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# Thermal Performance of MED-TVC Pilot at 95°C Elevated Temperature with Acid-anti-scalant Blend Treatment

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## To cite this article:

Osman Hamed, Amr Mohamed Mahmoud, Khalid Bamardouf, Ahmad Al Ghamdi, Ali Al-Hamzah. Thermal Performance of MED-TVC Pilot at 95°C Elevated Temperature with Acid-anti-scalant Blend Treatment. *International Journal of Mechanical Engineering and Applications*. Vol. 9, No. 1, 2021, pp. 15-18. doi: 10.11648/j.ijmea.20210901.13

**Received:** February 1, 2021; **Accepted:** February 9, 2021; **Published:** February 23, 2021

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**Abstract:** Enhancing the efficiency of desalination plants and economics of desalinated water are the major goal to researchers. In desalination industry; Multi Effect Desalination (MED) has an economic potential which proves its maturity among different desalination technologies. Large MED plants were built and operated with satisfactory performance in the last decade. They have been operated at low temperature compared to MSF and competitive operation efficiency. The Desalination Technology Research Institute (DTRI) which belongs to the Saline Water Conversion Corporation (SWCC) of Saudi Arabia has tested MED pilot plant with hybrid acid and anti-scalant treatment to control the scale. The test was conducted under 95 °C compared to 65 TBT which the current commercial standard operational temperature and previously tested 85 TBT within DTRI-SWCC pilot plant. Increase in the TBT would allow to increase the number of effects which lead to more system efficiency (the performance ratio) and then reduce fuel consumption which reflected in water unit cost of the desalinated water. The results showed that the thermal performance including fouling factor and performance ratio was constant and have very minor degradation during the test. The good thermal performance was confirmed by the post-operation visual inspection, which revealed that the heat transfer tubes were maintained in a clean condition after testing.

**Keywords:** MED-TVC, Top Brine Temperature (TBT), Scaling, Fouling Factor

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## 1. Introduction

Thermal desalination has a long reputation in the market especially in Gulf region as the result of its high reliability and ease of operation through decades. However seawater reverse osmosis (SWRO) desalination technology is mainly applied to new desalination plants, because it is considered as a more cost effective compared to thermal processes [1]. However, since SWRO is very sensitive to seawater conditions (i.e., clay, metal inorganics, organics and algal blooms), its performance is directly influenced by membrane fouling, leading to an increase in the O&M cost and a decrease in plant availability due to shutdowns [2].

Most thermal desalination technologies have relatively high energy consumption while those systems can be reliably operated under severe seawater conditions. There is also a

significant potential to reduce energy consumption of thermal desalination technologies [3&4]. Al-Mutaz describes the salient features of MED-TVC systems which makes it one of the most promising desalination technologies [5]. A MED-TVC system consumes a lower amount of electrical energy compared to the MSF technology and a conventional MED [6-9]. During the 1990s and early 2000s, MED-TVC systems were limited in unit capacities [10], but the 15 MIGD unit of the Yanbu Phase 2 plant and the 20 MIGD unit of Al-Shoiba plant in Saudi Arabia are examples of a modular evaporator concept which allows to build evaporators with any unit capacity considered as practical and economical [5].

A possible high performance ratio (PR) of the MED-TVC can result in considerable reduction of steam consumption for the

same water production in a cogeneration configuration [11] and would be the preferred form of thermal desalination technology in concentrated solar power (CSP) assisted cogeneration [12]. A higher top brine temperature (TBT) increases the operation temperature range of a MED-TVC system, allowing to design MED evaporators with a larger number of effects, which results in the increased PR [5], but it increases the risk of fouling/scaling potential [8]. While in a MSF process a forced brine flow inside the heat exchanger tubes leads to relatively uniform concentrations of the brine exposed to the heat exchange surface area, the concentration of a falling film applied to the outside of the tube bundles in a MED-TVC system can vary in a wide range due to factors like uneven feed water distribution, uneven evaporation, blocked nozzles, and etc. Also, a MSF process includes a ball cleaning system to remove scales which are generated inside of tube during operation, but a MED-TVC is physically difficult to remove scales which was formed outside of tube. For those reasons, MSF plants have been generally designed to be operated at higher TBT of 112°C, while existing conventional MED-TVC plants have been designed with a TBT in the range of 65°C to prevent scale occurrence. An advanced MED-TVC technology with a TBT of 85°C has been successfully developed through analytic and experimental studies in Korea [13-18].

As a step further to increase the TBT, MED-TVC pilot plant located in the premises of the Desalination Technology Research Institute (DTRI) which belongs to the Saline Water Conversion Corporation (SWCC) of Saudi Arabia has been operated over a period of 4 months at a TBT of 95°C using hybrid acid/antiscalant pretreatment. The trigger for this evaluation test was the promising results obtained during 85 C test conducted in cooperation with Doosan heavy industry [17] and previous experience of DTRI-SWCC of operating MED with acidified feed to inhibit the scale participation and merge both technique would assist the unit to operate at higher TBT. The objectives of the pilot test were: (1) to validate the stable operation at a TBT of 95°C, (2) to assess the efficiency of integrated a hybrid pre-treatment of acid followed by anti-scalant dosing under the seawater conditions in the Arabian Gulf.

