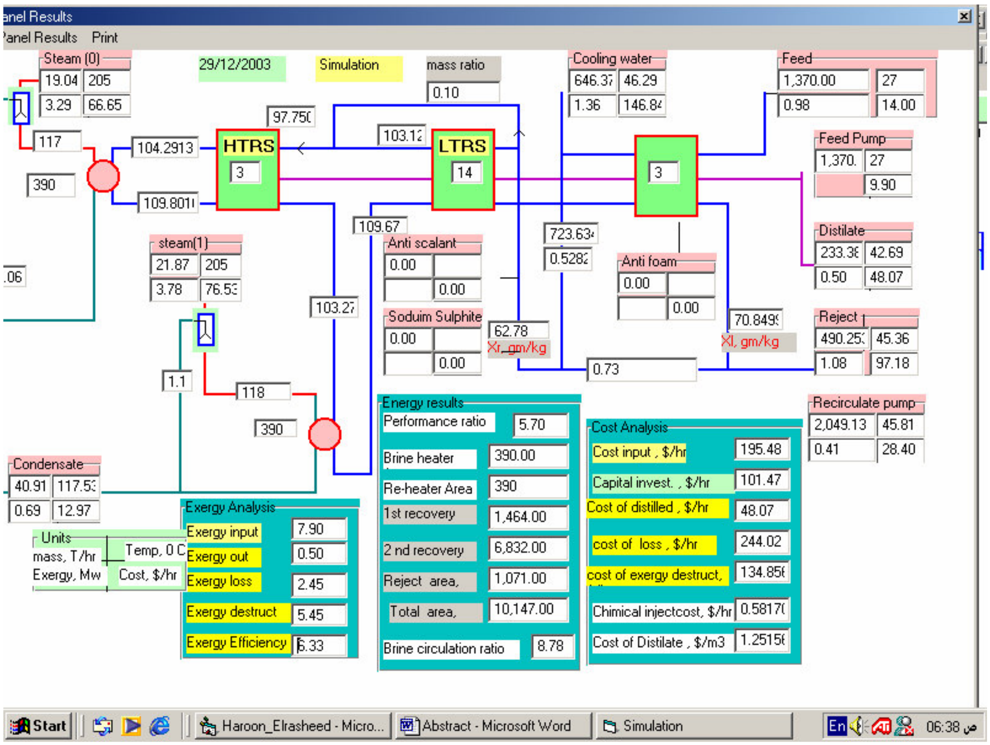
| Units | |
|---|---|
| mass, T/hr | Temp, 0 C |
| Exergy, Mw | Cost, $/hr |

| Energy results | |
|---|---|
| Performance ratio | 7.71 |
| Brine heater | 780.00 |
| 1st recovery | 488.00 |
| 2 nd recovery | 488.00 |
| Total area, | 10,147.00 |
| Brine circulation ratio | 8.39 |

| Exergy Analysis | |
|---|---|
| Exergy input | 5.91 |
| Exergy out | 0.37 |
| Exergy loss | 1.87 |
| Exergy destruct | 4.04 |
| Exergy Efficiency | 6.26 |

| Cost Analysis | |
|---|---|
| Cost input , $/hr | 149.03 |
| Capital invest. , $/hr | 33.15 |
| Cost of distilled , $/hr | 43.38 |
| cost of loss , $/hr | 206.12 |
| cost of exergy destruct, | 101.87< |
| Chimical injectcost, $/hr | 0.5817( |
| Cost of Distilate , $/m3 | 1.1369( |

