SWCC MSF DESALINATION PLANTS - CURRENT STATUS AND FUTURE PROSPECTS

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ABSTRACT

The Saline Water Conversion Corporation (SWCC) is currently producing around 20.7% of the total world production of desalinated water. Around 88.5 percent of SWCC total water production is produced by large MSF plants, 10.6 percent produced by large RO plants which are combined with existing dual MSF/power plants and 0.9 percent is produced by small size (satellite) RO, MSF and ME plants.

A wide range of design and operating features characterizes SWCC MSF distillers. Number of stages varies from as low as 16 up to 34, distiller capacity ranges between 2.5 and 10 MIGD and top brine temperatures are between 90 and 121^{o}C. Comprehensive thermal analysis, based on design data of various MSF plants of SWCC, was performed. The irreversibility inherited in the design of each plant is determined and quantified to facilitate a direct comparison between the different designs. Subsystems, which are responsible for uneconomic fuel consumption are identified. Prospects of reducing MSF irreversibility will be discussed and used as a guideline for selecting the main features of the prospective improved MSF distiller.

Operational performance of SWCC's major MSF plants was also monitored and evaluated. Actual operational data covering one-year period were collected from ten distillers representing Al-Jubail Phase-I and II, Al-Khafji Phase II, Al-Khobar Phase-II, Jeddah Phase-II, III and IV, Yanbu Phase-I, Shuqaiq Phase-I and Shoibah Phase-I. The thermal analysis revealed that plants' performance ratios are in most cases equal to or higher than the design values, which could be attributed to SWCC strict operating and maintenance procedure, which could result in extending the plant life to more than 30 years.

The R&D Center recently introduced an innovative concept using nanofiltration membrane (NFM) for pretreatment of make up to MSF pilot plant. The NFM is successful in removal of most of the scale forming ions (calcium, magnesium, bicarbonate and sulfate) from the feed seawater, which has enabled to increase the top brine temperature above the calcium sulfate solubility limits, which are normally encountered in conventional seawater pretreatment. Evaluation tests, which have recently been performed on a MSF pilot plant coupled to NF membrane and operating at a TBT of 120 ^{o}C with no scale control chemical treatment, will be reported in this paper.

Keywords: *SWCC, Desalination, MSF, Design, Operation, Performance, Pretreatment.*

الملخص

تنتج المؤسسة العامة لتحلية المياه المالحة بالمملكة العربية السعودية حوالي (٢٠,٧ %) من الإنتاج الكلي للمياه المحلاة في العالم، ويتم إنتاج حوالي (٨٨,٥ %) من الإنتاج الكلي للمؤسسة بواسطة محطات كبيرة تعمل بنظام التبخير الومضي المتعدد المراحل، و (١٠,٦ %) تنتجها محطات التناضح العكسي، و (٠,٩%) تنتجها محطات صغيرة بالمناطق النائية تتسم محطات المؤسسة للتبخير الومضي بخصائص تصميمية وتشغيلية مختلفة ومتعددة حيث يتراوح عدد مراحل التبخير من ١٦ إلى ٣٤ ، وسعة إنتاج المبخرة الواحدة من ٢ر٥ الى ١٠ مليون جالون امبراطوري يومياً ، ودرجة الحرارة القصوى للمحلول الملحي بين ٩٠ إلى ١٢١ درجة مئوية .

تعرض هذه الورقة تحليلاً شاملاً للأداء الحراري لعدة محطات لتحلية المياه مبنياً على خصائصها التصميمية لمعرفة فاقد الطاقة الغير مسترجع والموروث في تصميم كل محطة، وتحديد أجزاء المبخرة الرئيسة المسئولة عن إهدار الطاقة، وبناءً على ذلك تم مناقشه الأساليب المختلفة التي يمكن اتباعها لتحديد الخصائص الرئيسة للمبخرات المحسنة.

وقد تمت متابعة وتقييم الأداء التشغيلي للمحطات الرئيسة للمؤسسة والتي تعمل بنظام التبخير الومضي المتعدد المراحل حيث تم جمع البيانات الخاصة للظروف التشغيلية لفترة عام كامل لعشرة مبخرات تمثل المحطات الرئيسية للمؤسسة وقد أثبتت نتائج التحليل الحراري أن معدل الأداء لهذه المبخرات كان جيداً وقد كان هذا الاداء المميز لهذه المحطات نتيجة للأساليب التي تتبعها المؤسسة في تشغيل وصيانة هذه المحطات والتي وكان لها دور فعال في إيطالة عمرها الافتراضي لأكثر من ٣٠عاماً.

