GENERAL CORROSION AND CORROSION UNDER DEPOSITS ON A TUBE FOR AN AIR FIN COOLER SYSTEM

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ABSTRACT

An air fin cooler system consists of a tube bundle that is used to cool the various processing fluids in process industries that utilizes air as a cooling medium. The said tubes failed when exposed to corrosive environment(s). Tubes located at the bottom row of the air fin cooler were corroded as a result of exposure to rain water, brought in by induced air when the wind blows. The tube material is A179 Carbon steel. Two tubes, namely Tube A and Tube B along with an aluminum fin in each tube were investigated. A leak was observed on tube A, probably due to Corrosion Under Deposit mechanism. A general corrosion attack was observed at tube B, and macroscopic analysis showed that the corrosion occurred along the grain boundaries, which consist of ferrite and pearlite. Microanalysis showed that the corrosion product on the outer surface of the tube consists of Fe, O, S and Cl elements. It is concluded that the humid environment contains corrosive elements such as S and Cl. EDAX analysis on the fin showed that the material is pure aluminum. However, the aluminum was corroded by galvanized corrosion and produced brittle Al_2O_3 as a result.

ABSTRAK

Sistem pendingin sirip udara mengandungi satu tiub berkas yang ialah digunakan untuk bertenang pelbagai cecair-cecair pemprosesan dalam industri pemprosesan yang menggunakan udara sebagai bahantara pendinginan. Kata tiub-tiub menggagalkan apabila mendedahkan kepada persekitaran mengkakis(s). Tiub-tiub berkedudukan barisan bawah pendingin sirip udara dikakis akibat pendedahan untuk air hujan, dibawa oleh udara teraruh apabila tiupan angin. Bahan tiub ialah keluli karbon A179. Dua tiub, iaitu Tube A and Tube B bersama dengan sirip aluminium dalam setiap tiub telah disiasat. Satu kebocoran telah diperhatikan pada tiub A, mungkin disebabkan mekanisme Corrosion Under Deposit. Serangan kakisan umum telah diperhatikan di tiub B , dan analisis makroskopik menunjukkan yang kakisan berlaku selari ira sempadan-sempadan, yang terdiri daripada ferit dan pearlit. Microanalysis menunjukkan yang produk kakisan pada permukaan luar tiub mengandungi Fe, O, unsur-unsur S and Cl. Diakhiri yang persekitaran yang lembap mengandungi unsur-unsur mengkakis seperti S and Cl. Analisis EDAX pada sirip menunjukkan yang bahan ialah aluminium tulen. Bagaimanapun , aluminium dikakis dengan merangsangkan kakisan dan menghasilkan Al2O3 rapuh hasilnya.

Keywords: Corrosive environment; General corrosion; galvanized corrosion; Corrosion Under Deposit; corrosion products

INTRODUCTION

Air fin coolers are extensively used in refineries, petrochemical plants, oil & gas sector and condensing units. Various processing fluids in process industries are effectively cooled using air fin coolers with air acting as the cooling medium, resulting in economical optimization of running costs. The failure(s) occurred when the system was exposed to a generally corrosive environment(s), such as heavy industrial or marine areas. These atmospheres potentially contain heavy concentrations of sulfur dioxide, chlorides, phosphates, nitrates, or other specific industrial emissions. These compounds/elements, combined with precipitation or dew, will form a liquid corrosive agent (1).

Marine environments will also affect the failure mechanism. It has been shown that the amount of salt (chlorides) in the marine environment decreases with increasing distance from the ocean and is greatly influenced by wind direction and velocity (1).

