FAILURE ANALYSIS OF A SUPERHEATER TUBE OF A COAL-FIRED POWER PLANT

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ABSTRACT

Failure analysis of structures has gained a considerable interest in many engineering areas. The aim of this research is to determine the root cause of the structural failures which can reduce the failure risks and prevent similar failures in the future. This thesis presents experimental investigations for the failure of a superheater tube of a coal-fired power plant using several failure analysis procedures. The failure analysis comprised of visual inspection, optical microscopic, scanning electron microscopy combined with the energy dispersive X-ray spectroscopy (EDS) and energy dispersive X-ray diffraction (EDXD). A sample of a total-fractured superheater tube obtained from an industry was used in this investigation. Initial visual investigations found that the superheater tube had a longitudinal crack. This fracture appearance is called fish mouth stress rupture. The specimen was initially cut, mounted, grinded, polished and etched. A significant oxide layer of 1.75mm in thickness was occurred in the steam side surface. The optical microscopy and scanning electron microscopy were used to identify intergranular cracks, voids, elongated grain and deposit layers. The EDS and EDXD were used to identify types and compositions of the oxide substances. The results revealed that the steam and fire side surfaces consist of sodium iron oxide, hematite and magnetite. The study also demonstrates that the superheater tube of a coal-fired failed due to creep mechanism. This resulted in overheating problem inside the tube; caused by deposit layers, which contributes to the creep mechanism. Periodically cleaning and maintenance should be done in order to avoid accumulation of deposit layers.

ABSTRAK

Analisis kegagalan struktur merupakan suatu elemen penting dalam pelbagai bidang kejuruteraan. Kajian ini dijalankan untuk menentukan punca kegagalan sesuatu struktur bagi mengurangkan risiko kegagalan seterusnya menghindarkan kegagalan serupa daripada berulang. Tesis ini menjelaskan hasil kajian eksperimen yang dijalankan ke atas struktur tiub panas lampau sebuah loji kuasa arang batu menggunakan beberapa prosedur analisis kegagalan. Ini merangkumi kaedah pemerhatian, mikroskop optik, mikroskop pengimbas elektron dengan spektroskop X-ray serakan tenaga (EDS) dan pembelauan X-ray serakan tenaga (EDXD). Sampel bahan kajian yang digunakan adalah merupakan sebatang tiub panas lampau sebuah loji kuasa yang telah pecah. Pemerhatian visual telah mendapati bahawa tiub panas lampau telah mengalami keretakan membujur. Kegagalan ini dikenali sebagai "*fish mouth stress rupture*". Spesimen ini perlu terlebih dahulu melalui proses pemotongan, pemesinan, pencanaian, penggilapan dan punaran. Lapisan besi oksida setebal 1.75 mm dikesan di bahagian dalam dinding tiub. Mikroskop optik dan pengimbas elektron telah digunakan untuk mengenalpasti fenomena keretakan antara ira, lompang, pemanjangan ira dan lapisan endapan. Mikroskop EDS dan EDXD telah digunakan untuk menentukan jenis dan komposisi bahan oksida. Hasil kajian menunjukkan bahawa di bahagian permukaan dalam dinding tiub mengandungi sodium iron oksida, hematite and magnetite. Kajian juga memperlihatkan bahawa kegagalan tiub panas lampau sebuah loji kuasa arang batu berpunca dari mekanisma rayapan. Lapisan endapan yang wujud menyebabkan fenomena masalah panas lampau di dalam tiub yang menyumbang kepada mekanisma rayapan. Proses penyelenggaraan dan pembersihan tiub harus dilakukan secara berkala bagi mengelakkan pengumpulan lapisan endapan.

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CHAPTER I

INTRODUCTION

1.1 Introduction

Failure analysis is an engineering approach to determining how and why equipment or a component has failed [1]. The goal of a failure analysis is to understand the root cause of the failure so as to prevent similar failures in the future. The cause of failure can play a role in establishing liability in litigation. Failure analysis is important to determine the original, proximal cause of a failure.