## 2. Experimental Methodology

### 2.1. Pilot Plant Equipment Description

MED-TVC pilot plant as shown in Figure 1 is locate at the Desalination Technologies Research Institute (DTRI, Saline Water Conversion Corporation (SWCC), Jubail in the Kingdom of Saudi Arabia (KSA) on the Arabian Gulf coast. The distillate production capacity of the pilot plant is 1 m<sup>3</sup>/hr with a makeup seawater flow rate of 3.2 m<sup>3</sup>/hr. Figure 2 shows the flow diagram of MED process. In the MED, the seawater is heated up by rejected brine and distillate passing through plate heat exchangers. Then, it enters MED effect (i.e., top side of evaporator) to condense the vapor inside the tubes and gain heat. The heated seawater evaporates at corresponding temperatures in each effect, and brine is sequentially moved

from effect to effect. The distillate is produced by brine heating in each effect.



Figure 1. HT-MED pilot plant in DTRI, Jubail, KSA.

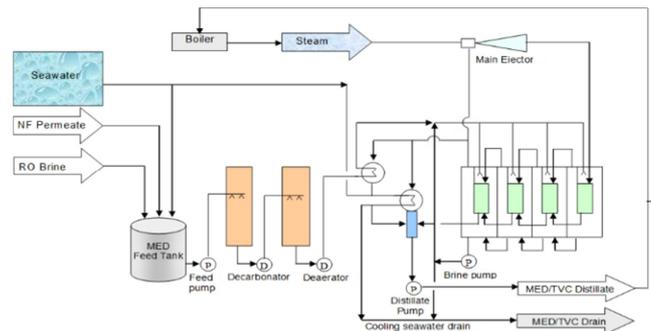


Figure 2. The flow diagram of MED process.

#### 2.1.1. Boiler

The MED-TVC unit receives steam from a steam header coming from the boiler room. The boiler has a capacity of 2,000kg/hr and is of the Fire Tube (FT) – RF type. Its working pressure is 12 bar and the hydro test pressure is 21 bar.

#### 2.1.2. Evaporator

The MED plant has 4 effects with tray type spray feed system (tray + perforated plate) and contains two passes. The tubes in the evaporator are made of Titanium and are 3.6m in length, 18.88mm in diameter and 0.7mm in thickness. The distance between the tubes is 9.5mm and they are arranged in a triangular pattern. First pass has 100 tubes and the second pass has 13 tubes, with 16 rows and 2 rows.

Some of the main differences that can be seen between the HT MED pilot test setup and the commercial MED plants are listed in Table 1.

Table 1. HT MED pilot test setup and the commercial MED plant.

	MED Pilot	Yanbu MED
TBT (°C)	95	65
Feed heating preheaters	No	Yes
Feed type	Parallel	Parallel
Feed method	Tray type	Nozzle type
Liquid Loading Rate (kg/m/s)	0.036	0.05
Max BBD TDS (ppm)	65,000	60,600
Feed (m <sup>3</sup> /h)	6.5	-
Number of Effect	4	5
GOR	3-4	7
Feed temperature	70	45
Bottom temperature	80	48
Brine recirculation	Yes	No

As seen from the table to simulate the lowest part of the tube bundle, brine recycle configuration was implemented to have high concentration factor in the pilot bundle c

## 2.2. Scale Treatment

The Anti-scalant was selected from standard market commercially available and combined with acid treatment sulfuric acid used to adjust feed to deaerator pH to 6.5. The seawater feed is first acidified to consume part of the bicarbonate ions and adjust its pH to 6.5 before entering the deaerator. A polymeric antiscalant is then injected in the seawater makeup to control the alkaline scale formation expected to be generated from the residual bicarbonates ions.

## 3. Results

The success of the trial test was based on the following criteria:

- 1) First effect overall heat transfer coefficient degradation
- 2) First effect fouling factor increase
- 3) Visual inspection

Detailed calculations were done in parallel to confirm reliable operation of the pilot plant under 95°C TBT conditions. TBT, feed, make up sea water, steam and vapor in each effect exhibited stable temperature profiles during the testing period as shown in figure 3 .

