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Short communication

Failure of 321 stainless steel heater tube in heavy crude oil

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ABSTRACT

Failure investigation was done on a 321 stainless steel charge heater tube which failed in a refinery unit processing heavy crude oil. Crude oil was the charge in the radiant and convection sections; while saturated stripping steam is present in convection section. After a leak was detected, visual inspection revealed that nine convection tubes had black oil/coke deposits on their external surfaces. The deposits were seen on the first three rows of tubes. When one of the tubes was lightly ground at the black colored area, a circumferential crack was visually observed. The investigation revealed that long-term aging, coupled with localized deposition of salts and coke from the heavy crude led to sensitization of the tube surface layers. This in turn resulted in sulphidation of the internal surface grain boundaries, formation of grooves, and cracking of the material. Thus, cracking was intergranular in nature in the initial stage, but became transgranular at later stages. It was concluded that cracking was due to chloride stress corrosion cracking catalyzed by the presence of sulphur-bearing species. It was recommended that the desalter operation be improved and frequent decoking and scale removal be carried out, with emphasis on the convection section at the refinery.

1. Introduction

Stabilized austenitic stainless steels (SSs) have since been widely used in the petroleum refining industry because of their resistance to sulphidic corrosion and polythionic acid stress corrosion cracking (SCC), as well as of their excellent strength and toughness [1,2]. However, in some instances, stabilized austenitic SSs have been found to be susceptible to pitting, crevice corrosion, and SCC [3–5]. The susceptibility to SCC occurs under conditions involving high stress, changes in metallurgical structure due to high temperature exposure, and the presence of specific chemicals that promote cracking [6]. It was found that the factors most affecting corrosion of SSs in the refinery industry are chloride and hydrogen sulphide [3]. Hydrogen sulphide is one of the constituents of crude oils and refinery sour waters and is also formed by the decomposition of organic sulfur compounds at elevated temperatures [7]. Chloride SCC of austenitic SSs is transgranular, but can be intergranular if the material is sensitized [8]. There are reported failure cases suggesting that the presence of hydrogen sulphide (H_2S) synergistically promotes chloride SCC [9,10].

Recent changes in refinery feedstocks in terms of increased H_2S content have accelerated corrosion failures of stabilized austenitic SSs equipment. The present paper presents an example of such failures, where a 321 SS charge heater tube carrying heavy sour crude oil suffered cracking.

2. Background

A leak occurred in a heater of a refinery unit handling heavy sour crude oil. Visual inspection revealed that eight convection tubes

