



Experiment and simulation study on alkalis transfer characteristic during direct combustion utilization of bagasse



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HIGHLIGHTS

- Alkalis issues during bagasse combustion were systematically studied.
- Alkalis remained in ash caused little agglomeration at 800 °C.
- Alkali vapor condensing on bed materials caused slagging in CFB.
- Ash slag and heater corrosion can be eased respectively under 750 °C and 850 °C.
- Kaolin is better additive than CaO by locking alkalis in infusible compounds.

ARTICLE INFO

Article history:

Received 25 April 2015

Received in revised form 23 June 2015

Accepted 24 June 2015

Available online 14 July 2015

Keywords:

Bagasse

Fluidized bed combustion

Alkalis

Agglomeration

Thermal equilibrium simulation

ABSTRACT

Bagasse is utilized as fuel in the biggest biomass power plant of China, however, alkalis in the fuel created severe agglomeration and slagging problems. Alkalis transfer characteristic, agglomeration causes in engineering practice, additive improvement effects and mechanism during bagasse combustion were investigated via experiments and simulations. Only slight agglomeration occurs in ash higher than 800 °C. Serious agglomeration in practical operation should be attributed to the gaseous alkalis evaporating at high temperature and condensing on the cooler grain surfaces in CFB. It can be speculated that ash caking can be avoided with temperature lower than 750 °C and heating surface corrosion caused by alkali metal vapor can be alleviated with temperature lower than 850 °C. Kaolin added into the bagasse has an apparent advantage over CaO additive both in enhancing ash fusion point and relieving alkali-chloride corrosion by locking alkalis in dystectic solid compounds over the whole temperature range.

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1. Introduction

Biomass energy utilization has been paid wide attention due to the concerns about worldwide energy crisis and global warming (Shen et al., 2015). Biomass gasification and direct combustion are becoming the main methods to utilize biomass energy in China nowadays (Saidur et al., 2011; Shen et al., 2015). With advantages of good fuel flexibility, low pollutant emission and relatively smaller investments, biomass combustion in fluidized bed boiler promises a broad prospect (Lin et al., 2003; van den Broek et al., 1996). However, biomass fuels usually contain potassium, sodium and alkali earth metals as principal ash forming constituents, together with chlorine and sulfur to a lesser extent

(Fryda et al., 2008; Guo et al., 2014). This will create severe issues in the fluidized bed boiler at high temperature, bed material agglomeration, heating surface corrosion and deposition, for instance, all will ultimately hinder the stability and safety of the biomass combustion system (Demirbas, 2005).

Under high temperature combustion condition, alkali metal-related compounds may release to the gas phase, then deposit and condense upon the rear flue surface as coarse fly ash, causing fouling and high temperature corrosion. In the fluidized bed combustion process, some reactions occur between alkali metals and bed solids, producing low melting point eutectic compounds that may lead to particles agglomeration (Duan et al., 2015).

Sucrose is the major product of sugar manufacturing in south China, therefore, four provinces in south China planted massive sugarcanes as sugar crops, which undertake 95% raw material supply of the nation. According to statistics, sugarcane planting area reached 154.51 million of hectares in four provinces in South

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China 2014. Thus the bagasse collected from the sugar manufacturing is over 700 million tons per year, waiting to be rationally deposited and utilized (according to statistical data). Direct combustion of bagasse is convenient and feasible since a biggest biomass power plant in China (2×50 MW) has been built in Guangdong Province. Yet still, severe agglomeration and defluidization problems exist during the combustion operation in the circulating fluidized bed boiler (CFB).

Many efforts have been devoted to the study of alkali metal problems in biomass combustion, mainly focusing on wood or straw fuels. (Li et al., 2014) studied release and transformation of alkali metals during co-combustion of coal and sulfur-rich wheat straw, obtaining the variation conditions of alkali-contained compounds with temperature. (Steenari and Karlfeldt Fedje, 2010) studied the whereabouts of the alkalis and chlorine in straw under high temperature, discovering that the melting temperature of the ash could be increased with kaolin or dolomite additives, both working by capturing the potassium and changing it into compounds with high melting temperature as KAlSiO_4 and KAlSi_2O_6 .

However, studies showed that inorganic element distribution of biomass was largely based on species and regions, and had key effects on the alkali metal evolving process (Cuiping et al., 2004), in addition to the combustion temperature (Li et al., 2014). Biomass fuels are usually divided into woody biomass and herbal biomass, the latter ash is more likely to fuse with higher alkalis content, in particularly biomass planted off the coast. However, such category is too vague for engineering decision (Bryers, 1996). The ash fusion extent is hard to determine specific to a certain kind of biomass without systematic investigation, therefore, the agglomeration and corrosion problems in large-scale practical engineering are difficult to forecast. In fact, ash fusion behavior of biomass is not solely determined by the alkalis content, it is comprehensively influenced by the existing form of alkalis, other relevant elements contents like Si, Al, Cl and Mg, and combustion conditions, these natures could be extremely various in different kinds of biofuels.