قام مركز الأبحاث والتطوير التابع للمؤسسة العامة لتحلية المياه حديثاً بابتكار أسلوب جديد للمعالجة الأولية لمياه تغذية محطة تبخير ومضي تجريبية وذلك باستخدام أغشية النانو الدقيقة لغرض إزالة الايونات المتسببة في تكوين القشور الملحية على اسطح الانابيب الحرارية، ولقد مكن استخدام هذا الاسلوب بتشغيل هذه المحطة بدرجة حرارة قصوى للمحلول الملحي تتجاوز حدود ترسب أملاح كبريتات الكالسيوم ، وتشمل هذه الورقة عرض نتائج التجارب التقييمية التي أجريت حديثا في هذه المحطة .

1. INTRODUCTION

The Saline Water Conversion Corporation (SWCC) is currently producing around 20.7% of the total world production of desalinated water [Wangnick, 1998]. Around 88.5 percent of SWCC total water production is produced by large MSF plants, 10.6 percent produced by large RO plants and 0.9 percent is produced by small size (satellite) RO, MSF and ME plants.

All SWCC's large MSF plants operate within the context of dual-purpose facilities for the simultaneous production of power and water. Such co-generation arrangement uses either backpressure or extraction condensing turbine. Some MSF/Power plants are also combined with RO plants (Jeddah, Yanbu & Al-Jubail) taking advantages of common seawater intake and outfall, part of common pretreatment facilities and blending of products in appropriate proportions from MSF and RO plants if the need arises, thus reducing power to water ratio.

SWCC, being the largest producer of desalinated water in the world, has acquired accumulated design and operation information, which can be effectively utilized for the selection of an improved and optimized MSF design. In this paper, design features and performance characteristics of SWCC's major MSF plants, which were previously reported by [Hamed, et al., 2001] would be highlighted. Recent operation performance of ten distillers representing SWCC major MSF plants covering around one-year period, will also be presented. Information on the current thermal performance and daily water production can be used as a guide to predict the plants' life expectancy and whether there is any possibility for further improvement in production. Attempts for future development of the MSF process are also discussed.

2. REVIEW OF DESIGN PARAMETERS

A wide range of design features characterizes SWCC cogeneration cycles and MSF distillers.

2.1 Cogeneration Cycles

Cogeneration cycles which were used till 1982 were employing extraction condensing turbines with power to water ratio ranging between 10.2 to 17.5 MW/MIGD as shown in Table 1. From 1983 onwards extraction condensing turbines were replaced by back pressure turbines in all new cogeneration plants. Backpressure turbines give lower power to water ratio (high water demand) and they are also characterized by high thermal efficiencies [Hamed, et al., 2001]. They make the best use of low-grade heat that would otherwise be rejected by the power generating plant cycle. Fuel consumption for water production in a backpressure turbine cycle is around 50 % less than that required by a single purpose water plant.

2.2 MSF Distillers

2.2.1 Common Features

SWCC is currently operating 117 MSF large distillers that are characterized by a wide range of design features. The common features of these distillers are that they are single deck, operating with brine recirculation mode and having on line sponge ball cleaning systems. All the distillers except those of Jeddah Phase-II and IV, which are having long tube configuration, are with cross-tube configuration. External deaerators are attached to all distillers except those of Al-Jubail Phase-I. The number of stages varies from 16 (in Al-Khobar Phase-II & III and Jeddah III) up to 34 in the unique design configuration of Jeddah II. Summary of the salient MSF design features are shown in Table 2.

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2.2.2 Main Performance Parameters

Distillers' distillate production ranges from as low as 2.5 MIGD in the Al-Khafji and Jeddah-II plants up to 10 MIGD in the recently commissioned Shoaiba Phase-II plant. With fewer units of higher production capacity, the need for interconnective and control piping and valves will be much reduced. The single unit is simpler to operate, and the number of operators required is smaller. Overall, major gains in initial cost, reliability, operation and maintenance can be expected with large unit sizes. The top brine temperatures range between 90 to 115 ^{o}C in additive plants and up to 121 ^{o}C in Yanbu phase-1 acid plant. The design performance ratio ranges between 2.78 to 4.56 kg/1000 kJ.

