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Numerical Investigation of Thermal Analysis of Boiler Tube for Cement Plant

Mohammed Imran[1], Gaurav Tiwari[2] and Pradeshi Ram[3]

[1]M.Tech Student/ Mewar University/ Chittorgarh
Rajasthan/ India

[2]Dept. of Mechanical Engg., Mewar University/ Chittorgarh
Rajasthan/ India

[3]Dept. of Mechanical Engg., Mewar University/ Chittorgarh
Rajasthan/ India

Abstract

An analysis is developed for the calculation of the stresses and the permanent strains at a particular time and at the steady state condition, resulting from loading of the tube under constant internal pressure and elevated temperature were evaluated when accounts is taken to the secondary creep characteristics of a given material. Boiler tube material plays an important role in efficient power generation from a fossil fuel power plant. In order to meet out the gap between fluids to increase heat available per unit mass flow of steam. Waste heat utilization phenomenon is a big challenge on fossil fuel power plants as after use of high grade coal in thermal power plants the efficiency of power plants is not at the level of required value. Clean and efficient power generation with economical aspects is the basic need of growing power generation plants to justify the quality of power and clean power generation. The failure can be caused by one or more modes such as overheating, stress corrosion cracking (SCC), hydrogen embrittlement, creep, flame impingement, sulphide attack, weld attack, dew point corrosion, etc.

Keywords: *Life assessment, Hoop stress analysis, Tube material characteristics and Stress corrosion cracking.*

1. Introduction

The object behind the successful operation of boiler is to take heat energy in its available form (for example, coal, oil, etc.) and to convert this heat energy into a form which can be conveniently used. This may be done by heating water in a boiler and then using the resulting hot water or steam for a desired purpose. There are many types of boilers developed tube), water tube and electric boilers.

Boiler tubes may fail in service condition due to many reasons. Some of these reasons are: tube surface pitting, corrosion cracking, creep rupture, carbide graphitization, oxidation, sulfidation order to meet a variety of duties and ever-increasing output demands. Broadly boilers can be classified as: shell type fire-embrittlement, etc. These conditions which give rise to early failure of tubes are attributed to one or a combination of the following reasons.

i. The environmental conditions within the boiler can be highly aggressive and alter the microstructure of tubing.

ii. Stresses caused by external loads, or induced by cold forming operations, uneven cooling or welding, may substantially lower the resistance of tubing to be attacked by certain corrosive media.

1.1 Pitting:- Pitting is a type of extremely localized attack which can be difficult to detect. Pitting is a destructive form of corrosion that affects the water side of boiler tubes. Surface imperfections and deposits can serve as initiation sites for pitting, and a consequent breakdown of the protective scale.

1.2 Sulfidation:- Sulfidation or sulfide corrosion is a problem often encountered if there are reducing conditions in coal and oil fired boilers. Sulfidation can become a problem when temperatures exceed 260oC

1.3 Embrittlement:- During exposure at elevated temperatures between 400°C and 540°C, high-chromium Ferritic and martens tic steels, as well as the ferrite phase in duplex austenitic Ferritic stainless steels are subject to a form of embrittlement.

1.4 Oxidation:- Resistance to oxidation is one of the most important characteristics of alloy and stainless grades. The chromium in these grades reacts with oxygen to form a tight, adherent scale that retards oxidation at elevated temperatures.

1.5 Stress corrosion cracking:- Austenitic chromium-nickel steels that are highly stressed in tension may develop trans crystalline or inter crystalline cracks when simultaneously exposed to a specific aqueous corrosive medium. The austenitic stainless steels are very susceptible to chloride stress corrosion cracking.

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1.6 Short-term Overheat:- Short-term overheat failures are most common during boiler start up. Failures result when the tube metal temperature is extremely elevated from a lack of cooling steam or water flow.