Compared with other typical kinds of biomass such as rice stalks or eucalyptus barks, the bagasse has extremely low ash content (Munir et al., 2009), besides that, distribution of other elements in the ash has considerable features, rich content of Si and K oxides, for instance. It could be speculated that complicated solid phase reactions and phase conversion reactions will occur during the combustion, which deserves detailed investigation.

There have been some studies focusing on bagasse resource utilization or biomass alkalis problems, mainly investigating the bagasse gasification process (Keown et al., 2005) or combustion kinetics (Ramajo-Escalera et al., 2006). The objective of this study is to investigate the effects of south China bagasse and temperature on the release and transformation of alkali metals during combustion, and conclude the chemical mechanism based on the experiments and software FactSage 5.0 simulation results. Besides this, the problem in practical engineering will be deeply discussed by SEM/EDS (Scanning Electron Microscopy/Energy Dispersive Spectrometer) experiments and thermodynamic calculations of slagging samples from the biomass power plant, and FactSage simulation of bagasse combustion with CaO and kaolin will be conducted for solving the problem by combustion additives.

2. Methods

2.1. Experimental materials

Bagasse experimented in this work was collected from the biomass power plant in Zhanjiang City, Guangdong Province, which was typical sugarcane crops in South China. Bagasse was bought

from farmers and sugar factories during the milling campaign by the power plant, primarily from November of this year to March of next year. The growth cycle of sugarcane was about half a year. Samples were pulverized and sieved into particles with sizes less than $250 \mu\text{m}$ in diameter. Prior to the experiments, samples were dried in an oven for 3 h at 105°C and then ambient-temperature stored.

Proximate, ultimate analysis results (E0870-82R98E01, ASTM) and the ash content analysis is given in Table 1. Routine detection of carbon, hydrogen, nitrogen and sulfur content was finished in a GmbH Vario EL CHNS element analyzer. Incineration of the material was carried out following the standard ASTM E1755, and the ash content detection was completed in the Atomic Absorption Spectroscopy (AAS, Persee, TAS-990SuperF) after being decomposed by the $\text{HClO}_4\text{-HNO}_3$ mixed acid and converted into homologous oxides. The chlorine content was tested by ion chromatography, and direct leaching method was used as the pretreatment method since it existed in ion form.

Slagging blocks were taken from the biggest biomass power plant operating at $800\text{--}900^\circ\text{C}$, bagasse fuel, mixed with a bit eucalyptus, and the bed material was silica sand. The samples were the corrosive on the final superheater, the corrosive on the platen superheater, the furnace clinker, the fly ash and the deposition in horizontal flueway, respectively.

2.2. Experimental setup

Bagasse combustion experiment was conducted in a fixed bed reactor as shown in Fig. 1. Dimension of the quartz glass reactor was 50 mm (outside diameter) $\times 5 \text{ mm}$ (thickness) $\times 1200 \text{ mm}$ (height). The reactor temperature was measured by thermocouple and controlled by PID controller. Samples were placed in a ceramic combustion boat with a mass density less than 0.1 g/cm^3 to ensure even heating and low heat transfer resistance. When the experiments started, the ceramic combustion boats were pushed into the reactor by an iron stick with a scale mark to ensure the samples were located exactly in the same spot inside the tubular reactor.

Each test consumed 0.5 g sample. The combustion temperature was set at 500°C , 600°C , 700°C , 800°C and 900°C . The combustion time in the reactor hot zone was controlled at 15 s, 30 s, 1 min, 2 min, 3 min, 5 min and 10 min, respectively.

The combustion experiment was carried out as follows: (1) the heating tube of fixed bed reactor was heated to an aforementioned temperature. (2) The ceramic combustion boat with sample was inserted into the reactor. (3) The air flow was controlled at 1 L/min by the flowmeters. (4) After a few minutes of purging, the sample was rapidly pushed into the heating tube by a hand-spike. (5) After the given combustion time, the sample was quickly withdrawn from the heating tube and moved into a cooling tank

Table 1
Elemental, proximate and ash contents analysis of bagasse (wt%).

Analysis content	Bagasse						
Proximate analysis	M_{ar}^{a}	A_{ar}^{b}			V_{ar}^{c}		$FC_{\text{ar}}^{\text{d}}$
	10.37	2.63			72.60		14.39
Elemental analysis	C_{ar}	H_{ar}	O_{ar}	N_{ar}	S_{ar}	Cl_{ar}	K_{ar}
	41.33	7.73	34.12	1.24	0.08	0.2209	0.47
Ash contents	K_2O	Na_2O		Al_2O_3	Fe_2O_3		CaO
	6.31	1.80		4.52	2.99		5.55
	MgO	TiO_2		SiO_2	Cl		Ash
	3.07	0.16		62.08	-		4.65

^a M_{ar} = moisture.

^b A_{ar} = ash.

^c V_{ar} = volatile matter.

^d FC_{ar} = fixed carbon.

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