

Corrosion Problems in Low-Temperature Desalination Units

by
S. Narain and Sami H. Asad,
Abu Dhabi National Oil Co., P.O. Box 898, Abu Dhabi, U.A.E.

Abstract

Corrosion problems experienced with different materials used in the construction of low-temperature desalination units during their early stages of operation are described. Severe crevice corrosion occurred at the joints of titanium tubes and alloy 904L (UNS N08904) tubesheets. Anodes, initially aluminum alloy but replaced within three to four months with iron, were installed to provide cathodic protection and neutralize acidity inside the crevices. Aluminum-brass tubes suffered impingement corrosion and were replaced with 90/10 Cu-Ni tubes. Erosion-corrosion attack on 90/10 Cu-Ni ejector condensers was mitigated by replacement with alloy 254 SMO (UNS S31254).

Introduction

Abu Dhabi National Oil Company's (ADNOC) 120,000 bpd Ruwais Refinery is located on the Arabian Gulf coast approximately 250 km west of Abu Dhabi City. The refinery facilities include 10 desalination (desal) units supplied by Société Internationale de Dessalement, France. These are used for supplying desalinated water to steam generators and recirculating cooling water systems and drinking water, after potabilization, to the refinery and its housing complex.

Of the 10 desal units, six (four of 600 m³/day each and two of 250 m³/day each) known as Temporary Community Desalination (TCD) units were commissioned in early 1979 to supply fresh water during the construction stage of the Ruwais Refinery. The remaining four units known as Permanent Community Desalination (PCD) units are larger units (1500 m³/day each) and were commissioned in mid-1981.

All desalinators are package units of similar design based on multi-effect evaporation supplemented with ejector vapor compression process, maximum distillation temperature being 59°C. Low-temperature desalination was selected to avoid corrosion and scaling problems. While scale formation was not a problem, corrosion problems besieged the desalinators during their early stages of operation and required considerable efforts to overcome them.

Materials of Construction

The schematic flow diagram of a typical PCD unit is shown in Figure 1. Different types of materials such as stainless steels (SS), aluminum brass, and cupro-nickels have been used for the construction of the desal units. The specific applications of these materials are summarized in Table 1.

The main features of the materials selection are as follows:

- For construction of evaporation cells, type 316L (UNS S31603) SS was used.
- For heat exchangers, titanium, aluminum brass, or copper-nickel tubes were used in combination with SS tubesheets.

It seems that the advantage of low-temperature operation of Ruwais desal units had not been fully exploited in the initial material selection in terms of cost or simplification. Based on actual experience of problems discussed in this article, in hindsight, we now believe that a combination of SS metallurgy with sacrificial iron anodes can provide reliable and cost-effective service.

Figure 1
Schematic flow diagram of a typical, permanent community desalination unit.