2.2.3 Flash Chamber Configuration

There is a wide variation in the dimensions of the flash chambers. Flash chamber width varies from 3 to 20m, stage length between 2.35 to 8.3 m and stage height ranges between 3.15 to 4.8m. The size of the flash chamber is depending on the vapor mass release rate (flow rate of vapor leaving the brine surface as flashing occurs in stage) and the shell load (flashing brine flow rate per unit width of the flash chamber).

The vapor release velocity is stage dependent due to the fact that the vapor specific volume in low temperature stages is substantially larger than those in the high temperature stages. This effect is slightly offset by making the low temperature stages slightly larger (larger plan area) than the remaining stages. The vapor release velocity must not be above the allowable value because otherwise brine droplets will be entrained with the vapor and can lead to carry over of brine into the distillate. For SWCC plants the vapor release velocity profile varies from one plant to another, i.e., between 0.6 to 1 m/s for the first (high temperature) stage and 3.5 to 7 m/s for the last recovery stages.

The brine tube velocity for the majority of MSF plants is around 2.0 m/s. Al-Jubail Phase-II (C 5 group) and Al-Khafji Phase-II are having relatively low tube brine velocities, which is around 1.5m/s. Normally, the maximum allowable brine velocities are chosen as per tube construction material (1.99 m/s for 90/10 Cu-Ni and 2.44 m/s for 70/30 Cu-Ni). This is done because heat transfer increases with increasing tube velocity, thereby reducing the required heat transfer surface area. Economic evaluation can sometimes lead the designer to choose lower tube velocities. However, minimum velocity chosen for design should never be less than 1.22 m/sec. At velocities less than this value tube surfaces shall be fouled at a substantial rate, thereby reducing heat transfer considerably.

The flashing brine flow rate per unit width of the flash chamber (shell load) is an important design parameter that affects the cost of shell as well as non-equilibrium losses in the stage. The shell load of major cross-flow SWCC's MSF plants ranges between 478 ton/hr.m (for plants with low rated capacity such as Al-Khafji-II) up to 965 ton/hr.m (for Shoaiba II plant).

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Using regression analyses the shell load of SWCC MSF cross flow distillers can be estimated from the following rule of thumb :

Shell load *ton/(hr.m)*

$$= 457.2 + 53.43 D$$

where D is the distiller rated capacity (MIGD)

An important design parameter that influences distillate purity is the demister height from stage floor and from brine surface. The majority of SWCC's MSF plants are having demister height from stage floor ranging between 2.3 to 3.3 m. Jeddah II and III are having relatively low demister heights, which are 1.57 and 1.89 m. Jeddah III which is currently operating on additive rather than acid treatment is currently experiencing high demister clogging especially in the first three high temperature stages.

3. OPERATIONAL ANALYSIS

A total number of ten distillers that are of different design configurations and covering a wide range of operating conditions, were selected. They included one distiller from each of Al-Khobar Phase-II, Al-Jubail Phase I, Al-Jubail phase II, Al-Khafji Phase II, Shoaiba Phase I, Shuqaiq, Yanbu Phase I and three distillers from Jeddah plants representing Phases-II, III and IV. Field visits were arranged to these plants to collect design and operation data. For each distiller, the operational data collected include temperature, pressure, flow-rate and salinity of all streams. Frequency of data collection ranged between 1 and 3 weeks.

Variation in performance ratio (PR) of each distiller with time is shown in Figure 1, which reveals that the distillers instead of being derated due to aging, the performance ratios are maintained equal or in most cases, more than the design values. The reasons for such good thermal, performance could be attributed to several design and operating factors, such as SWCC strict requirements of operation and maintenance, use of improved high temperature additives and use of on-load ball cleaning system.

