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Study on Semi-Gasification Combustion Technology of Stover

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Abstract: In order to develop a mechanism of clean and efficient combustion, this study studied the combustion mechanism of stover semi-gasification by a clean stove designed. The experimental material was corn Stover briquettes. Process of semi-gasification combustion can be divided into two parts: gasification stage and combustion stage. First, under the low primary air amount, stover gives off partly combustible gas (Volatile matter). Then, the combustible gas rises and burns in the upper Furnace when it meets higher secondary air amount. At the same time, the residue remained in bottom Furnace keeps on gasifying and burning under high temperature until the fuel is exhausted. In the process, two phases (solid and gas) combustion becomes into one phase (gas) combustion. Due to inadequate primary air and low temperature of semi-gasification chamber (550-750℃), all the ash was loose and no slag was found. Moreover, combustible gas produced was directly completely burned off and no tar appeared in the emissions. According to the result, the combustion thermal efficiency of clean stove (75%) is up to 75% and higher than primary stove (below 12%).

Keywords: Clean stove, efficiency, emissions, semi-gasification

INTRODUCTION

Stover is a kind of agricultural residue available in the world, which includes husks, leaves and stalks and so on. Stover has served as one of the primary energy forms utilized by humans for essential activities aside from nutritional from ancient times to the present. Stover is carbon neutral, i.e., the carbon emitted during their combustion is taken up in the re-growth of the biomass used to produce them, and has been used as an alternative energy biomass used to produce them. Currently, Stover has been used as an alternative energy source to abate the current energy and the greenhouse gas problems (Christiansen, 2009; Foley, 1978; Morey and Thimsen, 1980).

The amount of stover is tremendous, about 2.9 billion tons estimated globally every year. In China, stover is also abundant, about 0.7 billion tons every year. In the past, only a little part was utilized by the obsolete stoves (the thermal efficiency was very low, below 12%, Fig. 1), now, it has been used as fuel for generation in the power plant by direct combustion or gasification combustion. However, direct combustion or gasification related problems have more than occasionally been observed in Stover burners since it substituted for fossil fuel, which is caused by stover itself. Compared to fossil fuels, stover contains high levels of potassium and other alkalis which vaporize or react with other elements as they pass through the boiler during Stover direct combustion, partially condensing to form stick deposits on metal and refractory surfaces (Tomas *et al*., 1996) and then corrupting them; more organic compounds are very serious obstacles for stover gasification, when it is gasified, a lot of tar appears, which plugs up and corrupt the pipes. So, it is necessary to develop a mechanism of clean and efficient combustion.

Fig. 1: Ordinary obsolete stove, in China

Recognizing these, this study initiated to study the combustion mechanism of stover semi-gasification.

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Fig. 2: Corn stover briquettes extruded from HPB-III briquetting machine

MATERIALS AND METHODS

Concept of semi-gasification combustion: Process of semi-gasification combustion can be divided into two parts: gasification stage and combustion stage. In general, the primary air gets into stove from the bottom of stove and the second air gets in from the outer in the upper of stove. First, under the primary air, stover is ignited and gives off partly combustible gas (Volatile matter). Then, the combustible gas rises and begins to burn in the upper Furnace when it meets secondary air, at the same time, the residue remained in bottom Furnace keeps on gasifying and burning under high temperature until the fuel is exhausted. The result is that two phases (solid and gas) combustion becomes into one phase (gas) combustion, which reduces the emissions of particulates and CO and improves the indoor air quality.

Stover samples: This study took corn stover as experimental material, which were from Zhengzhou surrounding farmlands. Considering the low bulk density of corn stover, corn stover was compressed into briquettes (50 mm diameter-80 mm length) by HPB-III briquetting machine (Fig. 2). Unit density and moisture content of the briquettes were respectively 0.8-1.2g/cm^3 and 10-15% (w.b.). The components of organics in corn stover and calorific value and proximate analysis of corn stover briquettes are shown respectively in Table1 and 2.

