

Titanium Tube MSF Evaporator Two Decades of Operating Experiences

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Abstract

AL-Jubail desalination plants complex in the kingdom of Saudi Arabia comprise of 46 multistage flash (MSF) evaporators, out of which six (6) evaporators are Titanium tube construction including Brine heater, Heat recovery, Heat rejection. The base design distillate production capacity of each evaporator 5 MIGD with design Top Brine Temperature (TBT) 90.6 ° C. This paper discusses the choice and application of Titanium in combination with various alloys, precautions adopted for bi-metallic coupling, problems faced and remedial actions, life expectancy based upon designed conditions and operating method including tube cleaning and conservation during shutdown.

INTRODUCTION

The purpose of presentation of this paper is to share saline water conversion corporation (SWCC) kingdom of Saudi Arabia's experiences with the world desalination community concerning usage of titanium in multistage flash (MSF) evaporators. In order to meet fresh water requirements for the AL-JUBAIL industrial city under massive construction stage and building of world's biggest desalination plant AL-JUBAIL Ph-2 (base capacity 210 MIGPD) to supply fresh water to the kingdom's capital city Riyadh, AL-JUBAIL Ph-1 evaporators were built and subsequently commissioned in the year 1981. Ph-1 evaporators are conventional multistage flash (MSF) types. The peculiarity and specialty of this plant is that "they are the only all titanium tube evaporators" built for SWCC.

TECHNICAL SPECIFICATION

A- BRINE HEATER TYPE:-

Cylindrical shell and straight tube type

No of passes :- 1

Fluid :-

Shell side Heating steam

Tube side Recycle brine

Design temp. Shell side 100 deg.C

Tube side 100 deg.C

Design press. Shell side 3.45Bar.G

Tube side 10 Bar.G

Overall H.T.C 2,139 w/m²/deg.K

Heat transfer area 3,013.31 sqr. meter

No of tubes 2,222 pcs

Pitch 40 mm triangular

Tube size (mm) 32.0(O.D) x 30.73(I.D)x 0.635(thick) x 13,720(L)

Distance

(between tube plates) 13,492 mm

Operating temp. Recycle brine Inlet 84.85 deg.C

Recycle brine Outlet 90.56 deg.C

Heating steam Inlet 100.0 deg.C

	Condensate outlet	95.0 deg.C
Operating flow	Recycle brine	12,750 Ton (metric)
Heating steam		120.6 Ton (metric)
Hydraulic test press.	Shell side	5.2 Bar.G
	Tube side	15 Bar.G

B. EVAPORATOR TYPE:-

Cross tube multi stage flash type

No of stages	Heat recovery	19
	Heat rejection	3
	Total	22
Design temp.	Flash chamber	Recovery 94 deg.C
		Rejection 49 deg.C
	Tube side	Recovery 88 deg.C
		Rejection 43 deg.C
Design pressure	Flash chamber side	1.38 Bar.G
	Tube side	Recovery 10 Bar.G
		Rejection 4.5Bar.G
Heat transfer area	Heat recovery section	65,930 sqr.meter
	Heat rejection section	8,738.4 sqr.meter
No of tubes	Heat recovery section	44,517 pcs
	Heat rejection section	6,294 pcs
Dist.betn tube plts	Heat recovery section	14.732 meter
	Heat rejection section	14.732 meter
Tube size (mm)	Recovery	32.0(O.D) x 30.37 (I.D) x 0.635 (thick)
	Rejection	30.0(O.D) x 28.73 (I.D) x 0.635 (thick)
Oprtn g flow rate	Recycle brine	12,750 ton(metric)
Blow down		1,682 ton(metric)
Cooling water		11,267 ton(metric)

THE CHOICE AND COMBINATION OF TITANIUM WITH OTHER METALS AND ALLOYS

The following combination of materials has been used for the construction of PH-1 evaporators:

BRINE HEATER

SHELL	CARBON STEEL	JIS G 3106 SM 41 A
WATER BOX	ALUMINUM BRONZE	JIS H 3100 C 6161P
TUBE	TITANIUM	ASTM 338
TUBE PLATE	ALUMINUM BRONZE	JIS H 3100 C 6161P
TUBE SUPPORT	STAINLESS STEEL	SUS 316 L
IMPING. PLATE	STAINLESS STEEL	SUS 316 L
CATH. PROT	NI-IRON ALOY	9/91 %

EVAPORATOR

STAGES 1,2,3&22	(All internal surfaces)	SUS 316L CLADDED
STAGES 4 ~11	Front and rear	Carbon steel sus 316 cladded
	Floor and side walls	Carbon steel JIS G 3106
		Coated with epoxy rasin

STAGE 12 ~ 22	Floor and side walls 25.4 mm above top of dimister	Carbon steel JIS G 3106 Coated with epoxy resin
FLASH BOX	STAINLESS STEEL	316 L
WEIR	" "	"
BRINE ORIFICE	" "	"
DIST. TRAY	" "	"
DIST. ORIFICE	" "	"
TUBE	TITANIUM	ASTM 338
TUBE PLATE	ALUMINUM BRONZE	JIS H 3100 C 6161P
TUBE SUPPORT	NAVAL BRASS	JIS H 3100 C 4640
WATER BOX	ALUMINUM BRONZE	JIS H 3100 C 6161P

CATH. PROT.

STAGE 1~11	SPECIAL NI-IRON ALLOY	9/91 %
STAGE 12-22	PURE IRON	

OPERATING METHODS

During entire period of the evaporator operations, the conventional operation methods as recommended by the plant manufacturer in the O&M manuals have been followed. Unit startup Steps include;

- Filling of the evaporator with seawater
- Start-up of re-circulation pump
- Creation of vacuum by hogger ejectors up-to 0.25 barA
- Heating of brine maintaining recommended temperature and flow gradients
- Change over of vacuum system from hogger to normal holding ejectors
- Increase in steam, brine, make-up & chemical doses to bring evaporator to full load

CHEMICAL CONTROL

A major part in the evaporator tubes is to have a very close monitoring and chemical control either in the pre-treatment stage at intake area (2) or on line treatment stage while recirculation of the brine inside the tubes. This chemical control will prevent scale and corrosion of the evaporator tubes and to have distillate parameters within the design limits. Table # 1 shows a laboratory analysis of the sea water entering to the evaporator. In Al- Jubail PH-I , a pre-treatment steps include injection of sodium hypochlorite (NaOCl) at intake suction with a dosing of 0.50 ~ 0.70 ppm to avoid marine growth and get rid of any biological effects. The residual chlorine must be 0.25 ~ 0.30 ppm to enter to evaporator heat rejection section.

On the other hand, On line treatment and chemical control which include foaming control and scale prevention is carried out using the following chemicals :

1. Polyphosphate or polymer based anti-scale
(Dose rate optimized from 3.0 ppm to finally 0.8 ppm)
2. Anti-foam dose rate 0.1 ppm

Note: The evaporators have built in deaerator in the last stage flash chamber and the flash chamber materials are either carbon steel lined with stainless steel or coated with epoxy resin therefore no chemical oxygen scavenger i.e sodium sulfite has not been used.

TUBE CLEANING

There are two basic types of tube cleaning of the evaporator tubes :

- 1- On line cleaning
- 2- Off line cleaning

ON LINE CLEANING:

The plant design has on line tube cleaning



facilities using sponge rubber balls. The system allows brine heater only and/or brine heater and heat recovery section combined. The usual method adopted has been the latter one. The ball cleaning system have been operated on regular basis in each of the three shifts maintaining approximately 5~6 balls / tube / day. Starting size of the balls have been approximately 2.5 mm over sized than the tube I.D

OFF LINE CLEANING:

Off line cleaning normally used to remove soft or/and hard scales inside the heat transfer tubes of evaporator and brine heater. The criterion set we used to do the cleaning is the performance of evaporator in terms of Gain Output Ratio ($GOR = \text{kg distillate} / \text{kg steam}$) is < 7.6 as per the manufacture recommendations.