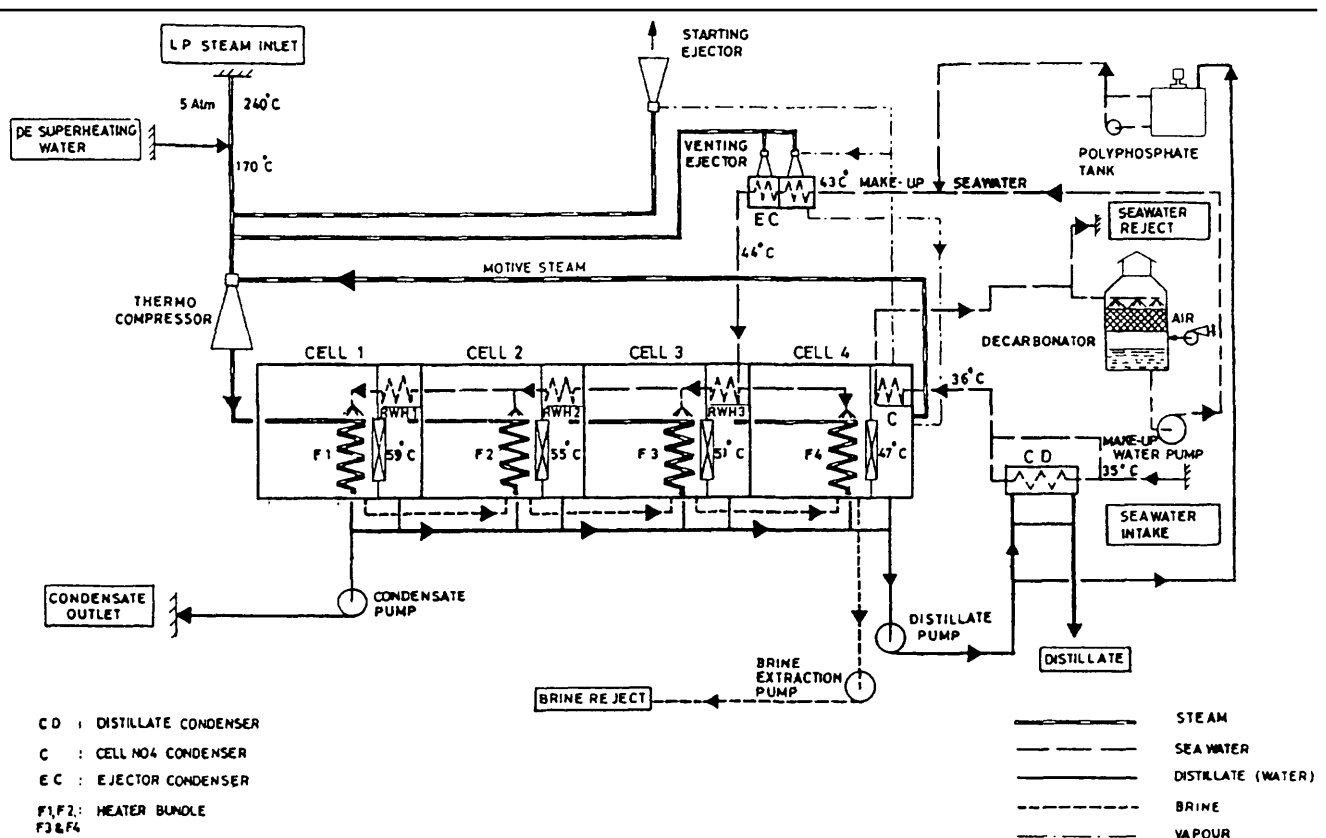


Table 1: Summary of Materials Construction of Desalination Units.

Item	Material Type	
	Permanent Community Desalination (PCD) Units	Temporary Community Desalination (TCD) Units
Evaporators:		
Body	316L stainless steel	316L stainless steel
Skid	Carbon steel	Carbon Steel
Heating bundles:		
Tube plates	316L stainless steel	316L stainless steel
Tubes	Aluminum brass	Aluminum brass
Raw water heaters:		
Tube plates	904L stainless steel	316L stainless steel
Tubes	Titanium	90/10 cupro-nickel
Shell	Carbon steel	Carbon steel
Cell condensers:		
Tube plates	317L stainless steel	-
Tubes	Titanium	
Shell	Carbon steel	
Ejector condensers:		
Tube plates	317L stainless steel	316L stainless steel
Tubes	Titanium	90/10 cupro-nickel
Shell	317L stainless steel	316L stainless steel
Ejectors:		
Thermo compressor	316L stainless steel	316L stainless steel
Distillate coolers:		
Tubesheets	904L stainless steel	316L stainless steel
Tubes	Titanium	90/10 cupro-nickel
Shell	304L stainless steel	316L/304L stainless steel
Brine, make-up water and distillate pumps:		
Casing	316L stainless steel	316L stainless steel
Impeller	316L stainless steel	316L stainless steel
Piping:		
Seawater pipes	GRP (FRP)	90/10 cupro-nickel
Brine pipes	GRP (FRP)	90/10 cupro-nickel
Distillate pipes	SS316L	304/316 stainless steel
Drain pipes	GRP (FRP)	90/10 cupro-nickel
Noncondensable pipes	SS316L	90/10 cupro-nickel

Crevice Corrosion

SS Tubesheets at T/TS Joints

Distillate coolers, Cell 4 condensers, raw water heaters, and ejector condensers of PCD units use titanium tubes in combination with alloy 904L (UNS N08904) tube-sheets. Within one year of service, these exchangers suffered severe crevice corrosion at tube-to-tubesheet (T/TS) joints, on gasket seating surfaces, and on weld seams of nozzles. In all cases, tubesheets at the seawater inlet side suffered more severe crevice corrosion.

The attack initially appeared at the bottom of tubesheet holes, spread along the periphery of the T/TS joints and extended through the thickness of the tubesheets. The depth of the crevice corrosion attack was typically 0.5 to 1.0 mm within one year of service. In the worst cases, crevice corrosion attack progressed up to two-thirds of the tubesheet thickness.

