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AN EXPERIMENTAL STUDY ON COMBUSTION EFFICIENCY OF LOW GRADE ANTHRACITE IN AFBC

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This is the basic study to develop a fluidized bed combustion boiler which can use low grade anthracite.
In this study, the anthracite of about 3400 kcal/kg was burned in the bench scale non-recycling atmospheric fluidized bed combustor of 200mm diameter and 2215mm height with the static bed height of 250mm and the combustion temperature range of 800-950°C.
During the combustion, the effect of factors such as the superficial gas velocity in bed, the air ratio, the coal supply location and the coal particle size on the combustion efficiency, the elutriation ratio and the unburned carbon content both in elutriated ash and in drained ash was thoroughly analyzed.
When the superficial gas velocity in bed is 0.7~2.2m/s, the air ratio is 1.0~1.6 and coal supply locations are 300,500 and 700mm above the air distributor, the combustion efficiencies range from 66% to 83.5% for the mean coal particle size of 0.209mm, and from 71% to 88% for the case of 0.265mm.
The combustion efficiency decreases as the superficial gas velocity in bed and the air ratio increase.
The lower the coal supply location is, the better the combustion efficiency becomes in general.

Key Words : Fluidized Bed Combustion, Low Grade Anthracite, Combustion Efficiency Elutriation Ratio

1. INTRODUCTION

Of anthracite reserves totaling 15 hundred million tons, the only energy source available in Korea, a large quantity or about 40% is composed of low grade anthracite below 3500kcal/kg(Son et al, 1982). Until now, although it comes out concomitantly during the process of coal mining, it has not been used as energy source and causes even air and water pollution.

Therefore, if the low grade anthracite can be used as an energy source, it will not only decrease the amount of energy imports but also solve the environmental pollution problems caused by it.

The most effective technique developed for the combustion of this kind of the low grade anthracite is known to be the fluidized bed combustion method(Rogers et al, 1973, Yaverbaum, 1977 & Howard, 1983).

However, since the Korean coal contains relatively high percentage of ash and breaks easily and it is very difficult to burn the low grade anthracite, the fluidized bed combustion technique used in other countries can not be applied in Korea(Son et al, 1982 & Moon et al, 1983).

Therefore, in this study, the Korean anthracite of about 3400kcal/kg was burned in the bench scale non-recycling atmospheric fluidized bed combustor. During combustion, the effect of factors such as the superficial gas velocity in bed, the air ratio, the coal supply location and the coal particle size on the combustion efficiency was experimentally studied.

In order to investigate combustion efficiency, the elutriation ratio and the unburned carbon content both in elutriated ash and in drained ash was thoroughly analyzed.

2. DEFINITION OF COMBUSTION EFFICIENCY

The combustion efficiency η_c is defined by the following equation(Water, 1975 & Poersch, 1979).

$$\eta_c=\frac{C_1\cdot\dot{M}_s-C_f\cdot\dot{M}_f-C_b\cdot\dot{M}_b-C_c\cdot\dot{M}_c}{C_1\cdot\dot{M}_s}$$

C_1 : Equivalent carbon content in the fuel
C_f : Carbon content in elutriated ash
C_b : Carbon content in drained ash
C_c : Carbon content in flue gas
$\dot{M}_s$: Flow rate of fuel
$\dot{M}_f$: Flow rate of elutriated ash
$\dot{M}_b$: Flow rate of drained ash
$\dot{M}_c$: Flow rate of flue gas

CO concentration in flue gas, showing hundreds of ppm at high limit as the result of combustion experiment under normal experimental conditions, could be neglected in the view of combustion efficiency(Water, 1975, Poersch, 1979 & Sarofin, 1980)

Therefore, the combustion efficiency is determined by the unburned carbon both in elutriated ash and in drained ash.

3. EXPERIMENTAL EQUIPMENT

Figure 1 is a schematic diagram of experimental equipment which consists of coal supply apparatus, fluidizing air supply apparatus, combustor, dust collector and instruments. Instruments are air flow meter, water flow meter, barometer, thermometer, data logger and gas analyzer.

The coal coming out of the hopper is transferred to the combustor through the screw feeder. The screw feeder driving motor is D.C motor with variable speed controller to control coal supply quantity. Fluidizing air is supplied by a rotary type fan of which maximum pressure and maximum free air delivery are 1.0 bar and 4.71m^3/min.

