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Study on Combustion Characteristics of Crystalline Product of Biomass Water Washing Leachate

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ABSTRACT

Water washing pretreatment could alleviate the problems of ash deposition and slagging during the combustion of biomass. A large amount of washing leachate will be produced during the washing process. In this study, two kinds of biomass (corn stalk, rice husk) are selected as the research object. The combustion characteristics of the crystalline product of the water-washed leachate are studied by a thermal synchronization analyzer. The influence of biomass species and washing temperature on the combustion characteristics of leachate crystallization products was analyzed. The results show that the maximum combustion rate of the leachate crystals of corn stalk increases with the decrease of heating rate. The ignition temperature of the crystalline product of the corn stalk washing leachate increases with the increase of washing temperature. The ignition temperature of rice husk leachate crystals with the washing temperature at 60°C is higher than 30 and 90°C. Compared with the corn stalk leachate crystals, the rice husk leachate crystals have a lower ignition temperature. It is important to investigate the combustion characteristics of biomass leachate crystals which could provide the assistance in the treatment of leachate after washing.

Keywords: water washing, biomass, leachate crystals, combustion characteristics.

1. INTRODUCTION

In recent years, with the rapid consumption of fossil energy, biomass energy as an alternative energy source has great potential for development due to its renewable, carbon neutral and low pollution advantages [1]. However, there is a serious problem of ash deposition and slagging when biomass is directly burned in the boiler [2]. Some scholars have proved that the alkali metal elements in biomass fuel can be removed through water washing pretreatment, thereby effectively alleviating the phenomenon of boiler slagging [3,4]. However, a large amount of biomass water-washed leachate is produced during the water washing process. Moreover, how to deal with it has become an urgent problem to be solved. There is little research on biomass washing leachate. Deng Lei et al. [5] carried out research on washing six biomass fuels at different temperatures. The influence of water washing on the meltability, fuel performance, pyrolysis and combustion characteristics and ash content is discussed. Liu et al. [6] found that the main components in the rice husk leachate were alcohols, phenols, hydroxycarboxylic acids, fatty acids and long-chain alkanes. Sun et al. [7] proposed that non-polar extracts (also known as lipophilic extracts) are contained in the water-washed leachate of wood and pulp. The washing temperature has a great impact on the content of inorganic ions and lipophilic substances in the washing leachate. Nevertheless, there are little studies focused on the treatment of water-washed leachate.

In this study, the leachate was evaporated to obtain crystals. Corn stalk and rice husk were selected as the research objects. A thermal synchronization analyzer was used to conduct experiments on the crystalline products of biomass leachate washed with water at different temperatures. The effects of biomass types,

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washing conditions and thermogravimetric heating rate on the leachate crystallization and combustion characteristics are discussed. It is necessary to obtain the combustion characteristics of leachate crystals for the treatment of water-washed leachate.

2. MATERIAL AND METHODS

2.1 Samples preparation

Two kinds of biomass (corn stalk and rice husk) are selected as the research objects. The biomass is dried for 24 hours in a constant temperature drying oven at 105 °C. And then the biomass is crushed by a crusher. The powder with a particle size range of 150-250 μm is sieved out. The biomass is washed in deionized water at 30, 60 and 90 °C according to the solid-liquid ratio of 12.5 g L^{-1} to obtain the washed leachate. Subsequently, the leachate is dried at a constant temperature of 60 °C. The combustion characteristics of the leachate crystals are carried out by thermal synchronization analyzer.

2.2 Characteristic parameters

The ignition temperature (T_i) and the burn-out temperature (T_b) are selected as the main parameters to characterize the combustion characteristics of the biomass leachate crystals. T_i and T_b are generally defined by the thermal weight loss curve. There are many ways to define them. In this study, one of them is selected and the thermal gravity research data is analyzed uniformly.

