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Experimental Study on The Synthetic Effects of Kaolin and Soil on Alkali-induced Slagging and Molten Slagging

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Abstract

With the depletion of fossil fuel, the exploitation and utilization of biomass have attracted attention widely. Unfortunately, high concentrations of alkali metals, especially K, in biomass result in serious slagging. Therefore, considering the co-existence of unnoticed and inevitable molten slagging as well as the highlighted alkali-induced slagging, the synthetic effects of kaolin and soil on both slagging are conducted by means of chemical fractionation and ash fusion testing. Addition of kaolin and soil into biomass can convert soluble-K into insoluble-K effectively, and thus reduce alkali-induced slagging. Moreover, soil, attributed to low-cost and wide range of sources, can be slagging inhibitor instead of kaolin. In addition, K_2O-SiO_2-Al_2O_3 ternary diagrams constructed by addition of K_2O, SiO_2 and Al_2O_3 into biomass underestimate IDT and over-estimate FT, and they should be constructed according to the biomass ash properties, rather than the simulated ash by adding various compounds into biomass.

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Keywords: Slag; Biomass; Combustion; Potassium; Molten; Alkali metal

1. Introduction

According to statistics, the biomass power generation capacity which has reached 10GW in USA[1] will reach 30GW by 2020 in China[2]. Although biomass power generation has been sprung up around the world, high concentrations of alkali metals, especially K, in biomass result in serious slagging [1, 3].

Generally, most attentions have been paid on the alkali-induced slagging mainly caused by alkali chlorides and sulfates. Johansson [4] reported that KCl is dominant in the fine particles($<1\mu m$) which is responsible for slagging. Nutalapati [5] simulated the release of alkali aerosols by chemical equipment software and reported that alkali aerosols decrease as non-reaction inorganic(Si ans Al) increase at 1300-1600℃. Based on the experiment and simulation research, kaolin has been recognized as the most effective alkali-induced slagging inhibitor, but high-cost restricts its industrial application[6].

Recently, some researcher begin pay attention on molten slagging. Li QH [7] reported that the fusion temperature increased with increase in SiO_2 and Al_2O_3, decreased with increased K_2O and SiO_2/Al_2O_3;

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Meanwhile, Xiong SJ[8] reported that potassium accelerate molten slagging. While Erica lindstrom[9] reported that SiO_2 contamination exacerbates slagging, and our recent research also indicted that K_2O decreased the initial deformation temperature(IDT) and may strengthen molten slagging as a result[10].

It seems that either alkali-induced slagging or molten slagging is associated with potassium, silicate and alumina, meanwhile, they both are not solved completely. For alkali-induced slagging, low-cost additive became the major challenge following detailed knowledge on slagging incentives; for molten slagging, the effects of SiO_2, Al_2O_3 and K_2O are still unclear. Therefore, the synthetic effects of kaolin and soil on both slagging are conducted by chemical fractionation and ash fusion testing.

2. Experimental materials

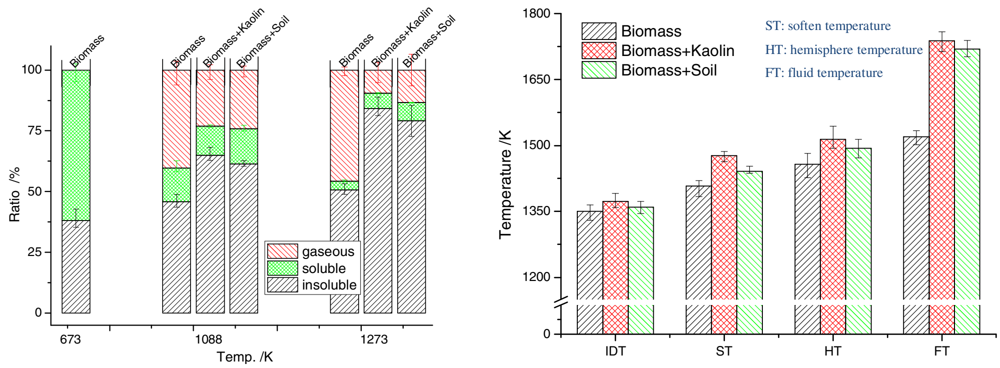
In experiment, kaolin and soil are selected as slagging inhibitors during the combustion of wheat straw. The corresponding experiment conditions and inorganic analysis are listed in Table 1. It can be seen that kaolin and soil has significant effects on the element compositions of biomass ash.