In this study, the air fin cooler is an induced draft type, whereby air will be induced by the fan to counter the tubes from the bottom-most row. The tubes have an outer diameter of 25.4mm with 2.77mm thickness and 20 bar allowable pressure in the tube. The design temperature in the tubes is about 80 ^{O}C while the outside is its ambient temperature as the tube is exposed to the environment. During commissioning, the operating temperature inlet tube is 51 ^{O}C and the outlet is 30 ^{O}C. The tubes were made with A 179 carbon steel and arranged in 6 rows, consisting of a total of 204 tubes. The tubes at the bottom row were directly exposed to rain water and corrosive environments. Proper maintenance, based on preventive maintenance, was carried out according to its preventive maintenance schedule, by external chemical cleaning and internal tube cleaning. However, the leak was detected after two years of maintenance, which has been the first row of tubes exposed and in contact with the induced air.

The cooler tubes, situated at the side of the building were more corroded compared to the middle region. The side of building is the first region to come into contact with induced air coming into the cooler tubes. It is also exposed to the rain water during wind blowing. The induced air will be dry by the time it reaches the middle row, hence the milder corrosion compared to the cooler tubes.

There are two types' corrosion that occurs in this situation, which is general corrosion and corrosion under deposits. General corrosion is a major problem for metal, and statistics shows that it is a leading cause for metal destruction when measured on a tonnage basis. The main cause for general corrosion is atmospheric exposure (especially polluted industrial environments); exposure to fresh, brackish, salt water, soils and chemicals. For this study, the outer surface of tube B was attacked by general corrosion and it produced a somewhat rough surface by removing a substantial amount of metal.

Under deposit corrosion affects a wide variety of metals and is of particular concern with passive alloys such as stainless steel, aluminium, nickel and titanium (3). In our case, Tube A was attacked by under deposit corrosion that creates a hole and a valley on the tube.

The tests conducted includes visual examinations, macroscopy, chemical analysis using spark emission spectrometry, fractography, metallorgraphic studies using Scanning Electron

Microscope (SEM), and Energy Dispersive-X-Rays Analysis (EDAX) to determine the cause of failure and recommend preventive measures.

METHODOLOGY

A site visit was conducted to gather the necessary information. The location and condition of the tubes were properly recorded and photographed. Sampling was done on the failed tube for examination purposes. A thorough visual examination was conducted to analyze the physical failure. Next, the tubes were carefully cut and cross sectioned. After that, the sample was ground, polished and chemically etched. Subsequently, the microstructure of the etched sample was examined using an optical microscope. Microanalysis was performed by FEI S600 Scanning Electron Microscopy (SEM) with an Energy Dispersive X-rays Analyzer (EDAX). The chemical composition analysis was performed by Sparks Emission Spectrometry (SES).

RESULT AND DISCUSSION

The failed tubes were made from A179 carbon steel. The chemical composition, determined by emission spectroscopy with spark excitation was (wt %) as shown in table 1. From the SES result, it was shown that the tube material was made by A179 carbon steel (4).

Table 1: Composition of the cooler tube

Element	**Actual Reading**	**Standard Chemical Composition of A179***
C	0.094	0.06-0.18
Mn	0.428	0.27-0.63
P	0.02	0.035 max
S	0.013	0.035 max
Si	0.12	-
Cr	0.038	-

The two cooler tubes labeled A and B along with the aluminum fin were investigated (Figure 1). The fins were filled with a whitish looking corrosion product (Aluminum Oxide), and this byproduct was trapped between the aluminum fins, covering the reddish corrosion product. Figure 2 shows the tube A and B after the aluminum fins were removed. This shows the rust covered tube surface, which is red in color (Fe_2O_3).

