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Effects of operating conditions on temperature profiles of a coal-fired thermal power plant

Ahmad Rashidi, Mook Tzeng Lim*, Noor Akma Watie Mohd Noor, Azmi Ahmad, Hamdan Hassan,

Abstract— **Thermal power plants have begun to shift their choice of fuel to cheaper coals such as lignite to reduce operating costs and to maintain fuel sustainability. However, the properties of the cheaper coals are highly fluctuating and pose challenges to the combustion process, leading to higher slagging or fouling propensities. The slagging process starts with the deposition of ash, which in turn originated from the complex process of soot formation in the flame area. Therefore, any abnormalities such as temperature distribution imbalances can be traced through monitoring techniques at the combustion state within the flame area. In this study, an imaging technique based on the visible wavelength regime was used to capture the temperature profiles of a 700 MW boiler near the burner area for different coal types and boiler operating conditions. The temperature profiles will serve as a point of reference for the plant personnel to determine the combustion state with respect to the boiler operating conditions. Results show that coal types with high ash content will deposit as slag on the heat transfer surfaces, hindering heat transfer, causing the flue gas temperatures to be higher. In addition, the temperature profiles show that that soot blowing activities reduce the differential temperature between the front and rear of the furnace, and can indeed improve the temperature distribution.**

Keywords—combustion, slagging, imaging, temperature profiles.

I. Introduction

Thermal power plants have begun to shift their choice of fuel to cheaper coals such as lignite to reduce operating costs and to maintain fuel sustainability, since coal reserves are reported to be able to last for more than 200 years [1, 2]. However, the properties of the cheaper coals are highly fluctuating and pose challenges to the combustion process. Some of the cheaper coals have higher ash content or lower ash fusion temperatures, causing them to have higher slagging or fouling propensities. Coals with higher slagging and fouling propensities cause layers of deposits to build-up on the boiler tube surfaces or water walls, reducing the heat transfer to the fluid in the boiler tubes [3, 4]. Thus heat is retained within the furnace, and the temperature will be higher after it exits the combustion section and enters the convective section. This phenomena is known as high rear pass temperatures (refer Figure 1.) [3, 5], and has been designated at some power plants to be at temperatures above 650 to 680 °C.

Ahmad Rashidi, Mook Tzeng Lim*, Noor Akma Watie Mohd Noor, Azmi Ahmad, Hamdan Hassan
Fuels and Combustion, Generation
TNB Research Sdn. Bhd.
43000 Kajang, Malaysia.

The slagging process starts with the deposition of ash, which in turn originated from the complex process of soot formation in the flame area. Monitoring and diagnosing the flame and combustion states becomes essential to identify any abnormalities such as temperature distribution imbalances.

The combustion state can be monitored through imaging techniques as it can capture the radiative energy from the flame in the form of wavelengths. There are various imaging methods such as laser imaging and visual imaging for monitoring the combustion state, and are based on the emission spectra of different components of the flame [6].

Hence, in this study, an imaging technique based on the visible wavelength regime will be used to capture the temperature profiles of a 700 MW boiler near the burner area for different coal types and boiler operating conditions. Temperature profiles for different coal types, before and after soot blowing, before and after coal mill switching were analyzed in terms of their elevation-averaged temperature, differential temperature and standard deviation respectively. The elevation-averaged temperature is used to determine the temperature profile along the furnace height for different coal types, while the differential temperature is an indication of the uniformity or distribution of heat at the respective elevations, and the temperature variation indicates the variation of temperature within an elevation.

II. Methodology

A. *700 MW_e coal-fired thermal power plant*

Temperature profiles were taken at elevations of 23, 27, 33, 39, 43.5, and 48 m (ref Figure 1.). Two peek holes are located on the front and rear side of the furnace for each level (refer Figure 2.), where the portable imaging camera is inserted to capture the images of the flame.

Pulverized coal is provided to the boiler by seven coal mills to seven elevations (ref Figure 3.). Each coal mill provides approximately 55 t/h of pulverized coal that is entrained by primary airflow at a flow rate of 101 kNm^3/h to tangential burners. The tangential burners are located at four corners at each elevation, and are located between furnace heights of 23 to 39 m. The superheaters are located above 39 m.

