CORROSION RESISTANT MATERIALS FOR SEAWATER RO PLANTS[1]

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ABSTRACT

A survey of corrosion resistant materials employed in Seawater Reverse Osmosis (SWRO) desalination plants in Saudi Arabia and the GCC countries has been carried out with special reference to stainless steels. The history of the application of these materials is reviewed along with the major corrosion problems encountered in those plants with main emphasis on SWCC RO desalination plants. The two SS alloys 316L and 317L have been used in the construction of two SWCC SWRO plants at the remote area plants of Al-Birk and Umm Lujj with no noticeable corrosion damage in either plant after their operation for over 5 years and 3 years, respectively. Similarly, other SS alloys 317LN, 904L, 254SMO and 329 performed well, without any significant corrosion when they were used in the construction of SWRO plants or parts there of in the GCC countries. These plants are in continuous operation for years. The paper also discusses the role of different alloying additions in determining the corrosion resistance and mechanical properties of stainless steels relevant to SWRO desalination applications. The possibility of some new cost-effective materials with emphasis on better corrosion resistance and mechanical properties are reviewed. Finally, like in MSF plants, the feasibility of using deaerated seawater feed in RO plants, hitherto not much used in RO plants is discussed.

INTRODUCTION

A proper selection of materials of construction is one of the important factors in the efficient and economic operation of a desalination plant. In Saudi Arabia and other GCC countries, multistage flash (MSF) process involving the multistage distillation of seawater at low pressure and reverse osmosis (RO) based on the separation of fresh water from seawater through a membrane under high pressure are the two main industrial processes used or desalination. Although the bulk of water is produced from MSF plants, due to the simplicity in design and operation of RO plants and their lower operation and maintenance costs, there is an upsurge in the number of RO plants in recent years especially in post 1980 era. Moreover, by comparison to MSF which was applied in seawater desalination during the late fifties, seawater desalination by RO process is a relatively new technology. The first major size SWRO plant was the 12,000 m^3/d Jeddah SWRO plant, built in 1978-1979 by the Saline Water Conversion Corporation (SWCC), Saudi Arabia. Since that time numerous SWRO plants have

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been built in the GCC countries with most of them in Saudi Arabia which presently has SWRO capacity in excess of 133,000 m^3/d, located mainly on the Red Sea coast (1).

A survey of literature on materials used in desalination plants indicates that although numerous references are available on corrosion resistant materials related to MSF plants but only a limited references are available on similar informations relevant to SWRO plants (2-7). The failure of materials due to corrosion in SWRO plants is not uncommon, the failure can be attributed either to the use of improper material(s) or poor maintenance or both. In an RO system, the corrosion products from a component material can block the membrane surface and adversely affect the efficiency of the operation. Improper selection of materials for a high pressure RO system consisting of pumps, pipings and valves and handling high levels of chlorides (22,000 to 36,000 ppm) and dissolved oxygen (5-10 ppm), results in pitting, crevice and stress corrosion.

The early SWRO plants were built utilizing 316L in the construction of the high pressure part of the SWRO plant. With the advancement in stainless steel (SS), alloys of newer and more corrosion resistant austenitic and duplex SS alloys of high strength are being used along with 316L in the construction of SWRO plants. These SS alloys include 317L, 317LN, 904L, 254SMO plus others. Duplex 329 was also used in certain cases in the internal parts of the high pressure pumps. Use of high grade alloys with larger content of chromium and molybdenum in their composition is intended to prevent and combat SS corrosion in seawater environment, mainly the pitting, crevice and stress cracking type corrosion.

This paper surveys the use of stainless steel alloys and their performance in several SWRO plants in the Gulf, with special emphasis on SWCC SWRO plants. The paper also presents a brief discussion on the role of different alloying additives in determining the corrosion resistance and mechanical properties of SS in seawater environment under different feed conditions of pH, temperature, flow rate, and oxygen level.

THE RO PROCESS

The seawater reverse osmosis desalination is a separation process by which the pretreated saline feed is separated into a product stream and a concentrate (brine) stream after passing the feed over the surface of a semipermeable membrane under high pressure. The product water containing less than 1.5% of the salt content in the feed, flows at a normal pressure and may require passage into a second stage RO plant (brackish water type) to lower its salt content even further. The final product is stabilized by the addition of hardness, mostly by lime and CO_2 treatment. The reject water which contains about 50% more salt than the feed maintains nearly the same pressure as that in the pressurized feed with the exception of small pressure drops. In a nonfouling membrane this drop is normally less than 1% of the feed pressure. The high energy in the reject which otherwise would be wasted can be recovered by the utilization of an energy recovery system.