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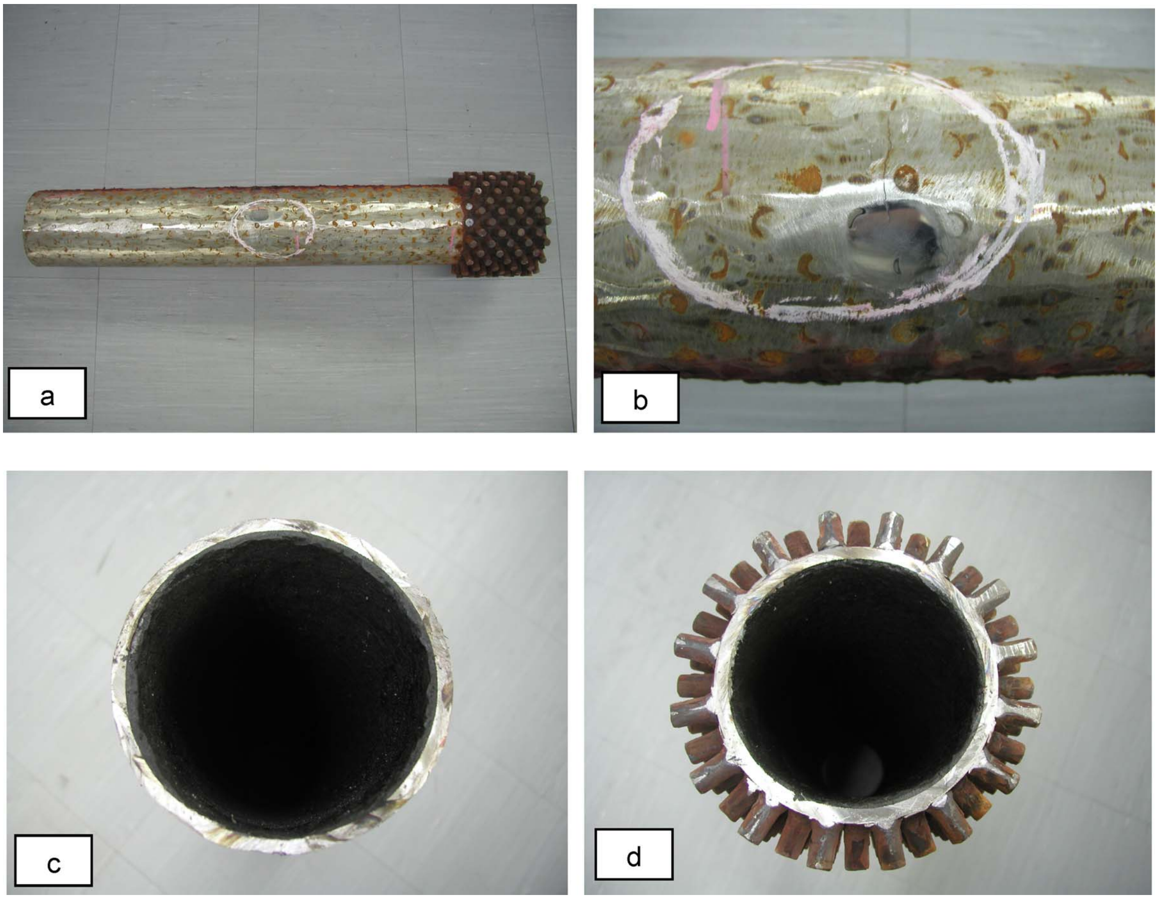

Fig. 1. Camera photographs showing (a) as-received tube section; (b) circumferential crack seen after removal of studs; (c) deposited black layer on internal surface; and (d) stud portion of tube.

made of 321 SS had black oil/coke deposits on their external surfaces. The deposits were seen on the first two rows of plain tubes. The observations were made through available gaps between tubes, as access to the convection tubes was severely limited. In order to identify the leaky tubes, the refinery engineers pressurized the heater. However, no leak was detected as seen from the radiant zone. The eight plain tubes having black deposits were removed from the heater, which facilitated inspection of stud tubes. One stud tube in the third row was found to have black deposits. This tube was also removed, and the removed nine tubes were replaced with new ones. The removed 321 SS tubes were examined using dye penetrant test. No indication was found on all tubes. However, when the stud tube was lightly grounded externally at the black colored area, a circumferential crack was visually observed (Fig. 1a and b). The presence of this crack raised the possibility that the remaining heater tubes in operation may also have cracks.

The heater is part of a heavy crude topping unit. The crude was the charge (tube side) in the radiant and convection sections since its commissioning over twenty years ago. Saturated stripping steam is present in the convection section. The temperatures at the inlet radiant and convection are 130 °C (266°F). On the other hand, the outlet temperatures are 345 °C (653°F) and 316 °C (601°F).

The heavy crude charge has gravity in the order of 17 American Petroleum Institute (API), a total sulphur content of 4.48% wt, and organic chloride content of 3 mg/kg. However, this crude was changed to another heavy crude oil, a year earlier than the date of the current failure. This latter crude has 20.48 API gravity, a total sulphur content of 3.91% wt, and organic chloride content of 1 mg/kg.

3. Experimental Details

Failure investigation was conducted on the cracked heater tube. The investigation included visual examination of the tube surfaces and deposits before and after splitting the tube into halves. Also, measurements were done for the variation in the tube wall thickness and deposits. The deposits inside the tube were scrubbed off the surface and analyzed using X-ray diffraction (XRD). Water extract of the deposits was also prepared, and pH measurement was taken.

Also, cross-sectional specimens were cut from the tube and metallographically prepared for microhardness measurements, as well as microscopic examinations and analysis of the material. The sections were cut at the crack location and away from the crack. The microhardness measurements (in Vickers) were conducted on a polished crosssection, using diamond pyramid indenter at an applied