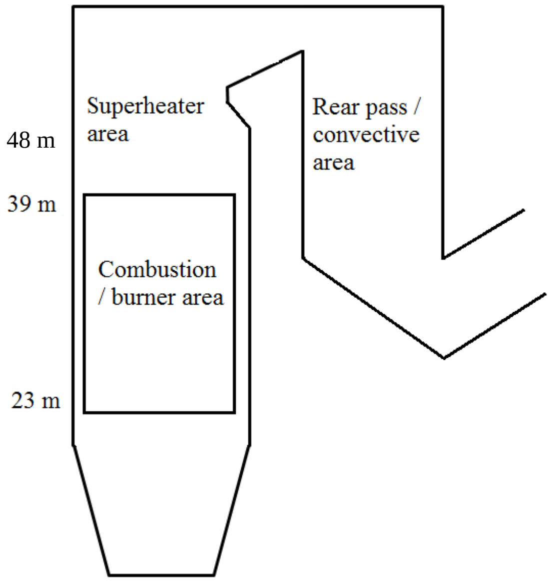

Figure 1. Simple diagram depicting the respective sections in a 700 MW coal fired thermal power plant.

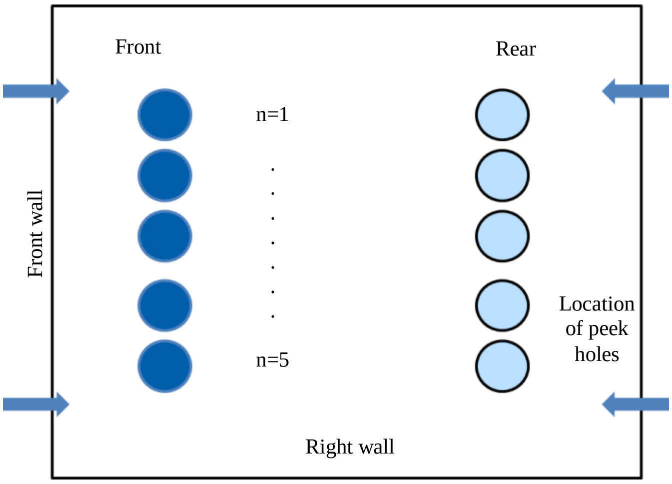

Figure 2. Location of peek holes (represented by arrows) on the furnace (viewed from the top). The circles represent locations where the temperature was taken to determine the differential temperature between the front and the rear.

B. *Portable imaging system*

To determine the combustion state within the furnace, a portable imaging camera developed by [6] was used to capture temperature profiles through the peek holes at the respective elevations. The lens at the end of an image guide of the portable imaging system was inserted into the peek holes to capture the images of the flame for approximately 10s. The images are then averaged and translated into temperature profiles based on calibrations with the temperatures of a blackbody furnace. A schematic of the portable imaging system is show in Figure 4. Details of the system can be found in the work of Lou et al. [6].

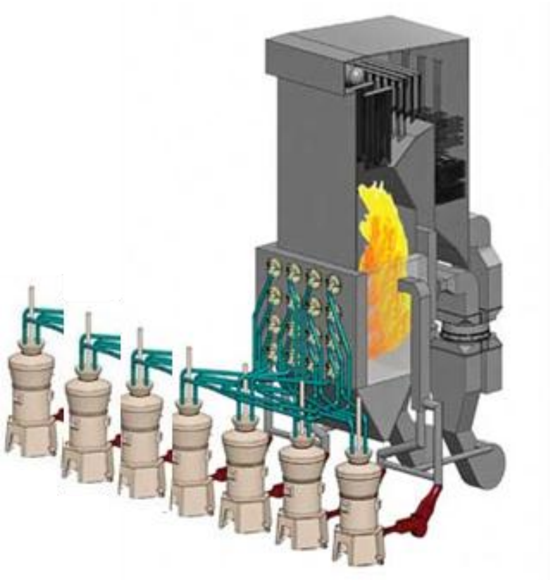

Figure 3. Coal mills that supply pulverized coal to the burners at different elevations.

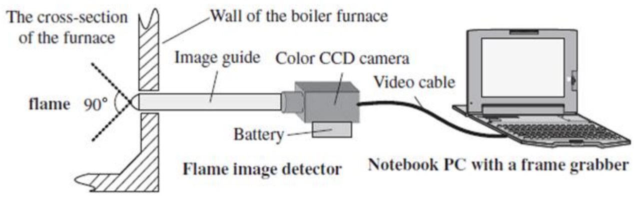

Figure 4. Portable imaging system developed by [6-9].

