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Breakdown of heat exchangers due to erosion corrosion and fretting caused by inappropriate operating conditions

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ABSTRACT

Damage analyses on two heat exchanger units showed that in both cases inappropriate flow conditions of media caused very different failure mechanisms that resulted in irreparable damage. The first incident was the breakdown of an unalloyed steel condenser, which operated in a coal-fired power plant. A considerably high number of tubes successively leaked. Metallography identified lines of segregation in the microstructure of the tube walls, thus, giving evidence that both uniform corrosion and erosion corrosion caused by low-pressure wet steam were the root cause. The second incident was the breakdown of a recuperator made from chromium–nickel steel due to mechanical damage to tubes and baffle. This unit operated as part of a pilot plant to regain heat from the drying process of sewage sludge. It turned out that soiled vapour caused clogging of the cross-sectional area and therefore accelerating the flow velocity of the vapour. This inappropriate operating condition caused the tubes to oscillate so severely that they even banged together. Abrasive wear especially at the intersection through the holes of the baffle damaged the tubes and the whole unit irreparably.

1. Introduction

1.1. General information

The duty of a heat exchanger is to provide a preferably extensive effective surface that allows the heat transfer between two liquids or gases of different temperatures. Generally, the technique is piping the conveying medium through a coil of tubes or stacked plates whereas the source medium flows along the outer surfaces of these tubes or plates so that a heat transfer through the surfaces can take place. With the principle of heat transfer, based on compensation the warmer medium warms up the cooler medium. Each of the two failed heat exchangers operated at low pressure and in an upright position. The condensation energy of the source medium, a flow of hot wet steam or hot vapour must pass to the conveying medium consisting of heating water circulating in tubes. In both cases, the tube bundles had a length of about 3 m and a diameter of about 0.7 m. The first example deals with a modern power station where the heat energy of the expanded wet steam that had passed the turbine line supplied a district heating system. This well-known technology enhances the efficiency of a power plant. Fig. 1 shows a photography of the defective tube bundle of the condenser that had operated in the power plant as it was already stored for some months in a horizontal position after disassembly.

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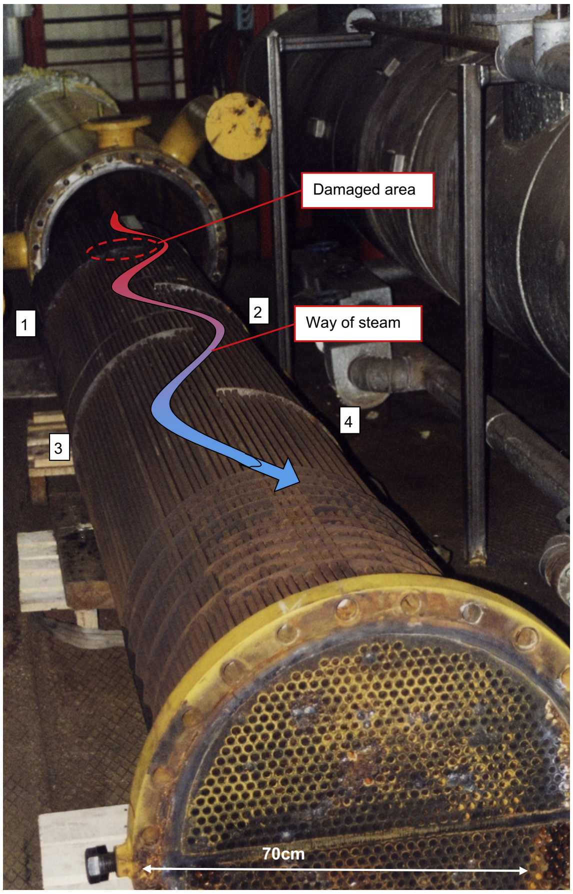

Fig. 1. Tube bundle of the defective condenser dismantled and stored in the power plant after breakdown; several tubes blinded because of leakage; numbers 1–4 refer to baffle.

The second example covers a recuperator that had operated in a pilot facility of a wastewater plant. Sewage treatment takes high-energy consumption due to the temperature control of the basins. The recovery of heat reduces the overall fuel consumption of the plant notably. An innovative process combined the drying of sewage sludge with the recovery of condensing energy from sewage vapours. The recuperator unit used for this process, however, already broke down after an operating time of about 3 months, only. Fig. 2 shows the tube bundle of the defective recuperator.

1.2. Short review of the history of heat exchangers

In the middle of the 19th century, coal and iron were the basis of the fast growing German industry. An important sector was mechanical engineering. Steam engines of different constructions and power ratings operated in large numbers to move trains, ships and a large diversity of machines in plants. An important component of each steam engine was the steam generator. Current tube heat exchangers still have a design similar to those steam generators. In comparison to other technologies, these components reached a high level of development very early. The construction of steam generators changed during their developing process. First cylindrical boilers were fired at the outer surface. Later the fire was inside the boiler and the flue gas passed a large number of tubes. The energy efficiency gradually increased. However, severe accidents with exploding steam generators flagged this developing process. These events showed the demand for a systematic study of materials.

Adolf Martens (1850–1914) was born into this era of industrial revolution. His publications [1,2], described testing methods and the basics of materials research. His achievements have found a wide distribution. Besides empirical knowledge engineers became more and more able to develop new products by calculations and make them more secure. Thanks to the high responsibility of operators and sophisticated operational control systems today, severe accidents with pressure vessels are very rare.

1.3. Usual problems with heat exchangers

During operation, leakage or blockage of the units often confirms defects. Steam or liquid may escape into the environment only in rare cases. Leakages cause a mixing of the two process media and hence, undesirable effects like contamination,