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Study on Co-combustion Characteristics of Superfine Coal with Conventional Size Coal in O_2/CO_2 Atmosphere

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ABSTRACT

The pulverized coal combustion in O_2/CO_2 atmosphere is one of the promising new technologies which can reduce the emission of carbon dioxide and NOx. In this study, the combustion behaviors of different mixing ratio of Shenhua coal with 20 μm and 74 μm particle size in the O_2/CO_2 atmosphere and air atmosphere were studied by using a thermal-gravimetric analyzer. The combustion characteristics such as ignition and burnout behavior were investigated in the temperature from 20℃ to 850℃. The influence of mixing ratio on combustion characteristics was conduced. The results obtained showed that the ignition temperature of the two kinds of particle size in O_2/CO_2 atmosphere is higher than in the air, while the activation energy in O_2/CO_2 atmosphere is lower. With the increasing ratio of 20 μm superfine pulverized coals, the ignition temperature and the activation energy decreased, while the DTG peak value increased, the maximum burning rate position advanced. There were three trends for the ignition temperature curve with the increasing of superfine coal ratio: the ignition of the mixed coal decreased rapidly, then changed less, at last reduced quickly.

Keywords: Coal Particle Size; Co-combustion; Thermo-gravimetric; Heat of Combustion

1. Introduction

Coal makes a significant contribution to energy production and because of its availability and flexibility，it is likely to continue to be a major part of the energy scene for some time. However, this fuel has the disadvantage of producing more CO_2 per unit of energy produced than the other fossil fuels which will in time require the application of carbon capture and storage technologies. Coal combustion in O_2/CO_2 is considered as a new generation of combustion technology that both direct access to high concentrations of CO_2 and comprehensively control the coal-fired pollutant emission [1-3]. During the O_2/CO_2 combustion, coal is burnt in a mixture of O_2 and recycled flue gas (mainly CO_2 and H_2O), to yield a rich CO_2 stream. Previous results have shown that the replacement of N_2 by CO_2 can cause significant differences in the area such as burning stability, char burnout, heat transfer and gas temperature profiles [4-6]. The flame propagation speed, flame stability and gas temperature in O_2/CO_2 environment are lower and the unburned carbon content is higher than those in air environment. Experimental studies on coal-fired O_2/CO_2 combustion have been performed in laboratory and semi-industrial scale test facilities of different size [7-10]. The coal combustion appears ignition delay and combustion instability in O_2/CO_2 [11], improving the oxygen concentration [12] and using the superfine pulverized coal combustion can improve the combustion characteristics, and the particle size has a great influence on the combustion characteristics [13-14].

In this study, the combustion process of mixed coal with 20 μm and 74 μm of Shenhua coal under both air and O_2/CO_2 atmosphere were employed by a thermal-gravimetric analyzer (TGA). The influence of superfine pulverized coal on the combustion characteristics was analyzed in the atmosphere of O_2/CO_2 and the ignition temperature and kinetic parameters were obtained. The results obtained provide a better understanding of coal combustion in O_2/CO_2 atmosphere.

2. Experimental

A NETZSCH STA449C simultaneous thermal analyzer was used in this work. The temperature was increased from 20℃ to 850℃ linearly at the heating rate of 10 $K \cdot min^{-1}$. The flow rate of evolved gas was fixed at 80 $ml \cdot min^{-1}$, 7.5 mg of fuel sample with 20 μm and 74 μm sizes were used for each test. Two kinds of different particle size with Shenhua coal and their mixture were used in this study and their proximate analysis was listed in **Table 1**. The sizes of coal are 20μm and 74μm respectively.

3. Result and Discussion

3.1. The Coal Combustion under Different Atmospheres

The TG and DTG profiles for all cases were obtained to analyze the combustion characteristic parameters. For all TG curves, it was shown that after an initial moisture removal, the volatile matter started to release and then a rapid weight loss were observed. Temperature at which the DTG curve showed peak value was denoted as the maximum weight loss temperature. The ignition temperature (Ti) was obtained by co-analyzed TG-DTG curves, at which the DTG has its peak value and the corresponding slope to the intersection with respect to the TG profile. Burnout temperature (Tb) was determined when the mass loss reaches 99% of final weight loss at the temperature of 850℃.