Table 1 Experiment conditions and inorganic analysis, 100g biomass

Conditions	Si	Al	Fe	Mg	Ca	Na	K	S	Cl
100%Biomass	1.99	0.24	0.22	0.50	0.93	0.03	1.51	0.12	0.20
97%Biomass+3%Kaolin	2.70	1.01	0.24	0.50	0.94	0.03	1.52	0.12	0.20
97%Biomass+3%Soil	2.72	0.66	0.37	0.51	0.93	0.03	1.56	0.12	0.20

3. Results and discussion

3.1. Alkali-induced slagging



a. K-conversions by chemical fractionation

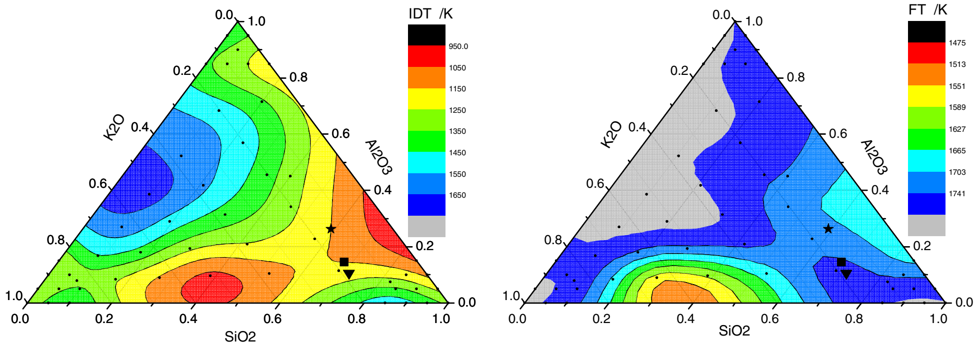
b. Ash fusion characteristics

Fig.1 Effects of kaolin and soil on K-conversion and ash fusion charateritics

Fig.1a shows potassium conversion by addition of kaolin and soil at 1088K and 1273K, respectively. It can be seen that the release of gaseous-K increases with increased temperature, that means it is easier slagging in grate furnace(typical combustion temperature at 1273K) than in CFB(typical combustion temperature at 1073K). Meanwhile, it can be seen that additives can convert gaseous-K into insoluble-K effectively, especially at 1273K. Approximate 40% of gaseous-K is converted at 1088K, while it reaches about 80% at 1273K. Therefore, it can concluded that although biomass is slightly easier slagging in grate furnace than in CFB, the aluminosilicate additives can reduce slagging significantly at the combustion temperature of grate furnace than of CFB. Moreover, from either Fig.1a or Fig.1b, it can be seen that soil holds almost the same level of efficiency on gaseous-K removal or alkali-induced slagging reduction, and soil possessing low-cost and easy source can be slagging inhibitor instead of kaolin.

3.2. Molten slagging

Commonly, the ash fusion characteristics reflect the molten slagging potential, so the ash fusion characteristics of the biomass with and without additives are tested and illustrated in Fig.1b. It can be seen that in comparison with pure biomass, both kaolin and soil additives raise the ash fusion temperatures, especially FT which is increased markedly. Meanwhile, the soil also presents almost same level of efficiency on ash fusion temperature increasing or molten slagging reduction. Concerning alkali-induced slagging together, soil can be as slagging inhibitor instead of kaolin.



"★"Biomass+Kaolin; "■"Biomass+Soil; "▼"Biomass; "·"Experimental value; unit: weight ratio

Fig.2 K_2O-SiO_2-Al_2O_3 ternary phase diagrams based on additives

The effects of SiO_2, Al_2O_3 and K_2O on molten slagging are conducted by K_2O-SiO_2-Al_2O_3 ternary diagrams which is constructed by mixture of SiO_2, Al_2O_3 and K_2O into biomass. It can be seen from Fig.2 that the IDTs are underestimated by the ternary diagrams, while FTs are over-predicted, especially on the pure biomass. It seems that the ternary diagrams constructed by addition of SiO_2, Al_2O_3 and K_2O may generate lower melting-point substances which pull down the IDT and results in earlier fusion, meanwhile, they may also generate some high melting-point substances which raise the FT and later the ash fusion completely. Li QH [6] pointed out that the ash fusion temperature of biomass was lower than the simulated ashes due to the existence of low-temperature eutectic substances in biomass ash, that maybe the reason that why the ternary diagrams underestimate the IDTs.

Otherwise, although the ternary diagrams constructed by addition of SiO_2, Al_2O_3 and K_2O can not provide accurate predictions on ash fusion characteristics and molten slagging, it tell us that the effects of SiO_2, Al_2O_3 and K_2O on molten slagging are varied according the ash construction, rather than constant promotion or inhibition. Meanwhile, it also indicate that in order to reveal the ash fusion characteritics and molten slagging potential comprehensively and accurately, the ternary diagrams should be constructed according to the biomass ash fusion characteristics, rather than the simulated ash by addition various compounds in the biomass.

4. Conclusions

Aiming at the co-existence of unnoticed and inevitable molten slagging as well as the highlighted alkali-induced slagging, the synthetic effects of kaolin and soil on both slagging are conducted by chemical fractionation and ash fusion testing. Results show that addition of kaolin and soil into biomass can convert soluble-K into insoluble-K effectively, and thus reduce alkali-induced slagging. And soil, possessing low-cost and wide range of sources, can be slagging inhibitor instead of kaolin. In addition, K_2O-SiO_2-Al_2O_3 ternary diagrams constructed by addition of K_2O, SiO_2 and Al_2O_3 into biomass underestimate IDT and over-estimate FT, and they should be constructed according to the biomass ash properties, rather than the simulated ash by addition various compounds in the biomass in order to predict the ash fusion characteristics and molten slagging potential comprehensively and accurately.

Acknowledgements

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Biography

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