Membrane is the heart of the RO plant. An ideal membrane is characterized by its unique properties of high water permeation (flow), very low salt passage and dimensional and chemical stability. Salts, in spite of their small size, are not permitted to pass through the membrane at a significant rate. Their passage is held at a very low level, normally less than 1.5% Passage of the larger size molecules and particles, such as colloidial and other suspended particles, also microorganism such as algae, bacteria as well as scaling and corrosion products is not permitted through the membrane's closed structure. These materials when present in the feed could be trapped by the membrane causing it to foul. To prevent membrane fouling, a pretreatment is included as part of the RO process to remove all potential foulants from the feed. This not only results in longer life of the membrane but also improves the overall plant efficiency and reduces the water cost. Thus, seawater desalination by the RO method is a three step process: feed pretreatment, water desalination and product water post treatment.

An aerated feed is normally fed to the plant and depending on the feed pretreatment and type of membrane used the feed pH could vary from 6-8. Acidity in this pH range has very little influence on SS metal corrosion. The entire RO process is carried out at a room temperature, 15 - 35oC, and at sufficient water flow rates that do not allow for water stagnation. These factors combined with a good flushing system to remove saline water during plant stoppage also minimize scale formation, fouling and contribute to inhibition of corrosion

By contrast to pretreatment and posttreatment processes which are done at low pressure, less than 6 bars, the desalination step is carried out at much higher pressure, between 60 - 80 bars. Moreover, due to the separation of fresh water from saline water, the salinity of the feed inside the RO modules and reject lines is considerably higher than that of the seawater feed by 40 - 50%. It is because of these differences, mainly the high pressure, that the materials used in SWRO desalination equipment are quite different from those used in the pretreatment and posttreatment plants.

MATERIAL PROPERTIES AND MATERIAL SELECTION

With the exception of pumps, low cost noncorroding plastic materials, e.g., PVC, GRP are used in both the pretreatment and the posttreatment parts of the SWRO plant. This includes piping, tanks, valves, joints, filter housing, etc. In large SWRO plants holding tanks and filter housing are made of special concrete structures. For the intake line, asbestos cement or GRP are the usual materials.

To be able to take the high pressure, only special corrosion resistance materials of high strength are used in the desalination part of the plant.

Stainless steels are the conventional materials used for high pressure inlet piping leading to the RO membrane module, brine rejection pipe, product water outlet pipe, and high pressure pump. These materials have adequate resistance to aqueous corrosion and therefore prohibit formation of corrosion products which could eventually block the membrane. Amongst stainless steels, austenitic steels are more commonly used due to their excellent resistance to general corrosion and erosion-corrosion along with good mechanical strength.

Austenitic steels owe their corrosion resistance to a passive film of Cr_2O_3 formed on the steel. These steels are, however, prone to pitting and crevice corrosion in certain waters notably those containing chlorides and/or in stagnant untreated seawater. The resistance to pitting and crevice can be improved by the addition of Mo to the SS. Since Mo is a ferrite former, it is necessary to increase the Ni content to maintain an austenitic structure. The presence of N, a strong austenitic former, also improves remarkably the pitting and crevice corrosion of stainless steels. Nitrogen also increases the proof stress, so that thinner sections can be used to withstand the high pressure in RO plants. The relative effect of Cr, Mo and N on crevice corrosion are assessed on the widely used PREN, Pitting Resistance Equivalent (7);

$$PR_{EN} = Cr\% + 3.3Mo\% + 16\ N\%$$

According to this empirical equation the pitting resistance of SS alloys increases as their content of these three alloying elements is raised. One part of Mo and N, however, has 3.3 and 16 times the effect of pitting resistance of one part of Cr, respectively. The nominal composition of some standard stainless steels that are mentioned in this study is given in Table 1, which also provides data on their mechanical properties, PR_{EN}, etc.