The TG-DTG curves for 20μm and 74μm coal in O_2/CO_2 and air atmosphere were shown in **Figure 1**. From these TG curves, it can be seen that, there were three stages of weight loss during the coal burning. First stage corresponds to the removal of inherent moisture until the temperature exceeds 100℃. Following that was the volatile matter release in the second stage; finally, the char combustion was observed. Compared with that under air atmosphere, the coal DTG curve moved to the right and the maximum weight loss temperature increased while the maximum weight loss values decreased in same concentration of oxygen under O_2/CO_2 atmosphere.

Table 2 showed the parameters of two particle size coal combustion characteristics in air and O_2/CO_2 atmospheres. For 20 μm coal in air atmosphere, the ignition temperature increased from 375℃ to 384℃ and the burnout temperature increased from 658℃ to 796.1℃ under O_2/CO_2 atmosphere. For 74 μm coal, the ignition increased from 396℃ to 401℃ and the burnout temperature increased from 648.6℃ to 784.5℃ in O_2/CO_2 atmosphere. The ignition temperature of coal with 20 μm was lower than the one with 74 μm, even lower than the ignition temperature in air atmosphere. In addition, under O_2/CO_2 atmosphere, for 20μm coal, the maximum weight loss decreased from 13.72% to 13.62%, while the maximum weight loss temperature increased from405℃ to 412℃ and the burnout rate increased from95.52% to 97.18%. For 74μm coal, the maximum weight loss decreased from 12.67% to 12.36%, while the maximum weight loss temperature increased from 437℃ to 441℃ and the burnout rate increased from 99.39% to 99.96%.

Table 1. Proximate analysis (mass/%).

Fuel	M	A	V	FC
ShenHua coal(SH)	4.80	5.00	31.90	58.30

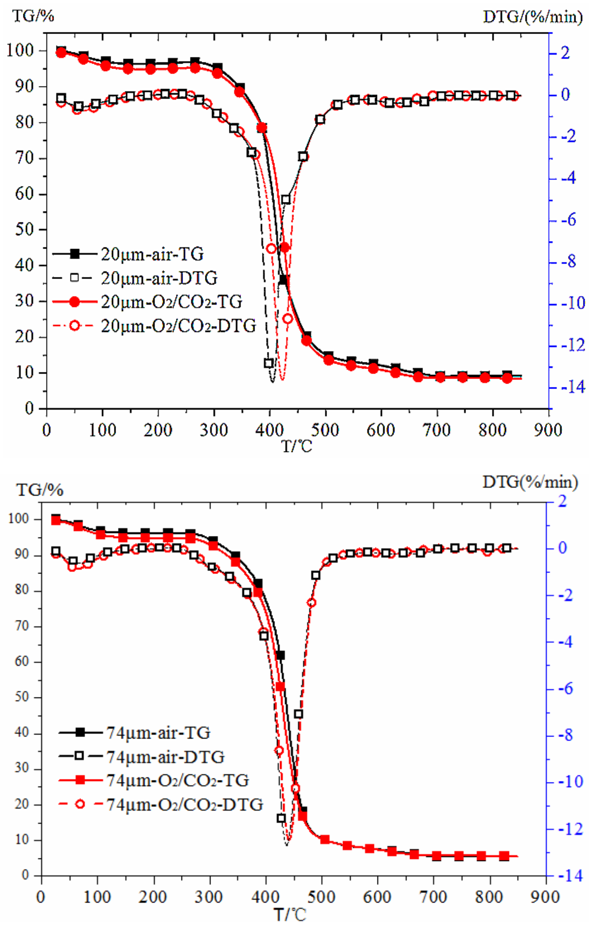

Figure 1. TG and DTG curves under O_2/CO_2 and air atmospheres.