The maximum hoop stress varied as a function of location, with the peaks in the range of 55-60 ksi generally at the uppermost tie welds and the outer-loop tubes, where the tube to tube temperature differences were highest. Corrosion results in Varying hoop stress caused by temperature fluctuations. Cyclic hoop stress can cause tube expansion resulting in creep-like longitudinal water wall tube cracking. Thinner walls and thinner walls result in higher hoop stresses which increases the potential for cracking. Such a component fails in since when subjected to an excessively high internal pressure. While it might fail by situated along a path following the circumference of the tube. This suggests that the hoop stress is significantly higher than the axial stress. Hoop stresses do not vary through the wall. The only stress in the lateral direction (see Figure 1) is contributed by the hoop stress.

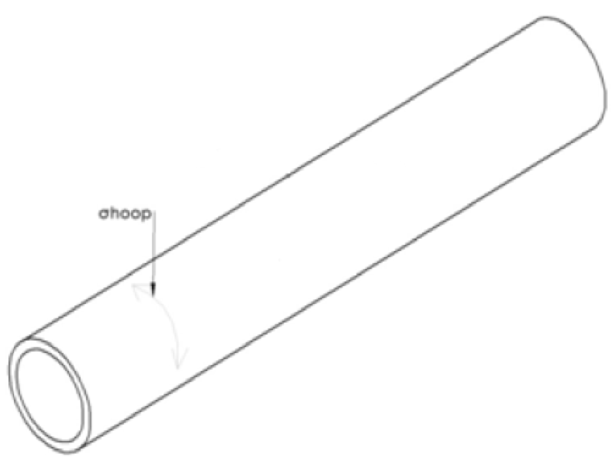

Figure 1 – Stress from internal pressure

2. Literature Review

When metals are subjected to stress at temperatures in excess of 0.33*Tm* where *m T* is the absolute melting temperate, the metal suffers time-dependent creep deformations. In addition, internal damage increases with time and ultimately the metal ruptures. Therefore, when designing shell structures operating at such evaluated temperatures, consideration must be made to ensure that creep deformations do not exceed operational requirements during the life of the component. Common allowable strains are 1% average and 5% maximum [5].

2.1 Common Boiler Tube Materials

According to Viswanathan (1993), boiler tubes are often categorized into three groups of alloys; carbon steels, Ferritic alloys and austenitic stainless alloys in which all the tubes are then graded according to its material compositions. The material grades listed by the author are based on the American Society of Mechanical Engineers (ASME) standards. Some of the alloy grades that are commonly used as superheater and reheater tubes are listed in the Table.1

Table 1: Ferritic alloys Used in Boiler Tube Construction

Nominal composition of Ferritic Alloys	ASME Specs.	Grade*	Composition (%)				
			P	S	Si	Cr	Mo
5Cr-0.5Mo		T5	0.030	0.030	0.50	4.0-6.0	0.45-0.65
9Cr-1Mo		T9	0.030	0.030	0.25-1.0	8.0-10.0	0.90-1.10
1.25Cr-0.5Mo	SA213	T11	0.030	0.030	0.50-1.0	1.0-1.50	0.44-0.65
1Cr-0.5Mo		T12	0.045	0.045	0.50	0.8-1.25	0.44-0.65
2.25Cr-1Mo		T22	0.030	0.030	0.50	1.9-2.60	0.87-1.13

*All tubes grades have same compositions of Carbon at 0.15% and Manganese 0.3-0.6%

2.2 Common Failure Mechanisms in Boiler Tube

In order to meet the growing demand of energy, Heat Recovery Steam Generator HRSG are often required to operate at high temperatures and pressures to increase the heating efficiency. As a consequence, the boiler tubes often experience frequent event of failures. These failure mechanisms are very much similar to the mechanism that have been reported by Robert and Harvey (1991) and EPRI (2007). The primary factors influencing the repetition of tube failures include:-

a) Wrong decision in the corrective and preventive actions
b) Lack of information in previous tube failures' reports
c) The standard operating and maintenance procedures are not carried out properly by the plant engineers and operators.The failure mechanisms and the specific analysis approach that are related to this project will be discussed further in the following subsections.