The fluidized bed combustor of 2215mm height consists of air plenum, air distributor, combustion chamber, freeboard and air preheater.

The combustion chamber has dimensions of 200mm in inner diameter and 1470mm in height.

The air distributor is a perforated plate type of which open area is 2.73% by taking 310 holes (diameter 2mm) inside diameter 210mm circle.

The cooling water is supplied through the copper tube (diameter 20mm) set up around the combustion chamber wall in order to keep constant combustion temperature. 13 thermocouples are set up along the axis of the combustor in order to measure temperature.

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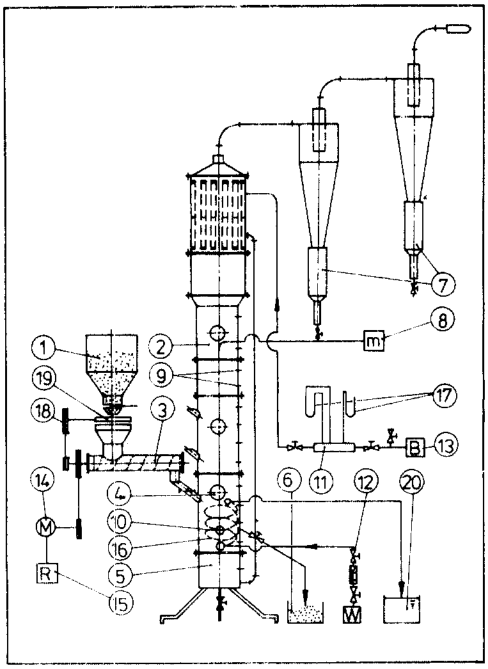

① Coal hopper
② Combustor
③ Screw feeder
④ Sight glass
⑤ Air plenum
⑥ Ash pot
⑦ Cyclone collector
⑧ Micromanometer
⑨ Thermocouple
⑩ Torch lamp hole
⑪ Orifice flow meter
⑫ Water flow meter
⑬ Blower
⑭ D.C motor
⑮ Controller
⑯ Cooling water tube
⑰ Manometer
⑱ V-pulley
⑲ Conveyer
⑳ Water pot

Fig. 1 Schematic diagram of fluidized bed combustor system

The screw feeder is connected to the pipe (diameter 50mm) which is set up at 60° angle in the location of 300, 500 and 700mm above the air distributor. In order to preheat air for combustion for smooth combustion and waste heat recovery, the air preheater with 31 pipes (diameter 25mm) inside cylinder of 332mm diameter and 450mm height is installed on the freeboard.

Fluidized bed height can be kept constant by draining the remained ash in combustor periodically, attaching the valve to the end of pipe (diameter 25mm) which is set up at 50mm above the air distributor.

Two cyclone collectors are installed in series to collect the flying ash and unburned carbon. Crucible, balance and electric furnace are used in order to analyze the unburned carbon antent in elutriated ash and in drained ash.

4. SAMPLES

For this experiment, the low grade anthracite of the higher calorific value of about 3400kcal/kg is used as a fuel.

Sample A is that maximum diameter of particle is below 2.0mm and mean diameter of particles is 0.209mm. Sample B is that maximum diameter of particle is below 3.36mm and mean diameter of particles is 0.26mm.

Table 1 shows the proximate analysis and higher calorific value of these samples and Table 2 shows the analyses of particle sizes in sample A and B and mean diameters which have the notation of $\overline{dp}$.

The specific gravities of sample A and B are 2.079 and 2.113. Main components of ash are SiO_2(58.8%), Al_2O_3(29.5%), and Fe_2O_3(7.1%).

Table 1 Proximate analysis of samples (mass based)

Component	Sample A	Sample B
Water content(%)	2.83	2.92
Volatile matter(%)	6.05	5.82
Ash content(%)	50.97	51.30
Fixed carbon(%)	39.89	39.68
Sulfur(%)	0.26	0.28
Higher calorific value(kcal/kg)	3440	3420

