Engineering Failure Analysis 31 (2013) 387–393

Contents lists available at SciVerse ScienceDirect

Engineering Failure Analysis

journal homepage: www.elsevier.com/locate/engfailanal

Failure analysis of a reactor effluent air cooler

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ARTICLE INFO

Article history:
Received 16 September 2012
Accepted 11 February 2013
Available online 26 February 2013

Keywords:
Ammonium chloride
Air cooler
Tube explosion
Failure analysis

ABSTRACT

In the present research, root causes of the tube explosion of a refinery hydrocracking reactor effluent air cooler (REAC) were studied. For this purpose, anatomical analysis was firstly used and ammonium salt crystals were found. Based on the actual operating conditions, ionic equilibrium model was established by Aspen software to calculate the crystal temperature of the NH_4Cl and NH_4HS. The results indicate that NH_4Cl crystal temperature ranged from 175 °C to 210 °C with different chlorine and nitrogen content of the feedstock, which is higher than the operating temperature of REAC. To analyze the impact of the air cooler structure on the ammonium salt deposition location, numerical simulation including the air cooler header box and bundles was conducted by the Fluent software. The results show that a bias flow regime exists because of the large vortex formed in both sides of the header box inlet. The velocity and aqueous phase fraction of the multiphase were low in the tubes of the header box inlet both sides, which result in the NH_4Cl deposition and under-deposit corrosion. In order to verify the failure analysis results, other in service air coolers were inspected using the infrared camera, and the results show that other air coolers had the plugging features at the same position. Finally, some recommendations were given to mitigate the NH_4Cl deposition.

1. Introduction

Reactor effluent air cooler (REAC) failure has been recognized as a serious problem since the commercial development of the hydroprocessing units [1,2]. Finding out the failure reasons and preventing the REAC system failure appearance again have long been a hot issue in the oil refining field. In recent years, many research focused on the erosion–corrosion problem of the multiphase flow and the results have played an important role in controlling the erosion–corrosion of the air cooler [3,4]. However, the ammonium salt deposition and under-deposit corrosion of the air cooler have not attracted sufficient attentions and accidents caused by the ammonium salt deposition still occurred frequently [5–7]. After a survey among more than 20 Chinese refineries in 2011, it was found that the accident caused by ammonium salt deposition is more serious than the erosion–corrosion. Recent years, some simplified thermodynamic models and multi-physical field coupling models were established to analysis ammonium salt deposition. However, the impact of other substances (hydrocarbons, water, hydrogen, etc.) and the unbalanced air cooler structure were not taken into account in the most of these models [8,9]. More researchers did not distinguish between the crystal and deposition of ammonium salt, which result in the inaccurate prediction of deposited position [10]. Under practical conditions, the ammonium salt deposition related to the multiphase equilibrium, fluid flow, and liquid distribution. In this paper, ionic equilibrium model and the CFD simulation were used to analyze a

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http://dx.doi.org/10.1016/j.engfailanal.2013.02.025

REAC failure caused by the ammonium salt deposition. The analysis results were validated by inspecting other in service air coolers. Finally, some recommendations were given to mitigate the ammonium salt deposition.

2. Process and air cooler failure

The reaction effluent cooling and separation process is shown in Fig. 1. The effluent stream is cooled through a series of feed/effluent exchangers before enters a hot, high-pressure separator (HHPS). Wash water is injected into the HHPS vapor stream before it enters the air coolers. The inlet and outlet header pipes of the air coolers (8 sets) are balanced designed [11]. After cooled from 160 °C to 45 °C in the air cooler, the multiphase flow enters a cold, high-pressure separator (CHPS) and separated into liquid, vapor and aqueous phase. The hydrocarbon liquid from the CHPS is routed into a cold, low-pressure separator (CLPS) and vapor, mostly hydrogen, recycled back to the reactor. The HHPS liquid stream is also separated in a cold, high-pressure separator (CHPS).

The explosion of the air cooler occurred in the 16th months of the run cycle, because of refining low-quality crude from the Middle East. Inspection revealed that the explosion tube located in the first row near the entrance of the header box (Fig. 2). The air cooler is made of 10# carbon steel and designed based upon the conventional design criteria [12]. Tube stream velocity is ranging from 3.0 m/s to 6.1 m/s. More than 20 vol% of water remains the aqueous phase at the injection point. NH_4HS concentration of the sour water is below 8 wt%.

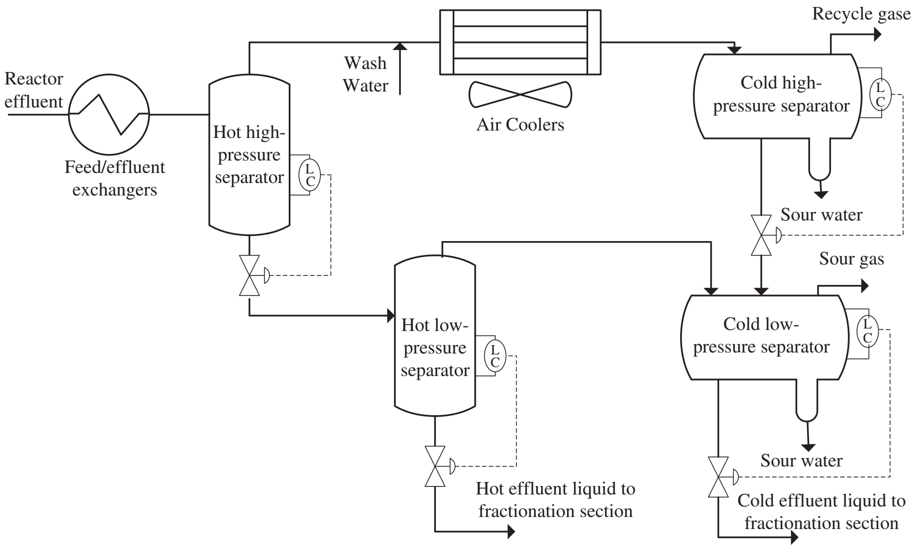

Fig. 1. Reactor effluent cooling and separation process.

Fig. 2. The location of exploded air cooler tube.