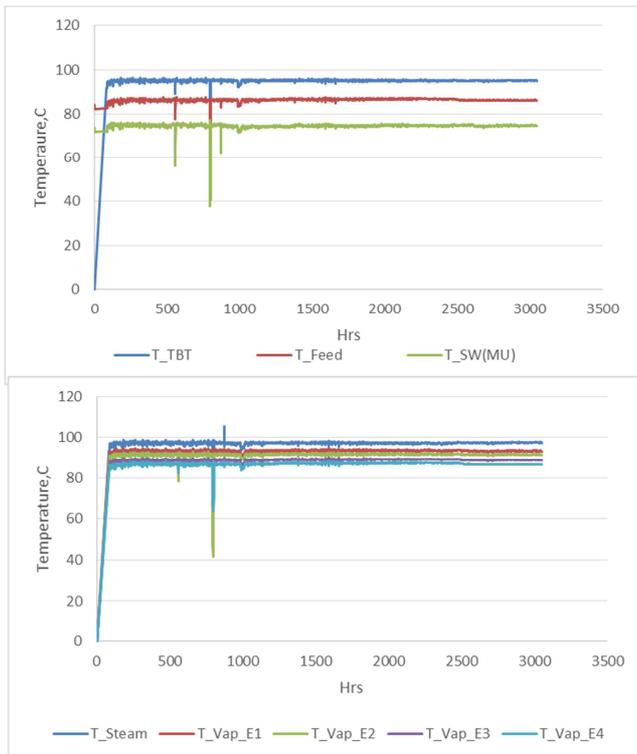


Figure 3. Temperature profiles of TBT, feed, make-up seawater, steam and vapor in each effect.

The flow rate of feed, brine, distillate and steam shows stable trend as well as salinities of feed and brine shown in figure 4.

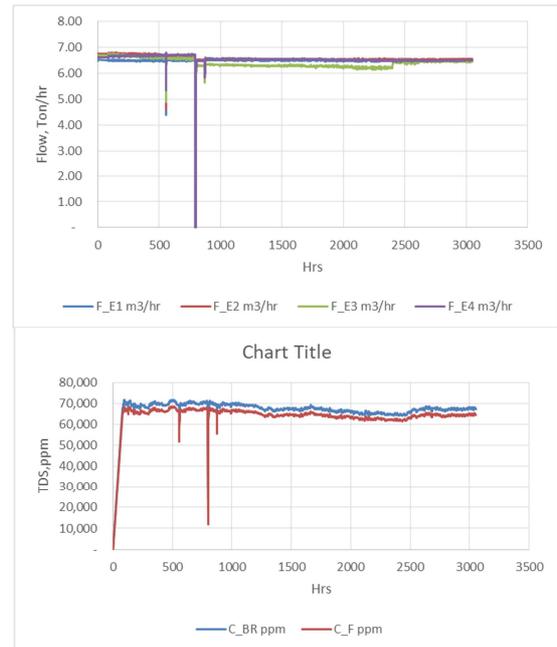


Figure 4. Flow rates and concentrations.

Figure 5. Shows the thermal performance of the first effect. First effect is experiencing the worst operation condition as the result of its high top brine temperature and high salinity. The overall heat transfer coefficient and fouling is stable. Only some increase in MTD and it was found to be related to the motive pressure increase.

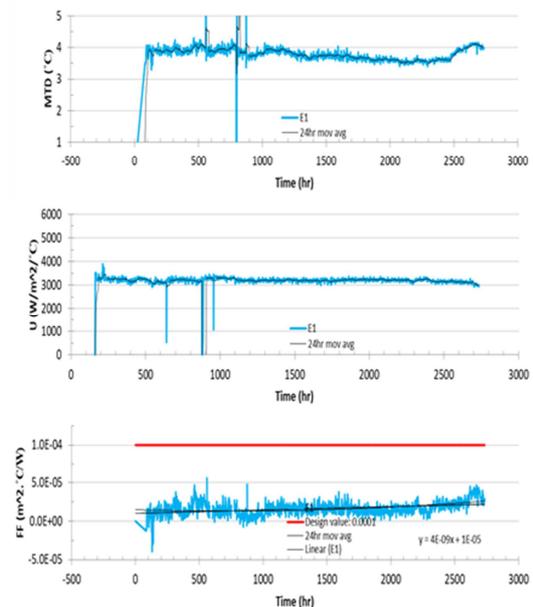


Figure 5. First effect MTD, HTC and FF.

At the end of the testing period, a visual inspection was performed in order to validate the performance of the hybrid chemical treatment. Figure 6 and 7 show the tube surfaces of the first effect before and after testing period. After the test, no scale was found on the tube surfaces which confirm thermal analyses results



Figure 6. Pre- test visual inspection.



Figure 7. After - test visual inspection.

## 4. Conclusion

The evaluation test of hybrid acid/antiscalant pretreatment was carried out in 24 m<sup>3</sup>/d MED unit. During the four month test period, the top brine temperature (TBT) was maintained constant at 95°C and antiscalant dose rate of 2 for four month & pH adjusted around 6.5. Based on the thermal performance and visual inspection results it can be concluded that the pilot plant test was successful. Satisfactory operation of commercial MED TVC desalination plants at elevated temperature of 95°C would lead to increase number of effects per evaporator and hence increase the thermal efficiency of the MED unit and enhance its economic viability.

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