Also design fouling factors (FF) of the brine heaters and heat recovery sections for SWCC's additive plants range between 0.000176 and 0.000325 m^2K/W while for acid plant range from 0.0000861 to 0.00012 m^2K/W. But due to the good performance of antiscalant in conjunction with effective use of sponge ball cleaning, these FF values are very conservative (larger than required). Selection of large FFs results in a heat exchanger containing more surface area than required. Low values of design fouling factors such as 0.00015 m^2K/W can be safely employed in new MSF designs.

However, the selection of high design fouling factors for the existing MSF plants, which result in over sizing of the heat transfer surface, will allow to operate these plants at top brine

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temperature equal to or even higher than maximum design values. This will result in the increase of water production. So, prospects for increasing water production from existing plants have to be explored. To achieve these objectives a number of feasible design and operating variables have first to be confirmed such as:

(1) Availability of extra heat transfer surface area.

(2) Increase of TBT for extra production might possibly overload the flash chambers and demister pads and give higher and possibly unacceptable distillate conductivities.

(3) Sizes of the various operating pumps (especially brine recycle, distillate and condensate) meet the requirements of the increased production.

(4) Overloading of distillate troughs.

(5) Possibilities of blocking small diameter tube of brine heater with scale.

(6) Capability of vacuum ejectors.

4. SCALE CONTROL

SWCC has been actively involved in the control of scale formation on heat transfer surfaces. A number of optimization tests, which have been conducted in Al-Jubail and Al-khobar plants were reported [Al-Sofi, et al., 1987; Al-Mudaiheem & Szostack, 1986; Nada, 1986; Al-Zahrani, et al., 1993; Al-Sofi, et al., 1994; Al-Sofi, et al., 1989; Hamed, et al., 2002].

The Research and Development Center has also been involved since its inception in the evaluation and dose rate optimization of commercial scale inhibitors in collaboration with Al-Jubail and Jeddah plants as shown in Table 3 [Hamed, et al., 1999; Hamed, et al., 1996; Hamed, et al., 1998; Hamed, et al., 2001; Al-Sofi, et al., 1999]. Antiscalant dose rate has been successfully reduced to as low as 0.8 ppm for low top brine temperatures (90-98^{o}C) and 1.8 for TBT of 110^{o}C. Summary of antiscalant dose rate currently used in SWCC MSF plants is shown in Table 4.

All SWCC's MSF plants are currently using on-load sponge ball cleaning system. The combined use of chemical additives and on-load sponge ball cleaning system has proved to be the most cost effective procedure to avoid tube scaling. But there is a wide diversity in the ball to tube ratio and number of cycles of ball cleaning operation. The ball to tube ratio for plants using chemical additive treatment varies from as low as 0.22 (in Al-Shuqaiq plant) up to about 0.45 (in Al-Jubail Phase-I and Al-Khobar plants). The number of cycles per operation varies between as low as 3 (in Al-Shoaiba-I) up to 13 (in Yanbu-II). The sponge ball cleaning frequency required to maintain the evaporator cleanliness depends on several factors, such as brine chemistry, type of inhibitor, ball type, MSF design parameters (temperature, number of stages, tube length, flow pattern) [Böhmer, 1998 & Böhmer, 1993]. There is no standard procedure for ball cleaning operation, which is followed by all SWCC's MSF plants.

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5. PROSPECTS FOR IMPROVED DISTILLATION CONFIGURATIONS

The majority of SWCC's existing MSF plants are currently having total number of stages ranging between 16 and 24 and operating at top brine temperature between 90 and 110°C. Increasing the number of stages and/or increasing the top brine temperature can reduce the specific energy consumption of MSF distillers [Hamed, et al., 2001 & Hamed, et al., 2001]. The top brine temperature is currently limited by the solubility limits of calcium sulfate salts. Recently, a promising approach for pretreatment of seawater using nanofiltration membrane has been successfully used which results in almost total sulfate removal [Hassan, et al., 1998; Hassan, et al., 1998; Hassan, et al., 1998].

Preliminary evaluation tests were recently conducted on a 20 ton/day MSF pilot plant coupled to a NF membrane. Seawater is first passed to a NF membrane. The NF membrane was capable to reduce 75% of M-alkalinity, 93% of total hardness as $CaCO_3$ and more than 99% of sulphate ions. The MSF was operated with NF permeate as make-up at a top brine temperature of 120 °C for a period of around 800 hours without using any antiscalant. The thermal performance of the unit during this period as depicted in Figure 2, shows that there was no sign of scale formation and the fouling factor was consistently well below the design value.

