A Study on Multi-Injection Methods of Over-Fire Air in Pulverized Coal Combustion*

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A study of over-fire air injection point and air-injection methods and multistage injection methods in pulverized coal combustion was carried out. It was possible to predict NO_x emission for multistaged combustion by treating it as a function of the over-fire air injection point and injection rate for two-stage combustion.

Key Words: Coal, Coal Combustion, Two-Stage Combustion, NO_x emission, Carbon Burn-out

1. Introduction

The use of power plants using coal has been advancing in Japan as part of an effort to diversify the sources of electric power. Compared to the burning of oil, however, the burning of coal generates higher NO_x emission, as well as a considerable quantity of coal ash which must be processed. As an environmental policy, it is necessary to develop technology aimed at alleviating these problems. Specifically, technology must be developed for reducing NO_x emission, and for lowering the amount of unburned carbon that remains in the fly ash. Coal-fired boilers are making use of the two-stage combustion method to achieve low NO_x emission^{(1),(2)}. However, there has so far been insufficient study of over-fire air injection points and injection methods. Development of superior two-stage injection technology remains the desired goal.

With the aim, then, of achieving both reduced NO_x emission and lower amounts of unburned carbon in the fly ash, this study investigated over-fire air injection points and injection methods. The study also considered an over-fire air multi-injection method for multistage combustion.

2. Test Facility and Procedures

The furnace was designed to be similar, in terms of exhaust gas characteristics and combustion characteristics, to a conventional electricity-generation boiler. Figure 1 shows the test burner used for this study. The burner is a small-scale model of low- NO_x , pulverized-coal-fired burners currently used with electricity-generating boilers. This type of burner has two important characteristics: a strong reduction zone is formed near the burner, which helps to promote NO_x decomposition; also, there is mixing of pulverized coal and tertiary air both around the external part of the flame and in the downstream, which serves to reduce the amount of unburned coal remaining in the fly ash. The rated capacity of the test supply burner was 100 kg/hr.

Figure 2 outlines the structure of the test furnace

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used. The furnace was a steel-plated, horizontal, cylindrical, watercooler type, lined with refractory material. The internal diameter was 0.87 m, and the length was 8 m. Over-fire air holes were provided at 11 places in the axial direction, and at six places circumferentially.

The characteristics of the two types of coal used for the test, Blair Athol coal (Australia) and Lemington coal (Australia), are shown in Table 1. Because the Blair Athol coal was supplied in separate lots, each lot was separately analyzed. The analysis values,

Table 1 Properties of tested coal

Item	Tested coal Unit	Blair athol ①	Blair athol ②	Blair athol ③	Lemington
		①	②	③	
Higher heating value	kcal/kg	7199	7210	7176	7125
Lower heating value	kcal/kg	6923	6980	6946	6844
Proximate analysis	Moisture content	wt %	6.63	—	8.10
	Volatile matter	wt %	30.56	30.52	30.65
	Ash content	wt %	8.27	8.08	8.75
	Fixed carbon	wt %	61.17	61.40	60.60
Ultimate analysis	Carbon	wt %	75.36	75.97	75.50
	Hydrogen	wt %	4.34	4.42	4.24
	Nitrogen	wt %	1.70	1.72	1.76
	Oxygen	wt %	10.08	9.54	9.36
	Total sulfur	wt %	0.25	0.28	0.27
	Combustible sulfur	wt %	0.25	0.27	0.27
Fuel ratio	—	2.00	2.01	1.98	1.51

Fig. 1 Tested burner

Fig. 2 Outline of combustion test furnace (injection point of over-fire air)

however, were all quite close. Further, the average particle diameter for each of the pulverized coal used in testing was 35–45 μm , with a 200-mesh pass ratio of 70–80 %. The O_2 concentration at the furnace outlet was fixed at 4 %.

3. Test Results and Discussion

Two-stage combustion method

For combustion of Blair Athol coal under a 30 % over-fire air rate, Fig. 3 shows the relationship of the over-fire air injection point, NO_x emission, and unburned carbon in fly ash.

NO_x emissions decrease as the over-fire air injection point moves downstream. Specifically, when the injection point is considered in terms of its distance from the end of the burner divided by the furnace diameter (L/D), NO_x emissions are seen to drop rapidly as L/D values move from 2.0 to 3.5. For higher L/D values, however, the effect on NO_x emission declines. At the same time, the amount of unburned carbon in the fly ash increases as the injection point moves

Fig. 3 Relationship between injection point of over-fire air and NO_x emission, unburned carbon in fly ash

downstream, and increases very rapidly for L/D values above 3.5.