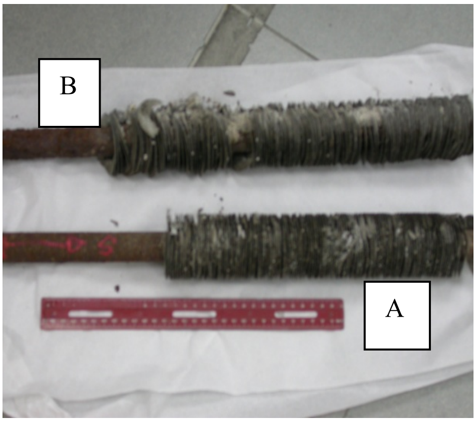

Fig. 1. Samples of cooler tube

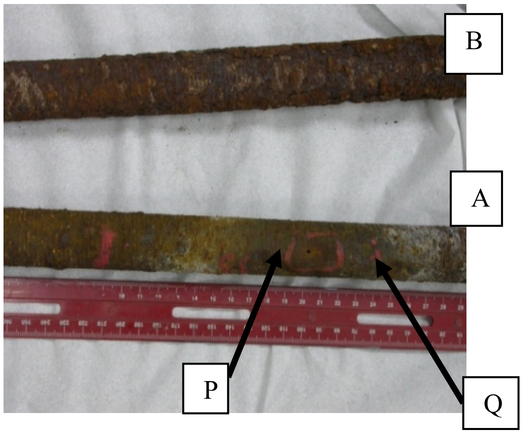

Fig. 2. Location of defect

Fig. 3(a). The valley at point P by side view

Fig. 3(b). The valley at point P by top view

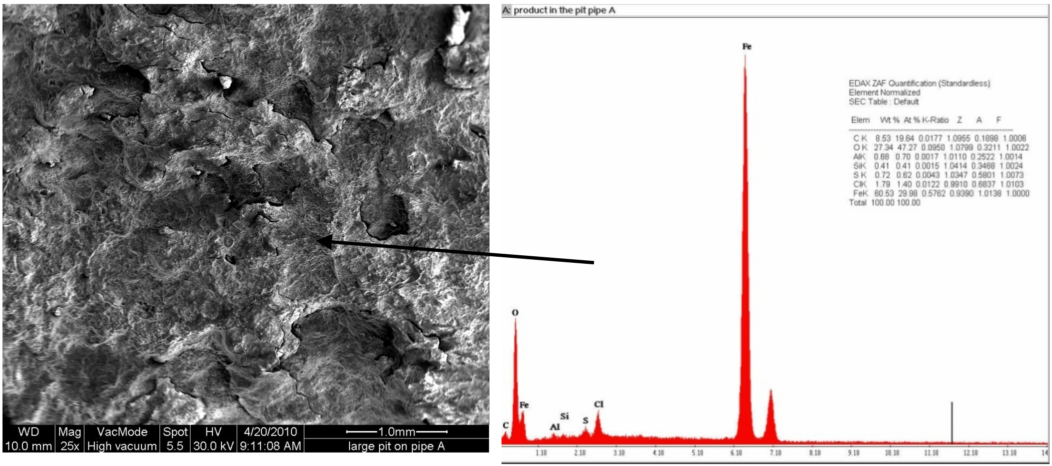

Fig. 4. SEM and EDAX analysis on the valley point P

Tube A consists of a valley P (Figure 3(a)) and a hole Q (Figure 3(b)). A valley at point P was formed due to perforation attacks on the tube's surface. SEM analysis shown that the corrosion product formed on the valley at point P has large amounts of Chloride (Cl) and Sulphite (S).

The concentration of Chloride (Cl) and Sulphite (S) from the corrosive environment acts as an aggressive ion under deposits and is capable of producing severe localized corrosion on the tube's surface. Deposits containing corrosive substances such as sulfur-containing and chloride-containing species serve as an occluding medium which develops concentration cells (1).