Three types off line cleaning has been used in PH-I evaporators:

- 1-Acid Cleaning
- 2-Tube Hydrojetting
- 3-Mechanical (Rodding)

ACID CLEANING:

The following are the main out lines of the procedure adopted for acid cleaning of the heat recovery and brine heater tubes of the evaporator. The original recommendations to use sulphamic acid in combination with a branded acid corrosion inhibitor was not followed due to very high sulphamic acid and the acid inhibitor cost. Rather using Titanium Institute's

(Japan) guide line (1) based upon various research works done by the institute and the SWCC Research Center's recommendations, Hydrochloric acid in combination with nitric acid as inhibitor was used.

CHEMICALS CONSUMED

1. Hydrochloric acid (30 % purity)	57.02 MT
2. Nitric acid	2.205 MT
3. Antifoam	60 Kgs

Acid Cleaning Procedure:

Cleaning is carried out only for the brine heater and heat recovery tubes through acid pipelines (Flash chamber is not included in this cleaning). The cleaning process is done at temperature 36~39 °C. If required, heating of acid solution is done using steam in Brine heater. The acid solution flow is adjusted at the inlet of brine heater at 250~300 M³/hr. When the circulation flow and pressure is stabilized, acid injection started. Acid flow is regulated to maintain pH value 1.5~2.0 at the inlet to brine heater. Simultaneously nitric acid is pumped to the acid solution tank to maintain approximately 0.05 % concentration in the acid solution. Periodic venting of gases from water box of the brine heater and heat recovery section is done. During acid cleaning, pH and acid concentration of inlet and return solution, Ca⁺⁺, Cu⁺⁺ and Titanium content in the return solution is checked on hourly basis. The process of cleaning is continued until the inlet to brine heater and return solution pH is almost equal and Ca⁺⁺ value does not change and further addition of acid lowers the pH of returning solution, the evaporator tubes then assumed to be cleaned. The evaporator then flushed with distillate water till pH reach > 6.5. Table # 2 shows analysis report of one of the PHASE-I Desals acid cleaning samples. A physical inspection of the tubes in brine heater and recovery sections is done to see the effect of the acid cleaning. Moreover, a pressure test of brine heater tubes is carried out to check for any faulty tubes. If everything is found satisfactory, the evaporator is made ready for start up. Table # 3 shows the evaporator production and performance before and after acid cleaning. The GOR gain was 21.2 % after acid cleaning.

TUBE CLEANING BY HYDROJETTING:

This type of cleaning (de-cocking) was carried out in PHASE-I units by an outside contractor using a high pressure water jetting (pressure is 5000 psi ~ 10000 psi) starting with a low pressure then gradually increased. This method gives an acceptable results of removing the hard scale and flow effects. However, this method should be done carefully to avoid tube failures.

MECHANICAL TUBE CLEANING:

The mechanical cleaning (De-chocking) was recently done in one of the PHASE-I units. Around 4,000 tubes (as total) were cleaned by this method. The typical device consists of a jig attached to the head, and connected to a driving motor through a flexible joint. The scale is cut by the rotation of the jig (1). Some of the tubes get damaged by this type of dechocking so, it is important to take care when applying this method. However, a good performance has been obtained using this type of cleaning.

EVAPORATOR CONSERVATION (STORAGE) PROCEDURES DURING SHUT DOWN

One of the main factors to save the evaporator tubes and flash chamber internals from corrosion or any unacceptable damages, a suitable conservation and preservation procedure must be followed during the unit is out of service. In AL- Jubail PH-I evaporators, preservation was a major role to have all evaporators in good and acceptable condition even after 20 years and hopefully it will continue more in future.