Failure analysis of boiler tube is important to understand the root cause of the failure in terms of both the material of the tube and the boiler operation. There are many types of approaches in analysis of the boiler tube failures. However, estimation can be made on the capability of tubes and thus simply boiler time of failure. The results and finding should able to identify the cause of failure and indicate the type of mode failure at the respective failure region.

1.2 Statement of Problem

As received one piece of superheater tube from industry with ASME specification SA-213-T22 grade steel. The superheater tube has undergone five years of service. The normal operation temperature of this tube was 540 °C and the type of the firing was coal-fired. The received superheater tube was completely fractured. Therefore the problem is to know what cause of fracture superheater tube.

1.3 Objective of Study

There are three primary objectives of this study. The first objective is to examine the evidence presented by the superheater tube failure and from that evidence, determine the failure mechanism. The second objective is to determine the root cause of the failure. The third objective is to recommend corrective measures that can prevent similar failures.

1.4 Scope of Study

The scope of this study is as follows:

1. Collect failure mode inventory of the fractured boiler tube.
2. Sample investigation conducted by optical microscopy (OM), scanning electron microscopy (SEM) combined with energy dispersive X-ray spectroscopy (EDS) and energy dispersive X-ray diffraction (EDX).
3. Analyze the investigation results in the cause of fractured superhater tube.

4. The findings results of superheater tube fracture will be compared with unused tube sample and failure mode inventory.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

Superheaters in utility boilers increase the temperature of saturated or near-saturated steam in order to increase thermodynamic efficiency of the power cycle or provide the desired process conditions. In general terms, they are simple single phase heat exchangers with steam flowing inside the tubes and flue gases passing the outside the tubes, generally in cross flow Figure 2.1 [2]. Platen superheaters are generally exposed to high temperature and pressure particularly at tip sections where the flue gas temperature may rise to more than 1000 °C [3]. With a steam temperature of 540 °C inside the tube the outer metal temperature may exceed 600 °C. Tube materials may vary from carbon steel to low Cr ferrite to austenitic stainless steel. Superheater tubes under operating condition are very much prone to the formation of oxides on both inner and outer layers. Initially the outer oxide layer is essentially Fe_3O_4 type and inside the tube is a spinel-type oxide containing steel alloying elements. The compositions of the deposit on the outer wall depend on the type and nature of the fuel and the conditions of the combustion. The corrosion of the outer wall is caused by the deposition of sodium and potassium sulphate. Fieldner [4] indicated at least 182 other investigators had examined the fusibility of ash based on eight fundamental oxides most frequently found in coal ash (i.e., SiO_2, Al_2O_3, TiO_2, Fe_2O_3, CaO, MgO, Na_2O, and K_2O.

These sulphates gradually accumulate by condensation. If the temperature of the tube surface exceeds 580 °C these sulphates will melt. The thin layer of highly corrosive molten layer, built on the initially formed oxide layer, attacks the oxide scale and forms Fe, Cr and Ni sulphates. It has been pointed out that in many cases a thin protective oxide of Fe_3O_4 is deposited on the waterside of the tubes. The protectiveness of this thin layer depends on the pH level of the water and on the amount of contamination [3].