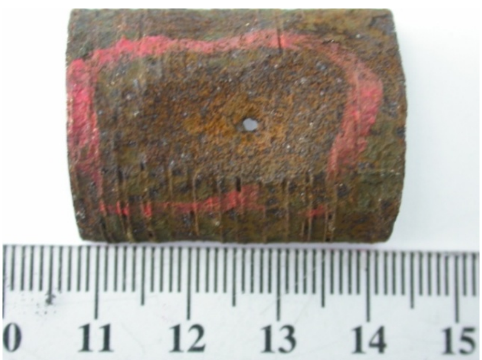

Fig. 4(a).Defect at point Q

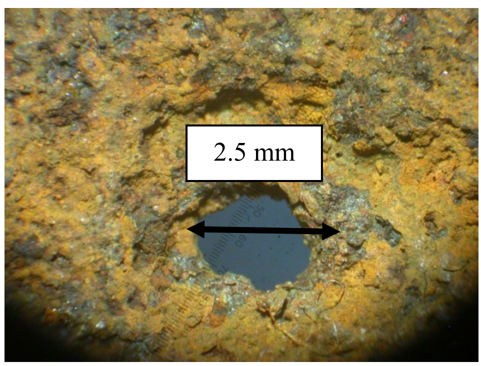

Fig. 4(b). Dimension of hole at point Q

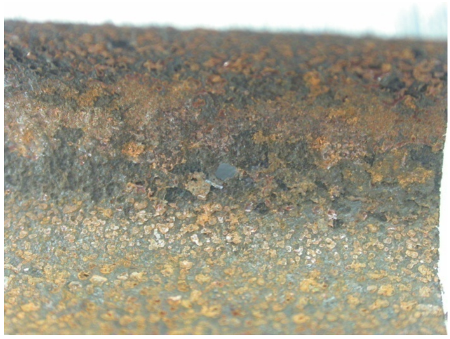

Fig. 4(c). Internal tube surface at point Q

The continuous attack from aggressive ions caused the formation of the hole at point Q, as shown in Figure 4. Figure 4 shows a deepening region with a flat surface (internal) around the hole (Figure 4(c)). It is confirmed that the perforation process started from the outside of the tube surface, working its way in. The size of the holes at the inner surface was about 2.5mm (Figure 4b). The hole on the outer surface is bigger and it gets smaller as it approaches the inner walls.