The conservation procedure has been classified in the following three categories.

- | | |
|----------------------|-----------------|
| 1. Shut down period. | Within 1~3 days |
| Procedure - 1 | Vacuum store |

After the evaporator has been shut down and cooled to below 45 deg.C, all pumps are stopped the evaporator is completely drained. It is there after conserved in boxed up condition under vacuum.

- | | |
|---------------------|---------------------|
| 2. Shut down period | Within 4~10 days |
| Procedure - 2 | Temporary dry store |

After the evaporator has been shut down, cooled and drained, it is flushed with fresh water using recycle brine pump. When the flushing water conductivity reaches less than 300 mic.mohs, the circulation is stopped. Flash chamber and water boxes are drained and the evaporator shell manholes are opened for natural drying.

- | | |
|---------------------|--------------|
| 3. Shut down period | Over 10 days |
| Procedure - 3 | Dry store |

After the evaporator has been shut down, cooled, drained and rinsed with fresh water till the flushing water conductivity reaches less than 300 mic.mohs. all component of the evaporator including distillate trough, water boxes, all piping, pump suction barrels are drained. The evaporator flash chamber surfaces are mopped to remove stagnant water. After that, the flash chamber manholes are closed on four bolts and the hogging ejector is run for approximately seventy hours to dry the evaporator.

Figure # 3 shows a non preserved waterbox and the effect of that on the tubes.



Figure # 3

PROBLEMS FACED AND REMEDIAL ACTIONS DONE

Prior to year 1991, no tube failure in any section of any of the evaporators was reported. The first case of steam condensate conductivity increase was reported in early 1991. Air pressure test of brine heater indicated one tube failure. Consequently the tube was plugged and the evaporator was back on load. After few days' condensate conductivity of the same evaporator increased. This time again air pressure test indicated failure of two tubes. The two failed tubes were the neighboring tubes of the previously failed tube all the failed tubes were located at the upper row of the circular tube bundle. After few months similar failure was experienced in an other evaporator's brine heater. The nature of failure being similar in two brine heaters raised serious concern. Study of the brine heater drawing indicated presence of self supporting (unbolted) steam impingement plates in the brine heater. The steam distributor pipe was cut to inspect the plate condition. On inspection one of the three plates was found split and resting on a section of tubes. This failure caused tube damages. Similar fault was found in two other evaporators. The brine heater shell was cut to remove and fix the plates. Improved grade of steel with increased thickness was used. Since after this incident no brine heater tube failure has been experienced.

Last year during routine evaporator overhaul few tubes in one of the evaporators' heat recover section got damaged when tube de-choking was done using water jetting.

TUBE FAILURE RECORD SINCE COMMISSIONING

BRINE HEATER	2 evaporators
	5 tubes damaged (total)

(After some none destructive testing i.e eddy current etc. few additional tubes indicating damages were plugged).

HEAT REC. SEC.	4 tubes in one evaporator.
	None of the other five evaporators have faulty tubes.

HEAT REJ. SEC.	None of the tubes in any evaporator has failed.
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Other than the mechanical reasons of tube damages due to breaking of impingement plates, and water jetting, no remarkable corrosion or erosion problems have been faced in the brine heater and heat recovery section tubes.

In heat recovery section and the brine heaters some tubes are found blocked by silt debries (generated in the flash chamber) and deformed sponge rubber balls.

In heat rejection section rust sludge produced by sacrificial pure iron anodes cause some tube blocking which require periodic removal from the tubes. Figure # 1 and Figure # 2 shows the upper and down side anodes.



Figure # 1 Anodes of the lowerside of a waterbox



Figure # 2 Anodes at the upper side of a waterbox.

LIFE EXPECTENCY BASED UPON THE DESIGN AND THE PREVAILING CONDITIONS.