Table 2 Analysis of particle sizes

Sample A			Sample B		
Mesh	Diameter, dp (mm)	Mass fraction, x	Mesh	Diameter, dp (mm)	Mass fraction, x
10-12	1.840	0.096	6-8	3.095	0.113
12-14	1.545	0.067	8-12	2.030	0.131
14-18	1.205	0.114	12-16	1.435	0.123
18-25	0.855	0.145	16-20	1.015	0.121
25-35	0.605	0.106	20-35	0.670	0.144
35-45	0.425	0.093	35-45	0.425	0.076
45-70	0.280	0.110	45-70	0.280	0.087
70-140	0.1575	0.117	70-140	0.1575	0.090
Under140	0.0525	0.152	Under 140	0.0525	0.115
$\overline{dp}=\frac{1}{\Sigma\frac{x}{dp}}=0.209mm$			$\overline{dp}=\frac{1}{\Sigma\frac{x}{dp}}=0.265mm$		

5. EXPERIMENTAL RESULTS AND DISCUSSION

5.1 Elutriation Ratio

Figures 2 and 3 show the effect of the superficial gas velocity in bed(850°C) on the elutriation ratio when the coal supply location is 300mm and 700mm above the air distributor respectively.

The elutriation ratio increases as the superficial gas velocity in bed increases and sample A has larger elutriation ratio than sample B at the same superficial gas velocity in bed. This is due to the fact that mass ratio of the particle size under mesh 35 of sample A is 47.2% and that of sample B is 36.8% from Table 2.

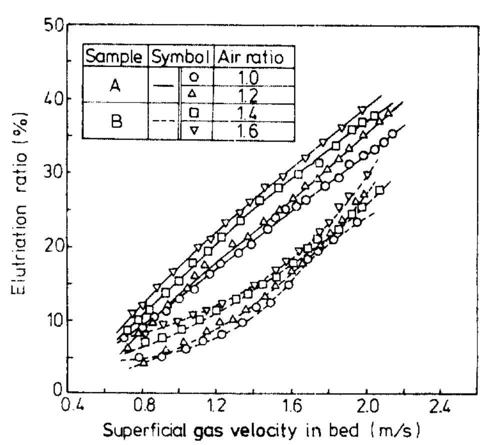

Fig. 2 Elutriation ratio vs. superficial gas velocity in bed at coal supply location 300mm

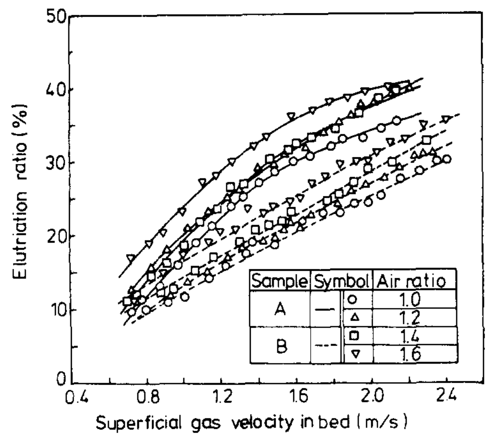

Fig. 3 Elutriation ratio vs. superficial gas velocity in bed at coal supply location 700mm

If the superficial gas velocity in bed and the sample size are constant, the elutriation ratio increases with the increase of air ratio.

The value of elutriation ratio becomes apparently lower under 2.0m/s of the superficial gas velocity when the coal supply location is 300mm above the air distributor than when the locations are 500 and 700mm. But there is very small difference in elutriation ratio when the coal supply locations are 500 and 700mm above the air distributor.

5.2 Analysis of Particle Size and Unburned Carbon Content in Elutriated Ash

Elutriated ash is accumulated in the cyclone collectors and is analyzed into particle size distribution using standard sieve at three ranges of superficial gas velocity in bed, that is, 0.8~1.0m/s, 1.3~1.5m/s and 1.8~2.0m/s.

The size distribution result is expressed by mass fraction and unburned carbon content according to the range of the

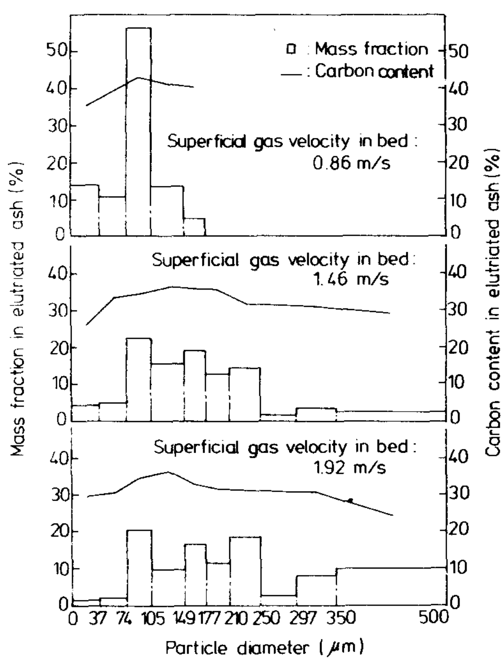

Fig. 4 Mass fraction and carbon content in elutriated ash vs. ash size at mean sample diameter 0.209mm, coal supply location 300mm and air ratio 1.2

