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Failure analysis of stress corrosion cracking in heat exchanger tubes during start-up operation

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ABSTRACT

The cracking failure of a new heat exchanger during first start-up operation has been analyzed. Through the investigation of the operating history of the equipment, analysis of the chemical compositions of tube material and corrosion products, metallographic test of specimens with cracks, the cracking mode can be described as the Stress Corrosion Cracking (SCC) of austenitic stainless steel. This kind of cracking was induced by the chloride in high temperature steam and tensile stress. The residual tensile stress due to seal expansion has been proved by numerical calculation. The pre-heating steam which was polluted by the catalyst with chloride is the main reason for the tube cracking in this case.

1. Introduction

Shell-tube heat exchangers are widely used in chemical, petroleum, medicine and nuclear industries. Crack development in tube and tube sheet region of a stainless steel heat exchanger is a common problem. Such crack is propagated by stress corrosion cracking or thermal fatigue, or localized corrosion [1]. The local stress levels, arising from a combination of the applied loading, as well as thermal and residual stresses, contribute to the failure scenario. The Stress Corrosion Cracking (SCC) of austenitic stainless steels may occur when an alloy is simultaneously subject to the tensile stress and a specific corrosive fluid [2,3]. The SCC of austenitic steel in a certain medium, such as hot chloride and hot alkaline solutions is a common failure mode in the process industry. Engineers have investigated this kind of SCC in a variety of ways, and lots of prevention solutions have been proposed [4–7]. Many SCC failure cases during long time service in process plants have been introduced in the history. However, new stainless steel heat exchanger tubes were also cracking during 8 days start-up pre-heating operation. It is uncommon and should be analyzed carefully. In this paper, a failure case of heat exchanger tubes during start-up operation will be discussed. The intention of this paper is not to figure out the micro mechanism and mode of SCC of austenitic stainless steel, but to show the reason and the characterization of SCC of a new austenitic steel tube during start-up operation.

2. Descriptions of the failure case

In 2014, a tube-shell heat exchanger E101/E102 for dimethyl ether to propylene project failed due to the leak of tubes during the first start-up operation. The specification of the heat exchanger E101/E102 is listed in Table 1. E101 and E102

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Table 1
The specification of the heat exchanger E101/E102.

Designation	E101		E102	
	Shell side	Tube side	Shell side	Tube side
Operating fluid	Water, dimethyl ether	Water, propylene	Water, methanol	Water, propylene
Design pressure/MPa	0.8	0.35	0.8	0.35
Working pressure/MPa	0.33	0.13	0.431	0.125
Design temperature/°C	450	550	200	420
Working temperature(in/out)/°C	155/340	483.5/383	150.7/150.7	383/153
Hydro-test pressure/MPa	1.26	0.66	1.03	0.66
Heat transfer surface/m^2	336.5		918.4	
Material of tubes	S30409		S30408	
Material of shell and head	S30408			
Material of tube-sheet	S30408II			

are assembled in one vessel with the serial tube side, as shown in Fig. 1. In the normal production process, the feed fluid of reactor R101, water and dimethyl ether are heated in shell side of E101. The water and methanol are heated in shell side of E102. The products of R101, water and propylene are cooled down in tube side of E101 and E102. In the first star-up operation, R101 and E101/102 are heated by the high temperature steam from the boiler, as shown in Fig. 1.

E101/102 was fabricated in May 1, 2014, and tried to start-up in June 21, 2014. The pre-heating steam flows through R101 to heat the catalyst bed, and then pre-heats E101/E102 through tube side. The temperature increased from 30 °C to 320 °C during 4 days and kept constant in the later 4 days. The leakage of E101/E102 was found in June 28, 2014. The tube cracks were located in the end of seal expansion section, Zone-I and Zone-II, as shown in Fig. 2. The inner surface of failed tubes was corroded, on which some reddish brown corrosion products were observed. Some circumferential cracks in inner and outer surfaces of tube can be found. Fig. 3 shows the appearance of cracks in Zone-I of Tube-A. No obvious plastic deformation can be found around the fracture zone. Fig. 4 shows the appearance of cracks in Zone-II of Tube-B. The cracks originated in inner surface and propagated to the outer surface, as shown in Fig. 3(b).

3. Failure analysis and results

3.1. Chemical composition

According to the manufacture specification, the Tube-A and Tube-B were made of S30409 and S30408. They are equivalent to TP304H and TP304 stainless steel according to ASME code.

Specimens from the Tube-A and Tube-B were analyzed by spectral analysis for their chemical composition. The measured results and their standard requirements of Tube-A and Tube-B are shown in Tables 2 and 3, respectively. According to the specification of the material of tubes which are used, we can find that the composition of Tube-A and Tube-B meet the requirement of GB/T13296-2007 *Boiler, heat exchanger with stainless steel seamless pipe* [8] and GB/T 222-2006 *Permissible tolerances for chemical composition of steel products* [9].

3.2. Microstructure

In order to evaluate the material microstructure, specimens from Tube-A and Tube-B were prepared for optical metallographic test.

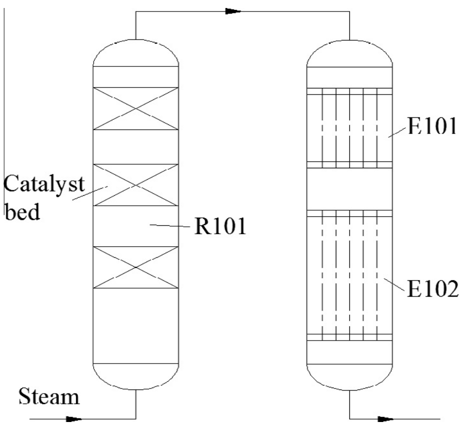

Fig. 1. The pre-heating steam flow during start-up operation.