Physical inspections carried out every three years during evaporator overhaul indicate the following:

1. No abnormal galvanic activity between tube and tube sheet.
2. No erosion of tubes at tube ends.
3. No pitting on tube external wall.
4. No abnormality in water boxes.
5. No abnormal increase in tube support clearance.
6. Both types of anodes used i.e. pure iron and the 9/91 Ni.Fe alloy have proved satisfactory.

No abnormal losses of anode materials have been experienced.

CONCLUSIONS

From Al-Jubail PH-1 evaporators 20 years experience gained with titanium tubes, the followings can be concluded :

- 1- The percentage of tube failure is negligible .Failures were neither corrosion or erosion related.

- 2- High quality of distillate water among whole Jubail desalination evaporators.(refer to table # 1) is being produced.
- 3- Units performance maintained above designed during that period.
- 4- Titanium tubes have proved that it's a corrosion resistance metal compared to other alloys.
- 5- The frequency of acid cleaning is minimum.
- 6- Mechanical cleaning might cause damages to the tubes if its not handled properly.
- 7- Hydrojetting of the tubes required to remove hard scale and this method of cleaning give a good flow effect .
- 8- Rough weather and increase in turbidity of the seawater could effect on the tube surface so, scale prevention dosing should be increased .
- 9- Optimization of the anti-scale did not show any side effects on the tubes or flash chamber components.
- 10- Reduction of Titanium tube thickness for new projects will be economical and competitive for MSF type seawater desalination plant.
- 11- If all operation parameters are carefully controlled, the lifetime of Titanium tubes will be more.

RECOMMENDATIONS :

With the 20 years gained experience using Titanium tubes , we recommend the following :

- Titanium is a good corrosion resistance material to be used in desalination plants.
- Maintain pre-treatment at intake continuously to prevent biofouling and biodegradation (2).
- On line chemical control of scale prevention to be monitored closely.in addition, routine laboratory analysis.
- Keep ball cleaning system healthy in running units as per manufacture recommendations.
- Conservation and Preservation procedures to be followed depending on the shutdown periods as it recommended by the manufacturer.
- When the performance and GOR becomes lower than the design value , the evaporator must be taken out of service and visual inspection of the tubes carried out and tube cleaning to be performed accordingly.
- Titanium tube thickness can be reduced to lower the total cost and still have long service lifetime (1) .
- When using mechanical cleaning method care should be taken to prevent tube damages.
- Hydrojetting (cleaning) to remove the hard scale should be done with care.
- Cathodic protection inspection to be done after six month of operation and replacement of consumed or loose anodes to be carried out.

Experience gained in operating the "all titanium tube evaporators " for over twenty years trouble free and feed back from other installations using titanium tubes in condensers operating at various temperature and environment, use of titanium tube in evaporators could be made compatible, long life and cost effective.

REFERENCES

- 1- LIGHT GAUGE TITANIUM TUBES FOR SEAWATER DESALINATION PLANTS PART 3, JTS , NOVEMBER 1994.
- 2- PREVENTION OF BIOFOULING IN AL-JUBAIL PLANT, TARIQ BAHMDAN, IDA SAN DIEGO 1998.
- 3- CONSTRUCTION AND COMMESIONING OF MSF PLANT AT AI-PHASE –I, DAUD S. KHUMYYIS, M. OHTANI, IDA 1983.