6. CONCLUSIONS AND RECOMMENDATIONS

1. Monitoring the thermal performance of ten MSF distillers representing SWCC MSF plants on the east and west coasts revealed that the distillers instead of being derated due to ageing, the production capacities and performance ratios are still maintained within or in most cases higher than the design values.

2. Excellent scale control capability of currently used scale inhibitors and on-load sponge balls cleaning allowed: (i) successful operation at low and optimized antiscalant dose rates, (ii) possibility of increasing water production through the increase of the top brine temperatures of a number of currently operating MSF plants and (iii) selection of low design fouling factors as low as 0.00015 m^2K/W for the brine heater and heat recovery section.

3. The wide diversity of the design features of SWCC MSF plants together with the accumulated operational experience can be effectively utilized for the search of an improved MSF design and adoption of enhanced and reliable operational and maintenance procedures.

4. Further optimization tests have to be carried out to understand and establish standard procedures for ball cleaning operation and reduce antiscalant dose rates to effective and reliable values.

5. Preliminary evaluation tests carried out in RDC showed that pretreatment of seawater with nanofiltration membranes is a promising approach to escape from the top brine temperature limitation imposed on the currently operating MSF plants. But its practical application in commercial units has to be explored and investigated.

7. REFERENCES

1. Al-Mudaiheem, A.M.A., and Szostack, R.M., 1986, "Evaluation of Chemical Additives for Scale Control in MSF Plants", Topics in Desalination (13), SWCC, Saudi Arabia.
2. Al-Sofi, M.A., Mustafa, G.M., Hassan, A.M., Dalvi, A.G.I and Kither, N.M., 1998, "Nanofiltration as a means of achieving higher TBT of ≥ 120^{o}C in MSF", *J. Desalination*, **118**, pp. 123-129.
3. Al-Sofi, M.A., 1999, "Fouling Phenomena in Multistage Flash (MSF) distillers", *Desalination*, **126**, pp. 61-76.
4. Al-Sofi, M.A., Al-Husain, M.A., Al-Omaran, A.A. and Farran, K.M., 1994, "A Full Decade of Operating Experience on Al-Khobar-II Multistage Flash (MSF) Evaporators (1982-1992)", *Desalination*, **96**, pp.313-323.
5. Al-Sofi, M.A., Al-Hussain, M.A. and Saleh, G.A., 1987), "Additive Scale Optimization and Operation Modes", *Desalination*, **66**, pp.11-32.
6. Al-Sofi, M.AK, Khalaf, S. and Al-Omaran, A.A., 1989, "Practical Experience in Scale Control", *Desalination*, **73**, pp. 313-325.
7. Al-Zahrani, G. S., Al-Ajlan, A.M.and Al-Jardan, A.M., 1993, "Using Different Type of Antiscalants at the Al-Jubail Power and Desalination Plant in Saudi Arabia". *Proceedings of IDA and WRPC World Conference on Desalination and Water Treatment*, Yokohama, Japan, Vol. **1**, pp. 421-431.
8. Böhmer, H, 1993, "On-load tube cleaning systems and debris filters for avoidance of microfouling in MSF desalination systems", *Desalination*, **93**, p.171.
9. Böhmer, H., 1998, "On-load sponge ball cleaning system", Encyclopedia of Desalination and Water Resource. Chapter II.
10. Hamed, O. A., Al-Sofi, M.AK., Imam, M., Ba-Mardouf, K., Al-Mobayed, A.S. and Ehsan, A., 1996, "DSB(M) Antiscalant Testing at low dose rate", Research & Development Center, Report No. TSR-3808/97026 Part I.
11. Hamed, O. A., Al-Sofi, M.AK., Imam, M, Mustafa, G. M., Ba-Mardouf, K and Al. Washmi, H, 2001, "Simulation of Multi-Stage Flash Desalination Process," *J. Desalination*, **134**, pp.195 – 203.
12. Hamed, O. A., Al-Sofi, M.AK., Ba-Mardouf, K, 2001, "Successful Operation of Multi-Stage Flash distiller at Low Antiscalant Dose Rate", *Proc. of the 4th Annual Workshop on Water Conservation in the Kingdom,* KFUPM, pp. D-2-1.23 - 25 April, Dhahran, Saudi Arabia,