Test device and instruments: To study the combustion mechanism of stover semi-gasification, a clean stove was designed and developed. Structure of clean stove is shown in Fig. 3.

In the experience, the components and parameters of exhaust gas were obtained by Flue Dust and Gas Measuring Instrument (Leibo3020).

The collected slagg deposits from the burner were characterized with X-ray Diffraction (XRD), Scanning Electron Microscopy (SEM) combined with energy-dispersive X-ray analysis (EDS).

To judge the design and running level of the clean stove, combustion thermal efficiency η was calculated by positive equilibrium method according to effective amount of heat consumed and its formula was:

$$\eta = \frac{100D(h_{cs} - h_{gs})}{BQ_{net \cdot ar}} \tag{1}$$

Table 1: Components of organics in corn Stover (% of dry matter)

Ash	Neutral detergent fiber	Cellulose[a]	Lignin[b]	Hemicellulose[c]
6.2	23.0	37.5	8.4	25.9

a Cellulose = acid detergent fiber – lignin; b Lignin values measured for the biomass materials were acid insoluble lignin contents (not total lignin contents, which would be much higher than the values reported in Table 1 (Kaliyan *et al*., 2009); c Hemi cellulose = neutral detergent fiber–acid detergent fiber; the hemicelluloses content is higher than cellulose content because of the approximate estimation of hemicelluloses content by the difference between neutral detergent fiber and acid detergent fiber contents

Table 2: Calorific value and proximate analysis of corn Stover briquettes (%)

C_{ad}	H_{ad}	N_{ad}	S_{ad}	O_{ad}	M_{ad}	A_{ad}	V_{ad}	F_{cad}	$Q_{net.ad}$ KJ/Kg
42.59	3.80	0.70	0.15	37.80	7.96	7.00	70.60	14.50	15840

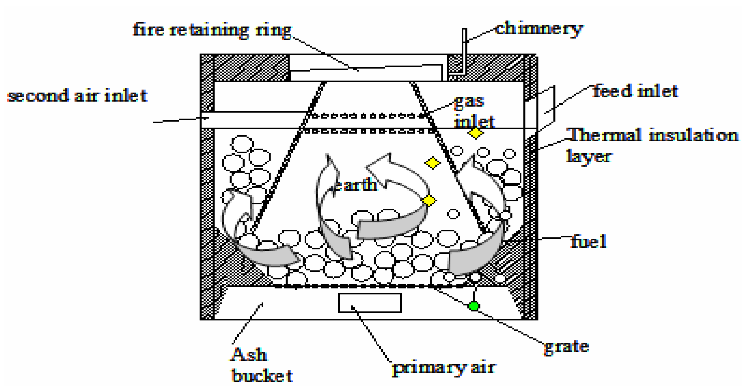

Fig. 3: Structure of clean stove

Table 3: Emissions from primary old stove

Emissions	Value
CO_2	18-22mg · m^3
CO	0.1%
NO_X	120 mg/m^3
SO2	12.5 mg/m^3
Ringelman black, level	<1
flue dust density	25 mg/m^3

Table 4: Main substance phases detected with XRD in corn Stover ash samples

KCl	SiO_2	$K_3Na(SO_4)_2$(aphthitalite)	K_2SO_4

where,

- B = The amount of fuel consumed every hour kg/h
- $Q_{net.ar}$ = The calorific value of fuel's received basis kJ/kg
- D = Average amount of hot water kg/h
- h_{gs} = The enthalpy of supplied water kJ/kg
- h_{cs} = The enthalpy value of hot water, kJ/kg

RESULTS AND DISCUSSION

Emissions: Due to the obsolete stoves are used or the heating units are inappropriately used or poorly maintained, the corn Stover as a fuel for heating purposes in residential areas can lead to low air quality and health risks. Many studies show that pulmonary tuberculosis and Asthma are related to the indoor air pollution. Emission regulations are necessary to protect inhabitants from hazardous exhaust gases and dust and to encourage manufacturers to use cleaner stove. The emissions from clean stove designed are shown as follows (Table 3).

