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Short communication

Root cause failure analysis of a division wall superheater tube of a coal-fired power station

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1. Introduction

Coal-fired boiler tubes are generally exposed to high internal pressure and high temperature of steam and flue gas. The common cause of any metallurgical failure of a superheater tube is due to the tube metal temperature higher than that as originally specified [1]. Tube metal temperature may increase gradually over many years due to the growing oxide scales inside tube or elevate rapidly caused by loss of internal steam or water-coolant flow. Internal pressurized tubes are critical components in water-tube boiler and steam superheater elements. Tubes in such application are vulnerable to high temperature upset condition, undergoing severe creep deformation or even final rupture. Therefore, boiler tubes in power plants have finite life because of prolonged exposure to high temperature, stress, aggressive environment, corrosive degradation, etc. However, uses of suitable boiler tube material in thermal power plants are required to ensure that the materials are safely used under higher temperatures and pressures for a long period of operation [2]. Many works concerning the failure problems in water-tube boiler have been reported.

The North American Electric Reliability Council (NERC) reported that the coal-fired boilers are among the highest economic risk components in any other power plant. By far, the greatest number of forced outages in all types of boiler is caused by failures [3]. Elimination of boiler tube failure could save the electric power industry about $5 billion a year [4]. Metallurgists from French, Inc. [1] published data of the top 10 causes of failures where creep (long-term overheating) is 23.4%, followed by fatigue (13.9%) (thermal 8.6%, corrosion 5.3%), ash corrosion (12.0%), hydrogen damage (10.6%), weld failures (9.0%), high temperature (short-term overheating) (8.8%), erosion (6.5%), oxygen pitting (5.6%), caustic attack (3.5%) and stress corrosion cracking (2.6%). In general, 30% of all tube failures in boilers and reformers are caused by creep [5–7].

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Ray et al. [8] conducted assessment of service exposed to boiler tube of the superheater and reheater made of 2.25 Cr-1 Mo steels in a 120 MW boiler of a thermal power plant. The results showed that although there was degradation of ultimate tensile strength (UTS) and stress rupture of the boiler tubes due to increasing temperature and prolonged service exposure. But at the operating condition of 540 °C and 40 MPa in pressure, all these service exposed tubes have a remaining life of more than 100,000 h, provided that there are no defects in the materials due to long-term service exposure. Husain and Habib [9] investigated the steel tubes failure in a superheater boiler at one of the Kuwait Electrical and Power plants which suffered localized overheating. The tube was made of low alloy steel, SA 213-T 12 and it has been in operation for 109,415 h before failed. The investigation indicated that the failure was attributed to the formation of thick scale of magnetite at the inner surface of the tube wall. This phenomenon prevented the accessibility of heat to the tube materials and consequently localized and prolonged overheating took place, in which the temperature raised up to 700 °C in a frequent manner for long period of time. The properties of the tube materials changed from its original design values due to the effect of the localized and prolonged overheating.

Baoyou et al. [10], analyzed a boiler tube rupture through chemical analysis, scanning electron microscope, and energy dispersion spectroscopy. The results showed that the tube burst due to overheating and excess temperature caused by obstruction of steam flow associated with the bubble clusters on the surface of local regions. Khajavi et al. [11] conducted investigation through visual examination, optical microscope, scanning electron microscope (SEM), and X-ray diffraction (XRD), to reveal the root causes of the boiler tube failure due to water-side corrosion problems. The results showed that corrosion failures are caused by a combination of ineffective control of water chemistry, deficiencies in design and material selection and operational problems such as inadequate water-side circulation which led to the formation of deposits in localized zones along a water line.

Srikanth et al. [12] conducted failure analysis of several evaporator tubes during commissioning and trial run of a waste heat recovery boiler using visual inspection, chemical analysis, X-ray radiography, fractography, microscopic examination at various locations, mechanical properties measurement and analysis using SEM. The results showed that the failure of the evaporator tubes at the bent tubes have been initiated by lamellar tearing because of inherent defects in the material, improper design of welding, and the absence of stress relieving treatment after the cold bending and welding operations.

Chattoraj et al. [13] have investigated the corrosive degradation and failures of vertical furnace wall tubes of a co-generation boiler. The investigations included chemical analysis of the corrosion deposit and microstructure observations. The results showed that the most probable degradation mechanism is acid corrosion and under deposit corrosion due to the presence of deposits, leading to localized heating (due to scale formation), and eventual rupture assisted by overheating and decarburization.

Recently, several works on the failure analysis of boiler tubes that included superheater tube, reheater tube as well as water wall tube have been reported [14–21]. The reported works are conducted either through experimentation or numerical simulation. Most of the boiler tubes reported in the previous works failed after thousands of hours in operation.

This work presents failure investigation on a division wall superheater tube of Boiler Unit 4 at Sultan Shalahuddin Abdul Aziz Shah Power Station by visual inspections, metallurgical examination and temperature estimation using the empirical formula. The findings obtained from the investigation are discussed to deduce the failure mechanisms and the root cause of the failure.

2. Boiler operational backgrounds

Boiler unit number 4 at Sultan Shalahuddin Abdul Aziz Shah Power Station was noticed to have operated normally until firing of Bontang coal. It is a medium standard coal that was imported from East Kalimantan, Indonesia. The coal started to be

Fig. 1. Massive clinkers covering superheater region.