

Evaluating the technologies of thermal desalination using low-grade heat

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Abstract

This paper compares the effectiveness of thermal schematics, thermal efficiency, and performance ratio. A sulfuric acid plant located at the coastal line of Morocco was identified as an example for comparison because it utilizes low-grade heat to produce desalinated water needed at the facility from the large volumes of cooling water used in current processes. Currently the acid cooling is performed in the shell-and-tube heat exchanger used for cooling hot sulfuric acid. The heat is then “rejected” to the sea. Both multi-effect distillation (MED) and multi-stage flashing (MSF) systems have advantages in that low grade heat can be used for evaporation and subsequent production of freshwater. The MED process is designed for utilization of low-grade thermal heat as a heat source in the form of hot water in the range of 0.8–3 bar, which is supplied to the first effect of the desalination unit. It operates with lower top brine temperatures in the range of 64–70°C. The thermal performance, operational and capital cost are directly proportional to the number of effects in the MED system. In MSF, the heated steam is routed to the brine heater. It operates with top brine temperatures in the range of 90–110°C. In comparison, the plate heat exchanger (PHE) could be used to recover heat from circulating acid for desalination feed water preheating. Despite the presence of these thermal schematics, comparison of the thermal desalination schematics to utilize low-grade heat is absent.

Keywords: Thermal desalination; Low-grade heat

1. Low grade heat utilization

Morocco has the world’s largest deposits of phosphate rock. The major processing and fertilizer facility is located in Jorf Lasfar. Over 25% of the heat available from converting

sulfur to sulfuric acid is due to the adsorption and dilution of sulfur trioxide in water. The sulfuric acid plant is a thermal energy plant. The facility has six modern sulfuric acid plants with a combined capability of 15,900 tons of sulfuric acid per day. At present, 27,600 m³/h

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of seawater is used for cooling plant equipment, where the average seawater inlet of 18°C rises to an average of 33°C after flowing through acid coolers. In the absorption and drying towers, a large amount of heat is generated and transferred into the circulating acid. This heat needs to be removed in order to keep the acid plant balanced. At present, the acid cooling is carried out in the anodically protected stainless steel shell-and-tube heat exchangers for cooling hot sulfuric acid. The acid cooler system is shown in Fig. 1. Both multi-effect distillation (MED) and multi-stage flashing (MSF) systems are considered to utilize the low grade heat from circulating acid for evaporation and subsequent production of freshwater.

2. Multi-effect distillation plant

This option is based on replacing the existing shell and tube exchangers of the sulfuric acid cooling system with new plate heat exchangers. The existing acid coolers are cooled by seawater. The performance parameters of the heat exchangers are shown in the following table:

The maximum temperature of the sulfuric acid in the system is 106°C; the required minimum temperature of the cooled acid is 43°C. The distribution of the temperature vs. released heat is presented in the composite curve (Fig. 2).

To insulate the hot sulfuric streams from the desalination unit, seawater shall be used as the heat transfer fluid. The installed plate heat exchangers with a very low temperature approach will help to minimize the energy losses. The maximum temperature of the final heated fluid can be 96–98°C. Equally important is the cold part of the curve as well. To utilize all the heat from the cooling process, a cold stream temperature should be below 30°C.

The heat from the cooling system will be utilized in multiple effect distillation units and transferred there in three closed loops with water heated according to the temperature level of the final destination. The hot water in plate heat exchangers replacing existing coolers E06, E07 and E08 will be used as

Heat exchanger	E08	E06 E17	E07 E09
Service	Final tower cooler	Drying tower/ Drying tower/ interpass tower cooler	Drying tower/ Product cooler interpass tower cooler
Acid flow,t/h	944	1463	112
Acid inlet temperature,°C	100.0	106.0	106.0
Acid outlet temperature,°C	84.0	79.0	79.0
Seawater flow,t/h	525	1450	1450
Seawater inlet temperature,°C	22.0	22.0	22.0
Seawater outlet temperature,°C	28.0	33.0	34.0
Heat duty, kWh	6562	19,726 8067	19,726 2 993