The 316L has been the most commonly used material for brackish or seawater RO plants. The alloy has been used in pumps and high pressure pipings. At high velocity of feed water, the corrosion is less frequent in pumps and pipings, however, failures in the forms of pitting and crevice corrosion are some time observed at flanges and seals of the pumps and at or close to the weld or heat affected zones in the high pressure pipings. The stress corrosion cracking (SCC) is not a common phenomenon below 7O^{o}C and since SWRO plants work at a much lower temperatures therefore SCC is not of much interest. Besides 316L, the other austenitic stainless steels used for RO applications are 317L and 904L (UNSO8904) (8 - 13). In RO plants, 904L has been suggested as a better alternative to 316L because of its superior corrosion resistance. The 317L has a much higher strength than 316L. 317LN exhibits about 40% higher strength than 317L, therefore the former is of special interest for high pressure sections of RO plants using large diameter pipes.

Although reasonably long life is expected from stainless steel grades such as 316L or 317L in RO applications provided high velocities of the feed water are maintained and the design of the RO module does not encourage formation of crevices. Even under these conditions, high pressure piping, headers, connectors and membrane containment vessels are prone to crevices corrosion attack. In such cases, the use of relatively less costlier material like 317L might not be economical in the long run and the use of higher grade stainless steels containing larger amounts of Cr, Mo or Ni is desirable.

In recent years, the manufacturers introduced a large number of other alloys which are practically immune to crevice and pitting corrosions and have much superior strength. Table 1 lists the compositions of some commercially available high grade alloy steels such as 20Cb-3, 254SMo, AL-6XN, C276, 20MOD, Cronifer 1925 HMo which are austenitic SS. A limited number of alloys such as 2205, 255 and 329 are duplex (austenitic-ferritic). Super ferrit Remanit 4575 and MONIT are the ferritic steels which are suggested for high pressure RO. piping. Amongst high alloy steels, 254SMO has been in use in some SWRO plants in Middle East. An equivalent replacement to 254SMO will be: AL6X, AL6XN, Cronifer 1925 HMo. All those SS alloys have PR_{EN} in excess of 42. It is also possible to use the nickel-base alloys 625 and Hastelloy C-276 with PR_{EN} of 50 & 68, respectively. Ni-base alloys such as Inconel 625 or Hastelloy C-276 are virtually immune to pitting and crevice corrosion in seawater but their high costs overshadow their good corrosion and mechanical properties.

STAINLESS STEEL ALLOYS USED IN SWRO PLANTS IN THE GULF

Table 2 lists several SWRO plants, their capacity, date of commissioning and type of SS used in their construction. The austenitic 316L and 317L have been the choice material for many seawater RO plants built by SWCC in Saudi Arabia. The 316L have been used in the construction of the 12,000 m^3/d Jeddah SWRO plant and the 2,270 m^3/d Al-Birk SWRO plant. The 317L was used at the 4,400 m^3/d Umm Lujj SWRO plant and the 56,800 m^3/d Jeddah 1 Rehabilitation SWRO plant. All these plants are located in the Western region of the Kingdom at the Red Sea. In the Ras Tanajib SWRO plant, built by ARAMCO, Saudi Arabia, the 317LN (DIN 1.4439) was used in all high pressure pipes and vessels. All other parts were made of 904L (DIN 1.4539). Carbon steel with rubber lining was used in a few other special parts (9).

Various stainless steel materials were used in the 3,000 m^3/d SWRO pilot plant in Doha, Kuwait. One SWRO line, capacity 1,000 m^3/d, utilized SS 317L in high pressure pipes, 316Ti (DIN 1.4571) in valves and duplex stainless steel 329 (DIN 1.4460) in high pressure pump (10). In the second line, capacity 1,000 m^3/d, 904L (DIN 1.4539) was used in the high pressure pipes & valves while Duplex 329 was used in the internal parts of the pump that are in contact with seawater (11). In the third line, also capacity 1,000 m^3/d, rubber lined carbon steel was used in the high pressure pipes (12). The high grade stainless steel alloy 254 SMO (UNS S31254) was used in the 46,000 m^3/d Ras Abu Jarjur SWRO plant (13). The feed TDS is about 13,000 ppm & contains H_2S.