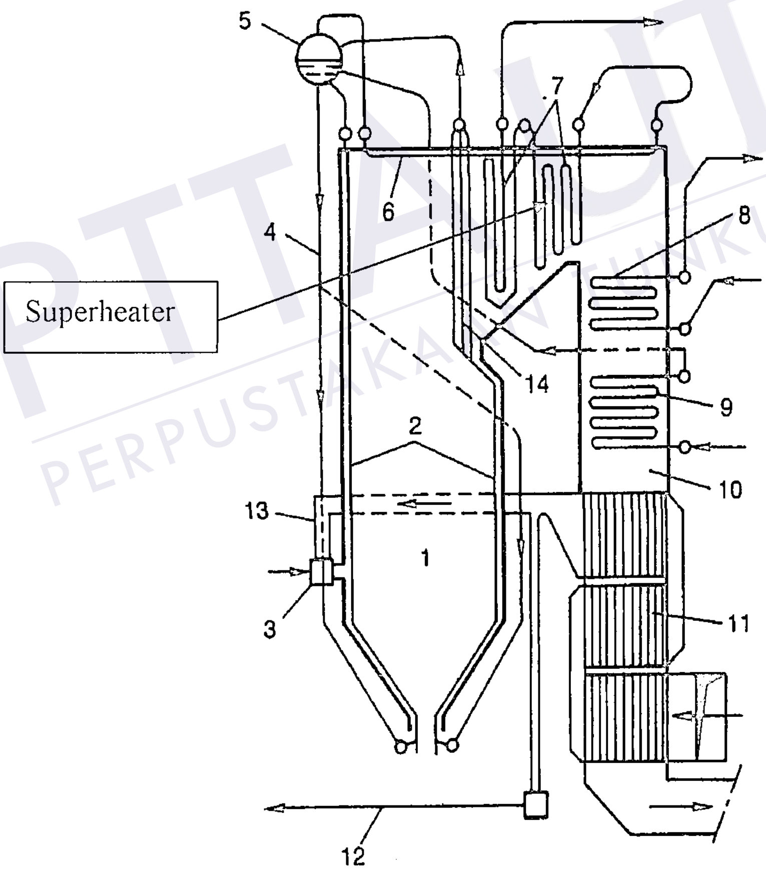

Figure 2.1: Flow diagram of the natural –circulation boiler: 1-furnace, 2-water wall, 3-burners, 4-downcomers, 5-drum, 6-radiant superheater, 7-convection superheater, 8-reheaters, 9-economizer, 10-gas duct, 11-air heater, 12-primary air, 13-secondary air [2].

2.2 Coal-Fired

Coal of different varieties being is used for big boilers, mostly for industrial and utility boilers. Coal is very economical fuel for using in the boilers for power generation plants. It is an attractive fuel owing to its low price linked to its world wide availability and due to the future shortage of other fossil fuel reserves such oil and gas. But combustion of coal generates very corrosive media particularly near the superheater tubes [5].

Many authors reported that condensation/accumulation of low melting-point salts from flue gas on the boiler tubes used for superheater and reheater is coal fired boilers is a root cause for the severe wastage of tube material. These slats sulfates of sodium and potassium easily liquefy at the operating temperatures and causes sever hot corrosion of boiler tubes [5].

The environment in the coal-fired system consists of ashes and gases at high temperatures and sulfur is considered as the main corrosive elements. According to published literature, the alkali-iron trisulphates $(Na,K)_3 Fe(SO_4)_3$ are held responsible for the degradation of coal-fired plant supeheaters. These compound stem from the reaction of alkali suphates with iron oxides (coming from oxide scales or ashes) in the presence of SO_3 (resulting from the oxidation of SO_2) according to the following reaction [5].

$$2Fe_3O_4 + 9M_2SO_4 + 9SO_4 + 1/2O_2 = 6M_3Fe(SO_4)_3$$
$$Fe_2O_3 + 3M_2SO_4 + 3SO_3 = 2M_3Fe(SO_4)_3$$
Where M=Na or K

They are molten at operations due to their low melting temperatures; 624 °C for $Na_3Fe(SO_4)_3$ and 618 °C for $K_3Fe(SO_4)_3$, and 552 °C for the mixed compounds $(Na,K)_3Fe(SO_4)_3$. These molten compounds can take part in fluxing causing dissolution of the scale or react with metal to form internal sulphids as per reaction given below:

$$2M_3Fe(SO_4)_3 + 6Fe = 3/2FeS + 3/2Fe_3O_4 + Fe_2O_3 + 3M_2SO_4 + 3/2SO_2$$

2.2.1 Combustion Properties

The combustion of coal is a more complex process than that of oil or gas. It can best be described as a series of processes [6]:

a) All coal contains some moisture. During the early stages of combustion this moisture is evaporated using some of the coal's energy in doing so.
b) As the temperature increases, a range of gases including carbon monoxide, methane, and a variety of hydrocarbons, is given off from the coal. However, all of these gases are fuels and carry as much as half of the energy of the coal. They comprise the volatile matter which can be captured and used.
c) The remaining fixed carbon is effectively charcoal and burns with oxygen from the air to create carbon dioxide.
d) With all the fuel burnt out, anything left over is ash.