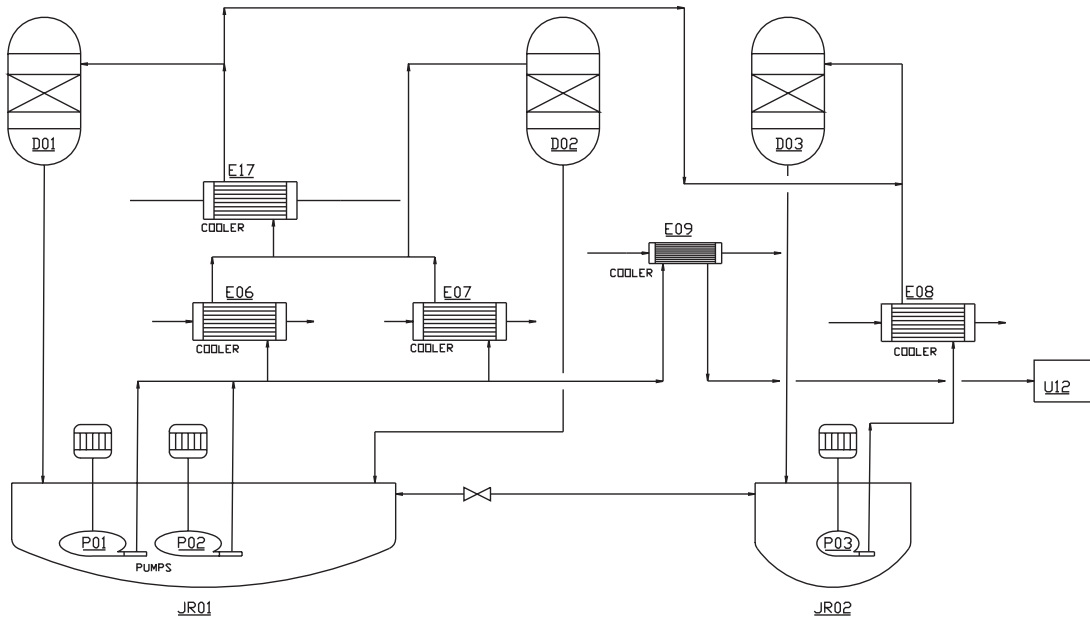


Fig. 1. Acid cooler system.

the main source of heat and will be directed to the flashing chamber at the temperature of 97°C. Here the water will evaporate at pressure corresponding to the pressure in the first effect of the multiple effect distillation unit. The flashed steam at a temperature of 76°C will be able to heat the first evaporation effect

working at the 33 kPa. The outlet temperature of the cooled acid from heat exchangers E06 and E07 limits the bottom temperature of the hot water in the flashing chamber, which is 79°C. The boiling point of seawater is 72°C. The steam generated in the first effect will be directed to the following effect where

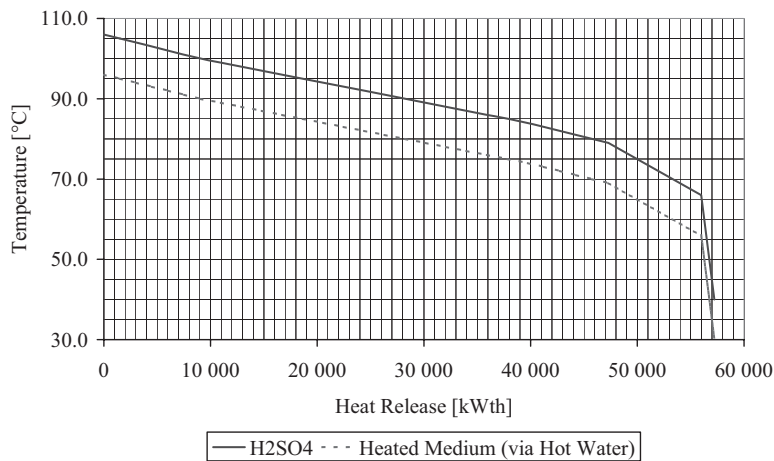


Fig. 2. Composite curve of the acid cooling system.

