

PREDICTION AND PREVENTION OF BOILER TUBING SYSTEMS EROSION IN THERMAL PLANT

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ABSTRACT

The problem of boiler tube erosion is a very complex problem and present in practically all fossil fuel power plants burning low heating value coals irrespective of their particular design and operating characteristics. Predicting the rate of material degradation processes due to operating conditions is the essential feature for assessing the remaining lifetime. This clearly includes the knowledge of the

type and kinetics of erosion phenomenon. In order to follow the erosion process and provide a reliable prediction of erosion rate and thus tube time to failure, models taking into account all relevant effects have to be developed. In this paper the is presented results of testing carried out on the evaporator hopper tubes of 350MW unit exposed to erosion and were used to assess their remaining life.
Key words: boiler tube erosion, remaining life

1. INTRODUCTION

The problem of boiler tube erosion is a very complex problem and present in practically all fossil fuel power plants burning low heating value coals irrespective of their particular design and operating characteristics [1–5]. As a result, significant differences in the damage levels of boiler heating surfaces as well as the prevailing erosion mechanisms are to be expected. Understanding of erosion damaging mechanisms derives from baseline data, operating and maintenance histories and external experiences. It is clear that the erosion problem of boilers is practically unavoidable.

The nature of the erosion processes involved originates primarily in the milling equipment, not in the boiler tubing components. Bearing in mind the fact that the coal is transformed from large chunks into fine powder particles, burned in the boiler transforming into ash with different finesse and characteristics, it is clear that these transformations and coal/ash characteristics are responsible for the initiation of different boiler tube erosion mechanisms.

Understanding the erosion degradation failure modes of the boiler heating surfaces is the key to the effective management of their life. It encompasses knowledge of boiler heating surface materials and

material properties, operating conditions, possible deterioration mechanisms and their deleterious effects and data needed for assessment and management of these effects [6].

The number of factors affecting the erosion processes is relatively large but can be classified into three basic groups:

1. Flow processes around the surface exposed to erosion
2. Eroder characteristics
3. Erosion resistance characteristics of materials

The first two groups of parameters depend on the operating conditions of a plant exposed to erosion, the boiler and furnace designs and technological processes involved. The second group is defined by the characteristics, means of preparation and combustion of fuel. The third group represents the material's initial state and is apparently time-independent. However, since the processes occurring in the furnace affect the state of material and erosion mechanisms resulting from the boiler operating conditions, material erosion resistance can also be considered as time-dependent.

In order to follow the erosion process and provide a reliable prediction of erosion rate and thus tube time to failure, models taking into account all relevant effects have to be developed. However,

determining the extent and impact of their influence is a very serious problem, particularly with a heterogeneous quality of fuel and changeable boiler operating conditions. Furthermore, according the operating practice on lignite fired power plant boilers, plant operating below design load conditions can lead to extremely high erosion in boilers showing practically no erosion under full loading conditions.

The experience has shown that the most efficient and reliable method for direct monitoring of the erosion process is continual measurements of tube wall thicknesses during the shutdowns or by indirect monitoring of indicators such as erosion of the coal mills equipment. Based on the results of erosion monitoring (direct or indirect), it is possible to define the following [7]:

- In cases where there is no well defined initial state, the current state can represent the initial state and be used for further monitoring.
- Based on the results obtained, inspection programs and methods of testing would enable the use of simple models determining the extent and rate of erosion.
- Maintenance program that will cover the preventive measure against erosion as well as determination of the optimal re-inspection interval with the least number of outages in the interoverhaul periods.

2. BACKGROUND

The basis for the methodology for prediction and prevention of erosion in thermal power plant boiler tubing systems, presented in this paper, were made during many years of surveillance of the erosion phenomenon on one 300MW [9], two 350MW [10] and two 620MW [11] power plant units after respectively 150 000 h, 90 000 h and 150 000h of operation. All fossil fuel power plants using pulverized lignite for combustion with lower heating value in the range 6.069–6.699 MJ/kg, average moisture content in the range of 44–55% and the average ash content in the range of 9–25%. All units have once-through forced circulation tower type boilers with a relatively similar disposition of heating surfaces and 300MW and 620MW units excided the design life. The average ash content in these boilers is relatively high, containing fairly high content of SiO₂, and thus with similar erosive effects.

