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Inspection of carburization and ovalness in ethylene cracking tubes by using a semi-robot

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ABSTRACT

Carburization and creep are the main causes of failure in the heat resistant tubes of ethylene cracking furnaces leading to a decrease in ductility and embrittlement of the cracking tubes. The aim of present study was to develop a semi-robot for inspection and classification of the carburized zones in heat resistant tubes. Regarding the magnetic characteristics of the formed matrix in carburized zones, the carburization sensors were successfully employed for examination of the carburized layers. The comparison between data acquired via this sensor-based method and those obtained from chemical etching implied a high enough compatibility and appropriate accuracy of the sensor-based measurements. This feasible analyzing method was effectively utilized in a semi-robot that moves on surface of the tubes and establishes a carburization profile. Finally, these carburization profiles together with ovalness graphs were employed for assessment of the points susceptible to embrittlement and failure in petrochemical industries.

1. Introduction

The tubes used in thermal cracking furnaces in an ethylene manufacturing process are usually made of HP and HK grades of heat resistant stainless steel; these parts significantly influence the economical/technical features of these plants. Each group of heat resistant steel tubes is called a coil and a furnace includes several coils. Fig. 1 shows a schematic view of the coil utilized in Jam petrochemical complex (Asalooyeh, Iran).

Typically, these coils work at temperatures 800–1100 °C [1,2]. After some preheating stages, the fluid (gas or liquid) feed enters through the inlet of coil, heats up to the thermal cracking temperature and then ethylene and other products exit from the outlet. Products of several coils are gathered and sent to refinery stage. Any failure in these tubes results in shut-down of the cracking furnaces and wasting both cost and time. Hence, the technical inspection and monitoring of the cracking tubes is mandatory.

Carburization and creep are the main phenomena that cause failure in these tubes and decrease their life time [3–6]. Thermal cracking of hydrocarbon feed in the tubes results in formation of free carbon and its diffusion into the tube. The depletion of free carbon and formation of an adherent coke layer on the inner surface of the tubes, as well as temperature enhancement especially at decoking process, intensify the carburization phenomenon [7]. Carburization leads to the formation of metal carbides in the grains and grain boundaries that consequently reduce the mechanical properties, creep resistance, service life time and weldability of the tubes. Moreover, the micro-cracks propagation and tube embrittlement are ascribed to the occurrence of carburization process [3,7].

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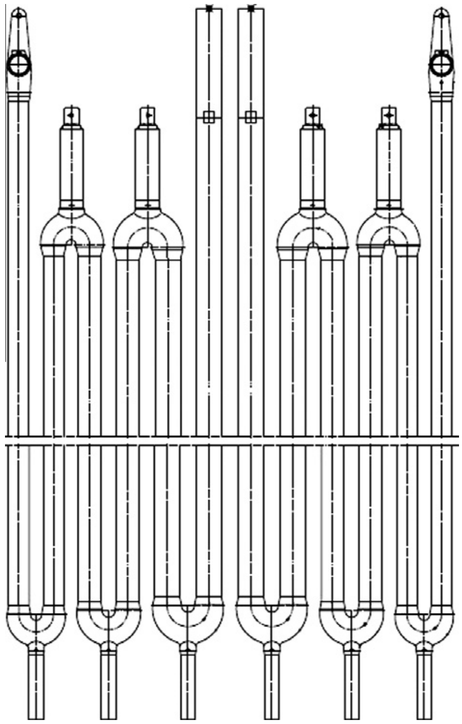

Fig. 1. Schematic of heat resistant ethylene cracking coil.

A conventional method for the evaluation of carburization is the measurement of fractional volumetric ratio of chromium carbides in the micro-structure of tube walls [8]. However, this method requires cutting off the tube (destructive method) and taking specimens from several zones of the tubes (time-consuming). It is worthy of note that during carburization, metal carbides such as M_7C_6 and $M_{23}C_6$ are formed and chromium accumulates at carburized zones [5–7]. Also, in carburized zones the field structure is rich of Ni and Fe–Ni and thus, these zones become ferromagnetic (Ni and Ni–Fe are paramagnetic). Therefore the other method, which is a very effective and useful technique under industrial conditions, is based on ferromagnetic property of the tubes; i.e. the non-magnetic (austenitic) microstructure of these tubes becomes ferromagnetic due to carburization reaction and when the carburized section of a tube is subjected to a magnetic field by applying a magnetic – incorporated probe, the lines of magnetic force deflect toward the carburized section.

The magnetic flux measurement can be applicably used to correlate the magnetic response of carburized austenitic steel tubes (ferromagnetic behavior) with the volumetric fraction of chromium carbides ($Cr_{23}C_6$ and Cr_7C_3) in the tube wall [9]. For instance, Stevens et al. [10] evaluated the changes in magnetic properties of ethylene pyrolysis tubes (due to carburization) by the use of vibrating sample magnetometer (VSM) measurements [10]. Takahashi et al. [11] also studied the chromium depletion in nickel based alloys (Inconel 600) employing magnetic force microscopy (MFM) [11].

A literature survey shows that there are some attempts to develop an appropriate technique for the detection of magnetic carburized layers inside thermal cracking tubes. Kasai et al. [12] have employed a C core probe and a magnetizer for analyzing such magnetic carburized layers [12]. Additionally, da Silva et al. [13] could successfully characterize the carburization of HP steels by non destructive magnetic testing. Moreover, Silva et al. [8] studied the carburization of ethylene pyrolysis tubes by magnetic measurements. These works indicate that magnetic flux detection is a suitable and feasible way for analyzing the carburization phenomenon in the cracking tubes [8,13].

Another sign that shows the risk of rupture in thermal cracking tubes is the ovalness of tube. Carbides formation in internal layers of the tubes leads to volume expansion of these areas. Generally, there is a proximate relation between the carburization ratio and the creep remaining life with outer diameter (OD) of the tubes [14,15]. Uneven carburization around the tube circumference results in ovalness and the developing high stress and brittle points. Additionally, tube ovalness is significantly intensified when carburization is very severe and non-uniform.

In present study, the magnet tests together with ovalness measurements have been conducted for detection and evaluation the high risk places in thermal cracking tubes in Jam petrochemical complex (Asalooyeh, Iran). From the industrial point of view, the maximum allowance of carburization in tube wall is 50% (according to manufacturer recommendations) to keep the process conditions suitable and safe and to decrease risk of carburization. Accordingly, a group of carburization and ovalness sensors have been utilized to develop a semi-robot that can move on the cracking tubes and make the profiles of carburization and ovalness along the tubes.