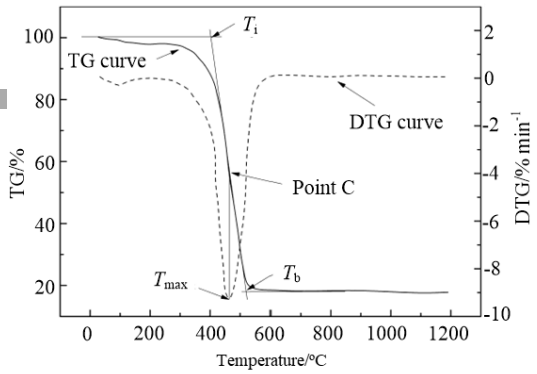

Fig.1 TG/DTG curve and characteristic temperature point definition

Fig.1 illustrates a schematic diagram of the thermal weight loss curve and characteristic temperature point definition of the biomass water-washed leachate crystals. The temperature corresponding to the minimum point of the differential thermogravimetry (DTG) curve is defined as the maximum combustion rate temperature, which is the $(dm/dt)_{max}$ temperature. In the thermogravimetry (TG) curve, $(dm/dt)_{max}$ is a tangent line at the corresponding point in the curve. The corresponding reaction temperature at the intersection of the tangent line and the horizontal line with a weight loss rate of 100% is the ignition temperature T_i. This tangent line is the weight loss when the weight loss is stable The intersection of the horizontal lines. The corresponding reaction temperature is the burnout temperature T_b.

3. RESULTS AND DISCUSSION

3.1 Analysis of combustion characteristic parameters of leachate crystals

The characteristic parameters obtained under different heating rate conditions are shown in Table 1. It can be seen from Table 1 that the ignition temperature decreases as the heating rate increases for the corn stalk water-washed leachate crystals. At the same time, the main combustion temperature range (T_b-T_i) shows an increasing trend, and the maximum combustion rate shows a decreasing trend. When the washing temperature is 30 °C, and the temperature rise rate is 10 and 20 K min^{-1} respectively, the temperature T_{max} corresponding to the maximum burning rate is in the temperature range of 500-600 °C. T_{max} is in the temperature range of 200-250 °C when the heating rate is 40 K min^{-1}. The corresponding maximum combustion rate can reach 4.48×10^{-3}% min^{-1} when the heating rate is 10 K min^{-1} at washing temperature of 60 °C. The maximum combustion rate corresponds to a temperature of 568.71 °C while the heating rate is 30 K min^{-1}.

Table 1 combustion characteristic parameters of corn stalk

Washing temperature /°C	Heating rate/K min^{-1}	Parameters					
		T_i/°C	T_b/°C	T_{max}/°C	T_b-T_i/°C	dm/%	$(dm/dt)_{max}$/%·min^{-1}
30	10	358.29	555.45	512.45	197.16	93.16	-4.42E-03
	20	290.51	616.40	561.37	325.89	93.61	-2.92E-03
	30	151.97	488.78	215.47	336.81	93.78	-2.28E-03
	40	156.71	500.61	237.58	343.90	94.01	-2.15E-03
60	10	356.61	556.25	519.53	199.64	92.63	-4.48E-03
	20	318.03	607.20	553.5	289.17	92.63	-3.29E-03
	30	263.43	652.69	568.71	389.26	92.56	-2.46E-03
	40	150.13	586.51	255.84	436.38	92.83	-1.97E-03
90	10	353.87	567.17	516.24	213.30	92.97	-4.17E-03
	20	326.70	613.33	540.82	286.63	92.56	-3.14E-03
	30	162.19	727.06	559.69	564.87	92.71	-2.59E-03
	40	167.92	488.54	244.00	320.62	92.56	-2.16E-03

