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Investigations on the breakdown of a heat recovery steam generator during the initial operation run

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ABSTRACT

Several years ago, in 2003, an industrial heat recovery steam generator in charge of generating process steam in a petrochemical refinery was installed and prepared for initial operation. The steam generator enclosed an evaporator section and a superheater section consisting mainly of bundles of tubes with the longest up to several metres in length. During initial operation test runs severe leakages in the evaporator and superheater modules became noticeable. The test runs were stopped and after disassembly, through-wall cracks in several tube bends were found. BAM was commissioned to carry out the investigations in order to find out the reasons for the failure of the tubes. During on-site inspection a number of relevant damaged components and parts were selected and taken away to the laboratories for detailed inspection. Planned analyses were to comprise metallographic as well as fractographic investigations, mechanical fatigue testing and experimental as well as finite element vibration analyses on specimens and components. Soon, the fracture mechanism was found to be mechanical fatigue due to the fact that the examined fracture surfaces showed the very characteristic beachmarks and colouring patterns. To identify the particular loading and time at which crack initiation and crack propagation took place, experimental and numerical vibration analyses of specific tubes as well as mechanical fatigue tests on tube bends were carried out. Thus it was possible to identify the eigenfrequencies of individual tubes, to estimate the dynamic response as well as the nominal stresses and, hence, experimentally characterise the in-service fatigue strength of the components. Mechanical and thermal comparative tests on tube bends were performed simulating the conditions during the initial test run in order to get crack surfaces comparable to that of the originally damaged components. Thereby it became obvious that the fatigue cracks were initiated by vibrations the tube bundles were exposed to during rail transport from the manufacturer's site to the place of installation. Based on these results, the damaged components could be repaired or exchanged without modification of the construction, but the rules relating packaging and securing for shipping had to be revised.

1. Introduction

The recovery heat steam generator which is shown in Fig. 1 was installed in the exhaust air stream of a petrochemical refinery in 2003 in order to produce process steam. The steam generator embodied an evaporator unit with 6 evaporator modules as shown in Fig. 2 and sketched in Fig. 3.

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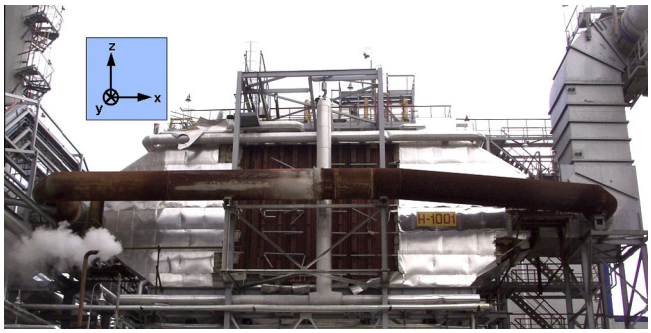

Fig. 1. Installation situation of the steam generator at a chemical plant, side view with temporary bypass tube. Coordinate "*x*" indicates the direction of airflow.

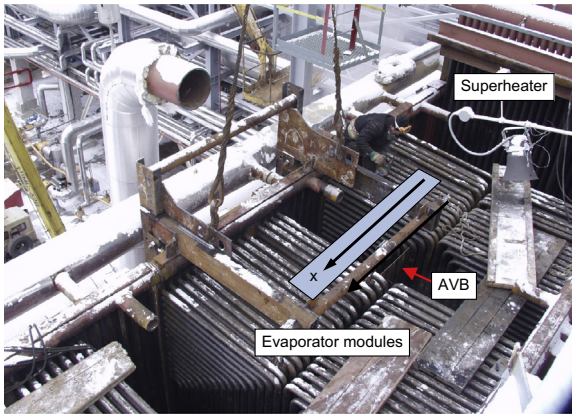

Fig. 2. Dismantling of the heat exchanger at the chemical plant. Top view of the evaporator. Arrow points to an anti-vibration plate (AVB). Coordinate "*x*" indicates the direction of airflow.

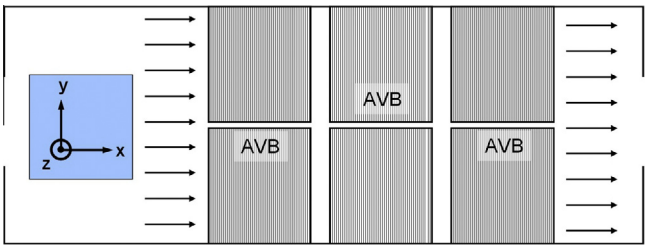

Fig. 3. Sketch of the positions of the six evaporator modules in the heat exchanger box, top view, compare Fig. 2. Arrows mark the exhaust air stream. "AVB" marks the positions of anti-vibration plates.

Each evaporator module was built from 15 pipe bends of different length nested as stacks and always 17 of this stacks were welded onto a finned wall, see Fig. 4. For shipping each evaporator module was fixed within a transport cradle. The distance for transport from the manufacturing site to the place of operation was about 2000 km. The largest section (1600 km) was realized by rail transport on a cargo waggon, as may be seen in Fig. 5. Only a small distance was covered on the road using a truck trailer. The heat exchanger was assembled at the site of operation and then tested extensively. In the course of these initial operation test procedures leakages were detected in the evaporator modules.

1.1. History of operation, failure and initial troubleshooting

The following facts concerning the history of operation, the detection of leakages and the initial troubleshooting were not performed by personnel of BAM, thus, are solely based on the descriptions given by the operator and the manufacturer.