The failures due to erosion, on all three type of units, were responsible for almost ~80% of all tube failures. Slow, wear-out causes of failure, like creep, erosion and corrosion, are time dependent and

generally regarded as ageing problems. They show an escalating failure rate with operating life, usually related to cumulative hours but sometimes to starts.

Maintenance and residual lifetime prediction. In complex maintenance systems, the results of remaining life assessment are being used more and more as a basis for decision-making in setting-up the re-inspection interval of critical components, determination of the optimal interoverhaul periods, optimization of inspection programs, evaluation of system reliability and risk analysis [12].

The general methodology of remaining lifetime assessment of boiler tubing systems of thermal power plants operating over an extended period of time is based on the use of [7, 12]:

- Analytical analysis of available data
- Computing methods
- Non-destructive methods of testing
- Determination of the rupture mechanisms of a particular component under the actual operating conditions.

Predicting the rate of material degradation processes due to operating conditions is the essential feature for assessing the remaining lifetime. This clearly includes the knowledge of the type and kinetics of degradation phenomenon.

So far, the majority of the developed remaining lifetime assessment methods, regulated by the standards and technical norms for which the data is gathered at the levels 1 and 2, have to be somewhat adjusted in order to assure higher precision of the results obtained. Since the volume of existing information determines the method accuracy, it is essential that the method describes as close as possible the behaviour of a material under given operating conditions that often deviate from the nominal ones defined by the design.

Using the results of residual lifetime assessment it is possible to determine the lifetime as a function of a measurable quantity such as tube wall thickness. Hence, based on the wall thickness measurements during regular overhaul activities, the remaining lifetime of boiler tubes with corresponding data scattering can be determined. Based on the data obtained, it is possible to predict the optimal re-inspection interval and optimal period for component replacements thus assuring timely planning for the purchases. However, it should be pointed out that due to the variability of operating parameters, the kinetics of erosion/degradation processes can change and thus, in predetermined time intervals, it is necessary to correct the remaining lifetime assessment curves with the newly obtained data.

Predicting the rate of material degradation processes due to operating conditions is the essential

requirement for assessing the remaining lifetime. This clearly includes the knowledge of the type and kinetics of degradation phenomena.

3. REMAINING LIFETIME ASSESSMENT OF EVAPORATOR HOPPER TUBES EXPOSED TO EROSION

The results of testing carried out on the evaporator hopper tubes of 350MW unit were used to assess their remaining life. Due to low operating parameters and intensive erosion, the assessment is expressed in terms of exploitation availability and re-inspection interval. Membrane water wall hopper tubes are made of 0.5% Mo low alloy steel, $\varnothing 38 \times 5.6 \text{ mm}$ exposed to operating pressure and temperature $p=20.4 \text{ MPa}$ and $T \approx 366^\circ \text{C}$, respectively.

In order to assess the remaining lifetime of an evaporator hopper under erosive conditions (it can be any heating surface exposed to erosion) it is necessary to carry out statistical analysis of the results of the wall thickness measurements obtained during overhaul periods using ultrasonic testing of different evaporator zones (across the height and width) and also standard testing of the selected samples. Visual control and the results of examination of the sample taken from the evaporator hopper zone show clearly that the fly ash particle erosion and falling slag erosion are the dominant damage mechanisms, Figure 1.

