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Influence of water washing pretreatment on ash fusion characteristics of biomass

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ABSTRACT

Water washing pretreatment is an effective method to remove alkali metals and chlorine elements in biomass, which could improve the performance of ash deposition and slagging of biomass fuels. In this study, two typical biomass fuels were pretreated with water washing. The effect of water washing on the ash fusion characteristics was carried out. According to the ash fusion characteristics test experiments, four characteristic temperatures and ash fusion dynamic curves of biomass ash samples were obtained, and the corresponding relationship between characteristic temperature and dynamic curve was studied. The results show that the fusion process of biomass ash contains four stage including shrinkage, expansion, melting and flow. Water washing can increase the deformation temperature of biomass ash by about 300 °C and the flow temperature by 150 °C, which can significantly reduce the biomass ash slagging.

Keywords: water washing, biomass, ash fusion characteristics, ash melting dynamic curve.

1. INTRODUCTION

In recent years, biomass energy has received extensive attention due to its wide distribution and renewable advantages. China is rich in biomass fuel resources, the common ones are wheat stalks, corn stalks, rice husks and sorghum stalks [1]. However, in the process of biomass combustion, high content of K, S and Cl will cause serious fouling and slagging and corrosion problems, which will affect the operation of the boiler [2-4]. Water washing pretreatment is proposed to solve the fouling and slagging problems of biomass fuels, which could effectively remove alkali metals in biomass [3,5-8]. The combustion characteristics and ash deposition characteristics of biomass after washing have received more attention, while less research concentrate on the ash melting characteristics of biomass after washing.

Much attention has been devoted to ash fusion characteristics of biomass without washing treatment. Roberts et al. [9] and Wang et al. [10] studied the influence of fuel composition and ash composition on the ash fusion characteristics of biomass by changing additives. Additives could reduce the concentration of problematic substances in the ash and increase the fusion point of the formed ash system to improve the deposition behavior and deposition rate. Furthermore, the fuel composition and ash composition have a greater influence on ash fusion characteristics. The ash fusion characteristics of water washing pretreated biomass might be different compared with that before washing.

The ash fusion characteristics of the fuel are mainly obtained by ash fusion temperature test (AFT). In AFT, four discrete temperatures are recorded: shrinkage temperature (ST), initial deformation temperature (IDT), hemispherical temperature (HT) and flowing temperature (FT) [11], which provide a basis for the prediction of the starting temperature of boiler slagging contamination. However, these four characteristic temperatures obtained by the AFT have limited reflection on the ash fusion characteristics. It is necessary to study the dynamic performance of the ash column during the ash fusion process.

In this study, the biomass ash samples were prepared by the standard method through the muffle furnace. The fusion characteristics of ash samples prepared by washed biomass with different temperature were investigated by ash fusion point instrument. The influence of washing condition on the ash fusion characteristics of biomass is investigated.

2. MATERIAL AND METHODS

2.1 Biomass ash production

Two common crops, wheat stalk and corn stalk are selected as the biomass fuels. The water washing pretreatment is performed at first. The biomass and 1L water are mixed for 24 hours in a beaker at a constant temperature controlled by water bath. The temperature of the water bath is 30, 60 and 90 °C. Then, the washed biomass samples after filtering were dried in a drying oven at 105 °C for 24 hours. Subsequently, the biomass is crushed by a crusher. The biomass powder with a particle size range of 150-250 μm is selected. The dried biomass powder was applied to prepare the ash samples at 575°C in the muffle furnace.

The 8 groups of experimental samples are respectively defined as CS0 (the original ash of corn stalk), CS30 (the corn stalk ash after washing at 30 °C), CS60 (the corn stalk ash after washing at 60 °C), and CS90 (the Corn stalk ash after washing at 90 °C). The same naming method is also used for wheat stalk ash samples, namely WS0, WS30, WS60 and WS90.

2.2 Ash fusion dynamic curve

During the ash fusion dynamic measurement experiment, the change in the height of the ash column could be recorded. The ratio of the real-time ash column height to the initial ash column height is defined as the ash column height ratio. The dynamic curve of biomass ash fusion could be obtained. The ash fusion characteristics of biomass are measured and recorded by the ash fusion point instrument. The four characteristic temperatures are defined as follows:

(1) Shrinkage temperature (ST): The ash column height begin to decrease, and the ash column height ratio is less than 1.

(2) Initial deformation temperature (IDT): The upper surface of the ash column changes, which is manifested by the obtuse of the upper surface of the cylindrical projection.

(3) Hemispherical temperature (HT): The ash column melts into a hemispherical shape. The height of column is about half the length of the bottom surface refer to the standard.

(4) Flow temperature (FT): The ash samples flow on the support plate, and the ash column height ratio is less than 0.2.

(5) In addition, after the deformation temperature, when the ash sample expands to the maximum, it can be defined as the melting start temperature.

3. RESULTS AND DISCUSSION

3.1 Ash fusion characteristics of corn stalk

Fig.1 shows the ash melting curve of corn stalk. The shrinkage temperature of CS30, CS60, and CS90 increased by 30, 30, and 340 °C respectively comparing with CS0, which shows that the chemical reaction temperature required inside the corn stalk ash column is higher after washing. It is worth noting that the shrinkage temperature of CS90 is significantly increased, and the temperature range in which shrinkage occurs is significantly shortened. The ash column shrinks to a minimum when the temperature rises to 1270 °C, and then its height begins to rise, only 30 °C higher than the shrinkage temperature. The corresponding temperature and the expansion ratio increase greatly when CS30, CS60, and CS90 reach the highest expansion value. The maximum expansion temperature increase which may be caused by that water washing can remove a large amount of alkali metal elements and part of the Cl element, and the content of low melting point substances in the ash column is small that make the temperature required to reach the maximum expansion is higher. For CS90, the ash column height ratio is 0.94 when the shrinkage stops, which is reduced compared with CS0, CS30 and CS60. It can be inferred that most of the alkali metal elements are removed and the content of low-melting substances in the ash column is reduced at the washing temperature of 90 °C.