2.2.2 Coal Processing

Black coal may be used without any serious processing: other than crushing and screening to reduce the rock to a useable and consistent size. However, it is often washed to remove pieces of rock or mineral that may be present. Washing reduces ash and improves the overall quality of the coal. Coking coal is heated in the absence of air to produce gases and coke. Coal can also be further processed to produce oil and petroleum products [6].

2.3 Boiler Water Treatment

The condition of the boiler feedwater can be critical to both maintenance and efficiency of the boiler. Poor quality water can cause corrosion and inhibit heat transfer. However, the subject of chemical water treatment associated with steam generation is an extremely complex one and will vary greatly with the type and quality of water in each area of the country and also be dependent on the pressure and type of boiler being used. The objects of water treatment are twofold (1) the removal of suspended and soluble solids and (2) the removal of gases [7]. Water treatment should reduce to minimum or absolutely prevent the following undesirable and dangerous conditions: foaming, scale formation and corrosion.

The formation of scale on boiler heating surface is the most serious problem in steam generation. The object of the process for treating water before it enters the boiler is to reduce the amount of scale and sludge-forming deposits. However, since no external treatment, regardless of efficiency, can remove all harmful chemicals, we must provide internal treatment to boiler water.

The primary cause of scale formation is a decrease in solubility of the salts accompanying an increase in temperature. Consequently, the higher the temperature and pressure in a boiler, the more insoluble are the scale-forming salts [8]. Deposits in boiler tubes can reduce circulation though tubes. This may enhance further deposit formation due to the reduction of the cleansing effect of circulating water on solids concentrating at heat transfer surface [9]. The inside diameter deposit layer is produced by oxidation in the boiler tube. The layer build up occurs when the tubes have experienced high temperatures for extended periods of time. The formation of inside diameter layer reduces heat transfer and results in a further increase of tube metal temperature. Higher temperatures promote further growth of inside diameter layer. The result is the inside diameter layer feeds on itself and as it continues to grow, it causes further thinning of the tube.

Inside diameter oxide scale can be produced when tubes in the reheater and superheater have experienced high temperatures for extended periods of time. The formation of inside diameter scale reduces heat transfer and results in a further increase of tube metal temperature. The increase in inside diameter scale and the associated tube metal temperature promotes creep in the tube metal. Formation of creep results in a loss of strength at high temperature. The final outcome of excessive scale is a thick lipped, long term overheats failure [10].

When a tube enters service the metal in contact with the internal steam begins to form a layer of magnetite (Fe_3O_4) scale. This layer grows thicker in service and its growth over time is dependent on metal temperature. This oxide layer is also a barrier to heat transfer and as its thickness increases; metal temperatures must also increase to maintain a constant outlet steam temperature. Typically, tube metal temperatures increase from 1 to 2F (0.6 to 1.1C) for each 0.001 inch (0.03 mm) of internal oxide formed [11]. Sarver et a.l [12] and Wreigh et al.[13] state that when the metal temperature is below approximately 580°C (1076°F) and sufficiently high partial pressure of oxidation is present, a double-layer scale consisting of magnetite (Fe_3O_4) and hematite (Fe_2O_3) is found on the steam side surface of ferritic alloys. The information of oxide scale can be used to estimate the metal temperature using Larson Parameter; $\log X = 0.0002\,[T\,(20+\log t)] - 7.25$ [11, 14, 15], where X is the scale thickness (in mills); T is the Temperature (in degree Rankin) and t is the operational time (in hours).

But more important is a possible overheating of the boiler metal due to the lack of heat transfer caused by scale deposit. The resultant damage caused by

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