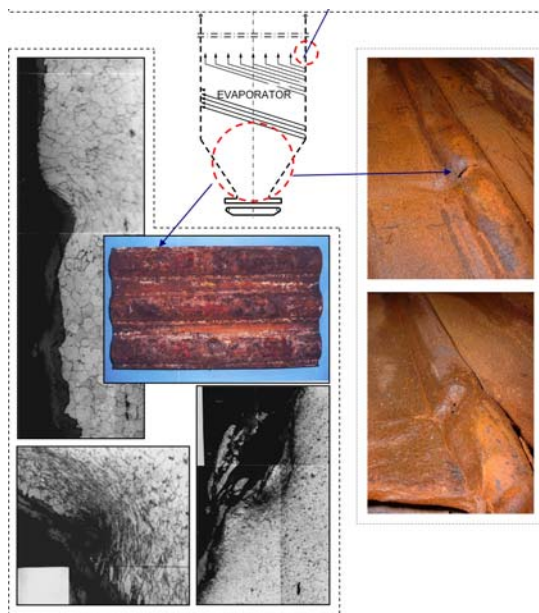


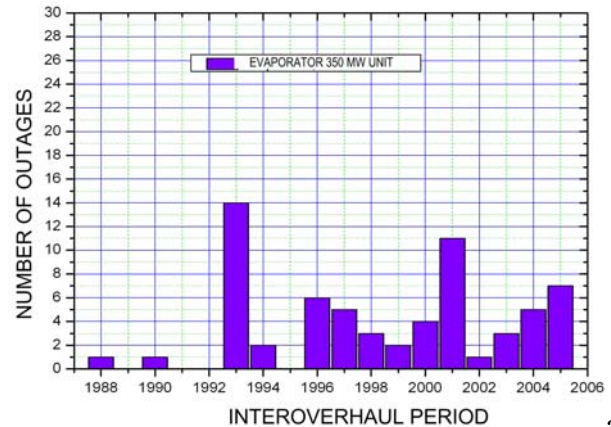
Figure 1. Hooper wall in pulverized coal fired boilers – microstructural features depicted erosion damage

3.1 Statistics of plant outages

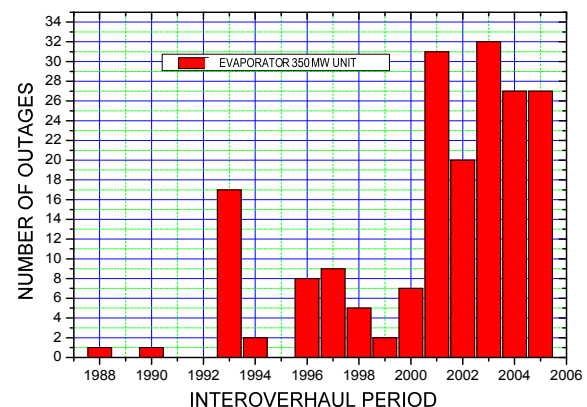
Pareto analysis of 350MW unit outages, indicates that evaporator was mainly responsible for the outages, causing 26% of the total number of outages. Outage distribution and repair number of evaporator vs. interoverhaul periods, shown in Figure 2 (a, b), indicate that this heating surface experienced some operating problems since 1992, mainly due to erosion.

To obtain the real information about the effect of evaporator erosion, spatial distribution of damage (outages + number of repairs) in different zones of evaporator, compared to the total number of evaporator outages/repair provoked by any of the damage mechanisms must be considerate. The erosion contributed to 20.7% of the total number of evaporator outages but was responsible for at least 61.35% of tube replacements or other forms of repairs. The boiler hopper is the most susceptible to erosion.

A large number of outages (65) of the evaporator did not occur evenly in all of its zones. Figure 3 show the spatial distribution of damages (outages + number of repairs) on the evaporator due to erosion only as compared with the total number of outages/repairs recorded at a particular site.



a)



b)

Figure 2 (a, b) Number of outages and number of repairs of evaporator as a function of interoverhaul period

3.2 Remaining life procedure

A procedure for assessing the remaining lifetime comprises three levels [6]:

- Level I – Acquisition and classification of the design data and data related to the operating history of the plant
- Level II – Acquisition and classification of operating and maintenance data and the results of previous testing
- Level III – Remaining lifetime assessment

The procedure for remaining life estimation follows:

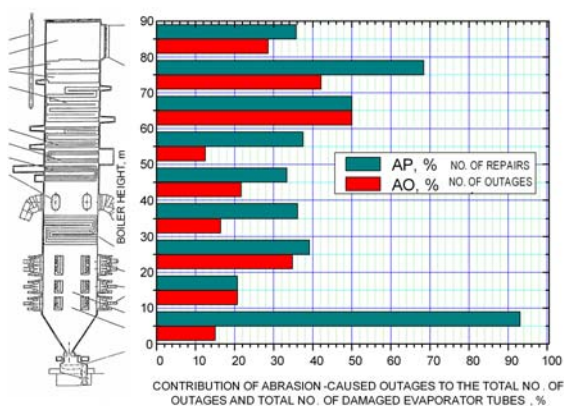


Figure 3. Spatial distribution of damage caused by erosion in evaporator zones compared with the total number of outages/repair recorded at the particular site caused by any of the damaging mechanisms