2.3 Waterside Corrosion and Scale Deposition in Boiler Tubes

Waterside corrosion is often present in any water tube boilers. This type of corrosion greatly influences the reliability of the heat recovery boilers as it deteriorates the tube material. The deposition of scale due to waterside corrosion is caused by the chemical reaction between the tube material and the chemical composition inside the water. These corrosion failures are the result of ineffective control of water chemistry. The intensity of corrosion greatly depends on the pH level of the water. Failure analysis carried out by Ranjbar (2007) indicated that the most prevailing corrosion mechanism occurred in reheater tubes were caustic corrosion.

2.4 Fireside Erosion-Corrosion and Wall Thinning on Boiler Tubes

Boiler tube samples collected for failure analysis carried out by Chandra, Kain and Dey (2010) on superheater tubes with carbon steel grade of SA213-T22 (2.25Cr 1Mo) .In their research, the formation of thick calcium sulphate deposited on the fireside tube wall and its spallation were the main cause of tube failure.

2.5 Tube Overheating and Creep Formation on Boiler Tubes

An investigation was carried out by Lee et al. (2009) on a superheater tube in coal power plant. From the investigation, it was observed that when the tube was heated more than the design temperature, formation of voids can be observed in the boundary between magnetite and spinel layer. After a long time, the void contents increased, causing adhesion weakness on the boundary layers which led to exfoliation of scales.

3. Calculation

σ = Hoop stress(N/mm^2)
σ_m = Membrane Hoop stress
D = Mean diameter
t = Boiler shell thickness (mm)
P_1= Normal operating pressure (N/mm^2)
P_2= Normal Partial Pressure (N/mm^2)

3.1 Boiler specification

- External diameter D=58mm
- Shell thickness t =3.4 mm
- Operating Pressure P_1 =345psi (2.3786 N/mm^2)
- Partial Pressure P_2 = 235psi (1.6202 N/mm^2)

3.2 Membrane Hoop Stress

Hoop stress

$$\sigma h = \frac{PD}{2t}$$

Membrane Hoop Stress σ_m

$$\sigma_{m1} = \frac{2.3786x58}{2x3.4}$$

σ_{m1} = 20.288 N/mm^2

$$\sigma_{m2} = \frac{1.6202x58}{2x3.4}$$

σ_{m2} = 11.819 N/mm^2

Resultant hoop stress

$$\sigma = \sqrt{\sigma m1^2 + \sigma m2^2}$$

$$\sigma = \sqrt{20.288^2 + 11.819^2}$$

σ = 23.4797 N/mm^2

For longitudinal:-

$$\sigma = \frac{PxD}{2tx\eta}$$

$$23.4797 = \frac{2.3786x58}{2x3.4x\eta}$$

η = 0.86 (86%)

RESULTS

Corrosive condensate formed by the condensation of leaked out steam from superheater tubes, initiated SCC of wall tubes fixed in the water drum. During this course of this investigation, three major areas were encountered for which further work is needed. The first area is the creep behavior and life analysis of cracked boiler tubes. In our analysis we considered very simplified assumptions that the surface of the tube is clean and no crack initiated or pitting formed on the surface. The second major area of further study may be the cases of surface pitted and corroded boiler tubes. While operation, boiler tubes are exposed to abrasion and corrosion by the particles in the flue gas and steam and/or water respectively. The calculation of remaining life of boiler tubes on behalf of longitudinal thermal stress may give feasible result bit on behalf of efficiency calculation the result obtained through longitudinal stress. The calculation of efficiency on behalf of hoop stress value give more accurate result of efficiency on behalf of this paper the hoop stress values and formulas are to be used for calculation of efficiency for safe and reliable operation of modern thermal power plant.

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