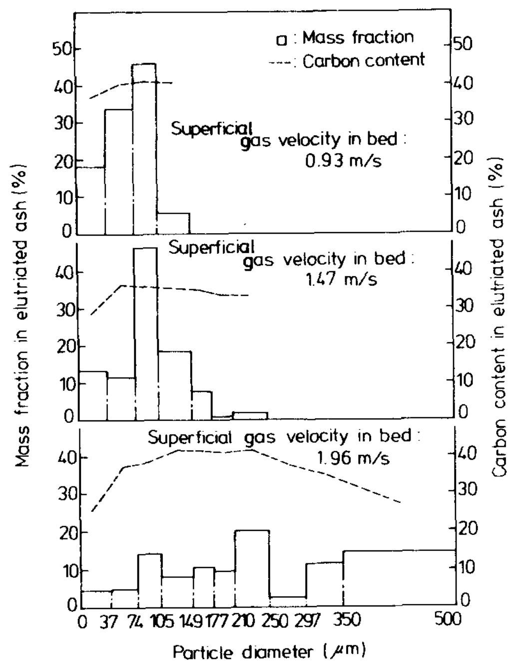

Fig. 5 Mass fraction and carbon content in elutriates ash vs. ash size at mean sample diameter 0.265mm, coal supply location 300mm and air ratio 1.2

elutriated particle diameter. For example Figs. 4 and 5 show the results when the coal supply location is 300mm above the air distributor, the air ratio is 1.2, and the mean particle size of sample is 0.209mm and 0.265mm respectively.

Maximum size of elutriated ash particle is increased with the increase of the superficial gas velocity in bed, but independent of the air ratio and the coal supply location.

Most of the elutriated ash size is under diameter 177 μm at the superficial gas velocity of 0.8~1.0m/s, 250 μm at 1.3~1.5m/s, and 500 μm at 1.8~2.0m/s. Unburned carbon content in elutriated ash is minimum 15.5% and maximum 43.1% according to the range of elutriated particle diameter shown Figs. 4 and 5. But the mean value of it is from 30.6% to 42.1%, and it is reduced by the increase of the superficial gas velocity in bed and the air ratio.

5.3 Unburned Carbon Content in Drained Ash

Figure 6 shows the unburned carbon content in ash drained from bottom of fluidized bed due to the superficial gas velocity in bed for the sample A and B at the coal supply location 300mm and the air ratio 1.2.

In general, unburned carbon content is decreased due to

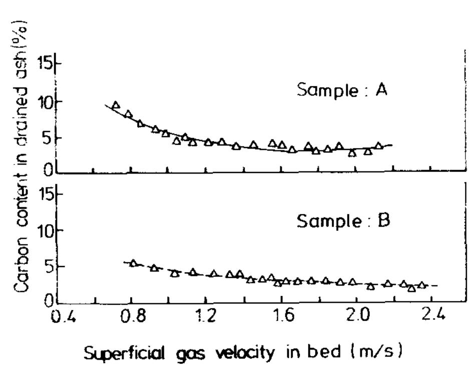

Fig. 6 Carbon content in drained ash vs. superficial gas velocity in bed at coal supply location 300mm and air ratio 1.2

the increase of superficial gas velocity in bed. Especially it is below 4% if the superficial gas velocity in bed is higher than 1.4m/s and it is slightly decreased with the increase of air ratio.

5.4 Unburned Carbon

The variation of unburned carbon in elutriated ash and in drained ash and their sum are expressed in Figs. 7 and 8 according to the superficial gas velocity in bed at the coal supply location 300mm and the air ratio 1.2 for the sample A and B respectively.

In general, unburned carbon in elutriated ash is increased, and unburned carbon in drained ash is decreased as the superticial gas velocity in bed and the air ratio are increased.

