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The fusion characteristics of ashes from anthracite and biomass blends

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ABSTRACT

Fusion characteristics of ashes from anthracite and biomass (pine sawdust and corn stalk) blends were investigated. These ashes were prepared in a muffle furnace (MF) and a drop tube furnace (DTF) at the temperatures of 815 °C and 1200 °C respectively. The fusion temperatures of ashes were measured in an ash fusion temperature analyzer, the morphological characteristics and element component of ashes were analyzed by means of SEM (Scanning Electron Microscope) fitted with EDS (Energy Disperse Spectroscopy). The minerals species and transformation characteristics were also detected using XRD (X-ray diffraction). The fusion temperatures of MF blends ashes were lower than those of DTF blends ashes because of the difference of ash preparation temperatures. The structures of ashes made in MF were dispersed and loose, but the ashes made in DTF were denser and larger resulting in obvious agglomeration. The fusion temperatures decreased with biomass addition ratio increasing due to large amounts of alkali and alkali-earth species in pine sawdust/corn stalk ash regardless the ash preparation method. K and Ca-bearing compounds can react with aluminosilicates in anthracite to create low temperature eutectics which can decrease the fusion temperatures of anthracite and biomass blends.

1. Introduction

As one of the most important fuels, coal will remain a major energy of electricity generation for the world [1]. In the past decades, environmental protection, fossil energy depletion and greenhouse effect had become the increasing concern for human beings. For solving these problems, the co-firing of coal and biomass has become a hot issue worldwide because of the zero emission of CO_2 and reduction in SO_2, NO_x emissions of biomass combustion [2–4].

However, the co-firing of coal and biomass has certain drawbacks such as ash deposition, sintering and fouling [5], leading to ash agglomeration in fluidized bed and fixed bed boiler [6–8]. Chen et al. [9] investigated the fusion temperatures of ashes of coal and of biomass mixtures. The fusion temperatures of blends were lower than that of coal ash. During blending ash melting process, coal and biomass ash reacted on each other, leading to co-eutectic forming and fusion temperatures of blends decreasing. Luan et al. [10] studied the sintering characteristics of ashes of coal and biomass blends in a drop tube furnace. The sintering temperatures reduced with biomass addition ratio increasing. Fang and Jia [11] studied the ash fusion temperatures of coal and straw blends, four typical temperatures of ash fusion were measured, the ash fusion temperature curves showed a trend of decreasing to increasing with ratio of corn straw addition increasing. All the four fusion temperatures strongly depended on the corn straw mass ration in blends, which decreased when the content of biomass increased from 0 to 50%, increased when the content of coal decreased from 50% to 100% due to porous structure of ash. Previous studies have demonstrated that fusion temperature of ash of coal and biomass blends was much different from pure coal and biomass because of the various species of minerals in coal and biomass. The own minerals in coal and biomass can affect the blends ash fusion temperature, furthermore, the new minerals formed by own minerals of coal and biomass ash reactions can also affect the ash fusion temperatures.

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In this research, fusion characteristics of ash of anthracite and biomass (pine sawdust and corn stalk) blends were studied. The ashes were made in a muffle furnace and a drop tube furnace. The fusion temperatures of ashes of coal, biomass and their blends were measured, the ash morphology and mineralogy were discussed for explained the fusion characteristics of blends ashes.

2. Experimental

2.1. Coal, biomass samples and raw ash samples preparation

Anthracite was taken from Jincheng City in China. It was dried, ground and sieved to get the fines of particle-size less than 75 μm. A pine sawdust and a corn stalk were chosen for this study. Both of them were dried and crushed into particle-size less than 200 μm. A series of blends of anthracite and biomass were prepared. The mass ratios of anthracite-to-biomass were 100:0, 80:20, 70:30, 60:40 and 0:100 respectively. Table 1 shows the proximate and ultimate analysis and ash compositions data of anthracite and two biomass samples.

An MF and a DTF were used to prepare ash samples. The preparation of ashes of the individual anthracite, biomass and coal/biomass blends by static combustion in an MF followed the Chinese Standard (GB/T 212-2008) [12–14]. Approximately 1.0 g of sample was evenly spread on a crucible and then heated to 815 °C at a heating rate of 10 °C in MF. After 1 h, the ash sample was took out and cooled naturally to room temperature. For simulating the dynamic combustion of the anthracite and biomass blends, a DTF was used to prepare ash samples at temperature of 1200 °C. It consisted of air supply system, electrically heated system, flue gas pre-treatment system, a vertical quartz tube (50 mm inner diameter, 1500 mm length) and an ash collector at the tube bottom. In this study, the DTF was preheated to 1200 °C and then the sample was fed from the top of quartz tube with feeding rate of 15 g min^{-1}. The air was introduced from the top of quartz tube with flow rate of 50 mL s^{-1}. The ashes were collected in the ash collector for further research.

2.2. Analysis methods

2.2.1. The measurement of fusion temperature ash

The ash fusion temperature was measured in an ash fusion temperature analyzer (HR-8000B) followed the Chinese Standard (GB/T 212-2008). The analyzer mainly consisted of temperature programmed tube furnace and computer controlled display system (CCD). In a typical experiment, the weight of ash sample was about 1.0 g, modeled as triangular cone with 7 mm for side length of cone bottom triangle and 20 mm for cone height, and dried at 105 °C for 120 min. The dried ash cone was placed in the tube furnace and heated to 1500 °C at a preset temperature program, the CCD system can take the images of morphology change of ash cone, four typical temperatures can be recorded according the images such as deformation temperature (DT), softening temperature (ST), hemispherical temperature (HT) and flowing temperature (FT). In the study, ST was selected as ash fusion temperature.

2.2.2. SEM–EDS and XRD analysis

The morphological characteristics and element component of ashes were also analyzed by means of SEM (Hitachi TM3030) fitted with EDS (Bruker Quantax 70). The XRD patterns of the ashes were measured using a XRD (Bruker D2 Advance).

Table 1
Proximate and ultimate analysis and ash compositions of anthracite, pine sawdust and corn stalk.

	Anthracite	Pine sawdust	Corn stalk
Proximate analysis (air dried basis, wt%)			
Moisture	1.83	3.45	3.41
Ash	22.0	1.98	5.44
Volatile	7.52	76.50	76.47
Fixed carbon	68.45	18.07	14.68
Ultimate analysis (air dried basis, wt%)			
C	66.95	52.01	44.67
H	2.61	5.4	5.99
O	4.98	41.97	36.18
N	0.80	0.13	0.45
S	1.23	0.02	0.168
Ash composition (wt%)			
SiO_2	54.19	11.9	38.06
Al_2O_3	27.91	2.43	6.63
Fe_2O_3	4.23	2.45	3.00
CaO	4.87	36.78	10.36
MgO	1.08	12.98	8.33
Na_2O	1.89	3.04	1.43
K_2O	1.84	22.65	13.55
SO_3	2.09	2.89	6.95
TiO_2	0.97	0.22	0.30
P_2O_5	0.25	4.19	1.17
Cl	–	0.2	–

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