

# Role of Oxide Scale Thickness Measurements in Boiler Conditions Assessment

M. Alardhi, A. Almazrouee, S. Alsaleh

**Abstract**—Oxide scale thickness measurements are used in assessing the life of different components operating at high temperature environment. Such measurements provide an approximation for the temperature inside components such as reheater and superheater tubes. A number of failures were encountered in one of the boilers in one of Kuwaiti power plants. These failure were mainly in the first row of the primary super heater tubes, therefore, the specialized engineer decide to replace them during the annual shutdown. As a tool for failure analysis, oxide scale thickness measurement were used to investigate the temperature distribution in these tubes. In this paper, the oxide scale thickness of these tubes were measured and used for analysis. The measurements provide an illustration of the distribution of heat transfer of the primary superheater tubes in the boiler system. Remarks and analysis about the design of the boiler are also provided.

**Keywords**—Superheater tubes; Oxide scale measurements; Overheating

## I. INTRODUCTION

COMPONENTS operating at high temperature environments are designed to have a finite life particularly when design conditions are observed and met. However, damage mechanisms such as creep, fatigue, creep-fatigue, erosion, localized corrosion can be limiting causes for components lives mainly when design conditions or quality assurance are not followed. Unexpected failure can be catastrophic and cost lives and money. To avoid catastrophic failures or unplanned outage it is important to correctly assess the condition and the remaining life of these components operating at elevated temperatures. In the past three decades, life assessment procedures such as oxide scale measurements have become one of the major focuses for research [1-6]. Failed components operating at elevated temperatures is often complicated by the presence of thick oxide scale on the fracture surface. However, the knowledge of time, temperature and the nature of the oxidizing environment, and their correlation to oxide morphology, can provide a powerful alternative technique for investigation of service failures and can be used for the purpose of life assessment [2, 7-8]. The thickness of the oxide of a component can also be used with unit operating data and wall thickness measurements to estimate the remaining creep-rupture life of a tube [9-10].

Oxide scale thickness measurements permit the estimation of exposure time or temperature whilst oxide morphology can provide a means by which exposure temperature may be estimated [10-11].

Chromium-molybdenum steels are used extensively in the manufacturing of piping, heat exchangers, pressure vessels and several other high temperature components in process and power plants, due to their creep and oxidation resistance [12-14]. They are used in Kuwaiti power plants in primary and secondary superheaters for long times. However, in one of Kuwaiti power plants, a number of failures were encountered mainly in the first row of the primary superheater tubes. As a results, the specialized engineer decide to replace them during the annual shutdown. The primary superheater, in the studied boiler, consists of four rows of tubes, each row having 116 tubes that are connected to the outlet header (Fig. 1). The design operating temperature for the outlet of the primary superheater is 436 °C.

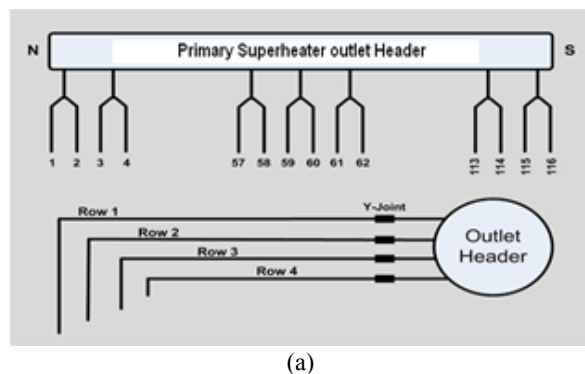


Fig. 1 (a) Schematic illustration of the primary superheater setup and (b) the tube bank

M. Alardhi is now with the Automotive & Marine Engineering Technology Department, College of Technological Studies, PAAET, Kuwait (e-mail : malardhi@ymail.com)

A. Almazrouee, is now with the Production Engineering Technology Department, College of Technological Studies, PAAET, Kuwait (e-mail : aalmazro@hotmail.com)

S. Alsaleh is now with the Shyiba Power Plant, Ministry of Electricity and Water, Shyiba, Kuwait

As a tool for life assessment, oxide scale thickness measurement were used to investigate the temperature distribution in a number of these tubes. Therefore, the aim of this research is to investigate the temperature distribution in the primary superheater of that boiler.