5.5 Combustion Efficiency

The effect of the superficial gas velocity in bed, the air ratio and the size of coal on the combustion efficiency is showed in Figs. 9, 10 and 11. The coal supply location is 300, 500 and 700mm above the air distributor respectively. In Fig. 9, the coal supply location is 300mm. Sample B gives higher combustion efficiency than sample A at the same superficial gas velocity in bed. Sample A has higher combustion efficiency due to the decrease of air ratio and has the 83.3% of combustion efficiency at the air ratio 1.0 and the superficial gas velocity 0.85m/s. Sample B has the best combustion efficiency which is 88.2% at the air ratio 1.2 and the superficial gas velocity 0.81m/s.

The combustion efficiency is decreased with the increase of the superficial gas velocity at the contant air ratio, and is decreased sharply due to the increase of the superficial gas

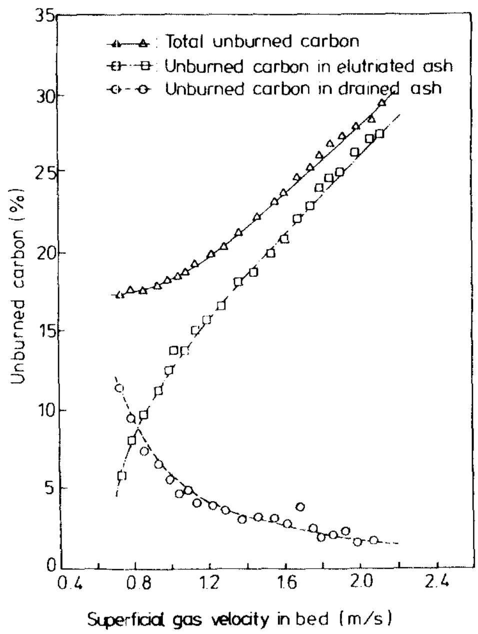

Fig. 7 Unburned carbon vs. superficial gas velocity in bed at mean sample diameter 0.209mm, coal supply location 300mm and air ratio 1.2

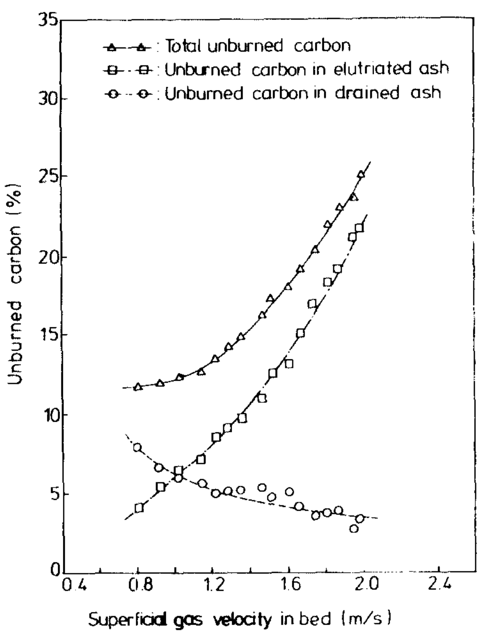

Fig. 8 Unburned carbon vs. superficial gas velocity in bed at mean sample diameter 0.265mm, coal supply location 300mm and air ratio 1.2

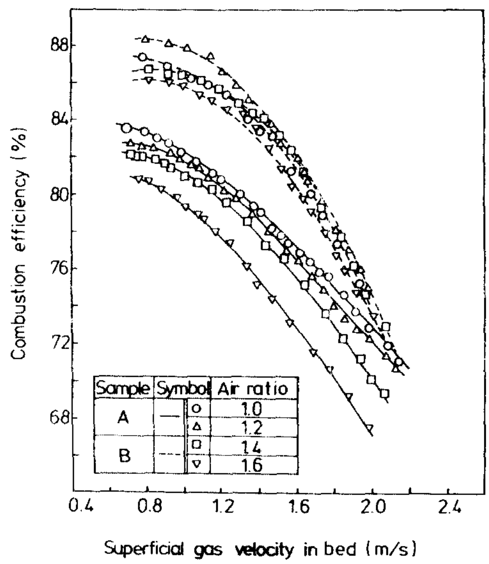

Fig. 9 Combustion efficiency vs. superficial gas velocity in bed at coal supply location 300mm

