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Research paper

Ash fouling monitoring based on acoustic pyrometry in boiler furnaces

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HIGHLIGHTS

- An approach to monitor ash fouling on the heat surface in boiler furnaces was developed.
- The paper provides acoustic technology to obtain the changes of flue gas temperature near the water-cooling wall.
- The sound rays close to the water-cooling wall bend toward the high temperature area inside the furnace.
- A new clean factor, &, was proposed based on acoustic pyrometry.
- The technique is applied to a domestic 600-MW coal-fired boiler.

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ABSTRACT

Unexpected fouling of heat transfer surfaces has always been one of the main operational concerns in coal-fired utility boilers. A cost-effective way to address this difficulty is the continuous monitoring of fouling tendencies. This article has adopted acoustic pyrometry to monitor the changes of the flue gas temperature near the heat surface and has proposed a new clean factor, &, based on this acoustic method to monitor the ash fouling. A laboratory study and field research using a boiler were conducted. The results indicated that the acoustic system could be adopted to monitor temperature changes near the water-cooling wall in the boiler furnace. The new clean factor, &, could be used to monitor the changes of the ash fouling on the heat surface. This study may help to develop a more intelligent use of soot blowers, save power station boiler furnace energy and reduce discharge.

1. Introduction

As industries develop, high-parameter, large-capacity boiler systems are put into operation successively. The fuel and load vary more often, the start-up and shutdown times of boilers increase, the average load decreases and boilers operate at low load frequently. Slagging and fouling on the heat transfer surface are familiar and unavoidable problems of power boilers and have adverse effects on a boiler running safely and economically [1]. In recent years, significant advances have been made in the field of coal characterization. One of the goals has been the prediction of ash deposition phenomena in coal-fired boilers [2,3]. Without on-line fouling supervising equipment, the ash blowing process must be operated at a regular time by an operator with experience and thus is vulnerable to human error. If the blowing time is less than needed, the ash blowing cannot reach the predictive result, but if it is longer than needed, it is possible to hurt the surface. Thus, the fouling monitoring and soot blowing optimization are very important [4]. Thus far, many systematic approaches have been described to predict ash deposits in coal-fired boilers by means of artificial neural networks [5,6]. The approaches are of a “grey box” nature, decomposing the problem into logical parts [6,7]. In addition, the expert system for fouling assessment development is one of the possible approaches to the mitigation of deposit formation on boiler heat transfer surfaces [8]. The monitoring system, composed of newly developed sensors with respective elements for the conditioning, acquisition and validation of the signal, is used in the design of expert systems for the fouling assessment concept. Many other prediction methods also have been recently adopted [3,4,9,10].

The methods described above have their respective merits. However, these methods are based on associated calculations of the design and operating parameters of boilers, which involve more parameters and complex calculations. The change of ash fouling is

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Nomenclature

&	clean factor
t	gas temperature
τ	time of flight
$R_{x_1x_2}(\tau)$	cross-correlation function
$G_{x_1x_2}(f)$	cross power spectral density function
$\|\gamma_{12}(f)\|^2$	modular square coherence function

bound to produce a change in the flue gas temperature near the heating surface. Thus, if we can directly monitor the temperature changes of the flue gas near the heating surface, the changes of the ash fouling will be monitored and the use of sophisticated data will be avoided. Because of the high temperature near the heating surface towards the fire, the traditional methods of temperature measurement cannot be adopted. However, real-time monitoring of the temperature based on acoustic pyrometry has many benefits, such as a high resolution of the temperature measurement, wide range, non-intrusiveness, real-time monitoring, and low maintenance [11,12].

In this study, our research focused on the flue gas temperature monitoring near the water-cooling wall by acoustic pyrometry with an electroacoustic system in coal-fired boiler furnaces. Then, a new clean factor was put forward. To verify this method, an experimental apparatus was built, and a laboratory study was conducted. Finally, the acoustic system was installed in a domestic unit, and a study of the hot state of a boiler was conducted.

