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Short communication

Failure analysis of heat exchanger tubes of four gas coolers

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ABSTRACT

A Number of leaks occurred on four heat exchangers used on an off-shore platform in the south of Iran. As a result heat exchanger tubes made of Inconel 625 failed after only two years in operation. The failure was caused by pitting corrosion in two contact regions, tubes and baffles as well as in tube sheet and shell contact regions in spite of sufficiently corrosion resistance of Inconel 625 to sea water. X-ray diffraction analysis was conducted on residual corrosion products, while micro structures of propagated pits were studied using scanning electron microscope and also examination of susceptibility of Inconel 625 to crevice corrosion was performed by multiple crevice assembly and anodic polarization in crevice solution. Investigation of failed exchanger tubes revealed that leaks in the tubes were due to the phenomenon of crevice corrosion.

1. Introduction

There are four gas coolers located on a platform in seawater in the south of Iran. The gas cooler is a shell and tube heat exchanger with the gas flowing inside the tubes (inlet temperature = 66 °C and outlet temperature = 45 °C) and the seawater is driven through the shell side (inlet temperature = 31 °C and outlet temperature = 38 °C). The tubes, tube sheet and baffles are made of Inconel 625. The first indication of the leakage in the tubes was observed only 6 months after commencement of operation. After one year, plant faced shut down due to low efficiency of gas coolers during production. At this time the gas cooler exchangers were dismantled. It was found out that a number of tubes had failed due to corrosion.

One of the most common failure mechanisms of heat exchanger tubes is usually due to crevice corrosion that it encountered in tube ends and at tube-to-tube sheet joints [1]. Crevice corrosion is a localized form of corrosion that occurs within crevices or at shielded surfaces, where stagnant solution is present. Degradation of materials due to crevice corrosion may cause leakage or loss of critical tolerances which may critically affect the performance [2].

Ni–Cr–Mo alloys (Inconel 625) are used in marine environments, where corrosion resistance is essential. This class of alloys generally has excellent pitting resistance in marine service conditions. However, exposure studies have shown that nickel super alloys are susceptible to crevice corrosion in marine environments [3]. Oldfield and Sutton have refined crevice corrosion model mathematically and conceptually by describing the progression of four stages:

Stage 1: Depletion of oxygen within the crevice.
Stage 2: Increase in acidity and chloride concentration of the crevice solution.
Stage 3: Permanent breakdown of the passive film, and
Stage 4: Propagation of crevice corrosion.

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Oldfield–Sutton model defines the initiation stage of crevice corrosion in terms of the time required to form a depassivating critical crevice solution (CCS). The CCS chemistry is argued to develop in crevices as a consequence of a sequence of events involving passive dissolution, crevice de-aeration, metal cation hydrolysis, and mass transport. In this model, the passive current density (i_{pass}) provides metal ion hydrolysis. This anodic reaction also promotes oxygen (O_2) depletion. Metal cations (e.g. Cr^{3+}, Mo^{3+}) hydrolysis within the crevice and the migration of chloride (Cl^-) ions into the crevice account for acidification. Acidification, in turn, leads to breakdown of the passive film and enhanced anodic dissolution [4–6].

In this investigation various tests were performed to determine the causes of failure and to investigate crevice corrosion susceptibility of alloy 625 under operational condition.

2. Experimental procedure and results

2.1. Visual inspection

During one of the overhauls, tubes were removed for inspection. Fig. 1 shows inside the gas cooler after the shell has been removed. It can be seen that they fouled by marine growth and corrosion deposits.

Visual examination of the failed tubes revealed that leaks had been found on several regions of the gas coolers. The leaks were located in confined areas where the tubes were in contact with the baffles (Fig. 2).

Furthermore, dye penetrate testing (DPT) was carried out on tubes and sheet. The DPT revealed that damages to the tube sheet were confined to the back face of tube sheet region (Fig. 3).

The heat exchanger tubes were examined with a binocular. In effect, the defects were very large. They were several millimetres in depth and in length. Fig. 4 Indicates that the corroded area is about 7 mm long and 2 mm deep.

2.2. Chemical analysis

The alloy composition was confirmed by optical emission spectroscopy method (Quantometry analysis). Table 1 gives the composition which corresponds to alloy 625, a high nickel alloy containing 9% molybdenum.

2.3. XRD analysis

Deposits scrapped from the tubes and shell in the gas cooler was analysed using X-ray diffraction method (XRD). The analyses were as follows:

(1) Scale in the tubes: compound made of elemental sulphur crystals.
(2) Deposits inside the shell: 60% carbonate compounds, 30% of iron oxides FeO(OH), Fe_3O_4 and the rest was minerals and NaCl.

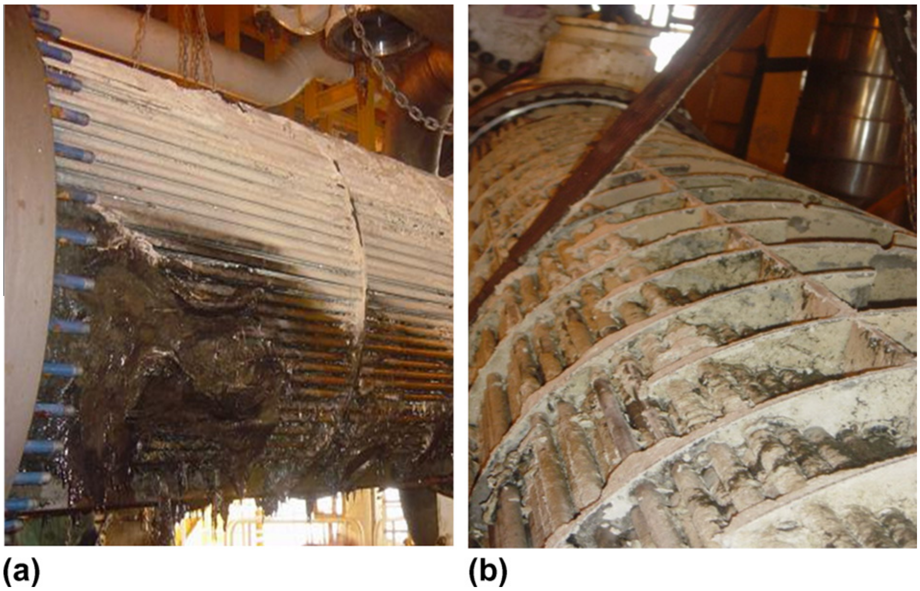

Fig. 1. (a) Fouling by marine growth on heat exchanger external tubes and (b) formation of deposit on tubes.