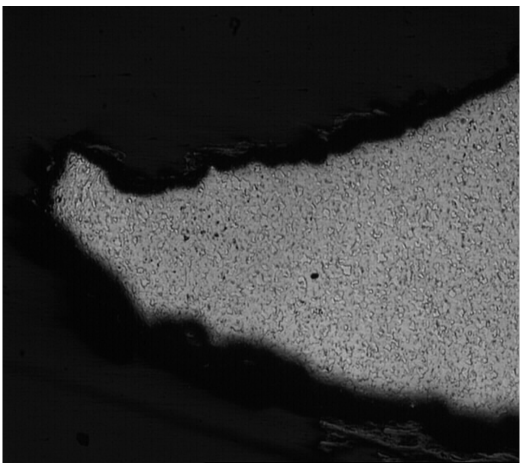

Fig. 5(a). Transverse cross section at hole - X50

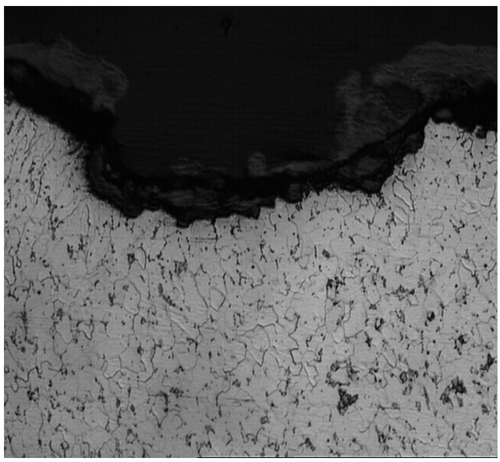

Fig. 5(b). X200

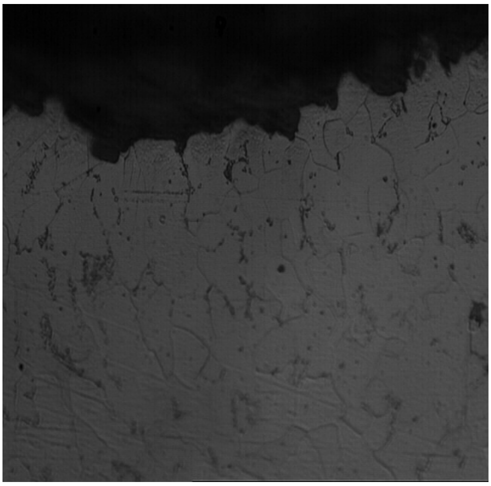

Fig. 5(c). X500

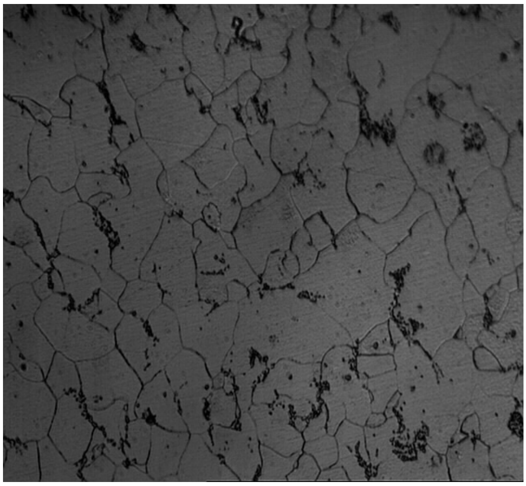

Fig. 5(d). X500, at the middle of tube

Perforation attacks at Q on the surface of tube A can be seen in figure 5a. The corrosion occurred at the grain boundaries as shown in Figure 5c-5d. It is caused by the potential difference between the grain boundary region and any precipitates, intermetallic phases, or impurities that form at the grain boundaries (3). The structure consists of ferrite and pearlite (Figure 5d)

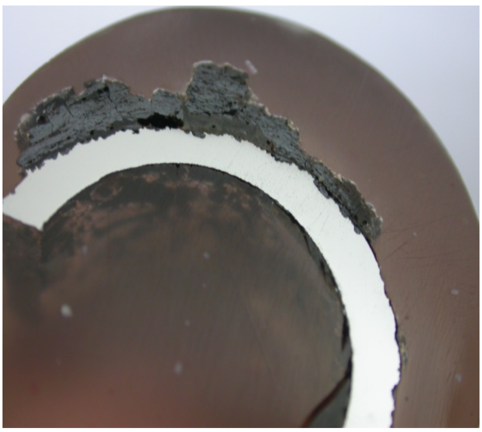

Fig.6. Macro-transverse cross section B
General Corrosion attacked on outer surface

Fig. 7. Aluminium fin

Tube B undergoes general corrosion at its outer surface. Figure 6 shows the corrosion product on the outer surface being somewhat rough. This roughness is attributed to an almost uniform corrosion throughout the piece; removing a substantial quantity of metal, by way of dissolving in the environment or reacting with it to produce a loosely adherent, porous coating of corrosion products (3).

Figure 7 shows the aluminium fin of the cooler tubes. The EDAX analysis (figure 7(a-b)) shows that the fin is purely aluminum. The same analysis was conducted on the corrosion product on the fin's surface and it was shown that the present (dominant) spectrum peaks are of O, S, Cl, Ca, Fe, Si and Na element respectively (Figure 8).