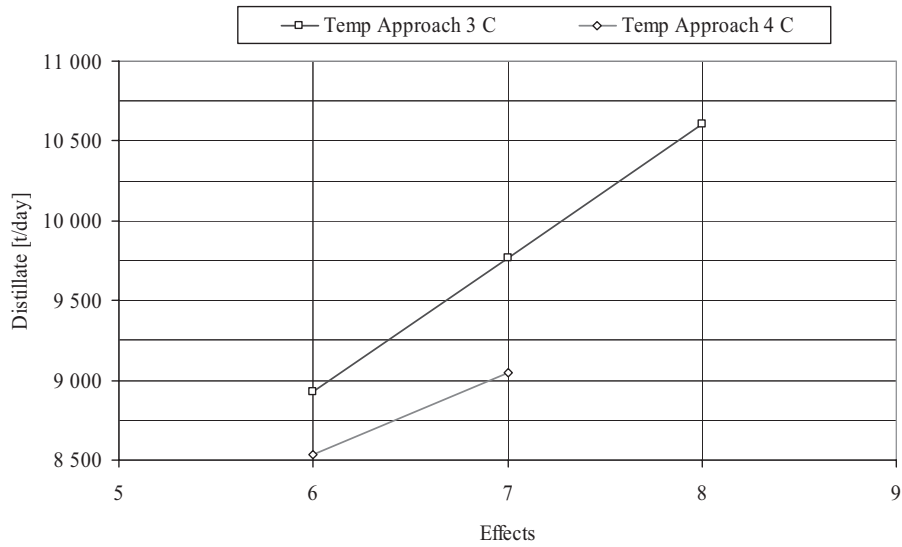


Fig. 4. Production of distillate vs. effects number and min. temperature approach.

temperatures of the seawater. At higher temperatures than the nominal temperature of 22°C it is necessary to increase the flow rate of the cooling seawater to the unit (Fig. 5).

Because changes in the plant capacity correlate to the changes of the acid stream temperatures and consequently with the heat, available for the desalting process, the desalting plant is very sensitive to the operation mode of the acid plant (Fig. 6). The amount

of the distillate is proportional to the plant capacity.

3. Multi-stage distillation plant

The heat from the cooling system will be utilized in a six-vessel multiple stage flash unit and will be transferred via a closed loop with heated water according to the temperature level of the final destination. The hot water

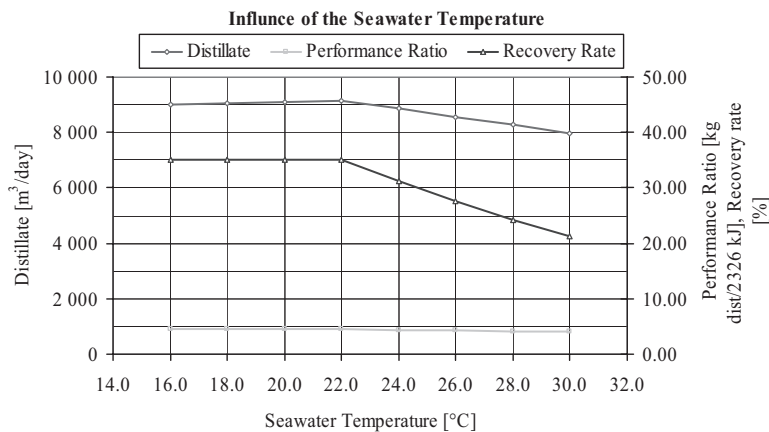


Fig. 5. Sensitivity of the desalination plant performance to the seawater temperature.