Table 2. Combustion characteristic parameters of two particle size coals.

coal	atmosphere	Ti(℃)	T_b(℃)	$(dW/dt)_{max}$ (%/min)	T_{max} (℃)	η(%)
20 μm	Air	375	658.0	13.72	405	95.52
	O_2/CO_2	384	796.1	13.62	412	97.18
74 μm	Air	396	648.6	12.67	437	99.39
	O_2/CO_2	401	784.5	12.36	441	99.96

Arrhenius kinetic parameters were obtained by analyzed the TG-DTG curves, as shown in **Table 3**. A simple kinetic analysis was performed which a single step reaction process is supposed.

The kinetic parameters of two particle size coals were listed in **Table 3**. It was clearly that in O_2/CO_2 atmosphere, the reaction activation energy of coal with both 20 μm and 74 μm diameters were lower than that in air environment, and the activation energy of 20 μm coals were lower than 74 μm coal.

Figure 2 showed the TG and DTG curves for blending coals with 20 μm and 74 μm Shenhua coal with different ratio under O_2/CO_2 atmosphere. From the figures, it can be seen that, blending the 20 μm coal into 74 μm coal moved the coal DTG curve to the left, increase the maximum weight loss and the maximum burning rate.

Combustion characteristic parameters of blending coals were listed in **Table 4**. From the figures, it can be seen that for the 20 μm and 74 μm blending coals, with the increasing ratio of 20 μm coal from 30% to 70%, the

Table 3. Kinetic parameters of two particle coals.

coal	atmosphere	*E*/(kJ · mol^{-1})	*A*/s^{-1}	*R*
20μm	Air	101.46	164737.3	0.9666
	O_2/CO_2	81.44	3246	0.9822
74μm	Air	122.94	4578628.6	0.9878
	O_2/CO_2	91.87	17248.9	0.9788

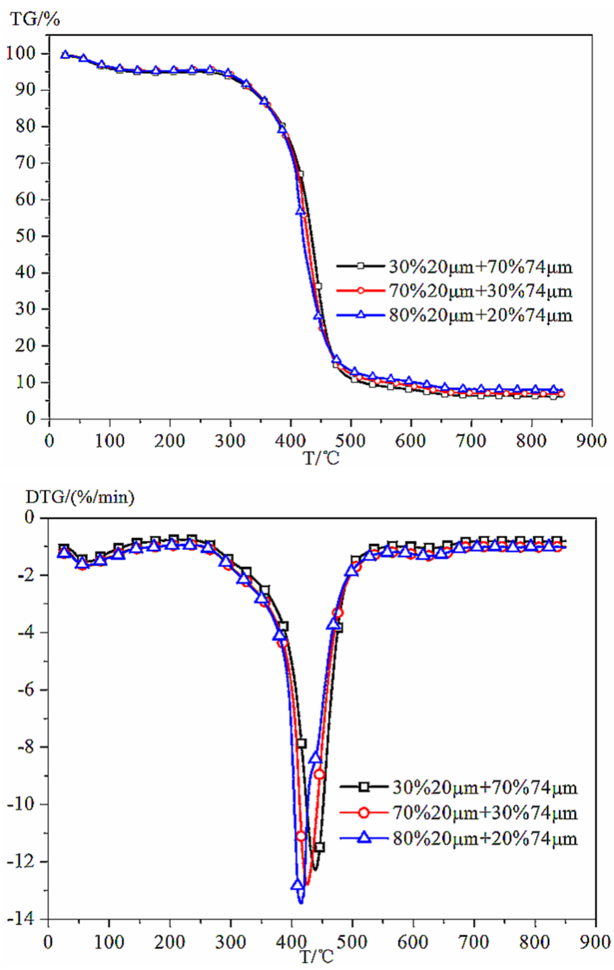

Figure 2. TG and DTG curves for different superfine coal ratio.

Table 4 .Combustion characteristic parameters of blending coals.