2. Method

2.1. Physical principles of acoustic pyrometry

Sound waves are emitted by a sound source on one side and are received by microphones that are installed in the wall of a boiler furnace, on both sides. First, a loud sound can be generated by the sound source, and it is received by the microphone near the source on one side. Then, the sound across the furnace is received by the microphone on the other side. Meanwhile, to calculate the acoustic velocity, time of flight (TOF) should be measured by estimating the time delay of sound wave transmission between the microphones. In a mixture of gases with a definite composition, such as boiler flue gas, the speed of the sound wave depends on the temperature of the gas [11,12]. The principle equation of acoustic pyrometry is as follows:

$$c = \frac{L}{\tau} = \sqrt{\frac{\gamma R}{m}T} \tag{1}$$

where c is the speed of the acoustic wave propagation in the medium, L is the distance between the different measuring points, τ is the TOF, γ is the isentropic exponent of gas, R is the universal gas constant of an ideal gas, m is the molar mass, and T is the gas temperature. $Z = \gamma R/m$ is a constant for a given gas mixture. The sound speed, which depends on the temperature of the medium and contains temperature variations, is obtained by measurement of the TOF. Hence, the calculation formula of the one-path temperature derived from Formula (1) is as follows:

$$T = \left(\frac{L}{\tau Z}\right)^2 \tag{2}$$

2.2. Mechanism to monitor local ash fouling near the water-cooling wall based on acoustic theory

Fig. 1 shows the placement of the test points to monitor the flue gas temperature; acoustic test points 1 and 2 were placed at water-cooling wall 1, where ash fouling accumulation was likely to occur. Acoustic waves were transmitted from the source at test point 1; by measuring the TOF of the acoustic wave, the average speed of the acoustic wave along the transmission path could be calculated. In addition, the flue gas temperature close to wall 1 could be calculated by placing the test points according to actual needs. The temperature measurement mechanism for water-cooling wall 2 was arranged identically.

When ash started to accumulate below the level at which the acoustic test points were installed near the water-cooling wall due to insufficient heat dissipation, the temperature of the water-cooling wall with the accumulated ash began to decline; at the same time, the corresponding near-wall flue gas temperature gradually increased. Based on this phenomenon, the clean factor was defined as:

$$\& = 1 - \frac{t'_w}{t_w} \tag{3}$$

where t_w is the near-wall flue gas temperature (in °C) of the boiler under the same operating condition measured by the acoustic method when ash fouling accumulated and t'_w is the near-wall flue gas temperature (in °C) of the boiler under the same operating condition measured by the acoustic method when the wall is clean.

When monitoring the flue gas temperature close to the water-cooling wall, the single-path furnace flue gas temperature t_Q could be monitored simultaneously as a reference for the operating status of the boiler. The water-cooling wall was assumed to be clean after soot blowing, and the near-wall flue gas temperature measured at this time was t'_w when the boiler had the same operating condition. If the operating conditions were different, the near-

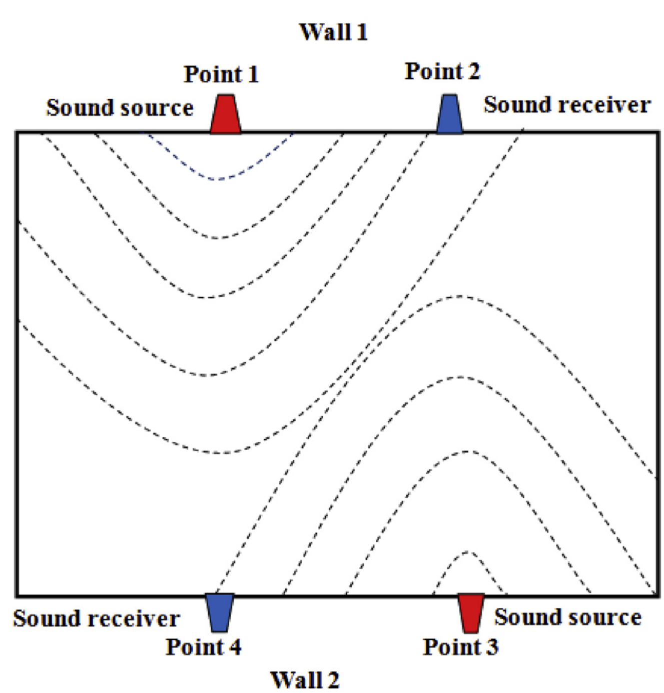

Fig. 1. Placement of flue gas temperature monitoring points near the water-cooling wall.