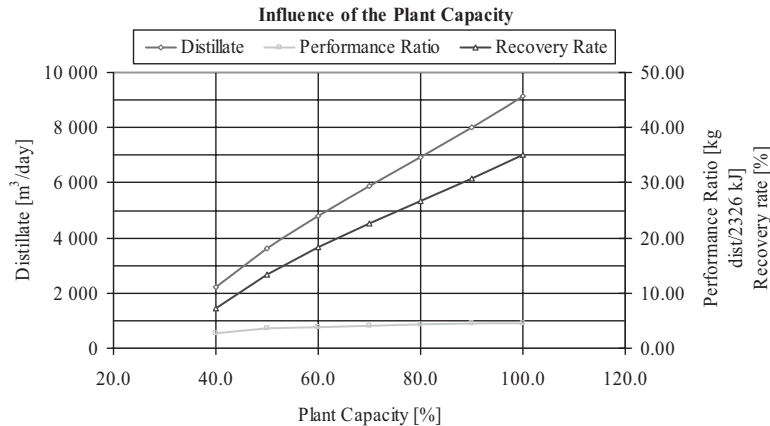


Fig. 6. Sensitivity of the desalination plant performance to the plant capacity (per one unit).

in plate heat exchangers replacing existing acid coolers will be used for heating of the brine heater. The top temperature will be 90°C. Because the seawater is preheated in the condensing parts of the multi-stage distillation (MSF) unit and the inlet seawater temperature to the brine heater is about 60°C it is not possible to use the heat from the other coolers.

The heated seawater from the brine heater is directed to the first flash stage at the pressure of 59 kPa. The flashed steam will condense at the surface of the seawater heater, the un-flashed liquid will continue to the next stage with lower pressure. The last stage will work at a pressure level of 5.5 kPa. The MSF unit will work with recirculation of the brine. It means that the flashing stages are divided in two parts—heat recovery stages (working at a higher pressure) and heat rejection stages (working at a lower pressure). Some portion of the brine from the outlet will be re-circulated to the heat recovery part and some portion of the entering seawater will be directed back to the sea. This arrangement allows controlling of the vacuum at the last stage as well as the decrease in cost of the seawater treatment (Fig. 7).

The produced distillate for six (6) sulfuric acid plants is 18,288 m³/d. The calculated

performance ratio is relatively low because the 6 stages were incorporated only. The normal economy range for multistage flash processes is 3–12 stages. Greater economy is possible, but this requires more stages, which reduces the temperature differential at each stage. The practical maximum number of the stages is about 40 to 50, where economy is about 12 stages.

Because the primary function of the cooling system is to provide the cooling of process acid streams, the seawater entering the brine heater must be at a temperature which allows proper cooling of these streams. It means that the number of the stages is very limited if the brine heater is used as a process cooler. This consequently influences both the GOR and the amount of the produced desalted water.

For the multistage flash process the high feed ratio (kg of feed/kg of distillate) is typical. The flashing is an adiabatic process and the amount of the flashed steam depends on the pressure difference between saturated pressure at the first stage inlet and the last stage. The smaller the pressure difference and the smaller the amount of flashed steam is released, the bigger the feed water flow is necessary. Shown in Fig. 8 is an illustration of this fact. It's evident that for the top temperature of 90°C, the steam fraction is 9.9%;