Level I. The main objective at this level is to define the critical components and possible causes of outages/failure under given operating conditions. The components considered as non-critical are those designed with the satisfactory wall thickness, erected properly and made of material with required properties/quality and with no excessive excursion in the operating parameters. In addition, separate analysis of the operating history data for each heating surface is also required. Data acquisition mapping of the erosion damaged zones on any heating surface with accurate locations of the tubes in the system and the lengths of the eroded zone must be considered. At this level, a tentative (preliminary) testing program is defined comprising the analysis of both critical and non-critical components. The analyses carried out at this level can significantly reduce the program comprehensiveness.

Level II. This level covers the plant history with all characteristics differing from other plants of the same designs but with different mode of operation. Very often for the particular components or the

whole plant, the data from the previous testing are lacking and therefore it is important to perform additional testing before the remaining lifetime assessment is made. At this level, based on the results obtained from the analyses carried out at the Level I, a final testing program is defined. In the case of erosion damage to tube heating surfaces obtained from mapping, and analysis of the plant operation and test data, the exact locations and the size of sampling as well the required testing methods can be determined. The aim of this phase is to determine the actual state (exhausting) of the component/plant.

Level III. Accurate remaining life assessment can only be done for the components for which a sufficient amount of data was obtained from the first two levels. For some components, determining the kinetics of damage mechanisms requires extensive and expensive studies that are often not important or critical. Using data obtained from Levels I and II coupled with experience and expert evaluation, the integrity and availability of these components can be determined.

4. THE REMAINING LIFE ASSESSMENT

In the case of an evaporator hopper, the first two levels require acquisition and analysis of data related to:

- Operating parameters of water and gas sides
- Operating hours of the investigated tubes
- Exact locations for the sampling sites
- Detailed description and characterization of the state of the sampled tube surfaces with all damages present
- Dimensional control of the tubes
- Materials (chemical compositions, mechanical properties at room and operating temperature, microstructural characteristics)

At **Level III**, for the thin-wall tubes, one of the most important parameters is the stress state of damaged tube and thus the following standard calculations can be used:

1. Calculation of the tube minimal allowable wall thickness according to the standards/codes.
2. Calculation of the stresses in the tube walls under operating conditions and minimal measured wall thickness in the damaged zone.
3. Actual working stress expressed by stress concentration coefficient.
4. Yield stress limit under biaxial stress state determined by the mechanical properties of the tested samples.

- The aim of these calculations is to determine:
1. Component design wall thickness resource
 2. Wall thickness current resource in the damaged area
 3. Safe limit wall thickness under given operating conditions and the acceptable damage rate assuring the safe operation until the next overhaul

Using this procedure, it was found by calculation on based on TRD 300 norms for evaporator hopper tubes ($\varnothing 38 \times 5.6 \text{ mm}$) that:

1. Designed wall thickness resource was 20%
2. Actual stress state in the tube walls with thickness corresponding to the measured one was close to that calculated by the design
3. Actual stress state (base on the minimal measured wall thickness) has not reached the allowable stress or yield stress limit values
4. According to the yield stress criterion determined from test results, evaporator hopper tubes have satisfactory exploitation availability due to:
 - negligible corrosion damages
 - preserved tube geometry
 - absence of excessive excursion of operating parameters (pressure)
 - up to 30% of the minimal allowable wall thickness as determined by standard calculation methods.

