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Failure analysis of bolt connections in fired heater of a petrochemical unit

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ABSTRACT

The main function of a fired heater in a petrochemical site is to produce supersaturated steam. Due to extremely difficult working conditions and high temperatures, there is a very high probability of failures in different parts of a fired heater. In the fired heater under study, tube guides are frequently damaged due to malfunctions and fractures in bolt connections. To investigate the nature of such fractures, Computational Fluid Dynamics (CFD), Finite Element (FE) method, Charpy impact test and fractography were used. To obtain the temperature of various components of the fired heater, a CFD analysis was carried out by considering the combustion process and modeling the central and side burners. Next, stress and displacement values in different components of the fire heater, particularly tube guides, were calculated using the uncoupled thermal-structural finite element analysis. It is found that when the dummy drain at the bottom of the tubes is stuck at the bottom of the fired heater, the expansion of tubes is impeded in addition to creating distortions in tube bundles and increasing the stress on the bolts of tube guides. Moreover, according to the performed tests, it is revealed that the increase in the stress of bolts leads to the activation of creep and Hydrogen embrittlement, causing the bolts to experience fractures in a considerably shorter amount of time.

1. Introduction

Fired heaters use the heat created by the combustion of fuels to heat fluids contained inside tubes and are used in industry for steam generation and petroleum refining. Common types of fired heaters are the box, cabin and cylindrical vertical. Tube bundles, burners, tube guides and tube supports are the main component in a fired heater. Tube distortion, crack and oxidation in tube supports and tube guides, breaking and oxidation of bolts are some common failure in fired heater.

The fired heater investigated in this paper, is a vertical cylindrical heaters with radiant vertical tube bundles that is used to produce super saturated steam. This fired heater has 84 vertical tubes, each 17,850 mm in length, converting saturated vapor at 331 °C, and 119 bar, to the superheated steam at temperature about 500 °C and pressure of 115 bar at the rate of 314 tons per hour. The fired heater has six U-shaped tube bundles, which each tube module consists of 14 tubes. At a distance of 10 m from the top of the tubes, there is a tube guide that each of them is in contact with two tubes. In other words, there are 42 tube guides in the fired heater. These guides are installed to maintain and direct the tubes in a vertical direction. There are also 6 supports in each module located at the top of the system and under the U section of tubes, bearing the weight of the system. Below the entrance tube of each module, a

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Nomenclature

C_p	specific heat capacity (kJ kg^{-1} k^{-1})
f	mixture fraction
p	pressure (Pa)
Pr_t	turbulent Prandtl number
T	temperature (K)
u	velocity (m s^{-1})
x	coordinate direction
Z	elemental mass fraction

Subscripts

i	i_{th}, i = 1, 2, 3
ox	oxidizer inlet
fuel	fuel inlet

Greek symbols

α	thermal diffusivity (m^2 s^{-1})
α_t	turbulent thermal diffusivity
λ	laminar thermal conductivity (W m^{-1} K^{-1})
μ_t	turbulent viscosity (Pa s)
ν	kinematic viscosity (m^2 s^{-1})
ρ	density (kg m^{-3})

drain is installed to exhaust the condensed vapor that formed in the system. At the end of the other tubes, there are dummy supports to let the tubes slide in a vertical hole. In other words, when tubes want to expand due to thermal strain, there is not any barrier in the expansion of the tubes. In Fig. 1, the general structure of the fired heater is shown. In Fig. 2, the upper supports, the tube guides and floor drains are shown.

Some of tube guides collapsed due to the failure of the connecting bolts and fell to the bottom of the fired heater. Also a lot of tube guides were highly distorted and made a failure in the contact areas with tubes. Fig. 3 shows some of failed supports that are related to the overhaul of fired heater. These connections were replaced with new ones, but similar failures occurred in the following years, 21 of the tube guides were replaced. In Fig. 4, the effect of the distorted supports on the connecting tubes for two different tube guides is shown.

Another failure, which was seen in the fired heater, was the damage of refractories located on the floor of fired heater and around dummy supports. For this purpose, distorted drains were replaced by new ones and the refractories around the drains were repaired.

A few researches have been done in the field of failure of fired heaters. Khodabandeh et al. [1] investigated the effects of excess air and preheating on the flow pattern and efficiency of a box-type fired heater. They applied three dimensional CFD modeling to study the flow pattern and found that multiple vortices are formed within fired heater. They found that optimal value of excess air is 18% and any further value reduces the flame temperature and efficiency of fired heater. Jegla et al. [2] numerically analyzed heat transfer in radiant section of a vertical cylindrical fired heater. They conclude that standard 1D design calculations of fired heaters according

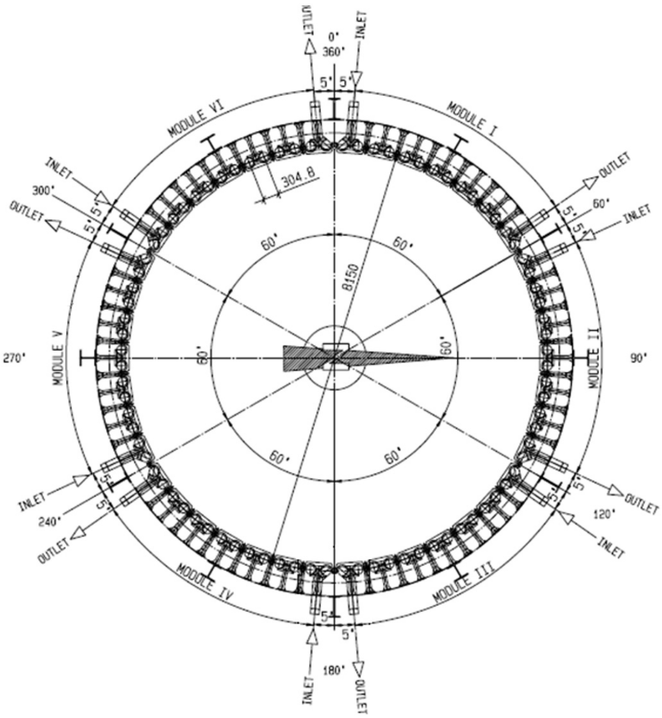

Fig. 1. Top view of arrangement of tube bundles in the fired heater.

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