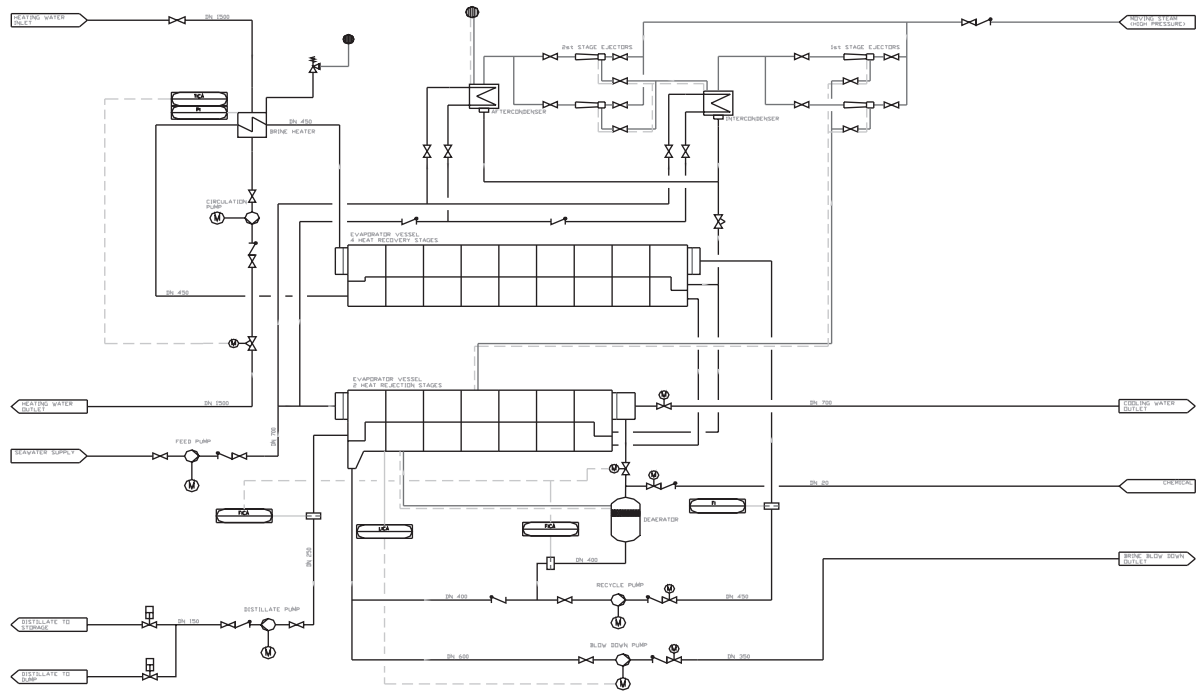


Fig. 7. Multi-stage distillation plant—P & ID.

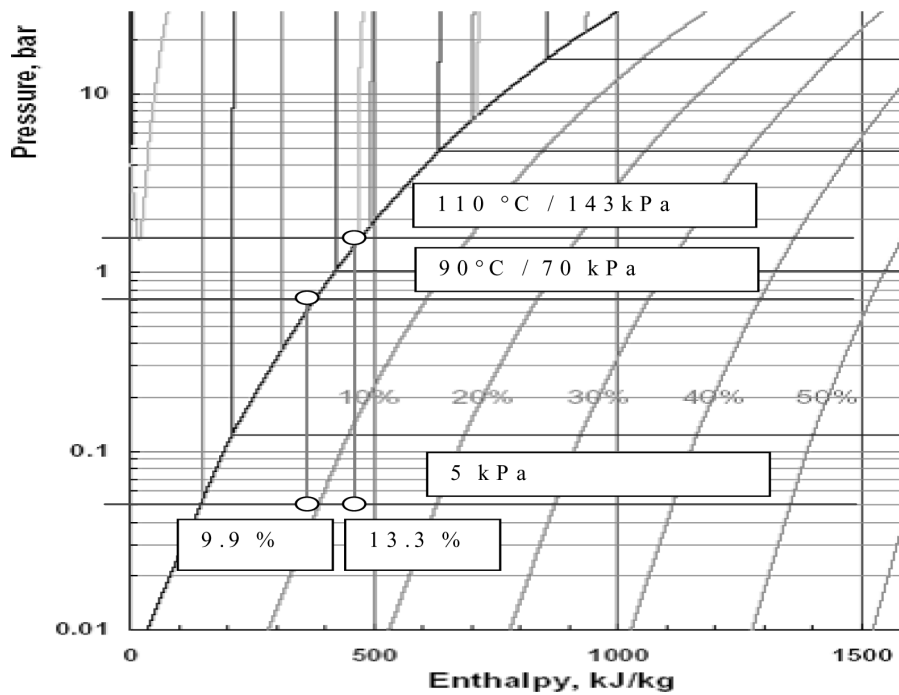


Fig. 8. Flashing in the pressure—enthalpy diagram.

and for the top temperature of 110°C the flashed steam fraction is 13.3 %. This percentage means the amount of the released steam from the flashed water. The feed ratio is the reciprocal value of this number.