## II. EXPERIMENTAL PROCEDURE

Five tubes from the first row were taken for analysis. These tubes are primarily made of ASTM A213-T12 and the nominal composition is given in Table 1. A transverse section from the upper section of the tube was used for the analysis. The section was ground/polished on transverse face and etched with 2% nital (98 ml methanol and 2 ml conc. HNO<sub>3</sub>). The oxide scale thickness were measured using optical microscope. The oxide scale thickness for each tube was measured at three points and then the three measurements were averaged. When needed, the microstructure was also observed to investigate any microstructural degradation.



(b)

Fig. 2 Optical micrograph of (a) Fireside oxide scale showing thick layer with some spallation and (b) intact steam side oxide scale

TABLE I  
THE NOMINAL CHEMICAL COMPOSITION THE ASTM A213-T12

Grade	Composition, wt%						
	C	Si	Mn	Cr	Mo	P	S
ASTM A213-T12	0.05-0.15	0.50 <sup>max</sup>	0.30-0.61	0.80-1.25	0.44-0.65	0.025 <sup>max</sup>	0.025 <sup>max</sup>
							Bal.

## III. RESULTS AND DISCUSSION

The repeated failure in the boiler can be caused by several reasons such as overheating, fireside corrosion, fatigue, and creep. The temperature of the boiler firing and the steam temperature play significant role in these failures. Therefore, the metal temperature which can be approximated by the oxide scale measurements should show whether the design conditions are met or not. The oxide scale were thicker in fireside when compared to steam side. Spallation were noticed in fireside oxide scales and as a result they are not considered in oxide scale measurements.



(a)

Determination of thickness of oxide layer has been used in recent years for the purpose of life assessment and failure analysis of components operating at high temperatures [2, 7]. Oxide scale thickness measurements permit the estimation of exposure time or temperature [10-11]. The temperatures of the upper section of the tubes were estimated based on the oxide scale thickness of the steam side of the tube, by using the following equation that specifically applies to 1-3% Cr steels [15]:

$$\log X = 2.1761 \times 10^{-4} (T) (20 + \log t) - 7.25 \quad (1)$$

where, X is the scale thickness in mils (1 mm = 40 mils), T is the temperature in °R, and t is the operational time in hours. Using equation 1, the averaged measurements were used to determine the approximated temperatures at these tubes. The averaged oxide scale thickness measurements, time in service and approximated temperatures are tabulated in Table II.

TABLE II  
AVERAGE MEASUREMENTS OF OXIDE SCALE OF THE INVESTIGATED TUBES

Sample Tube number	107	101	97	60	57
Average thickness of oxide scale ( $\mu\text{m}$ )	190	192	150	154	134
Time in service (hrs)	17250	52560	27720	36456	36456
The estimated temperature based on Equation (1) ( $^{\circ}\text{C}$ )	582	566	564	562	555

The temperatures of all tubes are above the design operating temperature by more than  $100^{\circ}\text{C}$ . This is a clear indication of overheating suffered by these tubes which can explain the repeated failures in this boiler. This overheating can reduce the life of these tubes as a result of creep in less than design time. Also, localized oxidation can be encountered which lead to localized overheating that reduce wall thickness and lead to tube burst. Another interesting remark, is the microstructural degradation that was found in some of these tubes. Some of these tubes suffer from spheroidization as a result of this overheating. Moreover, one of the tubes showed a clear decarburization zone of  $150\mu\text{m}$ . These microstructural alteration need more analysis to find the root cause of this degradation. However, one clear cause is the long term overheating of as a result of improper boiler firing. The temperature seems to raise gradually as the number of tube increases. This is an indication that a part of the boiler is overheated more than the other. Firing procedure should be reviewed to find out the reason for this overheating and the non-uniformity of the heating for boiler tubes.

