



# Hydrogen sulfide formation characteristics of pulverized coal combustion – Evaluation of blended combustion of two bituminous coals



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## ABSTRACT

This paper presents the characteristics of sulfur release during pyrolysis and hydrogen sulfide ( $H_2S$ ) formation for the pulverized coal combustion of blends of two bituminous coals in a pulverized coal combustion test furnace. The amount of sulfur released during pyrolysis is affected by the total sulfur content and the form of sulfur. Organic sulfur is more readily released to the gaseous phase than pyritic sulfur and sulfate sulfur. When blends of two bituminous coals releasing different amounts of sulfur are fired, the  $H_2S$  concentrations are between those for the combustion of the single coals. The peak  $H_2S$  concentration in the near-burner region in the blended combustion coincides with the value estimated from the blending ratio, which means that there is no interaction between the sulfur releases of the two coals during pyrolysis. The reaction behavior of  $H_2S$  and  $SO_2$  after the release of sulfur during the blended combustion is the same as that in the combustion of each single coal.

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## 1. Introduction

Low- $NO_x$  combustion technologies, such as two-stage combustion, low- $O_2$  combustion and low- $NO_x$  burners, are currently being employed in Japanese pulverized-coal-fired power stations to meet strict  $NO_x$  emission regulations. These low- $NO_x$  combustion technologies increase the fuel/air ratio in the burner and form a strong reducing atmosphere in the region from the burners to the two-stage combustion air ports. Hydrogen sulfide ( $H_2S$ ) is produced in this reducing atmosphere, causing sulfidation corrosion of the boiler water wall [1–5]. To reduce  $H_2S$  formation to prevent sulfidation corrosion, it is necessary to decrease the fuel/air ratio in the burner. However, this increases the  $NO_x$  emission. The  $SO_x$  emission regulations of coal-fired power stations are also very strict in Japan. To comply with these regulations, wet-type or dry-type desulfurization equipment is being installed in all power stations. In addition, low-sulfur coals, whose maximum sulfur content is 1.0%, are used to reduce  $SO_2$  emission from the boiler. It is thus very important to clarify the  $H_2S$  formation characteristics of low-sulfur coals under low- $NO_x$  combustion conditions.

Zghoul et al. [6] investigated the characteristics of gaseous sulfurs in an opposed-flow diffusion flame produced by propane/coal/argon/oxygen mixtures and showed that sulfur is released early in the flame, primarily in the form of  $SO_2$ . Zaugg et al. [7]

studied the formation and reaction of gaseous sulfurs in a laboratory-scale pulverized coal combustor and elucidated the effects of the secondary air swirl of the burner and the coal type. However, these studies were carried out using small-scale apparatus and the combustion conditions were very different from those in the two-stage combustion of pulverized coal. It is thus extremely difficult to apply these results to pulverized-coal-fired power stations.

In these circumstances, we have been experimentally investigating the  $H_2S$  formation characteristics of low-sulfur coals under low- $NO_x$  combustion conditions in a pulverized coal combustion test furnace, whose combustion characteristics are similar to those of pulverized-coal-fired power stations. In our previous study [8], three bituminous coals were fired in the test furnace and the following results were obtained. The sulfur in coal is mainly released to the gaseous phase during pyrolysis in the near-burner region, and high concentrations of  $H_2S$  are observed in this region. We also showed that the  $H_2S$  concentration is higher for coals with a low fuel ratio (fixed carbon/volatile matter) or high sulfur content. After the release of sulfur, the  $H_2S$  concentration gradually decreases in the downstream direction, where  $H_2S$  and  $SO_2$  are in chemical equilibrium.

Japanese pulverized-coal-fired power stations use various types of imported coals with different properties. The blended combustion of coals with different properties is thus commonly used to satisfy the acceptance criteria of the pulverizer, boiler, flue gas treatment system, and so forth, to meet the regulations of the flue

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gas and water discharge. The blending of coals that release small and large amounts of sulfur may be a means of reducing H<sub>2</sub>S formation in the near-burner region.

In this study [9], the effect of coal properties on the characteristics of sulfur release during pyrolysis in the near-burner region is first investigated by fundamental experimentation. The relationship between the amount of sulfur released and the coal properties, particularly the forms of sulfur existing in the coal, is examined. Blends of two bituminous coals releasing different amounts of sulfur are fired in the pulverized coal combustion test furnace. The results are compared and the H<sub>2</sub>S formation characteristics in the blended combustion of bituminous coals are discussed.