The range of wall thickness safe limits (1.6–4.0 mm) is determined from the intersections of the calculated yield stress limit for biaxial stress state ($\sigma_{lim} = 227.7 \text{ MPa}$) with the actual working stress curves (depending on stress concentration coefficient of local damage on tube wall). The lowest value of this range corresponds to tubes with negligible damage, as it is case at investigated hooper front wall. The working stress (σ_w) in some tubing wall system which developed and changed during the exploitation is responsible for controlling of its remaining life. This quantity is inversely proportional to the thickness of the tube. In addition to the thickness reduction due to oxidation and other corrosion-erosion processes, the elongated cavities and pin holes might act as stress concentrations and thus increase the actual working stress (σ_{aw}), which can be expressed, according to [13], as:

$$\sigma_{aw} = \sigma_w K = \sigma_{ow} x(1 + 2y) \quad (1)$$

where σ_{ow} is design stress in the tube wall, x is ratio between designed and measured thickness and y is ratio between the length and the width of a physical discontinuity. The presence of any local defect in the

structure, such as corrosion damages, or deviations from the design tube diameter can increase the lower value of the wall thicknesses safe limit. The diagram shown in Figure 4 is applicable to all evaporator hopper tubes, with or without corrosion damages, if the yield stress limit is not lower than the cited value.

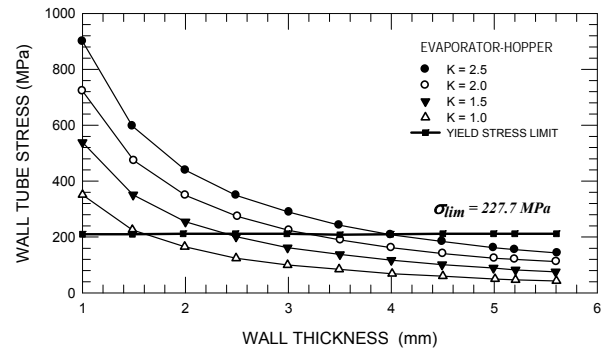


Figure 4. Safe limit wall thickness determination in a function of stress concentration coefficient for calculated yield stress limit

Using the data obtained by above calculations, the lifetime assessment of tube experiencing erosion as manifested by wall thinning can be made, providing the erosion rate is known. The approximate values for the erosion rate can be obtained by measuring the wall thickness changes over a predetermined operating period that can be expressed as the average erosion rate value (for complete operating time) or as erosion rate between two overhauls (Figure 5) assuming the linear relationship with time, as a first approximation, justified by grate erosion rate. The change in the average erosion rate between two overhauls is important since this information can be used to optimize the re-inspection interval for the given locations.

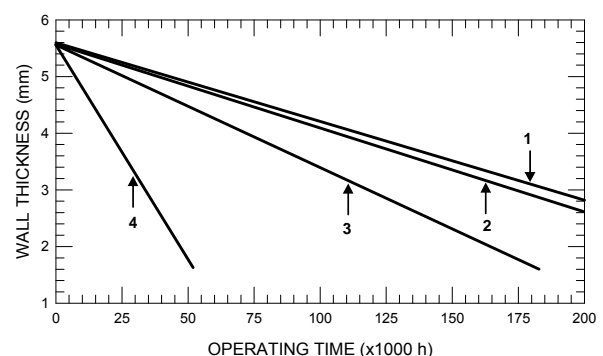


Figure 5. Tube wall thickness change due to erosion as a function of the operating time for:

- 1) average erosion rate on evaporator left wall, 2) average erosion rate on evaporator hopper rear – left wall 3) average erosion rate on evaporator hopper front – left wall, 4) erosion rate on evaporator hopper front – left wall determined for one interoverhaul period.

An example of the erosion rate changes for the evaporator hopper front wall with respect to the boiler width is shown in Figure 6, whereas Figure 7 depicts distribution of tubes affected by particular erosion rate. The zones affected by different erosion rates are shown in Figure 6: I – zone with low intensity erosion rate not threatening the plant reliability, II – zone with moderate erosion intensity, III – zone with intensive erosion. Hopper zones exposed to erosion in zones II and III should be monitored during different overhauls. The changes in the coal quality will affect the erosion rates and thus these diagrams have to be corrected by correlating coal quality and erosion rate.