From Table 3, no tar is found in the emissions, which showed that combustible composition was burned off and changed into CO_2, CO and so on. Yet, Ringelman black, level, density of flue dust density and CO are very low, thus it can be seen the gases from fuel in the clean stove completely burn out.

Ash and slag: When using corn stover as fuel, slagging was hardly found in the domestic stoves, due to the low temperature in the combustion chamber, while tendencies of severe slagging in some larger burners could be detected for the maximum combustion temperature appeared and was estimated to about 900-1150°C in the region where the slag was formed, i.e., on the grate.

In the experiment, because the primary air is not sufficient for the combustion corn of Stover briquettes, the temperature of semi-gasification chamber is low, about 550-650°C, well below the temperature that slag was formed. All the ash was loose and no slag was found. The collected ash samples from clean stove grate were analyzed with XRD, the Main substance phases were; These analyses showed that the ash formed consisted mainly of KCl, Si O_2, $K_3Na(SO_4)_2$ (i.e., aphthitalite) and K_2 SO_4 (Table 4). Thus, the alkalis

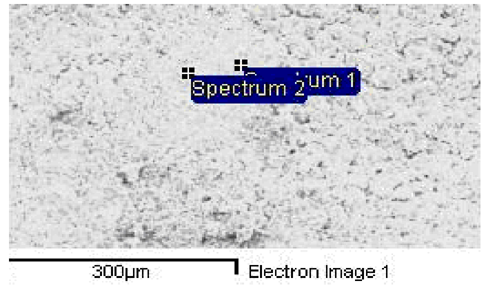

Fig. 4: SEM picture of ash sample

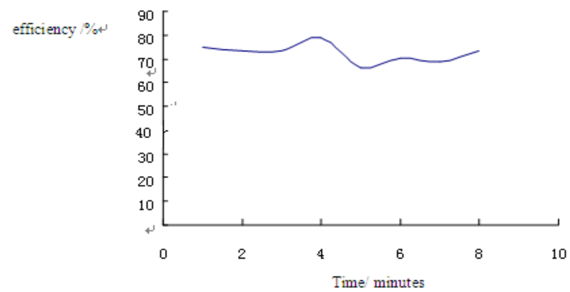

Fig. 5: The efficiency of combustion devices

(e.g., K, Na) and other substances produced chemical compounds and remained in the ash. The results from the SEM/EDS analysis of the ash samples also confirmed that almost all Cl, K and other alkalis from corn Stover remained in the ash (Fig. 4 and Table 5).

Combustion thermal efficiency: Taking some corn Stover briquettes into the clean stove, the temperature of supplied water and out water were respectively 6°C and 75°C. The rate of flow was 400 kg/h. According to Formula 1.1, the combustion thermal efficiency of clean stove is about 70% (Fig. 5), which exceeds that of primary stove (10-12%); when two buckets of water (each is 7 kg and the initial temperature is 6°C) were respectively heated to boiling (100°C) by the clean stove and primary stove, the clean stove needed 8minutes and the primary stove needed 25 min, which showed that the fire intensity of clean stove is higher than that of primary stove.

CONCLUSION

There is not the problem of slags on the grate and depositions on the heating surface found when stover is combusted in the semi-gasification way and no tar appeared, either. The efficiency of semi-gasification combustion stove designed is higher than that of obsolete primary stove. So, in residential area, the semi-gasification combustion stove designed can improve air quality and health. However how to popularize semi-gasification combustion technology to the bigger

Table 5: Components detected with XRD in corn Stover ash samples with EDX

Regions	O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	Fe	Undetermined	Total
Spectrum1	44.8	0.41	2.1	2.16	31.24	1.91	0.18	0.21	10.12	3.98	0.13	1.68	1.08	100
Spectrum2	45.3	0.43	1.8	2.39	30.42	1.96	0.18	0.19	9.63	4.03	0.14	1.42	2.21	100

furnace still need further study (e.g., the design of furnace, supplied air).

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