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Iterative technique and finite element simulation for supplemental condition monitoring of water-tube boiler

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ABSTRACT

Process of monitoring a parameter of condition in heat recovery steam generator (HRSG) system is particularly important. In this paper a new supplemental method for condition monitoring of water-tube boiler (superheater and reheater) through iterative technique and finite element simulation is proposed. The method is utilizing the empirical formula for estimating scale thickness developed on the inner surface of the tube over period of time. An iterative procedure is carried out to determine the average temperature in the tube as scale thickness on the inner surface increases. Different heat transfer parameters governing the problem are used and evaluated. The results obtained by using the proposed method are verified with the actual data of the available reports. Examples on failure analysis of the boiler tube utilizing the proposed technique are presented. The method may provide better estimation, provided that all the heat transfer parameters are well specified by the HRSG operators.

1. Introduction

Condition monitoring is a technique used to monitor the condition parameters in a system or equipment, such that a significant change is indicator of a developing failure. It is an essential element of condition-based maintenance in which the equipment is maintained on the basis of its condition, or it allows actions to be taken to avoid the consequences of failure, before the failure occurs. It is typically much more cost effective than allowing the equipments to fail. The basic principle of condition monitoring is to select a physical measurement which indicates that deterioration is occurring, and then the readings need to be taken at regular interval [1]. Since failure occurs to individual components, the monitoring measurements need to focus on the particular failure modes of the critical component. If a power plant has been operating with breakdown maintenance or regular planned maintenance, a change over to condition-based maintenance can result in significant improvements in plant availability and in reduced cost.

Related works pertaining to conditioning monitoring in power plants have been reported in [2–6]. Crowther et al. [2] described an application for thickness measurement of power station boiler tubes using Electromagnetic Acoustic Transducers (EMATs) that has been developed by Warwick University. Dubov [3] presented a technique for early detection of damage in boiler tube using the magnetic memory effect of metal. Taler [4] described the computer based boiler performance monitoring system for performing thermal–hydraulic and stress calculations of the boiler in the on-line mode. Measurements of temperatures, pressures, flows and gas analysis data are used to perform heat transfer analysis in the furnace and convection pass. Paterson and Wilson [5] reported the use of damage monitoring systems for component life optimization in power plant. Svensson and Pulliainen [6] stated that the recovery boiler on-line monitoring system may provide information on

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process conditions in the char bed and of deposits in the superheater area, which both are important for operating the boiler. The online information on deposit properties is the key to prevent superheater tube corrosion and scaling.

As reported by Port and Herro [7], almost 90% of failures caused by long-term overheating occur in superheaters, reheaters and wall tubes. Tubes exposed to overheating often contain significant deposits on the inner surface. The deposits have reduced coolant flow, and the tubes experience excessive fire-side heat input. They also described that heat transfer is markedly influenced by a thin gas film that normally exists on external surfaces. A temperature drop commonly occurs across this film. Scales and other materials on external surfaces will slightly reduce metals temperatures. The thermal resistance of the tube wall may cause a very slight drop in temperature across the wall. Conversely, when the heat transfer through the steam-side surface is considered, the effect of deposits is reversed. Steam layers and scales insulate the metal from the cooling effects of the steam, resulting in the reduced heat transfer into the steam and the increased metal temperatures.

Starr et al. [8] proposed an expert system for identifying the root causes of the failures in superheater tubing made of the P91 and P92 martensitic alloys. The system may encapsulate current knowledge about superheater problems in the form of "If-Then" rules. A characteristic of the P91 and P92 martensitic alloys was studied. It was found that scales as a result of the oxidation on the steam side of the tubing can induce premature failures due to the insulating effect of the oxide scales raising tube temperatures. In addition, scale spallation could also increase tube temperatures, as spallation debris may collect in the bottom of tubes, blocking steam flow. Attention is drawn to a potential "runaway affect" in which the tube temperature and rate of oxidation increase with time as the oxide builds up.

An accurate prediction of the temperature distribution in tube metal of the superheater and reheater will aid the power plant inspectors or engineers in evaluating the remaining life of the boiler tubes. With the respect to the concerns stated in [7,8] the present study confines the analysis in the absence of deposits developed on the external surface of the boiler tubes. A new supplemental method for condition monitoring of boiler tubes through iterative technique and finite element simulation is proposed in this work. The method may give an advanced warning of failure by estimating temperature increase in the tube metal. The method is utilizing the empirical formula correlating scale thickness with Larsen–Miller parameter [9] and the finite element modeling in order to estimate temperature distribution in the tube metal over period of time. The finite element analysis is carried out using software package of ANSYS [10]. Forced convections on the inner surface due to the turbulent flow of steam and on the outer surface due to cross flow of the hot flue gas over bare tubes are considered as the phenomena of the condition. An iterative procedure is carried out to determine the average temperature in the tube over period of time as scale thickness on the inner surface increases. Different heat transfer parameters governing the problem are evaluated. In order to verify the results obtained by using the proposed method, comparisons are made with the actual data of the available reports. Examples on failure analysis of the boiler tube utilizing the proposed technique are presented.

2. Iterative technique and finite element simulation

Three different geometries of the tube as shown in Table 1 are used. Model of the tube section used is 100 mm in length. In the modeling of the steady state heat transfer for the problem using ANSYS [10], the area of the model is divided into two regions, i.e. scale region and tube region (Fig. 1). The steam region is taken into account in determining the convection coefficient of steam film for fully developed turbulent flow in circular tube. Steam flows through the internal of tube with two different inlet temperatures of 540 °C and 605 °C, and the detailed heat transfer parameters are tabulated in Tables 2–4. The material of the seamless ferritic low-alloy steel tube used in this work is SA213-T22 as shown in Table 2. In this study material of the scale is treated to be all magnetite (Fe_3O_4).

Phenomenon of heat transfer inside the boiler tube is considered as a forced convection with turbulent flow. Correlation for fully developed turbulent flow in tube is expressed as [11]:

$$Nu = 0.023(Re)^{0.8}(Pr)^{0.4}, \tag{1}$$

where Re is Reynolds number that may be expressed as

$$Re_s = \frac{4\overset{o}{m}_s}{\pi D \mu_s}, \tag{2}$$

in which $\overset{o}{m}_s$ is mass flow rate of the steam; D is the inner diameter of the tube; μ_s is steam viscosity, and Pr_s is its Prandtl number that is defined as

Table 1
Geometries of the tubes.

Tube	Inner radius (m)	Outer radius (m)
1	0.0219	0.0254
2	0.0219	0.0274
3	0.0199	0.0254