**Fig. 3: Energy, Exergy and Thermoeconomic results of MSF_2RH configuration.**



29/12/2003

Simulation

mass ratio: 0.10

| Steam (0) | |
|---|---|
| 19.04 | 205 |
| 3.29 | 66.65 |

| steam(1) | |
|---|---|
| 21.87 | 205 |
| 3.78 | 76.53 |

| Condensate | |
|---|---|
| 40.91 | 117.53 |
| 0.69 | 12.97 |

| Cooling water | |
|---|---|
| 646.37 | 46.29 |
| 1.36 | 146.84 |

| Feed | |
|---|---|
| 1,370.00 | 27 |
| 0.98 | 14.00 |

| Feed Pump | |
|---|---|
| 1,370. | 27 |
| | 9.90 |

| Distilate | |
|---|---|
| 233.38 | 42.69 |
| 0.50 | 48.07 |

| Reject | |
|---|---|
| 490.253 | 45.36 |
| 1.08 | 97.18 |

| Recirculate pump | |
|---|---|
| 2,049.13 | 45.81 |
| 0.41 | 28.40 |

| Anti scalant | |
|---|---|
| 0.00 | |
| | 0.00 |

| Soduim Sulphite | |
|---|---|
| 0.00 | |
| | 0.00 |

| Anti foam | |
|---|---|
| 0.00 | |
| | 0.00 |

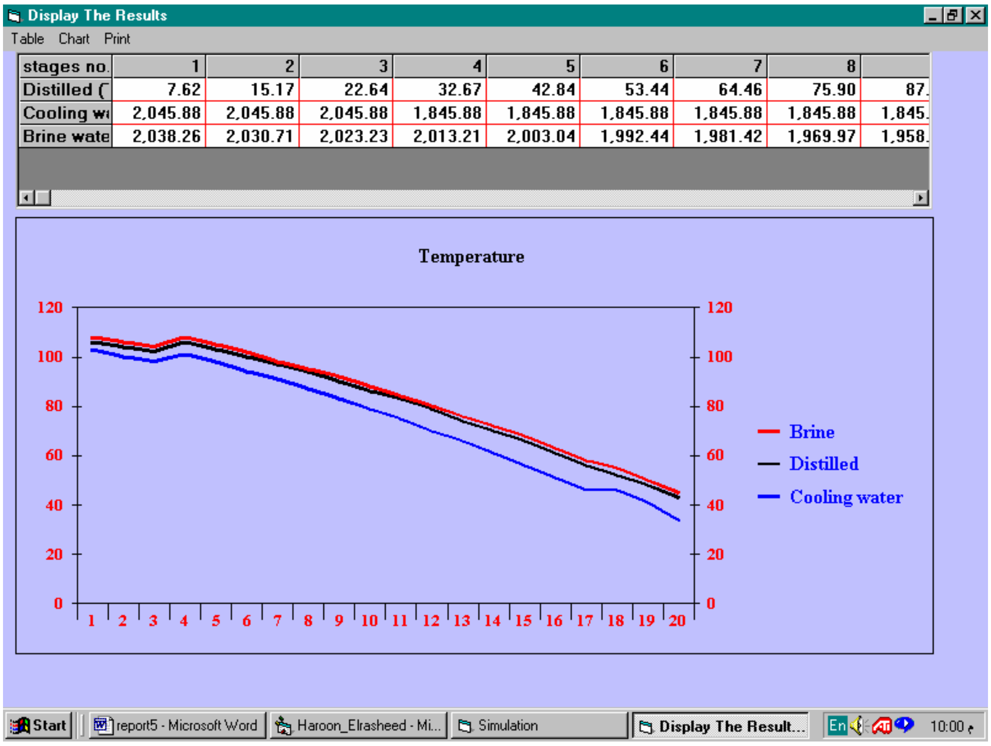
| Units | |
|---|---|
| mass, T/hr | Temp, 0 C |
| Exergy, Mw | Cost, $/hr |

| Exergy Analysis | |
|---|---|
| Exergy input | 7.90 |
| Exergy out | 0.50 |
| Exergy loss | 2.45 |
| Exergy destruct | 5.45 |
| Exergy Efficiency | 6.33 |

| Energy results | |
|---|---|
| Performance ratio | 5.70 |
| Brine heater | 390.00 |
| Re-heater Area | 390 |
| 1st recovery | 1,464.00 |
| 2 nd recovery | 6,832.00 |
| Reject area, | 1,071.00 |
| Total area, | 10,147.00 |
| Brine circulation ratio | 8.78 |