C. *Temperature distribution, profiles, and differentials*

The differential temperature was determined from Equation (1), which is based on the absolute value of the temperature difference between the front and rear side of the furnace, and was averaged over five locations as shown in Figure 2. .

$$\text{Differential temperature, } \Delta T = \frac{\sum_{1}^{n} \left| (T_{front} - T_{rear})_n \right|}{n} \quad (1)$$

The differential temperature before and after soot blowing was compared to determine the effectiveness of soot blowing in improving the temperature distribution. The impact of coal mill operation on the temperature variation was determined by obtaining the standard deviation of the profiles for each elevation. In addition, the temperature profiles for each elevation were averaged for comparison for different coal types. The properties for different coals are presented in Table I.

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TABLE I. COAL PROPERTIES

Coal type	Gross calorific value (kcal/kg)	Volatile matter (%)	Fixed carbon (%)	Ash content (%)	Moisture content (%)
A	4979	37.3	35.0	2.5	25.2
B	5029	33.3	41.6	5.1	20.0
C	5052	36.7	34.9	2.0	26.4

III. Results and Discussion

A. *Effect of mill operation on temperature fluctuations*

Figure 5. shows the raw image of the flame taken by the portable imaging system from one of the peek holes. The raw flame images from the four peek holes are then translated into temperatures and are then combined to result in the temperature profile for that elevation. Figure 6. shows examples of the resulting temperature profile. Details about the procedure to convert the images into temperature profiles can be found in [6-9]. Temperatures near the front and rear wall regions were excluded as there were no available peek holes to allow the camera to have a clear line of sight along those two walls.

Figure 5. Raw flame image taken from one of the peek holes of the furnace.

Figure 6. shows the temperature distribution at 33 m before (5(a)) and after (5(b)) a switch of coal mills. The temperature profile in Fig. 5(a) may indicate that along the horizontal direction, the temperature is more homogeneous. However, the overall variation of the temperature is relatively higher before coal mill operation was switched (±78°C), compared to the variation after switching (±29°C). A similar trend was observed at elevations of 27 and 39 m as well, as shown in Table II.

The larger variation in Figure 6. (a) indicates a sharper temperature gradient in the front wall direction, where the high temperature regions (coloured red) decrease to lower temperatures (blue and green) at a faster rate. The decrease in temperatures was more gradual in Figure 6. (b), where there are larger transition regions (yellow). This is shown in Figure 7. where the temperatures in positions 2, 5 and 8 on the right wall for both figures are presented. After the coal mill was switched, the temperature gradient was lower and the temperature distribution was more homogeneous (Figure 7. (b)).

TABLE II. STANDARD DEVIATION OF TEMPERATURES WITHIN AN ELEVATION

	Standard deviation of temperature within elevation before and after coal mills were switched (°C)	
Elevation (m)	Before	After
27	78	29
33	49	18
39	37	19

The switch in coal mills could have caused the coal particle size to be better distributed, thus causing the combustion process to be more homogeneous, as represented by the temperature profiles (Figure 6. (b) and 7(b)). Further investigation is required to determine the coal particle size distribution.

B. *Effect of coal type on temperature profiles*

Figure 8. shows the elevation-averaged temperature profiles for different coal types at different elevations. The temperature profile for coal type C showed a dramatic decrease after 40 m (above the burners) compared to coals A and B. The average temperature for coal C at 23 m is the highest (1561°C) compared to the other two types of coal, but the temperature still decreased to 1280°C at higher elevations, and was lower compared to the temperatures from the other two coals (at 1340 °C).

The lower temperature of coal C above 40 m is caused by a lower ash content, which is 2.0% compared to coal A and B. The slagging propensity would be lower, allowing the heat transfer from the flue gas to the boiler tubes to be more efficient, thus allowing the temperature to be lower compared to the other coals.

C. *Effect of soot blowing on temperature differential*

Figure 9. shows the averaged differential temperature before and after the soot blowers were activated. The figure shows that the averaged differential temperature at elevations of 27, 39 and 43.5 m was reduced by 10-50°C. This shows the effectiveness of the soot blowers in removing slag layers, improving the temperature distribution and thus the differential temperature.