## 2. Experimental

### 2.1. Experimental apparatus and methodology

#### 2.1.1. Measurement of the amount of sulfur released and the forms of sulfur

The amount of sulfur released during pyrolysis was fundamentally estimated as follows. Char samples were prepared by the proximate analysis method and the sulfur contents of these samples were measured. The amount of sulfur released was calculated from the sulfur contents of the raw coals and the char samples and from the results of proximate analysis. We focused on the forms of sulfur as a property of coal that affects the release of sulfur. The sulfur in coal is classified into pyritic sulfur, organic sulfur and sulfate sulfur. The amounts of these types of sulfur were measured by ASTM-D2429, which is the most reliable method for measuring the amount of each form of sulfur.

#### 2.1.2. Pulverized coal combustion test furnace and test procedure

Fig. 1 shows a schematic diagram of the pulverized coal combustion test furnace. We have been operating the furnace for more than 30 years, and have fired various types of solid fuels including bituminous coals, sub-bituminous coals, high-fuel-ratio coals, high-ash coals and biomass fuels under a wide range of combustion conditions [10–16]. We confirmed that the peak temperature and the contents of the exhaust gas such as the NO<sub>x</sub>, are almost the same as those of Japanese power stations. On the other hand, the unburned carbon content in fly ash (Uc) of our furnace is slightly higher than that of Japanese power stations. This means that the combustion efficiency of our furnace is lower than that of the power stations. This is due to the small size of our furnace, which results in greater heat loss. However, we elucidated that the

qualitative relationships between Uc and the boiler operating conditions are similar to those of Japanese power stations.

The furnace is a water-cooled, horizontal and cylindrical furnace made of steel. The furnace is 0.85 m in inner diameter and 8 m in length. Refractory materials are coated on the inside wall of the furnace to a thickness of 0.075 m. An advanced low-NO<sub>x</sub> burner [17,18], which was designed to have a combustion capacity of approximately 100 kg/h for bituminous coal combustion, was used. Combustion air, supplied by a forced draft fan, is injected into the furnace through the burner and the two-stage combustion air ports, and the air through the burner is divided into primary air, secondary air and tertiary air. The primary air carries the pulverized coal from the table feeders to the burner. The secondary air and tertiary air are fed into the furnace via a wind box. The air used for the two-stage combustion is divided before the wind box and injected through the side ports of the furnace. Fourteen two-stage combustion air ports are installed on the furnace sidewall. A thermocouple and a gas sampling probe were inserted into the furnace through these ports. In this study, we use the cylindrical coordinate system ( $r, Z$ ) with the origin at the center of the burner exit.  $r$  and  $Z$  are the radial distance and streamwise distance from the center of the burner exit, respectively, as shown in Fig. 1.

In the combustion tests, the furnace was preheated by the combustion of kerosene. After preheating the furnace sufficiently, the pulverized coal with the primary air was introduced into the furnace, and the supply of kerosene was stopped. The combustion conditions are shown in Table 1. The coal feed rate was defined by the thermal input of coal as shown in the table. The air ratio, which is defined by the following equation, was set to 1.24.

$$\text{Air ratio} = \frac{\text{Actual air flow rate (kg/h)}}{\text{Theoretical air flow rate (kg/h)}} \quad (1)$$

In this study, the O<sub>2</sub> concentration in the exhaust gas was set to 4.0%, which is slightly higher than that of Japanese power stations (typically 2.0–3.5%). This is because when we reduced the O<sub>2</sub> concentration, the flame tended to be unstable. However, the difference between the O<sub>2</sub> concentration in our furnace and that in the power stations is small and does not affect the H<sub>2</sub>S formation characteristics.

Two-stage combustion was applied to simulate the combustion profile of Japanese power stations. As mentioned before, the combustion air is introduced into the furnace through not only the burner but also the two-stage combustion air ports in two-stage combustion. The two-stage combustion ratio, which is defined by the following equation, is an important index in understanding the combustion behavior in two-stage combustion.

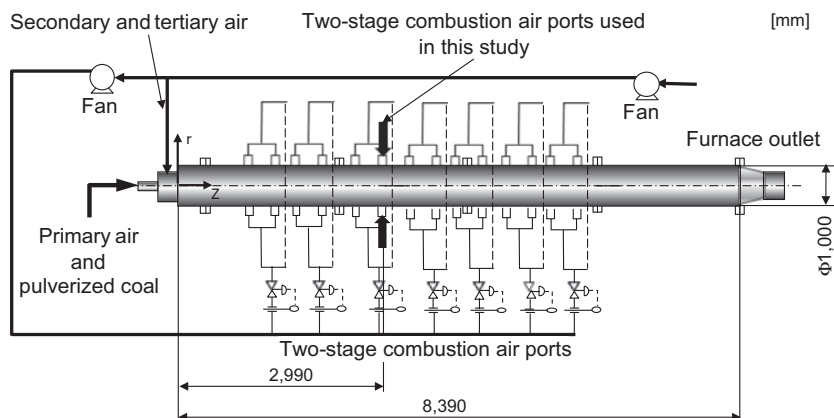


Fig. 1. Schematic diagram of the pulverized coal combustion test furnace.

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