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Ash deposition behavior of upgraded brown coal in pulverized coal combustion boiler

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ABSTRACT

Ash with a low melting point causes slagging and fouling problems in pulverized coal combustion boilers. Ash deposition on heat exchanger tubes reduces the overall heat transfer coefficient due to its low thermal conductivity. The purpose of this study is to evaluate the ash deposition for Upgraded Brown Coal (UBC) and bituminous coal in a 145 MW practical coal combustion boiler. The UBC stands for Upgraded Brown Coal. The melting temperature of UBC ash is relatively lower than that of bituminous coal ashes. Combustion tests were conducted on blended coal consisting 20 wt.% of UBC and 80 wt.% of bituminous coal. Before actual ash deposition tests, the molten slag fractions in those coal ashes were estimated by means of chemical equilibrium calculations. The calculation results showed the molten slag fraction for UBC ash reached approximately 90% at 1523 K. However, that for blended coal ash decreased to 50%. These calculation results mean that blending UBC with bituminous coal played a role in decreasing the molten slag fraction. This phenomenon occurred because the coal blending led to the formation of alumino-silicates compounds as a solid phase. Next, ash deposition tests were conducted using a practical pulverized coal combustion boiler. A water-cooled stainless-steel tube was inserted in locations at both 1523 K and 1273 K in the boiler to measure the amount of ash deposits. The results showed that the mass of ash deposition for blended coal did not greatly increase, compared with that for bituminous coal alone. Therefore, appropriately blending UBC with bituminous coal enabled the use of UBC without any ash deposition problems in practical boilers.

1. Introduction

Bituminous coals, which are categorized as high-rank coals, are most commonly consumed in industrial sectors. In contrast, demand for low-rank coals such as sub-bituminous coal, lignite and brown coal is limited because of their lower calorific value and/or higher moisture content compared with bituminous coal. Therefore, low-rank coal is usually utilized as fuel only in some specific local regions around its mines. Recently, efficient technologies to utilize low-rank coals have been focused on because there are limited reserves of high-rank coals.

Some Indonesian low-rank coals have a high moisture content, and so their heating values are relatively lower than those of high-rank coals. However, the ash, nitrogen and sulfur contents in low-rank coals are lower than those of high-rank coals. If effective drying or dewatering technologies for those coals could be developed, therefore, it would be possible to use them as new fossil fuels. Kobe Steel, Ltd. has developed an UBC process based on a slurry dewatering technology [1–3]. The UBC stands for Upgraded Brown Coal. Akiyama et al. [4] also evaluated the combustion characteristics of UBC. However, the ash melting points of Indonesian low-rank coals are relatively lower than those of high-rank coals. Therefore, slagging and fouling problems may occur in pulverized coal combustion boilers. Ash deposits on heat exchanger tubes reduce the overall heat transfer coefficient because of the deposits' low thermal conductivity. Consequently, it is difficult to use such low-rank coals alone in pulverized coal combustion boilers.

Ash deposition phenomena are influenced by factors such as the type of coal (ash compositions, melting temperature and distribution of mineral matter), reaction atmosphere, particle temperature, surface temperature of heat exchanger tubes, tube materials, and flow dynamics. Several reviews relating to the ash deposition characteristics have already been reported [5]. For instance, Raask [6] elucidated the deposit initiation. Walsh et al. [7] and Baxter [8] studied the deposition characteristics and growth. Beer et al. [9] attempted to develop theories of ash behavior. Benson et al. [10] summarized the behavior of ash formation and deposition during coal combustion.

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Li et al. [11] investigated coal char-slag transition under oxidation conditions. Naruse et al. [12] evaluated the ash deposition characteristics under high-temperature conditions. Bai et al. [13] studied the characterization of low-melting temperature coal ash at high temperatures in a reducing atmosphere. Vuthaluru et al. [14] evaluated ash formation of brown coals. Harb et al. [15] predicted ash behaviors using chemical equilibrium calculations. Hansen et al. [16] quantified ash fusibility using differential scanning calorimetry. Additionally, Gupta et al. [17] developed a mechanistic model for growth of ash deposition during PF combustion. Hurley et al. [18] also investigated ash deposition at low temperatures in boilers burning high-calcium coals. Even for those references, however, precise and quantitative knowledge of the deposition of coal ash with a low-melting temperature in practical coal combustion boilers has been insufficient. Our previous studies [19] have proven that the molten slag fraction in ash obtained by chemical equilibrium calculations is a useful index for predicting the coal blending method to reduce the ash deposition.