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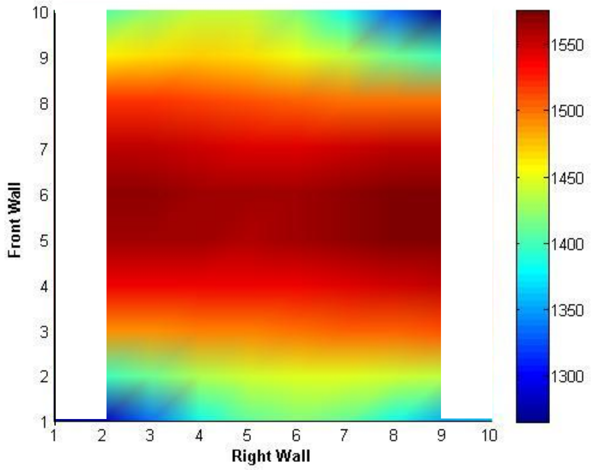
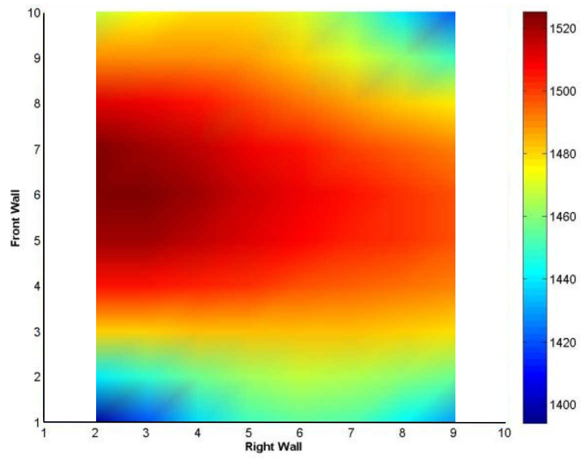
The lower differential temperature after soot blowing corroborates with the lower rear pass temperatures on the right hand side (RHS) and left hand side (LHS) of the furnace (Figure 10. (a) and (b) respectively), which is the temperature in the convection section (refer Figure 1.).

The average differential temperature is highest at 23 m, where the first elevated pulverized coal burners are located. The higher differential temperature could be caused by the transfer of heat toward the bottom ash hopper where no burners are located, thus causing the temperature distribution to be less even. At the upper elevations, the burners from of several elevations are able to concentrate the combustion. The transfer of heat is more even, thus the differential temperature is lower compared to the elevation at 23 m.



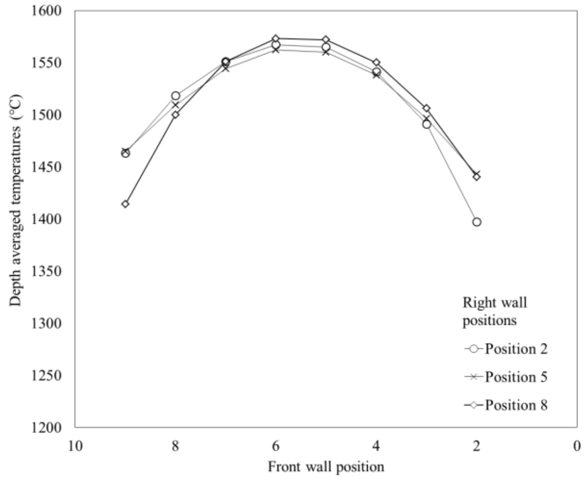
(a)



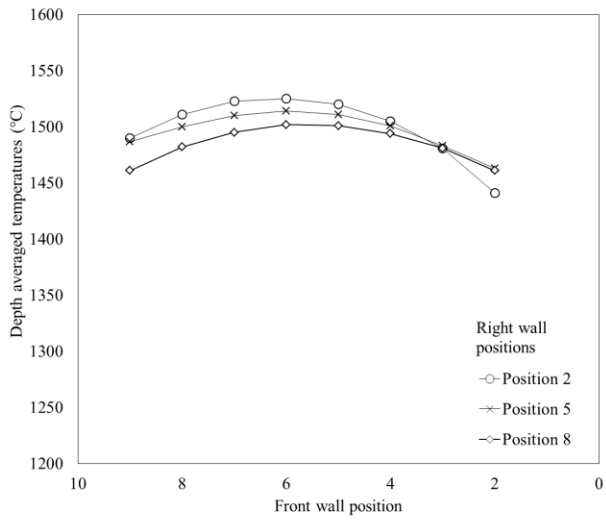
(b)

Figure 6. Temperature profiles taken at 33 m for coal B (a) before and (b) after coal mills were switched.

The differential temperature at 23 m increased significantly after soot blowing, possibly caused by an alteration of the heat transfer pathway from the lower levels to the upper levels after soot layers have been removed. However, further investigation is required to determine the exact cause for the significant increase in the differential temperature at 23 m.



(a)



(b)

Figure 7. Front wall temperature profiles at 33 m for coal B (a) before and (b) after coal mills were switched.