13. Hamed, O. A., Al-Sofi, M.AK., Imam, M, Ba-Mardouf, K., Al-Mobayed, and Ehsan, A, 2000, "Evaluation of Polyphosphenate Anti-scalant at a low dose rate in Al-Jubail Phase II MSF Plant", Saudi Arabia, *J. Desalination*, **128**, pp. 275-280.
14. Hamed, O. A., Al-Sofi, M.AK., Imam, M, Ba-Mardouf, K., Al-Mobayed, and Ehsan, A, 1998, "DSB(M) Antiscalant Testing at low dose rate in Al-Jubail Plant", Research & Development Center, Report No. TSR-3808/97026 Part II.
15. Hamed, O. A., Al-Sofi, M.AK., Mustafa, G. M., Ba-Mardouf, K and Al. Washmi, H, 2001, "Prospects of Improving Energy Consumption of the Multistage Flash Distillation Process", *Proceedings of the 4th Annual Workshop on Water Conservation in the Kingdom,* pp. F-2-1 – F-2-14, KFUPM, 23 - 25 April, Dhahran, Saudi Arabia.
16. Hamed, O. A., Al-Sofi, M.AK., Mustafa, G. M., Ba-Mardouf, K and Al. Washmi, H, 2001, "Overview of Design features and Performance Characteristics of Major Saline Water Conversion Cooperation (SWCC) MSF plants", *Proceeding of WSTA 5th Gulf Water Conference*, pp.357-368, Doha, State of Qatar.
17. Hamed, O. A., Al-Sofi, M.AK., Mustafa, G. M., Ba-Mardouf, K and Al. Washmi, H, 2001, "Power / Water Cogeneration Cycles Analysis Part-1 Design Data Theoretical Analysis", *Proceedings of IDA World Congress on Desalination and Water Reuse*, Manama, Bahrain.
18. Hamed, O. A., Al-Sofi, M.AK., Mustafa, G.M.and Dalvi, A.G.I., 1999, "The performance of different antiscalants in multistage flash distillers", *Desalination,* **123**, pp.185-194.
19. Hassan, A.M., Al-Sofi, M.AK., Al-Amodi, A.S., Jamaluddin, A.T.M., Kither, N.M., Mustafa, G.M. and Al-Tissan, A.R., 1998, "A new approach to membrane and thermal seawater desalination using nanofiltration membranes", Presented at the IDA, Madrid, p.19.
20. Hassan, A.M., Al-Sofi, M.AK., Al-Amodi, A.S., Jamaluddin, A.T.M., Kither, N.M., Mustafa, G.M. and Al-Tissan, A.R., 1998, "A New approach to membrane and thermal seawater desalination", *Desalination & Water Reuse*, **8** (1&2), p. 53.
21. Nada, N., 1986, "Evaluation of Various Additives at Al-Jubail Phase-I during Reliability Trials", Topic in Desalination No. 13, SWCC, Saudi Arabia.
22. Wangnick Consulting GmBH, 1998, IDA World wide desalting plants inventory, Report 16.

Table 1. Power Production System

Till 1982			After 1982		
Extraction Condensing Turbine	**Commissioning Date**	**P/W (MW/ MIGD)**	**Back Pressure Turbine**	**Commissioning Date**	**P/W (MW/ MIGD)**
Jeddah II	1978	10.2	Jubail II	1983	6.8
Jeddah III	1979	15.3	Khafji-II	1986	8.1
Jeddah IV	1981	14.7	Shoaiba I	1989	6.2
Yanbu –I	1981	17.5	Shuqaiq	1989	5.9
Al-Khobar-II	1982	16.8	Al-Khobar-III	2000	9.46
Jubail I	1982	13.8	Yanbu-II	2000	3.0
			Shoaiba-II	2000	6

