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Failure assessment of composite cooler tubes in a gas boosting station

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ABSTRACT

The present study describes origin and failure mechanisms of air cooled heat exchangers tubes, in a gas pressure boosting station. Hydrocarbon gas was circulating within aluminum finned tubes and cooling was done by forcing ambient air over the exterior of the tubes, made of carbon steel A-214 material. The hydrocarbon gas was contained traces of H_2S and substantial level of CO_2. The investigation was carried out in a station located in southern part of Iran. The process involved condensation of water and hydrocarbon along the length of tubes, resulting in a wet gas multiphase flow situation. Such type of coolers is also called composite coolers. The failure of tubes was characterized on the bases of all the available evidences and metallurgical examinations, such as analysis of tube materials, feeding gas, condensate water, and the residue inside the tubes. The processing was also simulated by Hysis-3.1 software, in order to evaluate and compare various parameters such as gas flow rate, liquid water and hydrocarbon formation, in actual and design condition. The air cooled tubes showed highest corrosion rate and was experienced leakage regularly. The results indicated that, low velocity assisted sweet corrosion caused severe pitting inside the tubes, and led to failure.

1. Introduction

A gas boosting station includes separation facilities to remove liquids (water and hydrocarbons), a compression unit to increase pressure, a cooling system, controlling system and auxiliaries. Usually boosting station is installed at variable distances to compensate for loss in gas pressure that occurs along the pipeline. This will ensure adequate flow at the delivery end of the pipeline. While pressure is increased in stages by compressor, the temperature raised need to be cooled by coolers.

Air cooled heat exchangers use finned tubes in which a pressurized fluid at high temperature is circulated. Ambient air is forced over tube bundles to dissipate the heat. This is done by placing fans beneath the tube bundles. In this way no cooling water and therefore no chemical treatment is required. This type of cooler is (finned) tubing usually suited for natural gas process applications.

Based upon temperature, pressure and the chemical composition of the gas being circulated, air cooler material is selected. There is an extensive use of carbon steels as construction material for cooler tubes in the oil and gas industries. The widespread use of these alloys in petroleum industry is mainly due to economic reasons. However, they exhibit poor corrosion resistance [1]. Besides the failure mechanism, the other important parameter to be considered for air coolers performance is the gas velocity. Erosion is controlled by fluid velocity circulating inside the air cooler tubes. High fluid velocity leads to severe erosion and thinning of tubes, whereas low velocity, causes sedimentation of residues and corrosion products. In latter case, not only under deposit corrosion (pitting) takes place, but also corrosion inhibiting materials, if injected, do not reach the bare surface of the tubes. The flow induced corrosion–erosion [2] is often used to describe this type of failure

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in exchangers. In general, it is believed that [3,4], high gas velocity, increases corrosion rate, since it creates turbulence and removes protective layer by corrosion products/inhibitors.

A typical natural gas is composed of several hydrocarbon compounds. Water, carbon dioxide, and even hydrogen sulfide are also present more or less in its composition. However, on cooling natural gas, condensation of water and liquid hydrocarbon are taking place. As far as corrosion mechanisms are concerned, the presence of water, carbon dioxide and hydrogen sulfide are major factors in such processes. Carbon dioxide dissolved in water or aqueous solution, is known to cause corrosion damage to steel equipments/pipes/tubes in oil and gas industry. It is also called CO_2 corrosion or sweet corrosion. Many studies can be found on the corrosion caused by CO_2, in the literature [1,4–7]. In fact, CO_2 gas hydrates in water to form H_2CO_3, and reacts with steel surface to form iron carbonate which is a corrosion product [8–11]. The overall reactions can be written as:

$$H_2O + CO_2 = H_2CO_3 \quad (1)$$

$$H_2CO_3 + Fe = FeCO_3 + H_2 \quad (2)$$

Similar to carbon dioxide, hydrogen sulfide when dissolved in water, forms a weak acid and therefore is corrosive. When it reacts with iron, its corrosion products are iron sulfide and hydrogen [12,13]. The H_2S corrosion is referred to as sour corrosion. Its reaction can be written as:

$$Fe + H_2S = FeS + H_2 \quad (3)$$

Iron sulfide forms a scale and at low temperature acts as a barrier to slow corrosion [9]. Carbon dioxide and hydrogen sulfide are known as acid gases and can cause internal corrosion in the presence of liquid water.

In this study, failure of the air cooler tubes under the multiphase flow of hydrocarbon gas containing condensate water, substantial amount of CO_2 and traces of hydrogen sulfide was analyzed. The corrosion mechanism and various parameters affecting the failure of tubes were identified and discussed.

2. Experimental procedures

2.1. Back ground

Maroon-3 gas pressure boosting station is located in Khozestan province of Iran. The hydrocarbon gas that feeds through two main supply lines, at a pressure of 0.5 psi, proceeds to increase the pressure to about 460 psi, prior to supply as a fuel gas to various industries and domestic consumers. In this pressure boosting processes, the hydrocarbon gas is compressed, and the temperature gradually increased. Air coolers are used to bring down the temperature for further processing. The schematic drawing of the mentioned station, and the location of the final air coolers the subject of the present study, is shown in Fig. 1a. Each cooler has five rows of 48 tubes each and a total of 240 tubes per cooler. Tubes are finned by aluminum. The inlet, outlet, and circulation of the fluid inside a cooler with a four passes flow arrangement is shown in Fig. 1b. It is a forced draft air cooled heat exchanger, using fans to force air across the fin tube bundles.

In the station, hydrocarbon gas is regularly analyzed. Nevertheless, due to variations of temperature and pressure as shown in Table 1, the chemical composition and the type of hydrocarbon compounds varied at different stages. In the present study, the chemical composition of circulating hydrocarbon gas is considered only before and after the final coolers, and presented in Table 2. The H_2S content of the circulating gas was determined as per ASTM D5504 [14], by using a Varian CP-3800 gas chromatograph with SCD detector. The result of analysis is tabulated in Table 3.

2.2. Tube materials and properties

Table 4 presents the chemical composition of the tube material. It is a simple carbon steel corresponding to ASTM A-214. Each tube has 9140 mm length, 25.4 mm outside diameter and 2.64 mm thickness. Tubes were finned by commercially pure unalloyed aluminum of grade 1060.

2.3. Metallography

Samples were prepared from tubes and after normal polishing and etching by nital solution, their microstructure was revealed under optical and scanning electron microscopes (SEM). SEM micrographs were taken by using a Leo 455VP SEM. Samples from inside the tubes were also prepared in order to study the extent of pitting and crack formation under the deposits. Corrosion products and residue inside the tubes were collected for chemical analysis. Elemental analysis also carried out via Energy Dispersive X-ray probe (EDX).

2.4. Corrosion rate monitoring

Corrosion rates at various points of the gas station were determined by installing the circular washer type coupons of 1018 AISI carbon steel inside the supply lines, following the NACE standard recommended practice [15]. These points are