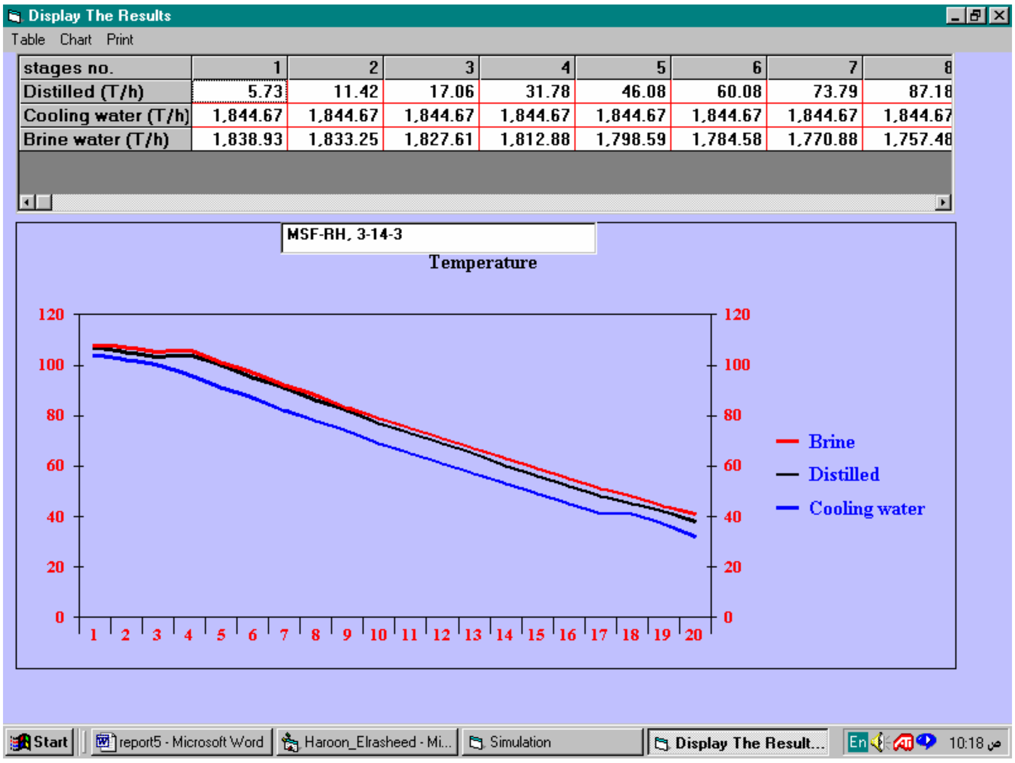
| Cost Analysis | |
|---|---|
| Cost input , $/hr | 195.48 |
| Capital invest. , $/hr | 101.47 |
| Cost of distilled , $/hr | 48.07 |
| cost of loss , $/hr | 244.02 |
| cost of exergy destruct, | 134.856 |
| Chimical injectcost, $/hr | 0.58170 |
| Cost of Distilate , $/m3 | 1.25156 |