Crevice corrosion attack posed the risk of crippling these exchangers. Immediate steps had to be taken to arrest the propagation of corrosion attack. Aluminum alloy anodes were installed in the water boxes of these exchangers to provide cathodic protection (CP) and neutralize acidity inside the crevices. This step, however, involved a risk of causing hydriding attack on titanium tubes. Even though hydriding of titanium below 80°C was not indicated in the technical literature, its occurrence was not ruled out altogether. Therefore, aluminum alloy anodes were replaced with iron anodes within three to four months after installation.

After installation of aluminum alloy anodes and their subsequent replacement with iron anodes, propagation of crevice corrosion attack was controlled and units were successfully kept onstream. However, due to damage already suffered, tube leaks in heat exchangers were occasionally encountered and long-term reliability of these exchangers was considered doubtful. Therefore, permanent repairs had to be undertaken.

Repair Methods

The distillate coolers were repaired by replacing the tubesheets. The titanium tubes were salvaged by cutting off tubes just behind the tubesheets using special inside tube cutting tools. New tubesheets were welded to the shortened shell and salvaged titanium tubes were then inserted and roll expanded into the new tubesheets.

The ejector condensers and Cell 4 condensers were repaired in a different manner. Leaky T/TS joints were identified by a shell-side hydrotest and were rerolled in an attempt to stop leaks. Where T/TS joint leaks persisted even after rerolling, the tubes had to be pulled out to permit repair of the tube holes. The repair method involved grinding the tube holes to the depth of crevice groove, welding with nickel filler metal, and machining to original dimensions. New titanium tubes were then installed.

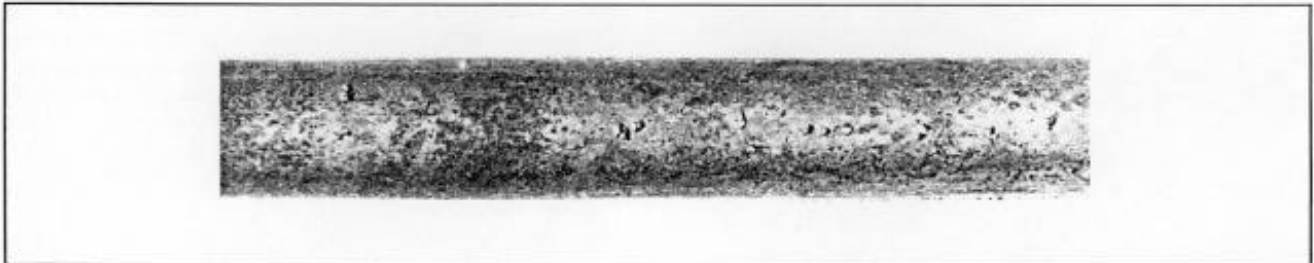
These repairs were conducted in 1982. Since then, these exchangers have provided trouble-free service. Iron anodes installed in the water boxes of the exchangers need replacement about once a year.

Impingement Attack Aluminum-Brass Tubed Heating Bundles

Heating bundles in the evaporation chambers of TCD units are fitted with aluminum-brass tubes in SS tubesheets. Within a year of service, the upper two rows of aluminum-brass tubes suffered perforations through series of straight line pits directly below the impingement area of spray nozzles (Figure 2). The aluminum-brass tubes in lower rows, however, were generally in good condition, though a few had also failed occasionally.

Since aluminum brass is susceptible to impingement corrosion, particularly in chlorinated seawater, choice of aluminum-brass tubes in the top two rows was not considered correct and, therefore, these were replaced with 90/10 cupro-nickel (UNS C70610) tubes. These provide good service without any signs of impingement attack. A few tubes of iron- and manganese-modified cupro-nickel alloys (CA716, [UNS C71640 and C71630]) were installed in the top row as an experiment. These were also free from impingement corrosion attack.

Figure 2
Typical outer surface of aluminum-brass tube in the top rows of heating bundles showing lines of pits.



Erosion-Corrosion Attack

90/10 Cupro-Nickel Tubed Ejector Condensers

Ejector condensers in TCD units were the most troublesome pieces of equipment; frequent failures of 90/10 cupro-nickel tubes were encountered after only one-and-a-half years of service. Ejector condensers consist of two parallel coolers in one shell separated by vertical longitudinal division plate, with ejectors working in series. Tube failures were encountered only in the second condensers. The top rows of the tubes suffered the most frequent failures, generally confined to an area near the tubesheet.

