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Application of non-destructive and fracture mechanics techniques for the condition assessment of naphtha hydrotreater furnace tubes in oil refinery

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ABSTRACT

Furnace tubes of oil refineries undergo thermal, mechanical and environmental loadings during the lifetime of the plant. Apart from highly corrosive conditions, components are also under severe temperatures and pressures which lead to the material degradation and ultimately causing failure. Due to these loadings, the tubes have a finite life and it is important to monitor the condition of the tubes during inspection to avoid any rupture during the service.

The aim of the present work is to evaluate the condition of the naphtha hydrotreater furnace tubes of an oil refinery. These tubes were manufactured of SA 312 P321 material and remained in service for about twenty-five years. Two different techniques were applied for the condition assessment of used and fresh tubes – non-destructive (ND) examination and fracture mechanics based fractographic evaluation. Based on the ND testing, significant deterioration of material was noted in the used specimens. Similarly, besides micro-structural defects, the used material also exhibited sufficient loss of hardness. On the other hand, mechanical properties obtained from standard tension, impact and bend tests also exhibited the poor condition of the tubes. A comparison of the used specimens with the un-used one shows that the condition of the furnace tubes has been considerably deteriorated and its further use for the long term service cannot be considered as satisfactory.

1. Introduction

Oil refineries undergo chemical processes such as kerosene hydrotreating and naphtha hydrotreating for the refinement of petroleum products [1]. These processes takes place in high temperature and high pressure furnaces which run around 700 F and 600 psi respectively [2]. Due to prolong service under such aggressive conditions, the major parts of the furnace such as tubes have a finite lifetime [3]. Consequently, it is important to carry out extensive inspection of such components, to avoid any catastrophic failure. Several cases of tube failures have occurred within the US and outside [4–6], which resulted in tragic loss of human and/or expensive equipment. Therefore, the condition of furnace tubes against corrosion, cracking, metal wear and other material degradation mechanisms is regularly monitored [7]. Accordingly, based on the condition of the tubes, the lifetime of the component is defined for the future service.

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Conventional methods for monitoring degradation of material are non-destructive techniques like visual inspection, liquid penetrant tests and ultrasonic testing [8]. Based on these inspection techniques, the extent of the damage defining the damage mechanism and severity is reported. Codes like API 579 [9], BS 7910 [10] and ASME BPV Section XI [11] have defined methods for the life assessment of such components. A detailed guideline is available for the assessment of components undergoing high temperature and pressure loadings in the presence of cracks or crack-like defects. However, one of the important considerations for such analyses is the availability of base line data acquired from initial or previous inspections. Depending upon the available data, it is possible to obtain a quantitative measure of the remaining life time of components having the aforementioned working environment [12]. On the other hand, there are certain other methods that are also used for the monitoring of the service condition of furnace tubes. These include hardness testing, non-destructive metallography and material identification techniques [13]. These parameters are used to give a qualitative as well as quantitative assessment for the remaining condition of the part in question [14]. Additionally, Material properties and fractographic results, obtained from destructive mechanical testing of specimens taken from the replaced tubes or using material data base, published data or lower bound values, monitoring and prediction for the lifetime is performed [15].

The present work consists of the condition assessment of tubes of naphtha hydrotreater furnace of a local oil refinery. The plant was installed about forty years ago and remained out of service for nearly fifteen years after its last use. A total number of ten tube specimens, including one unused specimen were provided by the client. The aim of the work was to determine the present condition of the used tubes that was desired to operate under aggressive environment and at a temperature of 440 C. In the absence of base line data, the condition of the sample tubes of the used furnace was compared with the condition of fresh tube of the same material. The study presents the material degradation of the used tubes which was investigated both with microstructural and fractographic verifications.

2. Experimental investigations

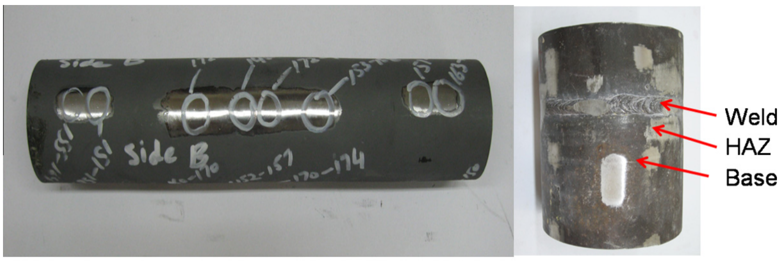
2.1. Specimen detail

For the condition assessment of in-service tubes, nine specimens of the serviced tubes were provided by the client. These specimens were extracted from South West (SW), South East (SE), North West (NW) and North East (NE) loops of the furnace. The specimens were of approximately 150 mm diameter and 300 mm length each. Both, unwelded and welded locations were selected for evaluating the condition at base, heat affected zone (HAZ) and weld region. An additional sample of unused material was also provided in similar dimensions. Fig. 1 shows the different regions of the welded specimens along with the un-welded specimen.

2.2. Testing details

The condition assessment of the tube materials were approached using destructive and non-destructive methodologies. The various tests performed on the tube samples are listed in Table 1. The following work plan was implemented to investigate the status of the material:

a. Determination of chemical composition of material.
b. Non destructive hardness testing of weld, HAZ and base material.
c. Microstructural investigation.
d. Evaluation of material condition through ultrasonic attenuation coefficients.
e. Observance of wall thinning.
f. Determination of mechanical properties.



(a) (b)

Fig. 1. Un-welded (a) and welded specimens showing base, HAZ and weld regions (b).