The reasons for these effects may be explained as follows. As the injection point moves downstream, the reductive atmosphere of the primary combustion zone is widened, so that NO_x emission drops. There is insufficient time for the injected air to cause the carbon to fully burn, so that the quantity of unburned carbon in the fly ash increases as the injection point moves downstream.

It is therefore necessary to use an injection point which provides a large reductive area, but which at the same time keeps the quantity of unburned coal controlled. The L/D value of about 3.5 is best.

Figure 4 shows the relationship of NO_x emission and over-fire air rate when Blair Athol coal is burned using an air injection point corresponding to an L/D of 3.4.

NO_x emission decreases as the over-fire air rate increases. As the over-fire air rate increases so as not to exceed 20 %, the corresponding decline in NO_x emission is gradual. Once the over-fire air rate exceeds 20 %, however, NO_x emissions decline rapidly. The reason for this seems to be that, until the over-fire air rate reaches 20 %, the burner air ratio is above 1.0; in other words, the fuel in the primary burning zone is relatively refueled so that NO_x emissions decline only gradually. In order to significantly reduce NO_x using two-stage combustion, an over-fire air rate above 20 % should be used. A fuel-rich condition in the primary combustion zone will effectively reduce the NO_x emissions.

Figure 5 shows the relationship between NO_x emission and over-fire air flow velocity when Blair Athol coal is burned using an L/D value of 3.4 and an over-fire air rate of 25 %. The flow velocity was varied between 5 m/s and 15 m/s, but this did not effect the

Fig. 4 Relationship between over-fire air rate and NO_x concentration

NO_x emission or the amount of unburned carbon in the fly ash. This is apparently because the average main flow velocity in the furnace is approximately 2 m/s; the flow velocity of this test was sufficient to allow adequate mixing.

Figure 6 shows the effect of swirling of the over-fire air on the NO_x emission and the quantity of unburned carbon in the fly ash, as observed when using Blair Athol coal, an L/D value of 3.4, and an over-fire air rate of 25 %. The air was swirled in the same direction as the swirling produced by the burner. Swirling of the over-fire air tended to cause NO_x emissions to slightly increase. It therefore appears that over-fire air injection points of this test sufficiently mix using the conventional method.

Over-fire air multi-injection method

Figure 7 shows the relationship between injection points and NO_x emissions when over-fire air was supplied in two stages, in three stages, and multiple stages. Blair Athol coal and a 30 % over-fire air rate were used for this test.

In the figure, the air injection points are averaged

Fig. 5 Relationship between over-fire air velocity and NO_x concentration, unburned carbon in fly ash

Fig. 6 Effect of over-fire air swirl

Fig. 7 Effect of multistage combustion to NO_x emission

Fig. 8 NO_x emission distributions in furnace

according to the weighted average for the over-fire air rate. (The average injection point is determined considering the injection rates as between respective injection holes. For example, in run No. 1, 15% injection rates were applied at 1-1 and 2-1, so that the average point was taken as 1-2.) A solid line in this figure shows the relationship between injection point and NO_x emission in the case of two-stage combustion. The NO_x emission for multistage combustion can be forecast from NO_x emission with two-stage combustion by treating it as a function of over-fire air injection points and injection rate.

Figure 8 shows the NO_x emissions along the central axis of the furnace for two-stage and for multistage combustion. For the former, NO_x tends to decrease rapidly around the injection points. For the latter, the tendency is for a gradual reduction.

Fig. 9 Effect of multistage combustion to unburned carbon in fly ash

Figure 9 shows the relationship between the air injection point and unburned carbon in fly ash for multistage injection. If the unburned carbon is forecast by the same method used to forecast NO_x , the result indicates that unburned carbon tends to be slightly higher for multistage combustion. This is apparently because of the difference of the residence time is each combustion stage with different excess O_2 conditions.

4. Conclusions

With the aim of simultaneously reducing the NO_x emission and the amount of unburned carbon in fly ash that accompany the combustion of pulverized coal, a study was conducted of over-fire air injection point and multi-injection method. The results showed that, for two-stage combustion, the over-fire air rate of more than 20% and the injection point of over-fire air of approximately 3.5 of L/D (where L is the distance of the injection point from the end of the burner, and D is furnace diameter), are promising for achieving low NO_x emissions. Further, the use of a multi-air-injection method with two-stage combustion seems to show about the same effectiveness for reducing NO_x at does two-stage combustion alone.

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