To decrease the feed ratio is to increase the top temperature. However, the practical maximum top temperature is about 115°C because it is limited by sulfate scale precipitation.

Fig. 9 shows influence of the pressure at the last stage for two values of top temperature—for 90°C and for 110°C. The graphs are valid for process with very high numbers within the flashing stages. The curve of the boiling temperature curve was added for information.

For MSF processes, the high demand for inlet seawater and power consumption is typical. For the required 10,000 t/d, and the maximum GOR of 8.5 and a top temperature of 90°C it requires three MSF units with 6 vessels which will consume 32 MW of heat, with a feed ratio of 11.3 and the seawater demand of 113,000 t/d, and a power consumption of 1.5 to 2.1 MWe and a required area of 3 × 31 × 21 m. But, this value

of GOR supposes an inlet temperature of the brine heater above 80°C. This arrangement doesn't provide required cooling of the acid streams. Via cooling of the acid under these conditions it can obtain 28 MWh only. The remaining cooling duty must be provided by seawater in existing acid coolers.

It's obvious that the use of the MSF process under conditions of the low grade heat facility, where the amount of the seawater is strictly limited up to 2900 t/h per one plant, is impossible.

4. Summary

During developing the study two (2) options of desalination plant arrangement were evaluated.

The MED plant is relatively simple; the usage of the waste heat from acid coolers is high. The low value of performance ratio is due to the limiting level of the heating fluid temperatures. It is because the primary service is to provide cooling of the acid streams to

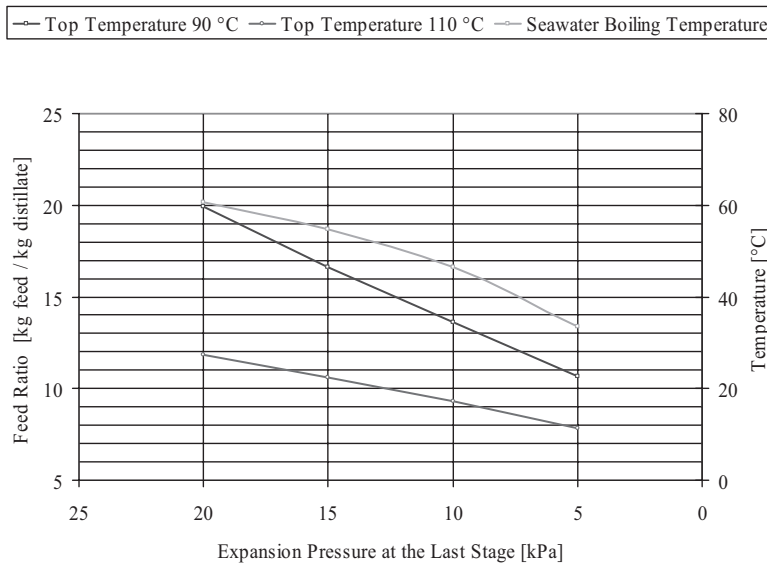


Fig. 9. Feed ratio vs. outlet pressure.

required temperatures. This option was chosen for further economical evaluation.

For the MSF plant, connection of the multi stage flashing unit with utilizing low enthalpy heat from the cooling system is rather problematic. There is a strong collision between the requirements of the desalination process and the requirements of the cooling system. The limiting factor is the request on low tempera-

ture at the inlet into the brine heater, which is heated through heat from the acid cooling system. It means a very low performance ratio. This fact multiplies the typical disadvantage of the MSF process, which is a very high feed ratio (amount of feed water / amount of distillate).

The relevant data of all discussed options are presented in the following table:

Item	MED	MSF
Seawater flow rate, m ³ /d	417,600	576,000
Process inlet seawater flow rate, m ³ /d	156,240	142,848
Product – distillate/demi water, m ³ /d	54,720	18,288
Brine/concentrate, m ³ /d	101,520	124,560
Recovery rate, %	34	12.8
Performance ratio, kg dist./2326 kJ	4.48	1.78
Power consumption, MWe	2.64	2.79