PERFORMANCE EVALUATION OF SS ALLOYS IN SWRO PLANTS

Table 2 lists the various SWCC SWRO plants examined in this study, their capacity, type of membrane and SS used in the high pressure desalination part of plants. It also summarizes their corrosion performance which was established from their operation and maintenance data and also from visits made to the plants. Except for damage in bucket surface of the Pelton Wheel energy recovery system used at Umm Lujj plant, no noticeable corrosion occurred at the Al-Birk plant, constructed from 316L, nor at Umm Lujj plant in which 317L was used in plant construction. The first plant has been in operation over 5 years while the second plant was in operation about 3 years. The two plants are spotlessly clean and in appearance they resemble a newly constructed, recently commissioned plant. Because the two plants provide the only source of drinking water to both towns they are well-maintained and well-operated on a continuous basis: Umm Lujj plant operates at full capacity year around. Al-Birk plant which has excess capacity, has only one of the two trains in continuous operation year round. Moreover, each of the two plants is well-designed and equipped with a good flushing system thus avoiding saline water stagnation in the units during shut-down or stoppage. Evidently the two SS alloys 316L and 317L have sufficient corrosion resistance to SWRO operation. The good plant operation and programmed maintenance along with plant operation at pH greater than 6, relatively low temperature 20-35ºC and low water recovery (less than 30%) are important factors that also contributed to their excellent corrosion performance in such saline water environment.

By contrast to the good corrosion performance of the above two plants, the 12,000 m^3/d Jeddah plant which was the first major SWRO plant to be built, now about 10 years old, showed corrosion in some parts of the plant. Corrosion occurred in some parts of the 316L high pressure feed pipes, external coupling joints and some parts of the module end-caps. Very little corrosion was observed in the 316L header, the distribution pipes, and the 316L pipes connector to the module.

The good corrosion resistance of 317L in SWRO plants was also reported after two years of plant operation at Doha-Kuwait SWRO plant, in which the high pressure feed pipes in one unit of the 3 X 1000 m^3/d units were constructed from this SS alloy. The plant has 97% availability (10). Similar behaviour was also established for 317LN after one and one half years operation at Tanajib plant. The plant which employs a deaerator also has high availability and maintained good productivity (9). Although some valves exhibited minor erosion-corrosion, the 904L alloy, with molybdenum content in the alloy of 4.5% compared to 3-4% in 317L alloy and 2-3% in 316L (See Table l), also shows good corrosion resistance, after 2 years of plant operation, in SWRO plant at Doha- Kuwait where it IS used in high pressure pipes and valves (11). The alloys also performed well at Tanajib plant where it was used in high pressure valves and the internal part of the high pressure pump (9).

After two years of operation no corrosion has been observed in Ras Abu Jarjur SWRO plant in which the SS 254SMO, with Molybdenum content of 6.5%, was utilized in the high pressure pipes and pumps. Alloys 20 which was used in the construction of valves in the same plant did not show any corrosion either. Some pitting corrosion due to cavitation, however, was observed in wheel buckets of the energy recovery system (13,14). Use of Duplex 329 in high pressure pumps at Doha-Kuwait SWRO plant proves satisfactory in resisting corrosion after 2 years operation (11,12).

From the above discussion it can be concluded that the numerous SS alloys: 316L, 317L, 317LN, 904L, 254 SMO and 329 which were used as described above in various SWRO plant in the GCC countries performed well against corrosion. With good plant design and good operational and maintenance procedures it should be safe to use any of those alloys in the construction of SWRO plants even at high TDS in seawater, i.e., 43,000 ppm. The question that arises is why should SWRO plant builders and users select 254 SMO or 904L rather than 316L when their price ratio varies considerably in the order of 2.7 to 2.45 to 1, respectively? (For SS cost comparison see Table 1, final column). Truely the former alloy will have greater pitting, crevice corrosion and stress corrosion resistance than 316L but does that justify this price differential? The suppliers argue that with higher strength of 254 SMO it is possible to use a much thinner material of construction when using this alloy than when using 316L or 317L which have lower yield strength (See Table 1). Calculations made by SS suppliers showed that when this factor is taken into consideration the price differential in SS material between 254 SMO & 317L drops significantly. So far SWCC has been specifying 317L in its latest plants, e.g., the 56,800 m^3/d Jeddah SWRO plant, the 4,400 m^3/d Umm Lujj SWRO plant. This is a good compromise choice since 317L is an improvement in properties over 316L and is much cheaper than 254 SMO which has higher Molybdenum and Nickel content.