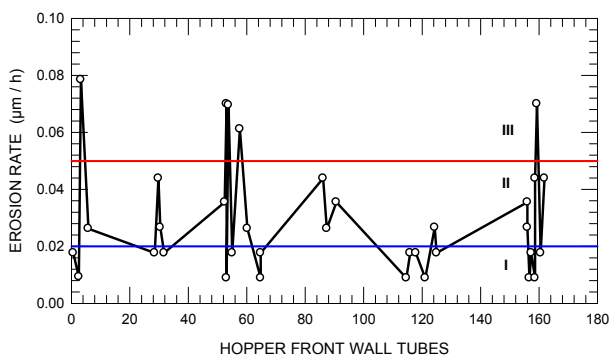


Figure 6. Erosion rate of evaporator hopper front wall based on the results obtained during different overhauls. I – relatively slow erosion rate up to 0.2 mm/year; II – moderate erosion rate; III – intensive erosion rate over 0.5 mm/year.

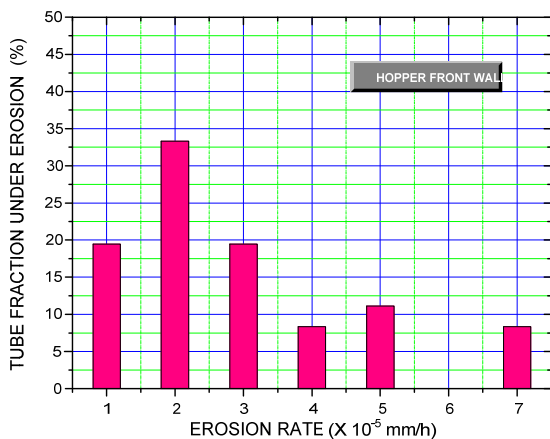


Figure 7. Fraction of hopper front wall tube affected by particular erosion rate. Data collected from the tests carried out during three overhauls.

Based on the results obtained and corresponding analyses, it is possible to make the final assessment of the remaining lifetime of hopper tubes in terms of erosion-caused damages (Figures 7, 8). It is clear that:

- Different zones have different remaining lifetime
- Particular attention has to be given to the zones affected by the erosion rates responsible for significant reduction of the lifetime
- For the most threatened zones, the period of 2 years is the optimal re-inspection interval with a continuous monitoring of the coal quality during operation

Application of special measures such as inserting the tube control samples aimed at reducing the number of tube wall measurements during the subsequent overhauls.

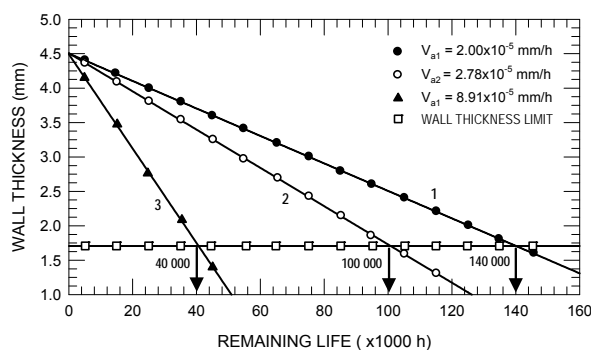


Figure 8. Times to reach the limiting wall thickness for hopper front wall tubes
1 – most frequent erosion rate ($2.00 \cdot 10^{-5}$ mm/h, see Fig. 7), 2 – averaged erosion rate ($2.78 \cdot 10^{-5}$ mm/h); 3 – highest erosion rate ($6.91 \cdot 10^{-5}$ mm/h, See Fig. 7)

5. CONCLUSIONS

Although much progress has already been made in the diagnostics and monitoring of the different erosion mechanisms of fossil fuel power plant boilers using low heating value lignite, there still remain many topics related to the detailed and precise knowledge of the degradation mechanisms/failure modes which require further study and analysis.

The decision to establish a reliability centered maintenance management program is the first step toward controlling maintenance costs and improving efficiency of boiler heating surfaces from the erosion point of view.

Maintenance and corrective actions should be implemented in response to an identified deterioration of boiler performance. Depending on the degree of degradation and the residual integrity of the component, the objective of corrective measures should be structural and protective.

Effective use of the utility-centered preventive/predictive technologies would ensure the maximum interval between repairs; minimize the number and cost of unscheduled outages and improve the overall reliability of the thermal plant. Used cor-

rectly, a considerable fraction of wasted maintenance expenditures can be eliminated and effective use of utility resources, both production and maintenance, can be achieved and sustained.

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