The objectives of this study are to evaluate the ash deposition behavior such as slagging and fouling for Upgraded Brown Coal (UBC) and bituminous coal in a 145 MW practical coal combustion boiler. The melting temperature of UBC ash is relatively lower than that of bituminous coal ash. The combustion tests were conducted on blended coal consisting 20 wt.% of UBC and 80 wt.% of bituminous coal. Before actual ash deposition tests, the molten slag fraction in the coal ashes was estimated by means of chemical equilibrium calculations. Next, the ash deposition tests were conducted using a practical boiler that was operated for 8 days.

2. Chemical equilibrium calculations

An Indonesian UBC and an Australian bituminous coal of Coal A were selected as samples. Those coal properties are shown in Table 1. As seen from the table, the hemispherical temperature for Coal A under oxidizing conditions is 230 K higher than that of the UBC. The prominent features of Coal A are a higher SiO_2 content and lower CaO and Fe_2O_3 contents in the ash, compared with UBC. The ash particles tend to adhere more to the tube as the amount of molten particles increases [19]. Therefore, the molten fractions of each ash were calculated by a chemical equilibrium theory, using Fact Sage Ver. 6.1 software. Table 2 shows the conditions of the chemical equilibrium calculations. The gaseous compositions near a burner in the pulverized coal combustion boiler were obtained. In the calculations, the partial pressures of CO, CO_2 and H_2 gas were fixed. The calculations were carried out in 50 K increments to determine the mass percentage of molten slag in the ash in the temperature range of 1273–2073 K.

Table 2
Conditions of chemical equilibrium calculations.

Temperature (K)		1273–2073
Gas composition (%)	O_2	8.3×10^{-8}
	CO_2	12.3
	CO	8.2
	H_2	1.5
	N_2	70.6
	H_2O	7.4
Ash composition (wt.%)	SiO_2, Al_2O_3, CaO, Fe_2O_3, MgO, Na_2O, K_2O, SO_3 P_2O_5, TiO_2, V_2O_5, MnO	

3. Experimental section

Fig. 1 shows a flow diagram of the coal combustion power station used in this study. This power station is located in the Kakogawa Works of Kobe steel, Ltd., and was designed to burn bituminous coal. The coal was fed into the coal mill and pulverized. The particle diameter was less than 75 μm, and its mass fraction was more than 85 wt.%. Flue gas passed through the de-NO_x tower, air heater, electric precipitator and de-SO_x tower. The ash deposition tests were carried out at the 145 MW boiler. Fig. 2 shows a schematic diagram of the boiler and location of the ash deposition tests. It is a tangential firing boiler, equipped with 16 pulverized coal burners arranged in four

Table 1
Properties of coals tested.

Coal sample			Coal A	UBC	Coal A (80%)+UBC(20%)
Heating value [MJ/kg]			29.70	24.22	28.60
Proximate analysis [wt.%, dry]	Ash		11.50	4.60	10.12
	Volatile matter		35.60	48.70	38.22
	Fixed carbon		51.54	45.98	50.43
Fuel ratio [-]			1.45	0.94	1.35
Ultimate analysis [wt%, daf]	Carbon		83.43	72.77	81.30
	Hydrogen		5.78	5.70	5.76
	Nitrogen		1.86	1.08	1.70
	Sulfur		0.73	0.11	0.61
	Oxygen (Balance)		8.20	20.34	10.63
Ash fusion temperature [K]	Oxidizing	Initial deformation	1329	1426	1586
		Hemispherical	1753	1523	1689
		Fluid	>1823	1658	1694
	Reducing	Initial deformation	1293	1340	1499
		Hemispherical	1725	1503	1603
		Fluid	1804	1610	1608
Ash compositions [wt%]	SiO_2		60.80	40.70	56.78
	Al_2O_3		25.60	12.10	22.90
	CaO		2.79	11.90	4.61
	Fe_2O_3		4.83	16.00	7.06
	MgO		1.06	10.20	2.89
	Na_2O		0.23	0.11	0.21
	K_2O		0.95	0.83	0.93
	SO_3		1.80	7.80	3.00
	P_2O_5		0.22	0.05	0.19
	TiO_2		1.27	0.67	1.15
	V_2O_5		0.11	0.07	0.10
	MnO		0.04	0.37	0.11