USE OF DEAERATORS IN R.O. PLANTS

The role of oxygen is found to be of key importance in corrosion of desalination plants' equipment in general and MSF in particular. Oxygen invariably acts as a cathode during a corrosion process involving an electro-chemical cell and therefore, always has a significant effect on corrosion rates. Virtually complete removal of oxygen is a prime step in saline water treatment by flash distillation using acid treatment. Even for MSF plants operated at low temperature of 90.6ºC, such as Jubail Phase II MSF plant, feed deaeration followed by SBS injection is carried out to remove dissolved oxygen from the seawater make-up feed. Proper degasification is essential to minimize corrosion of evaporator internals, to prevent carbonate scale and to minimize condensor fouling by non condensable gases. Generally, in MSF plants the level of dissolved oxygen is kept to minimum (less than 20 ppb) by using a deaerator followed by deoxidizer like sodium bisulfite. However, a very low concentration (perhaps a few ppb) of oxygen may be required to heal a ruptured oxide film if it occurs. Although the deaerator forms a vital unit of a MSF plant, it has only sparsely been considered for SWRO plants. In one SWRO plant a vacuum deaerator has been used in the Aramco SWRO plant at Tanajib, Arabian Gulf Coast, with a total capacity of 0.6 mgpd (9). The deaeration provided a residual oxygen of 0.2 ppm in the feed water. For elimination of the residual oxgen after the vacuum deaeration, a dosing pump injects approx. 20 - 30 ppm of $NaHSO_3$ into the main pipe down stream of the aerator. Main objective for using the deaerator is the avoidance of destruction by oxidation of the polyether composite membrane which is highly sensitive to oxygen and chlorine. Removal of oxygen by deaeration also minimizes the corrosion problems in materials and reduced consumption of sodium bisulfite. Even after elimination of oxygen from water, the alloy 317LN was chosen for high pressure piping while in other parts 904L was used.

No conclusion can be drawn from this plant on the effect of deaeration on the corrosion performance of SS alloys material in oxygen free feed. In this plant the prime objective of deaeration was the complete removal from the feed of oxygen which is destructive to this type of membrane. The observed good corrosion performance of the two alloys used in Tanajib SWRO plant operating with deaerated feed was also observed for the same alloys when used in other plants without deaeration (10,ll). A more informative experiment, however, will be in utilizing 316L or 317L in two similarly constructed SWRO plants but one-with deaerator and the second without. As already has been demonstrated in MSF plants, definitely, feed deaeration should allow the use of lower grade SS alloys in SWRO plants as well.

CONCLUSIONS

A survey of corrosion resistant materials employed in Sea Water Reverse Osmosis (SWRO) desalination plants in Saudi Arabia and GCC countries shows that the conventional SS alloys: 316L, 317L, 317LN, 904L, 254SMO and 329 used in the construction of RO plants do not show any significant corrosion provided the plant design & operation are made correctly. Most of these plants are in operation for more than 5 years. Some new cost effective materials with better corrosion resistance and mechanical properties offer potential for applications in new generation SWRO plants.

The relative effect of Cr, Mo and N on Crevice Corrosion can be assessed from the widely used PR_{EN}, Pitting Resistance Eauivalent.

$$PR_{EN} = Cr\,\% + 3.3\,Mo\% + 16N\,\%$$

Use of Deaerators in RO Plants

Although the deaerator forms a vital unit of a MSF plant it has only sparsely been considered for SWRO plants. Like MSF plants, feed deaeration should most probably allow the use of low grade SS alloys in SWRO plants. More information regarding the usefulness of deaerator in SWRO plants can be obtained by utilizing 316L, 317L or similar SS steels in two similarly constructed RO plants but one with deaerator and second without.

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TABLE-1
COMPOSITION AND PROPERTIES OF SOME STAINLESS STEEL ALLOYS
[Those Marked with * have been used in SWRO Application]

