Available online at www.sciencedirect.com
ScienceDirect
Engineering Failure Analysis 15 (2008) 118–128
ENGINEERING FAILURE ANALYSIS
www.elsevier.com/locate/engfailanal

Failure analysis of heat exchanger tubes

A. Usman, A. Nusair Khan *

Metallurgy Division, G.P.O. Box 502, Rawalpindi, Pakistan

Received 23 September 2006; accepted 20 November 2006
Available online 26 January 2007

Abstract

Primary waste heat exchanger tubes of material ASTM A213 grade T11 failed after operation of only three and a half months. The heat exchanger was of the bayonet type with boiler water inside the tubes and secondary reformer outlet process gas at the shell side. The heat exchanger environment was rich in hydrogen, carbon monoxide and nitrogen. The temperature of the process gases was 960 °C and the heat exchanger was producing steam at a temperature of 306 °C and a pressure of 1500 psig. The failed, used and new heat exchanger tubes were subjected to stereo/optical microscopy, chemical analysis and hardness testing. The cause of the failure was thoroughly investigated using optical/scanning electron microscope equipped with energy dispersive spectrometer. The study revealed that the material was exposed to thermal cycling and excessive local heating. The same was also confirmed by simulated experimentation. These conditions lead to thermal fatigue of the material with consequent failure.

Keywords: Bulging; Dendrite; High temperature; Failure analysis; Heat exchanger

1. Introduction

Primary waste heat exchanger (C-101) was attached with the ammonia plant. The heat exchanger was of bayonet type with boiler water in the tube side and secondary reformer outlet process gas was at the shell side. The chemical composition of the process gas is given in Table 1. The temperature of the process gas was 1760 F (960 °C) at the entrance and 740 F (393 °C) at the exit. The temperature of the steam in the tubes was 583 F (306 °C). The heat exchanger was producing steam at a high pressure of 1500 psig. In normal operation, these temperatures and pressures remain the same.

The ammonia plant was revamped in the year 1989–1991 to enhance its ammonia production capacity by 25%, thus increasing the heat load on C-101 heat exchanger by about 22%. The C-101 was not modified in the revamp. Before revamp, the maximum service life of C-101 was about 13 years which reduced to 2 years after the revamp.

* Corresponding author.
E-mail address: nusairy@yahoo.com (A.N. Khan).

1350-6307/$ - see front matter
doi:10.1016/j.engfailanal.2006.11.051

Table 1
Chemical composition of the outlet process gas on dry basis

Gases	Ar	N_2	CH_4	CO	CO_2	H_2
Mole%	0.26	22.49	0.44	12.05	8.19	56.57

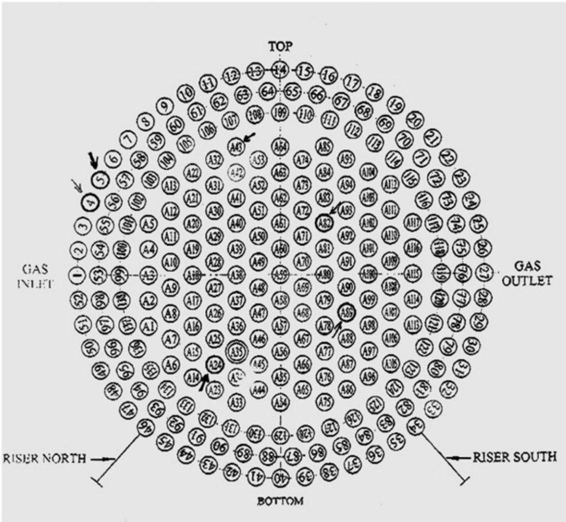

Fig. 1. Sketch showing the position of failed tubes.

The first indication of the leakage in the bundle was observed only after 20 days of its induction but the plant continued to run. After three months the plant faced emergency shut down due to sudden loss of Natural gas pressure. During this shut down the bundle of tubes was removed for inspection. Circumferential cracks were observed on five tubes, whereas three had longitudinal cracks. The location of the tubes is shown in Fig. 1. The standard tube material is 1.25Cr–0.5Mo, ASTM A213, Grade T-11.

Various tests were performed including visual examination, chemical analysis, fractography and metallographic studies using optical and scanning electron microscopes to determine the cause of failure. Further a simulated experimentation was also performed to confirm different hypotheses.

2. Nomenclature

For convenience, the following nomenclature will be used for the various tubes in this report.

Received tubes	Nomenclature
New and un-used tube	NT
Used but un-failed tube	A-43
Failed tube No. 05	T-05
Failed tube No. A-24	A-24

3. Results

3.1. Visual examination

All the received tubes were observed with the help of a hand magnifier and stereomicroscope.