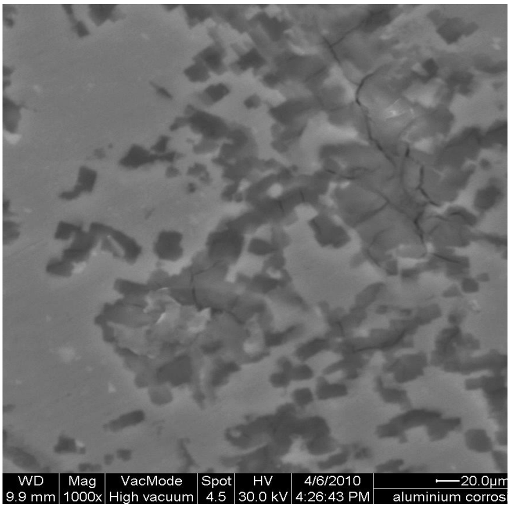

Fig. 7a. Aluminum surface X 1K

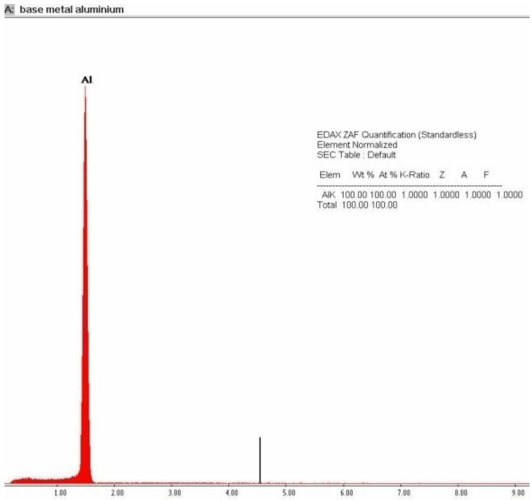

Fig. 7b. EDAX analysis on aluminum matrix

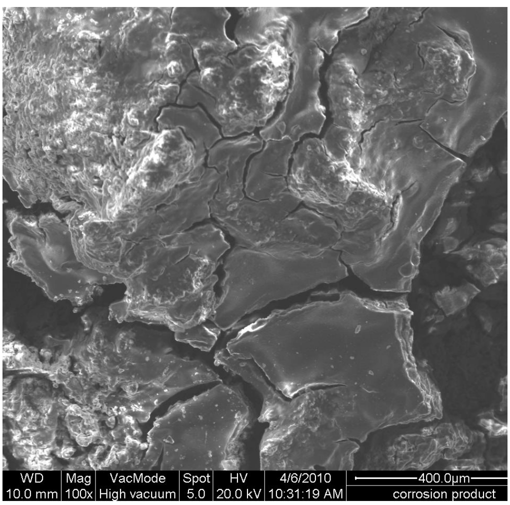

Fig. 8a. Corrosion product on Al surface

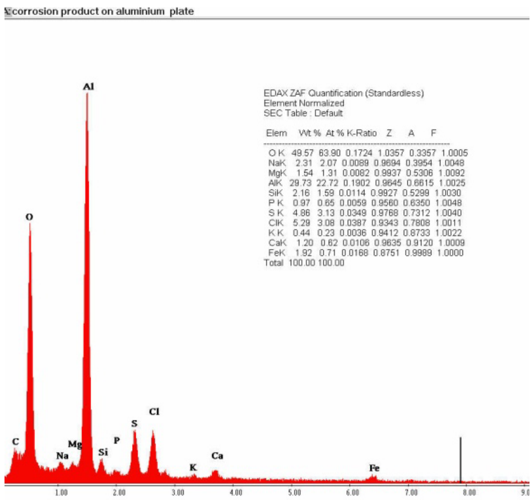

Fig. 8b. EDX analysis on the product (scan analysis)

CONCLUSION AND RECOMMENDATION

From this investigation, it is concluded that the cause(s) of failure are general corrosion and corrosion under deposit, facilitated by the surrounding wet air containing Cl and S from the water and gases. The hole was formed due to the perforation corrosion attack, caused by an aggressive ion like Cl and S that accelerates the corrosion attack. The overall corrosion rate was comparatively slow, and this is evident by the slight metal thinning of the tubes.

In order to prevent corrosion attacks, the tube should be coated with a coating that contain good heat transfer material to avoid direct contact with aluminum fin. The cooler tube should not be exposed to rain water and it should also be subjected to a hydrostatic test before installation.

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