Table 1 combustion characteristic parameters of rise husk

Washing temperature /°C	Heating rate /K·min^{-1}	parameters					
		T_i/°C	T_b/°C	T_{max}/°C	T_b-T_i/°C	dm/%	$(dm/dt)_{max}$/% min^{-1}
30	10	271.13	581.90	455.99	310.77	84.12	-2.54E-03
	20	185.06	533.23	288.30	348.17	77.91	-2.14E-03
	30	191.74	534.77	285.22	343.03	78.12	-2.20E-03
	40	195.46	540.62	286.03	345.16	78.04	-2.14E-03
60	10	328.11	605.23	563.11	277.12	78.64	-2.30E-03
	20	347.02	611.48	556.05	264.46	78.92	-2.48E-03
	30	192.62	528.14	288.94	335.52	78.79	-2.17E-03
	40	194.03	536.15	289.96	342.12	78.99	-2.12E-03
90	10	291.46	561.07	484.99	269.61	76.24	-2.72E-03
	20	277.28	598.99	502.62	321.71	75.95	-2.31E-03
	30	195.57	545.79	284.40	350.22	75.04	-2.19E-03
	40	202.48	547.50	290.73	345.02	74,98	-2.08E-03

Table 2 shows the combustion characteristic parameters of rice husk leachate crystals obtained under

different washing conditions. For the rice husk water-washed leachate crystals, the main combustion temperature range (T_b-T_i) basically increases with the augment of the heating rate. The maximum burning rate of the leachate crystals obtained under the water washing condition of 90 °C shows a decreasing trend as the heating rate increase. However, for the ignition temperature and the burnout temperature, there is no obvious change, and the mass change d*m* also remains basically unchanged with the heating rate augmentation. The rice husk washed leachate crystals have a lower ignition temperature comparing with corn stalk leachate crystals, which means that they have better ignition performance. But it also has a higher burnout temperature. Furthermore, there is no significant difference of the main combustion temperature range (T_b-T_i) of leachate crystals of corn stalk and rice husk.

3.2 Thermogravimetric Analysis of leachate crystals

The TG/DTG results of corn stalk and rise husk leachate crystals with different heating rates are shown in Fig.2 and Fig.3 at the washing temperature of 90 °C. The combustion reaction is divided into four stages: the first stage is the dehydration stage (100-200 °C), which is mainly the removal of free water, external water and internal water [8-10]. A large peak appears in the corresponding DTG curve. The second stage is the initial carbonization or dry distillation stage (200-300 °C), accompanied by the production of a small amount of CO_2 and other gases [9]. The third stage is the combustion stage (400-800 °C). The C-C bond and C-H of aliphatic hydrocarbon compounds is broken [11]. The fourth stage is the burn-out stage (800-1200 °C). The C-C bond of aromatic compounds [12] and other compounds is broken.

The corn stalk leachate crystals are dehydrated at about 180 °C and begins to dry distillation. It reaches the maximum weight loss rate of the second stage at about 210 °C. A shoulder peak appears at 300 °C and disappears when the heating rate increases. This might be that cellulose and hemicellulose in the leachate crystals could be decomposed sequentially under the low heating rate condition, showing separate decomposition peaks. However, as the heating rate increases, the decomposition of several substances proceeds at the same time, causing several adjacent peaks to overlap and no single peak appears. The leachate crystals mainly combust at the temperature range of 400-800 °C. The weight loss rate gradually decreases, but the combustion temperature range augments with the heating rate increasing. The temperature between 800 and 1200 °C is the burn-out stage, and the material that is not completely thermally cracked during the combustion stage will continue to have carbon chain scission in this temperature range, such as aromatic compounds.

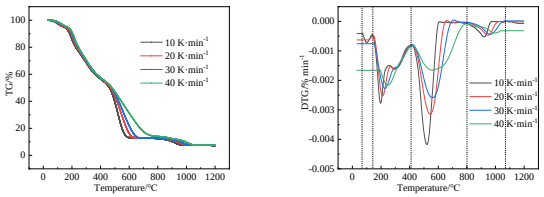

Fig.2 Combustion characteristics of crystalline products of corn stalk washed (90°C) leachate

Fig.3 displays the TG/DTG curve of the rice husk washed product. It can be observed that the rice husk leachate shows a similar weight loss law to corn stalk. The dehydration is carried out at 110-180 °C. In the combustion stage, its weight loss rate is significantly lower than that of corn stover, and even lower than that in the dry distillation stage. It might be that the content of hydrocarbons in the rice husk leachate is low, which results in fewer substances decomposed during the combustion stage so that the weight loss is not obvious. In the combustion stage, as the heating rate increases, the weight loss rate of the crystals decreases.

