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Combination Non-Destructive Test (NDT) Method for Early Damage Detection and Condition Assessment of Boiler Tubes

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Abstract

Boilers, the most troublesome components of electric power, chemical and processing plants generate high costs in unscheduled shutdowns, repairs and power replacement. Every occurrence of ruptured tubes leads to emergency shutdown of the entire plant. This paper describes the joint international effort to develop faster and more efficient methods for condition assessment and remaining life prediction for boiler tubes. The work was performed under the grant from Kazakhstan Ministry of Education and Science.

The authors have visited a number of coal-fired electric plants throughout Central Asia and found that a combination of wall thinning and overheating were major damage mechanisms contributing to boiler tube failures. The periodic inspection of boiler tubes include ultrasonic measurement of remaining wall thickness and in many cases, it involves cutting tube segments and performing metallurgical analysis for loss of original strength due to overheating. Systematic research was undertaken with the objective to correlate the results of combined non-destructive testing (NDT) with condition assessment of boiler tubes. The evaluation included non-contact wall thickness measurement with EMAT technology plus internal oxide layer measurement with specialized ultrasonics. The first method shows the remaining tube wall thickness, thus allowing to calculate total stress, and the latter one has the potential to indirectly characterize microstructure degradation, which up to now could only be determined by destructive analysis. The existing tube removal criteria are treating each damage mechanism separately while in reality, a combined effect of wall thinning and the "degree of overheating" decides about true condition of a tube. The procedure that utilizes the results of both described NDT methods was developed for improved methodology to assess tube condition and to predict its remaining life.

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Nomenclature

p	pressure inside boiler tube (psi)
d_m	mean tube diameter (m), calculated as: (*outside dia + inside dia)/2*
b	tube wall thickness (in)
b_0	nominal (original) tube wall thickness (in)
t	time (hrs)
t_r	time-to-failure (hrs)
T	temperature (R)
X	thickness of internal oxide scale (mils)
S_u	ultimate strength (psi)

1. Most common boiler tube failure modes.

The objective of the described research was to develop an optimum non-destructive testing (NDT) method or combination of methods that would improve the reliability of coal-fired boilers by reducing down-time related to failure of water-wall tubes. Similar work has been continuing throughout the world for the last 20-30 years, however, the research was always concentrated on low alloys steels, usually Cr-Mo type. Since this project was funded by Kazakhstan Ministry of Education and Science, it had to concentrate on local conditions in Central Asia where low carbon Steel20 is the most widespread tube material in water-wall section (although Cr-Mo steels are used in re-heater and superheater sections). The carbon steel is much cheaper than Cr-Mo steels and in addition, the cost of labour for replacing fossil boiler tubing in Central Asia is considerably lower. It is worth mentioning that India and parts of Southeast Asia use similar boiler water wall and superheater materials to those used in Kazakhstan and that the types of coal used in their power plants has many similarities to Kazakhstan coal. Therefore, it seems that at least some of test and maintenance procedures could be successfully adapted to other Asian locations.

It is well known that the main damage mechanism in Cr-Mo tubes in water-wall section of a boiler include fireside and internal corrosion and erosion causing wall thinning, therefore ultrasonic wall thickness survey is conducted as a preventive maintenance measure. Low Carbon steel, however, brings new requirements as overheating, creep as well as hydrogen embrittlement should be considered as an additional and sometimes major damage mechanisms. It is generally recognized that creep may occur in carbon steels in temperatures over 400-440C, which is well within the range in water-wall boiler tubes [11]. For that reason, any preventive maintenance procedures have to consider overheating as a possible cause of failure. Indeed, during numerous visits by the research team to coal-fired electric plants throughout Kazakhstan, it was found that creep damage was the main reason for tube failures and consequently, the analysis for overheating condition was the main type of preventive maintenance. The usual way was a destructive method, i.e. cutting and removing tube samples from affected section of a boiler and performing metallurgical analysis for evidence of overheating. On the other hand, our team did not find an instance where hydrogen embrittlement would be a major cause of failure.

These initial investigations that included plant visits and literature search had concluded that in order for this research to be useful to plant operators, it has to concentrate on carbon steel as a material of choice for water-wall section of the boiler. The most common reasons for tube failures in Steel20 were: (i) external and internal corrosion and erosion - it is common for combustion products to erode portions of the tube surface or for chemical reactions of molten sulfates, carbonates and oxides with the iron in tube material to locally reduce the tube wall thickness (ii) long-term overheating damage where the material strength gradually decreases with time (iii) short-term overheating, usually occurring during start-up or due to some unexpected occurrences, such as tube blockage, when tube temperature rises suddenly with consequent loss of tensile strength, so that hoop stress from internal pressure causes a violent rupture. It needs to mention at this point that both above types of failure are easy to recognize by a simple observation: while a long-term overheating causes a “thick-lip rupture” with many bulges and cracks visible around, a short-term overheating is connected with “thin-lip rupture” having sharp edges and usually no evidence of other damage around the burst [5]. Samples of actual tube failures are shown in Figure 1.