Corrosion of copper alloys in ejector condensers due to carbonic acid, oxygen, and ammonia is a common experience, but in this case the erosion-corrosion attack was attributed to steam impingement. The design of the condensers did not provide for automatic adjustment of motive steam; therefore, operators manually adjusted the steam to the second ejector to maintain the required vacuum in the evaporation cells. This sometimes led to excessive steam flow, causing impingement attack. The steam flow to the second ejectors was reduced and controlled by modifying the design of impingement plate.

Cupro-nickel tubes were replaced in 1981 with alloy 254 SMO (UNS S31254) SS tubes. With these measures, the erosion-corrosion problem was mitigated.

Discussion

Materials Selection

Type 316 SS

The choice of type 316L SS for construction of evaporation cells was generally adequate for controlling crevice and pitting corrosion. Stress corrosion cracking (SCC) of type 316L welds, however, remains a potential problem even in desal units operating at temperatures below 60°C.

With type 316L, the possibility of SCC from an external marine atmosphere also needs to be considered because several instances of external SCC were reported in some plants located on the Arabian Gulf coast. This may be typical for Arabian Gulf seawater and marine atmosphere. Internal SCC risks can be minimized by installation of iron anodes at strategic locations. External SCC problems can be remedied by painting the external surfaces of SS.

Type 904L and Ti Combination

The crevice corrosion seen in heat exchangers established that a bimetallic couple of titanium tubes and SS tubesheets is not advisable. It appears that susceptibility of SS to crevice corrosion increases when it is coupled to titanium. Crevice corrosion attack at T/TS joints can, however, be controlled effectively with CP. Use of aluminum-zinc alloy or zinc anodes for CP is not advisable due to the risk of hydriding titanium tubes. There may be a risk of hydriding titanium tubes even with iron anodes, particularly during acid cleaning operation. However, this risk can be minimized by using sulfuric acid inhibited by cupric and ferric ions.

Corrosion of copper alloys in ejector condensers due to carbonic acid, oxygen, and ammonia is a common experience, but in this case the erosion-corrosion attack was attributed to steam impingement.

Considering the risks of crevice corrosion and hydriding of titanium by cathodic polarization, use of titanium tubes in SS tubesheets should be avoided. On the other hand, use of titanium-clad tubesheets makes the exchangers expensive. With later development of SS that are resistant to crevice and pitting corrosion, there is now a cost-effective alternative to titanium for seawater applications. High-alloyed SS can be used for all seawater exchangers. It is, however, important that selection of SS should be made on the basis of field performance tests in the Arabian Gulf waters.

Resistance of alloy 904L to crevice corrosion was inadequate in the Arabian Gulf seawater. Alloy 254 SMO was superior. Desal units with SS exchangers are likely to be most cost-effective compared to the exchangers with titanium or copper-nickel tubes. Furthermore, the reliability of SS exchangers can be greatly increased by installing iron anodes.

Conclusions

Low-temperature desal units are not free from corrosion problems. These could be mitigated if design takes into account the limitations of the materials used. From ADNOC's experience, consideration of the following points on material selection could be relevant for low-temperature desal plants using Arabian Gulf waters.

- Evaporation cells constructed of type 316L pose some risks of Cl⁻ SCC. Remedial measures such as relieving stress and CP by iron anodes should be considered at the design and fabrication stage. External SS surfaces also need protection against pitting corrosion and SCC from the marine atmosphere.
- The top two or three tube rows in heater bundles directly below the spray nozzles should be made with erosion-corrosion-resistant materials such as SS, titanium, or cupro-nickels instead of aluminum brass.
- Combination of titanium tubes and SS tubesheet materials should be avoided.
- Use of 90/10 cupro-nickel tubes for ejector condensers can be problematic. High-alloyed SS such as alloy 254 SMO or titanium tubes can give better service.
- Materials such as 90/10 cupro-nickel or alloy 254 SMO SS can be more cost-effective for seawater strainers compared to Monel* (alloy 400, UNS N04400).
- Wherever SS in combination with copper-based materials are specified, CP by sacrificial iron anodes for seawater side should be incorporated during the design stage.
- Low-temperature desal plants can be constructed of SS materials, which in combination with CP, can give reliable service.

* Trade name.

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Comments and correspondence can be directed to
Sten von Matérn, Technical Editor, Avesta Sheffield AB,
S-774 80 Avesta, Sweden. Tel. +46(0)226-818 00.
Telex 40976, AVESTA S, telefax +46(0)226 812 99.



AVESTA SHEFFIELD AB, S-77480 AVESTA, SWEDEN

TEL. + 46 226 810 00, TELEFAX + 46 226 812 99