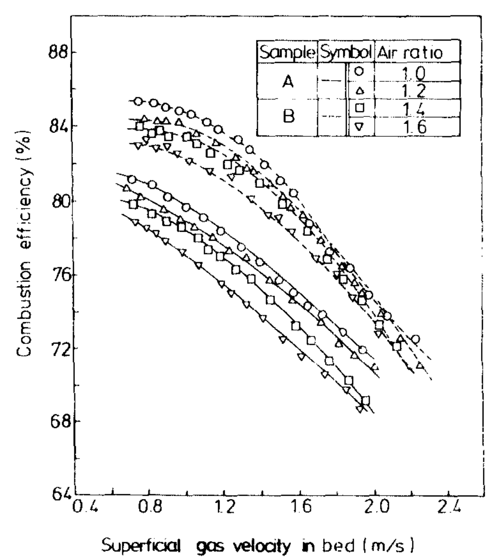

Fig. 10 Combustion efficiency vs. superficial gas velocity in bed at coal supply location 500mm

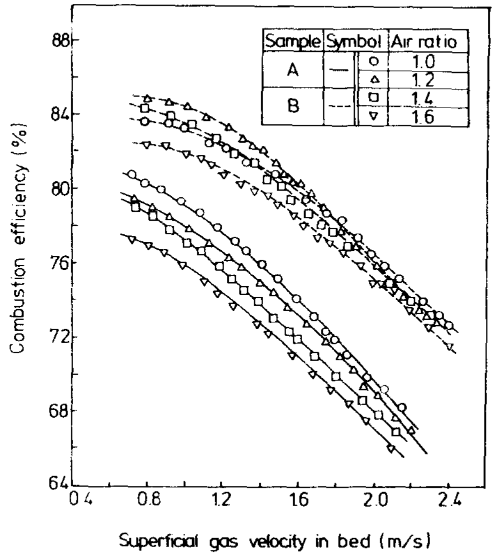

Fig. 11 Combustion efficiency vs. superficial gas velocity in bed at coal supply location 700mm

velocity.

When the coal supply position is 500mm above the air distributor, the combustion efficiency is decreased as the superficial gas velocity and the air ratio are increased, and also sample B has the larger value of combustion efficiency than sample A. The combustion efficiency of sample A is 78.4% at the superficial gas velocity 1.20m/s, the air ratio 1.0, and that of sample B is 83.8% at the superficial gas velocity 1.19m/s, the air ratio 1.0.

Figure 11 shows that the combustion efficiency is reduced due to the increase of the superficial gas velocity at the coal feeding point 700mm. In general, the combustion efficiency of sample B is higher than sample A at the same superficial gas velocity.

That of sample A is increased as the air ratio is decreased and has the maximum value at the air ratio 1.0.

The combustion efficiency of sample B has the maximum value at the air ratio 1.2 when the superficial gas velocity is under 1.8m/s, and at the air ratio 1.0 when the superficial gas velocity is higher 1.8m/s.

Combustion efficiency is 71.1% for sample A and 78.4% for sample B when the operating condition at that time is 1.86m/s of superficial gas velocity, 1.0 of air ratio for sample A and 1.84m/s of superficial gas velocity, 1.0 of air ratio for sample B.

6. CONCLUSIONS

This is the basic study to develop a fluidized bed combustion on boiler which can use Korean low grade anthracite.

The combustion efficiency of Korean anthracite of about 3400kcal/kg is investigated in the bench scale non-recycling atmospheric fluidized bed combustor of 200mm diameter and 2215mm height with the static bed height of 250mm and the combustion temperature range of 800~950°C.

The combustion efficiency depends on the elutriation ratio and the unburned carbon content both in elutriated ash and in drained ash. Especially the combustion efficiency is affected very much by the elutriation ratio because Korean anthracite breaks easily.

When the superficial gas velocity in bed is 0.7m/s~2.2m/s, the air ratio is 1.0~1.6 and the coal supply locations are 300, 500 and 700mm above the air distributor, the combustion efficiencies range from 66% to 83.5% for the mean coal size of 0.209mm and from 71% to 88% for the case of 0.265mm.

The combustion efficiency is decreased by the increase of the superficial gas velocity and the air ratio. The lower the coal supply location is, the better the combustion efficiency becomes generally.

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