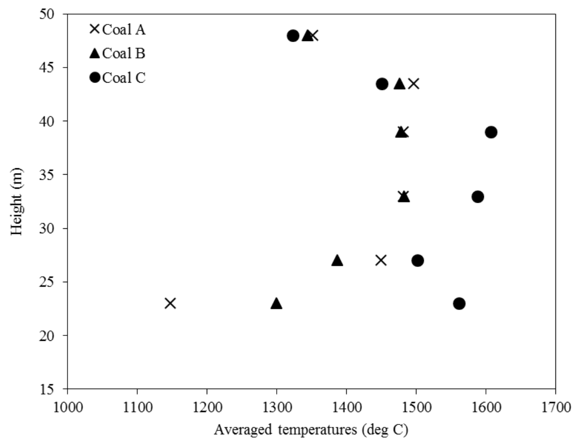


Figure 8. Average temperatures at different elevations for different coal types. Total primary airflow is 613 kNm^3/h, total secondary airflow at 710 kNm^3/h, load at 680 MW.

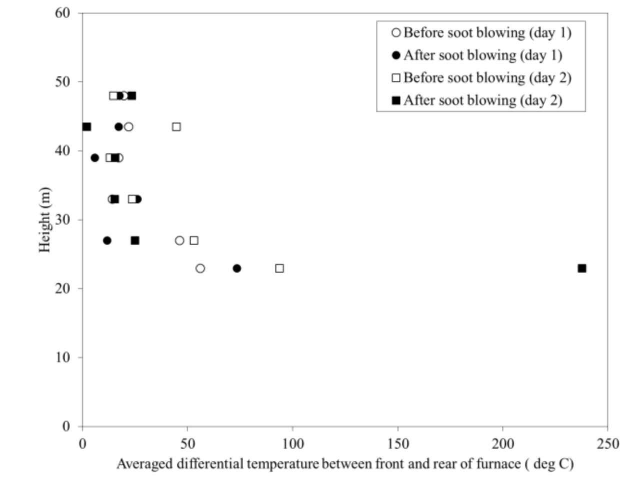
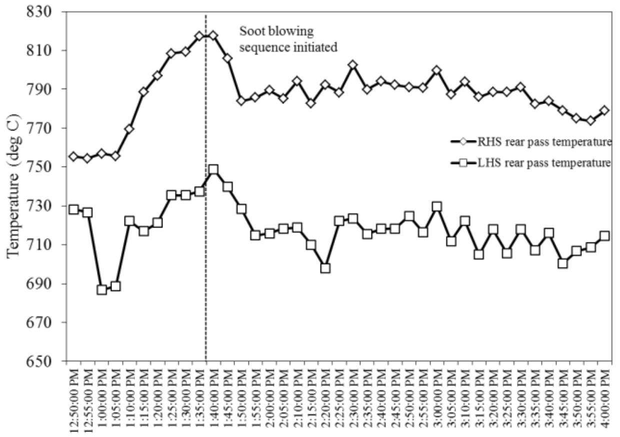
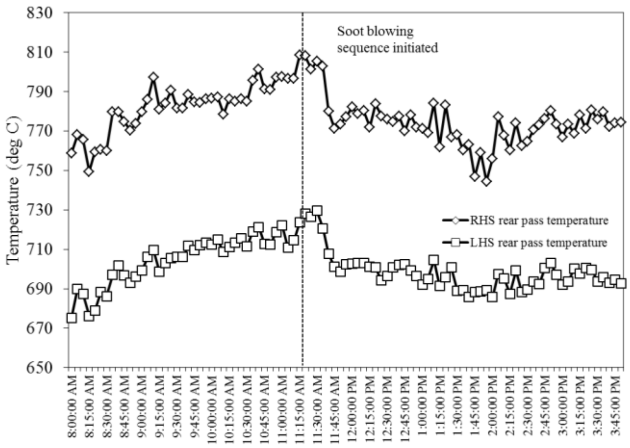


Figure 9. Differential temperature for each elevation for coal B before and after soot blowing.



(a)



(b)

Figure 10. RHS and LHS rear pass temperatures for (a) day 1 and (b) day 2.

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About Author (s):

Dr. Mook Tzeng Lim obtained his PhD. from Uni. of Canterbury (NZ), focusing on the hydrodynamics of a dual fluidized bed gasifier. He was a postdoctoral researcher with Uni. Of Canterbury, Uni. Teknologi Petronas, and Newcastle Uni. (UK), and is also a Chartered Engineer with the Institution of Mechanical Engineers (UK). He is currently a Principal Researcher in the Fuels & Combustion section of TNB Research Sdn. Bhd.