Table 2. Summary of the salient design features of SWCC MSF distillers

Parameters	**Range**
No. of stages	16-34
PR	6.5 – 10.6 kg/2326 kJ
Distiller capacity	2.5 – 10 (MIGD)
Top brine temperature	90 – 121 °C
Design fouling factor BH	0.086-0.325 m^2K/kW
Design fouling factor HR	0.086-0.279 m^2K/kW
Brine velocity (m/s) BH & HR	1.5 – 2.1
M_{SW}/M_d	3.27 – 13.35
M_R/M_d	3.63 – 13.63
Concentration ratio	1.2 – 1.7
Flash chamber stage length (m)	2.35 – 8.0
Flash chamber width (m)	3 – 20
Flash chamber height (m)	3.15 – 4.8

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Table 3. Evaluation Tests Carried Out by R&D Center in Collaboration with the Commercial Plants to Reduce Antiscalant Dose Rate

Plant	Type of Antiscalant	Dose Rate (ppm)	TBT (^oC)
Al-Jubail Phase-II	DSB(M)	0.8	90
Al-Jubail Phase-II	Belgard EV 2030	0.8	90
Al-Jubail Phase-II	Sokalan PM 10	1.5	105
Al-Jubail Phase-II	Belgard EV 2030	0.8	98
Jeddah IV	Belgard EV 2030	2.0	110
Jeddah IV	Sokalan PM 10	1.8	110
Jeddah III	DSB(M)	3.0	108
Jeddah III	POC 3000	2.5	108

Table 4. Current Antiscalant Dose Rate of SWCC MSF Plants

Plants	Top Brine Temp. (^oC)	Dose Rate (ppm)
Al-Jubail Phase-I	90	0.8
Al-Jubail Phase-II	98	1.0
Al-Khafji	88	1.0
Al-Khobar Phase-II	90	1.0
Al-Khobar Phase-III	103	1.5
Jeddah Phase-III	108	3.0
Jeddah Phase-IV	110	2.0
Shoaiba	96	1.1
Yanbu	115	3.0
Shuqaiq	90	1.0