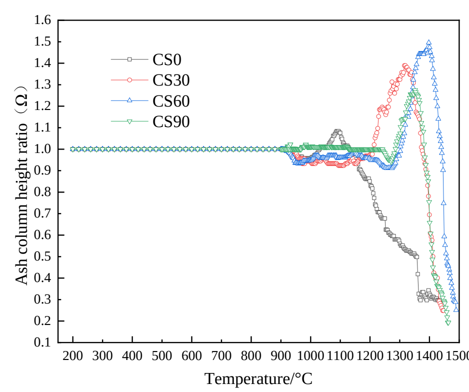

Fig.1 ash melting curve of corn stalk

Table 1 shows the characteristic temperature of corn stalk ash obtained by AFT. It can be observed that the shrinkage temperature corresponds to the temperature when the ash column height ratio begins to decrease, comparing Fig.1 and Table 1. The initial deformation temperature corresponds to the temperature at which the ash column stops shrinking and turns to expansion, and corresponds to the extreme point where the ash column height ratio in dynamic curve changes from decreasing to increasing. The hemispheric temperature corresponds to the inflection point where the height of the ash column in the ash melting dynamic curve changes from slow to faster in the descending stage. The flow temperature corresponds to the temperature when the ash column completely collapses. It can be inferred that the ash melting dynamic curve could well reflect the characteristic temperature of biomass ash melting. Furthermore, it is easy to divide the internal changes of the biomass ash column in stages during the test.

Table 1 ash fusion characteristic temperature

	Characteristic temperature/°C			
	ST	DT	HT	FT
CS0	900	980	1300	1380
CS30	930	1180	1350	1412
CS60	930	1250	1380	1430
CS90	1259	1285	1380	1412
WS0	/	946	1185	1292
WS30	980	1226	1359	1456
WS60	990	1300	1470	1499
WS90	1272	1326	1444	≥1500

*3.2 Ash fusion characteristics of wheat stal*k

Figure 2 illustrates the ash melting curve of wheat stalk. The initial shrinkage stage of WS0 was not observed. The possible reason is that the WS0 has already shrunk when it is lower than 900 °C. However, since the ash melting point instrument only started recording at 900 °C, the shrinkage process of the ash column could not be recorded. The ash column height of WS30, WS60, and WS90 starts to decrease at 980, 980, and 990 °C, respectively, which is the shrinkage temperature. When the shrinkage of WS30 stops, the ash column height ratio is about 0.87, which increases the shrinkage ratio compared with the corn stalk ash treated with 30 °C water washing. It shows that in the wheat straw ash column, the liquid phase structure produced during the temperature increase is more, and the solid particles in it are smaller, resulting in greater attraction between the solid particles in the ash column under capillary action. Therefore, the contraction of WS30 is greater. At the same time, the temperature when the ash column reaches the highest shrinkage value after washing is greatly increased. It can be inferred that the proportion of high melting point substances in the wheat stalk ash column increases after washing. The maximum shrinkage ratio of WS60 is significantly higher than that of WS30. The high melting point substance particles in the wheat straw ash column washed at 60 °C are smaller and they are more evenly distributed in the liquid phase, which lead to the attraction between solid particles is greater under capillary action. The maximum expansion ratio of WS90 is lower than that of WS0 and WS30, but the temperature at the maximum degree of expansion increases significantly. The expansion ratio and the corresponding temperature of WS90 is similar with WS60, indicating that after 60 °C, the washing temperature has less effect on the ash melting characteristics of wheat straw.

As the temperature increases, the wheat stalk ash column is basically in a molten state which is similar to the corn stalk ash, showing a spherical shape under the action of surface tension. As the temperature continues to rise, all solid particles inside the ash column melt, and the ash column gradually becomes hemispherical.

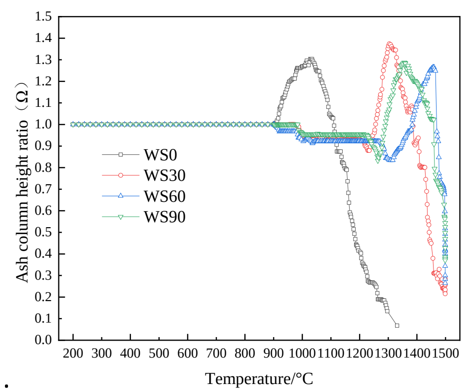

Fig.2 ash melting curve of wheat stalk

4. CONCLUSION

In this study, corn stalk and wheat stalk are used to investigate the ash fusion characteristics of biomass and the ash melting dynamic curve. The influence of the washing temperature on the ash fusion characteristics of the two biomasses was explored on the ash fusion dynamic measurement system. The conclusions can be drawn as follows:

(1) The ash fusion characteristic temperature increased after washing, indicating that water washing treatment has a significant effect on solving the slagging problem of biomass ash. Water washing pretreatment can increase the deformation temperature of biomass ash by about 300 °C and the flow temperature by 150 °C.

(2) The ash melting curve could clearly show the dynamic process of ash melting, including shrinkage, expansion, melting and flow. At the same time, the

judgment of the ash melting characteristic temperature is more accurate.

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