EVAPORATOR PRODUCTION AND PERFORMANCE BEFORE AND AFTER ACID CLEANING								
Evaporator condition		Before Acid cleaning			Design	After Acid cleaning		
Description	Date	03/01/99	03/02/99	03/03/99	winter condition (27 °C)	14/3/99	15/3/99	16/3/99
Distillate flow, m³/hr		913	923	920	954	1005	1005	1005
condensate flow m³/hr		130.8	131.4	130.8	120.8	118.9	118.4	117.8
Recycle Brine flow m³/hr		11600	11400	11400	11183	11600	11600	11600
Make-Up m³/hr		2750	2800	2800	2562	3000	3000	3000
Blowdown flow m³/hr		1650	1600	1600	1604	1720	1740	1750
Heat Rej. Seawater m³/hr		6300	6200	6200	7212	7000	7100	7100
Brine Heater Inlet temp. °C		79	80	80	81.9	82	82	82
Brine Heater Outlet temp. °C		87	88	88	87.9	89.5	90	90
Condensate Temp. °C		97	97	97	95	93	93	93
Heat Rej. Inlet temp. °C		26	26	25	27	25	25	25
Heat Rej. Outlet temp. °C		35.6	36	36	36.2	34	34	34
Shell Pressure , Bar		0.95	0.98	0.97	0.86	0.8	0.8	0.8
G.O.R kg dist./kg steam		7.24	7.28	7.30	8.19	8.77	8.81	8.85
Average G.O.R.			7.27		8.19		8.81	
Overall H.T.C.(W/M².K)			2034		2480		3785	

TABLE#3

ANALYSIS REPORT OF DESAL (PHASE#1) ACID CLEANING SAMPLE

UNIT NO#2 (PHASE-I)

DATE:08\03\99 ~10\03\99

Time hrs	Inlet soln.		Return soln.					Remarks
	pH	%HCl	pH	%HCl	Ca ⁺⁺ ppm	Cu ppm	Ti ppm	
1705	0.35	1.25	9.65	—	12		ND	Acid charging started at 1640 hrs
1745	0.33	1.29	9.68	—	14		ND	
1830	3.95	—	6.30	—	44		ND	Acid charging completed at 1820 hrs
1930	4.19	—	4.17	ND	1920		ND	
2030	3.42	—	3.39	ND	1800		ND	
2130	3.27	—	3.28	ND	1000		ND	
2230	5.09	—	5.09	ND	1840		ND	
2330	5.14	—	5.09	ND	2000		ND	
0030	5.35	—	5.37	ND	1400		ND	
0130	5.53	—	5.55	ND	2000		ND	
0230	5.58	—	5.59	ND	1600		ND	
0330	5.73	—	5.74	ND	1680		ND	
0430	5.75	—	5.78	ND	1560		ND	
0530	5.85	—	5.86	ND	1360		ND	

TABLE#2

DESALINATION DAILY ROUTINE ANALYSIS REPORT

SAMPLE	TEST	1	2	3	4	5	6
SEA WATER	CHLORIDES ppm	S	23550				
	CONDUCTIVITY ms/cm	H	60600				
	M ALKALINITY As CaCO3 ppm	U	131				
	PH VALUE	T	8.25				
	R-CHLORINE ppm		0.32				
	TURBIDITY NTU	D	1.06				
MAKE-UP	A/S DOSING RATE ppm	O	0.8	0.8	0.8	0.8	0.8
	A/F DOSING RATE ppm	W	0.1	0.1	0.1	0.1	0.1
RECYCLE BRINE	CHLORIDES ppm		33389	33330	32960	33000	33200
	CONDUCTIVITY ms/cm		80800	80900	80000	80100	80600
	D/O2 ppb		70	70	80	60	60
	PH VALUE		8.69	8.71	8.63	8.65	8.68
	CONCENTRATION RATIO		1.41	1.41	1.4	1.4	1.41
	CHLORIDES ppm		36700	36800	36100	36300	36700
BRINE BLOWDOWN	CONDUCTIVITY ms/cm		86800	87000	85300	85800	86700
	COPPER ppb						
	IRON ppb						
	M ALKALINITY As CaCO3 ppm		202	203	200	201	202
	PH VALUE		8.79	8.83	8.73	8.76	8.78
	LOSS OF TOTAL ALKALINITY		+1.45	+1.15	+0.53	+0.60	+1.40
PRODUCT WATER	CONDUCTIVITY ms/cm		2.15	1.02	1.97	2.95	4.05
	COPPER ppb						
	IRON ppb						
	PH VALUE		6.75	6.7	6.68	6.78	6.82

TABLE#1