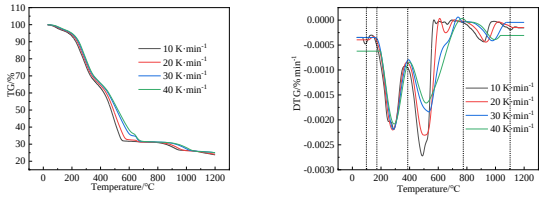

Fig.3 Combustion characteristics of crystalline products of rise husk washed (90°C) leachate

4. CONCLUSION

In this study, the combustion characteristics of the crystallization products of corn stalk and rice husk washing leachate were obtained through thermogravimetric experiments. The effects of biomass types, washing temperature and heating rate on combustion characteristics were discussed. The conclusions are as follows:

1 The ignition temperature of the crystalline product of the corn stalk washing leachate increases with the augment of the washing temperature. The ignition temperature of rice husk leachate crystallization under 60 ℃ water washing conditions is higher than 30 and 90 ℃.

2 The ignition temperature of the crystals of corn stalk and rice husk washing leachate will decrease as the heating rate increases. The main combustion

temperature range shows an increasing trend, and the maximum combustion rate max shows a decreasing trend.

3 The crystals of rice husk washed leachate have a lower ignition temperature compared with the crystals of corn stalk leachate at low heating rate condition.

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REFERENCE

[1] Frandsen F. Utilizing biomass and waste for power production—a decade of contributing to the understanding, interpretation and analysis of deposits and corrosion products. Fuel, 2005; 84 (10): 1277-1294.

[2] Miles TR, Miles TR, Baxter LL, et al. Boiler deposits from firing biomass fuels. Biomass & Bioenergy, 1996; 10 (2-3): 125-138.

[3] Jenkins BM, Bakker RR, Wei JB. On the properties of washed straw. Biomass & Bioenergy, 1996; 10 (4): 177-200.

[4] Zhang Z, Song Q, Yao Q, et al. Influence of the atmosphere on the transformation of alkali and alkaline earth metallic species during rice straw thermal conversion. Energy & Fuels, 2012; 26 (3): 1892-1899.

[5] Deng L, Zhang T, Che D. Effect of water washing on fuel properties, pyrolysis and combustion characteristics, and ash fusibility of biomass. Fuel Processing Technology, 2013; 106: 712-720.

[6] Liu JS， Yang WD， Gao J, et al. Inhibition of rice and wheat straw on the growth of Phaeocystis globosa. Acta Ecologica Sinica(China)，2007; (11)：126-133.

[7] Sun R, Salisbury D, Tomkinson J. Chemical composition of lipophilic extractives released during the hot water treatment of wheat straw. Bioresource Technology, 2003; 88 (2): 95-101.

[8] Ahmed A, Afolabi EA, Garba MU, et al. Effect of particle size on thermal decomposition and devolatilization kinetics of melon seed shell. Chemical Engineering Communications, 2019; 206 (9): 1228-1240.

[9] Zhao P, Zhong L, Zhao Y, et al. Comparative studies on the effect of mineral matter on physico-chemical properties, inherent moisture and drying kinetics of Chinese lignite. Energy Conversion & Management, 2015; 93: 197-204.

[10] Liu PKT, Feltch SM, Wagner N. Thermal desorption behavior of aliphatic and aromatic hydrocarbons loaded on activated carbon. Industrial & Engineering Chemistry Research, 1987; 26 (8): 1540-1545.

[11] Xu Z, Lin M. Ab initio kinetics for the unimolecular reaction C6H5OH → CO+C5H6. Journal of Physical Chemistry A, 2006; 110 (4): 1672-1677.

[12] Alzueta MU, Glarborg P, Dam-Johansen K. Experimental and kinetic modeling study of the oxidation of benzene. International Journal of Chemical Kinetics, 2000; 32 (8): 498-522.