Fig. 4: MSF_RH_CS configuration at y = 10 %



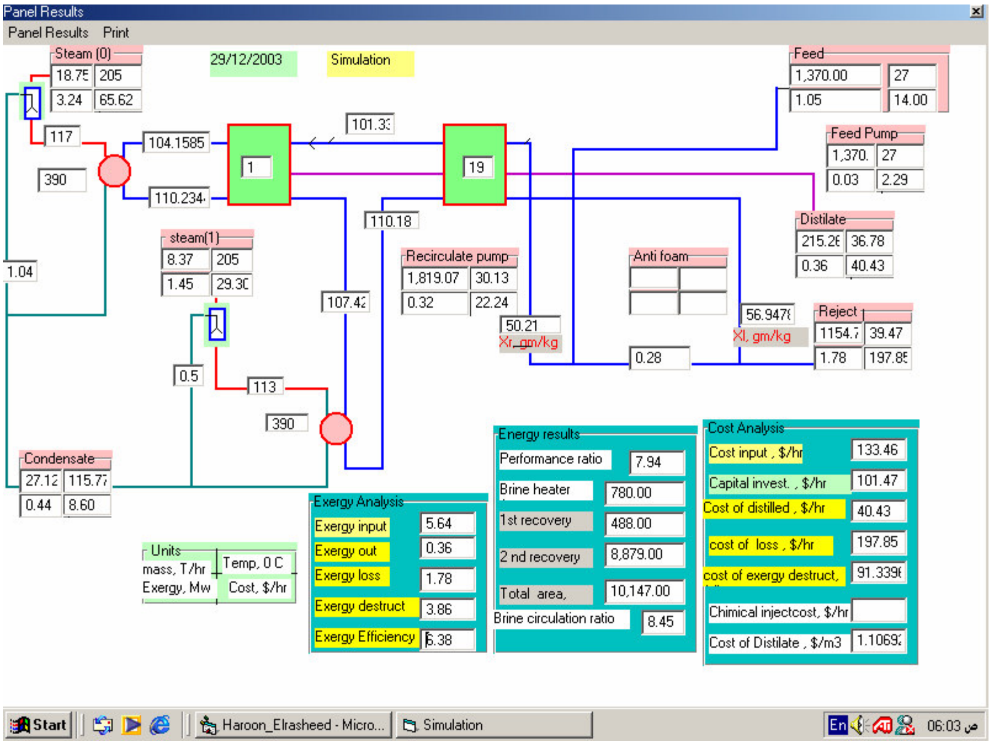
| stages no. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | |
|---|---|---|---|---|---|---|---|---|---|
| Distilled ( | 7.62 | 15.17 | 22.64 | 32.67 | 42.84 | 53.44 | 64.46 | 75.90 | 87. |
| Cooling wa | 2,045.88 | 2,045.88 | 2,045.88 | 1,845.88 | 1,845.88 | 1,845.88 | 1,845.88 | 1,845.88 | 1,845. |
| Brine wate | 2,038.26 | 2,030.71 | 2,023.23 | 2,013.21 | 2,003.04 | 1,992.44 | 1,981.42 | 1,969.97 | 1,958. |

Fig. 5: Mass and temperature in the MSF_RH_CS configuration



| stages no. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Distilled (T/h) | 5.73 | 11.42 | 17.06 | 31.78 | 46.08 | 60.08 | 73.79 | 87.18 |
| Cooling water (T/h) | 1,844.67 | 1,844.67 | 1,844.67 | 1,844.67 | 1,844.67 | 1,844.67 | 1,844.67 | 1,844.67 |
| Brine water (T/h) | 1,838.93 | 1,833.25 | 1,827.61 | 1,812.88 | 1,798.59 | 1,784.58 | 1,770.88 | 1,757.48 |

**Fig. 6: Mass and temperature in the MSF_RH configuration**



Exergy Analysis

| | |
|---|---|
| Exergy input | 5.64 |
| Exergy out | 0.36 |
| Exergy loss | 1.78 |
| Exergy destruct | 3.86 |
| Exergy Efficiency | 6.38 |

Energy results

| | |
|---|---|
| Performance ratio | 7.94 |
| Brine heater | 780.00 |
| 1st recovery | 488.00 |
| 2 nd recovery | 8,879.00 |
| Total area, | 10,147.00 |
| Brine circulation ratio | 8.45 |

Cost Analysis

| | |
|---|---|
| Cost input , $/hr | 133.46 |
| Capital invest. , $/hr | 101.47 |
| Cost of distilled , $/hr | 40.43 |
| cost of loss , $/hr | 197.85 |
| cost of exergy destruct, | 91.3396 |
| Chimical injectcost, $/hr | |
| Cost of Distilate , $/m3 | 1.10693 |

**Fig. 7 : MSF_M_RH configuration**