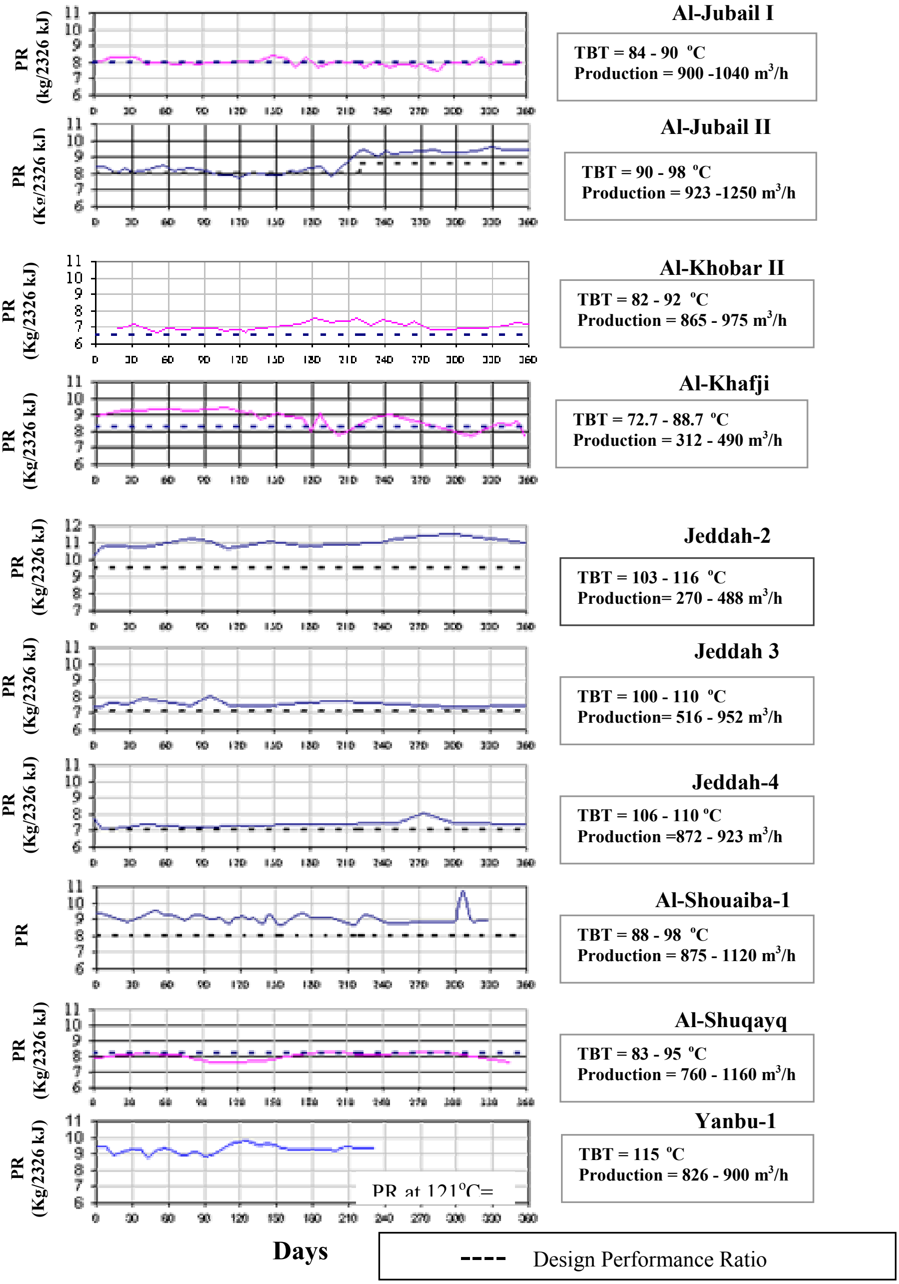
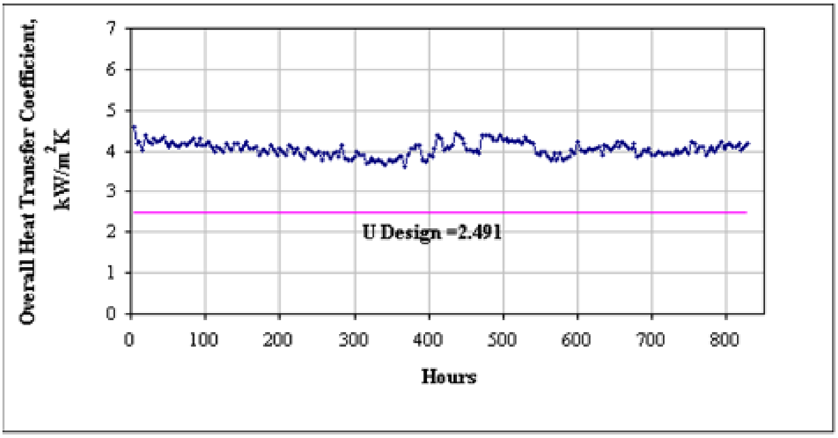


Figure 1 - Operational Performance of MSF Distillers



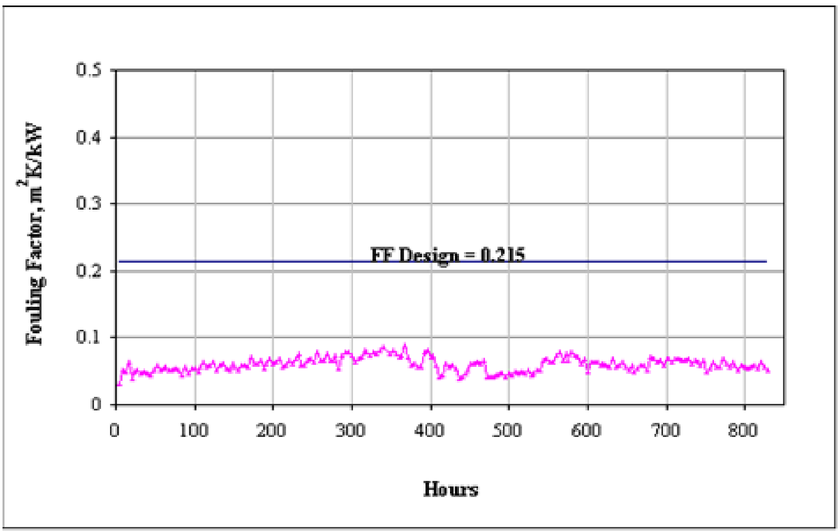


Figure 2. Performance Evaluation of MSF Pilot Plant with Nanofiltration Trisep 80 at TBT 120 °C and CR 1.4

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