Coal	T_i/°C	T_b/°C	$(dW/dt)_{max}$ /%·min^{-1}	T_{max} /°C	η/%	C_b /×10^{-5}
30%20μm +70%74μm	392	782.6	12.27	438	99.69	7.98
70%20μm +30%74μm	388	779.6	12.78	425.5	98.99	8.49
80%20μm +20%74μm	386	778.1	13.25	415.5	97.82	8.89

Table 5. Kinetic parameters of blending coals.

coal	*E*/(kJ · mol^{-1})	*A*/s^{-1}	*R*
30%20μm + 70%74μm	87.85	8994.2	0.9787
70%20μm + 30%74μm	82.73	3652.3	0.992
80%20μm + 20%74μm	81.79	2352.7	0.9821

maximum weight loss temperature decreased from 438 ℃ to 425.5℃, increasing the ratio of 20 μm coal to 80%, the maximum weight loss rate appears at 415.5℃; With the increasing ratio of superfine coal, the peak value of DTG curves increased, and the maximum weight loss was from 12.27% to 13.25%. Increasing the ratio of 20μm coal lower the ignition temperature from 392℃ to 386℃ and the burnout temperature decreased from 782.6℃ to 778.1℃. From **Table 4**, it also can be seen that with the increasing ratio of superfine coal, the burn-out rate decreased which may be caused by the small coal particle size and packing density.

This paper used the flammability index to compare the combustion characteristics of different blending coals. It is defined as $C_b = (dW/dt)_{max}/ T_i^2$;C_b mainly reflect the coal combustion reaction capability which the higher the value, the better the flammability of coal. For the blending coals, with the increasing of 20 μm coal, the flammability index of mixed coals increased from 7.98 to 8.89(×10^{-5}).

Table 5 showed the kinetic parameters of blending coals. It can be seen that increasing the ratio of 20 μm coal decreased the reaction activation energy from 87.85 to 81.79 (kJ · mol^{-1}). Higher the ratio of 20 μm coal, the lower the activation energy value.

Figure 3 showed the ignition temperature of different ratios of blending coals. It can be seen that with the increasing of 20 μm coal, the ignition temperature tends to a downward trend. When the ratio of 20 μm was from 0 to 20%, the ignition temperature decreased rapidly, while the ratio was 20% to 60%, the ignition temperature

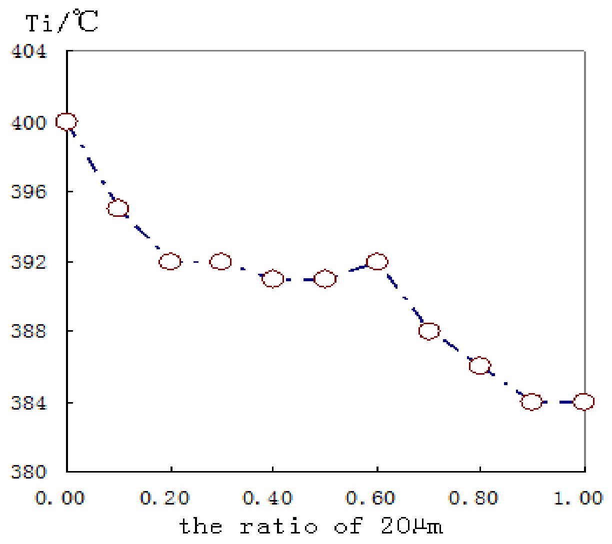

Figure 3. The ignition temperature of blending coals.

changed less. Increasing the ratio of 20 μm coal further, the ignition temperature decreased rapidly again.

4. Conclusions

In this paper, the combustion characteristics of ShenHua coals with diameters of 20 μm and 74 μm and their mixture under air and O_2/CO_2 atmosphere had been investigated using the TG analysis. The conclusions were listed as follows.

1) The coal burning rates decreased and the ignition temperature lowered under O_2/CO_2 atmosphere compared with coal combustion in the air environment.

2) For coal burning both in O_2/CO_2 atmosphere and air, the ignition temperature with superfine size coal was lower than that of large particle size, and the maximum weight loss rate was higher than the large particle size coal.

3) The addition of 20 μm coal into 74 μm lowered the ignition temperature under O_2/CO_2 atmosphere. With the decrease of coal particle size, the DTG curve moves to the left, the ignition temperature and the burnout temperature decreased which indicating that the coal ignition advanced and it's easy to reach the ignition temperature and combustion.

4) Activation energy of blending coals combustion varied with the ratio of 20 μm for blending coals. For 20 μm - 74 μm blending coals, the activation energy decreased with the increasing ratio of 20 μm coal.

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