Structure	Common Designation	UNS No.	Cr	Ni	Mo	C Max	N Max	Others	PR EN	Y.S. MPa	T.S. Mpa	Relative Cost*** ($)
Austenite	304L	S30400	18-20	8-10.5	-	.03	.10	Mn,P,Si,S	18-20	170	480	
"	316L*	S31603	16-18	10-14	2-3	.03	.10	"	28	170-210	485	1.00
"	316N	S31651	"	"	"	.08	.16	"		240	550	
"	316LN*	S31653	"	"	"	.03	.16	"		205	515	
"	317L*	S31703	18-20	11-15	3-4	.03	.10	"	30.5	205	515	
"	317LN*	S31753	"	"	"	.16		"	31.5			
"	904L*	N08904	19-23	23-25	4-5	.02	-	", Cu	36	220	490	2.27-2.45
"	254SMO*	S31254	19.5-20.5	17.5-18.5	6-6.5	.02	.22	", Cu	44	300	650	2.70
"	AL-6X	N08366	20-22	23.5-25.5	6-7	.03	-	"	42.5	205	515	3.50
"	AL-6XN	-	"	"	"	"	.3	"	47.0	-	-	
"	20Cb-3	N08020	19-21	32-38	2-3	.07	-	", Cu,Nb	31	275	585	4.03
"	Alloy 20*	N08320	22	25	5	.02	-	"	39	-	-	
"	Cronifer 1925 HMo	N08925	21	25	5-6	.03	.15	"	43	-	-	
Structure	Common Designation	UNS No.	Cr	Ni	Mo	C Max	N Max	Others	PR EN	Y.S. MPa	T.S. Mpa	Relative Cost*** ($)
Duplex	2205	S31803	21-23	4.5-6.5	2.5-3.5	.03	.20	"	37	-	-	
"	329*	S32900	23-28	2.5-5	1-2	.08	-	"	34	440	-	
Ferrite	Monit	S44635	24.5-26	3.5-4.5	3.5-4.5	.025	.035	", Ti,Nb	38	550	650	
"	Remanit 4575	-	27-29	3-4.5	2-3	.020	.025	", Nb,Zr		500	600-750	
Austenite	625**	N06625	21.5	61	9	0.05		", Fe,Nb, Ta	50	-	-	6.72
"	Hastelloy C- ** 276	-	15.5	57	16	0.01	-	", W,V,	68	-	-	7.7

** Nickel-base Alloys.

*** See Reference 2, prices were also obtained from suppliers. In all cases thickness ratio is one.

TABLE-2

CORROSION PERFORMANCE OF VARIOUS SS ALLOYS IN SWRO PLANTS: (A) SWCC SWRO PLANTS, (B) OTHER SWRO PLANT IN GCC COUNTRIES

Plant Name	Owner*	Membrane System**	Capacity m3/d	Date Commissioned	SS MATERIALS Pipes	Valves	Pumps	Comments
A. SWCC SWRO PLANTS								
JEDDAH	SWCC S.A.	UOP TFC-SW	12,000	1979	316L	316L	316	Corrosion of some high pressure feed pipes, coupling, SS module end-caps.
AL-BIRK	SWCC S.A.	DUPONT HFF	2,275	DEC 83	316L	316L	316L	No noticeable corrosion.
UMM LUJJ	SWCC S.A.	UOP TFC-SW	4,400	JULY 86	317L	317L		No noticeable corrosion. Short life of bucket surface material in Energy Recovery System.
JEDDAH I	SWCC S.A.	TOYOBO HFF	56,800	APR-MAY 89	317L	317L	317L	
B. OTHER SWRO PLANTS IN GCC COUNTRIES								
TANAJIB	ARAMCO S.A.	TOROY SW	2,280	SPRING 83	317LN	904L	904L	No noticeable corrosion after 1.5 yrs operation (9).
RAS ABU JARJOUR	GOVT. OF BAHRAIN	DUPONT HFF	46,000	OCT 84	254SMO	ALLOY 20	254SMO	No corrosion in SS after 2 yrs operation except for pitting corrosion due to cavitation in wheel bucket of Energy Recovery System (13,14).
DOHA-KUWAIT (CAPACITY 3000 m^3/d)	JOINT PROJECT KUWAIT - FEDERAL REPUBLIC OF GERMANY	DUPONT HFF	1,000	AUG 84	RUBBERLINED			After 2 yrs operation: no noticeable corrosion.
		UOP SW	1,000	DEC 84	317L	316Ti	329	No noticeable corrosion (10)
		P.F. FIAT	1,000	DEC 84	904L	904L	329	No noticeable corrosion. Some corrosion-erosion in some valves (11).

* S.A. = SAUDI ARABIA, KT = KUWAIT, BN = BAHRAIN

** SW = SPIRAL WOUND, HFF = HOLLOW FINE FIBER, PF = PLATE AND FRAME