#### IV. CONCLUSIONS

The analyses of five tubes in a boiler where more failures than usual were encountered were carried out which have led to the following conclusions:

1. Thick oxide layers were found in both fireside and steam side of the boiler,
2. The measurements of steam side oxide scale thickness indicated high temperature exposure than design operating conditions which is believed to be the cause of repeated failures in this boiler,
3. Microstructural degradation in a form of decarburization and spheroidization were noticed in some tubes which require more analysis to find the root cause of this degradation.

Therefore, it is recommend that boiler firing should be checked and adjusted to fit the initial design.

#### REFERENCES

- [1] Hsuan-Chin Lai, Component life assessment methods for nuclear power plant, *International Journal of Pressure Vessels and Piping*, vol. 59, pp. 227-240, 1994.
- [2] D.K. Bhattacharya, NDT for residual life assessment in Indian industry, *Insight: Non-Destructive Testing and Condition Monitoring*, vol. 45, pp. 31-40, 2003.
- [3] Rudolph Blum, The Danish experience in materials aspects in power plant life assessment and in life extension, *International Journal of Pressure Vessels and Piping*, vol. 39, pp. 29-40, 1989.
- [4] J.A. Daleo, *et al.*, Metallurgical considerations for life assessment and the safe refurbishment and requalification of gas turbine blades, *Journal of Engineering for Gas Turbines and Power*, vol. 124, pp. 571-579, 2002.
- [5] J. D. Parker and B. Wilshire, Non-destructive life assessment of high temperature components and weldments, *International Journal of Pressure Vessels and Piping*, vol. 50, pp. 337-347, 1992.
- [6] Takashi Sakurai, *et al.*, Life assessment of high-temperature components of thermal power plants in Japan, *Nuclear Engineering and Design*, vol. 139, pp. 311-317, 1993/3 1993.
- [7] R. Viswanathan, "Life assessment technology for fossil power plants," in *Proceedings of the 57th Annual American Power Conference. Part 3 (of 3), Apr 18-20 1995*, Chicago, IL, USA, 1995, pp. 1749-1768.
- [8] Roger H. Richman, "ANALYSIS OF OXIDE SCALES FOR FAILURE INVESTIGATIONS," in *Proceedings - ISTFA 1982, International Symposium for Testing and Failure Analysis 1982*, San Jose, CA, USA, 1982, pp. 219-225.
- [9] P. Auerkari, NDT for high-temperature installations - a review, *Welding in the World, Le Soudage Dans Le Monde*, vol. 39, pp. 351-362, 1997.
- [10] T. J. Wardle, "Creep-rupture assessment of superheater tubes using nondestructive oxide thickness measurement," in *International Conference of Life Management*, China, 2000.
- [11] L. W. Pinder, OXIDE CHARACTERIZATION FOR SERVICE FAILURE INVESTIGATIONS, *Corrosion Science*, vol. 21, pp. 749-763, 1981.
- [12] Carl D. Lundin, *et al.*, Literature review on characteristics of high temperature ferritic Cr-Mo steels and weldments, *Welding Research Council Bulletin*, pp. 1-36, 2000.
- [13] R. L. Klueh, Chromium-molybdenum steels for fusion reactor first walls -- a review, *Nuclear Engineering and Design*, vol. 72, pp. 329-344, 1982/10/1 1982.
- [14] R. L. Klueh and Donald R. Harries, *High-chromium ferritic and martensitic steels for nuclear applications*. W. Conshohocken, PA: ASTM, 2001.
- [15] Ramaswamy Viswanathan, *Damage mechanisms and life assessment of high-temperature components*. Metals Park, Ohio: ASM International, 1989.