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Experimental study on fragmental behavior of coals and biomasses during rapid pyrolysis

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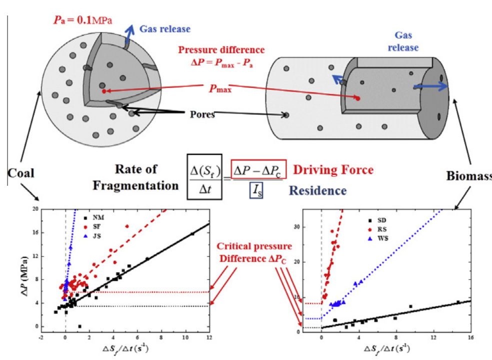
HIGHLIGHTS

- Rapid pyrolysis of different residence time was carried out in a special DTF.
- Fragmental behavior of coals and biomasses was observed.
- Viscous flow model was used in calculate the driving force of fragmentation.
- Ohm principle was employed to analyse the fragmenting process.

GRAPHICAL ABSTRACT



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ABSTRACT

In order to study the primary fragmentation behavior of coals and biomasses, experiments of rapid pyrolysis were carried out. This work focused on the devolatilization and fragmentation characteristics including the solid/gas yield, particle density/morphology, particle size and fragmental probability (S_f). The effects of temperature, time and solid property were investigated. The viscous flow model was employed to characterize the pressure difference (ΔP), which was considered as the driving force of diffusion and fragmentation. The Ohm principle was used to establish the linear relation of devolatilization rate and fragmentation rate. The result showed that temperature and time have positive contribution to the fragmentation. The occurrence of fragmentation was observed more apparently with the decreasing of the ash content in the biomass. The pressure difference has a positive correlation with the fragmental rate, which shows the validity of application Ohm principle in the prediction of fragmenting process.

1. Introduction

Biomass is a renewable and clear energy which offers a potential alternative to the fossil fuels. Biomass has advantages in reactivity and low S & N content (Emami-Taba et al., 2013), however it still confronts such drawbacks including low heating value, high spending on transportation, storage and feeding (Krerkkaiwan et al., 2013; Li et al., 2014). These features make it difficult to gasify biomass in large scale. In order to utilize biomass efficiently, an increased interest has impelled recent efforts towards co-gasification of coal and biomass blend to reduce the emissions of pollutants and CO_2 (Zhang et al., 2016; Yu et al., 2015; Peng et al., 2012; Yuan, 2012; Fermoso et al., 2010). In co-gasification process, biomass ash which has a high alkali-content may give a catalytic effect on coal conversion (Brown et al., 2000). Such effect is strongly affected by the particle shape and size, which determines the contact between catalytic compound and carbon. During

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Nomenclature

P	pressure in the particle from the released gases (MPa)	r_{pore}	average pore radius responsible for volatiles transport (m)
P_{max}, P_a	pressure at the particle center (maximum), pressure of atmosphere (MPa)	μ	viscosity of released gases (Pa s)
ΔP	pressure difference between particle center and atmosphere, $\Delta P = P_{max} - P_a$ (MPa)	T	temperature in Kelvin unit (K)
S_f	fragmentation probability	R	gas law constant, 8.314 J mol^{-2} K^{-1} (J mol^{-2} K^{-1})
Is	resistive stress impulse of particles against the fragmentation (MPa s)	ε	porosity of the solid
N	molar flow rate of released gases in coal particles (mol m^{-2} s^{-1})	r, R	particle radial position, particle external radius (m)
N_l, N_r	molar flow rate of released gases in axial and radius direction in biomass particle (mol m^{-2} s^{-1})	l, L	cylinder axial position, half length of the cylinder (m)
		n_g	molar number of released gas from 1 kg coal (mol kg^{-1})
		t	pyrolysis time of particle (s)

rapid pyrolysis, the first step of gasification, the particle morphology (Pereira and Pinho, 2014), solid conversion efficiency (Senneca and Cortese, 2014; Kim et al., 2016) and ash formation (Baxter, 1992) are strongly affected by the occurrence of primary fragmentation. Investigation on primary fragmental behavior of biomass and coal is essential to have a further understanding of co-gasification mechanism.

The fragmentation characteristics of solid fuels is widely different (Scala and Chirone, 2004) and many factors have impact on the fragmentation. During the devolatilization, these factors are mainly on two sides, the driving forces from the thermal process and the resistance from the particle structure. Thermal process is the main cause of fragmentation and the release of volatile is one of the main driving forces of course fragmentation (Senneca et al., 2016, 2013). It was reported that the fuel solid with higher volatile content is more fragile (Scala and Chirone, 2004). Also, at a rapid rate of devolatilization, the fragmentation was observed to be more intense compared to mild heating process (Senneca et al., 2011; Sreekanth, 2014). On the other hand, the particle structure is the primary force to prevent itself from breaking up; this kind of resistance depends on its own strength. The fragmentation of coals is closely connected to coal rank (Friedemann et al., 2016, 2014; Kim et al., 2014), that the coal of lower coalification has a loosely porous structure and tends to be fragile during the pyrolysis. Another interesting research reported that the fragmentation of solid after palletization became less apparent than the parent particles (Ammendola et al., 2011, 2013; Miccio et al., 2013; Chirone et al., 2008), which seems to be attributed to the improvement of particle compactness. In addition, the size and shape of the particles (Sreekanth et al., 2008; Scala et al., 2006), which may have effect on both sides, also affected their fragmental characteristics.

This work was concentrated on primary fragmentation of coals and biomasses during rapid pyrolysis. We propose to use the Ohm principle to analyse the mechanism of driving force on particle fragmenting. This principle has been widely used in describing a complex chemical or physical process (Alan et al., 1980). It assumes that the rate of a certain process is proportional to the driving force meanwhile inversely proportional to the resistance. The pressure difference between particle center and outer shell (ΔP) was calculated based on the diffusion model, which was regarded as the driving force. Also, a series of parameters describing the devolatilization behavior, such as the solid yield, gas release, particle density, size and shape, was measured experimentally and used in this model. The rate of fragmental probability (S_f) was calculated as the rate of fragmentation. In addition, the correlation of pressure difference and rate of S_f was studied to check the validity of application of Ohm principle in analysing the fragmentation process.

2. Materials and methods

2.1. Materials and experiment

Two kinds of solid fuels, coals and biomasses, were used in this work. Coals included NM (lignite, originated from Erdos, Inner-Mongolia), SF (bituminous coal, originated from Yulin, Shaanxi), JS (anthracite, originated from Jincheng, Shanxi). Biomasses were chosen as WS (wheat straw, originated from Shandong), SD (saw dust, from a furniture factory) and RS (rice straw, originated from surrounding area of Shanghai). The proximate analysis results and ultimate analysis results of samples were listed in Table 1 (ASTM-D5142, ASTM-D5373 and ASTM-D4239).

The coals (NM, SF and JS) were ground and meshed into a size ranging from 125 μm to 180 μm. The biomass samples (WS, SD and RS) were distributed between 180 and 250 μm. Both coals and biomasses were presented by drying at 378 K for 2 h. The physical characteristics of pretreated samples, including particles density, size and morphology were presented in Table 2 (ISO 5072:2013 and ISO 9276-6:2008).

Table 1
Proximate analysis and Ultimate analysis of biomass samples used.

Samples	Proximate analysis (wt%)				Ultimate analysis (wt%)				
	M_{ar}[a]	A_d	V_d	FC_d	C_d	H_d	N_d	S_d	O_d[b]
NM	11.58	16.64	42.31	41.05	56.37	3.81	0.82	0.29	22.07
SF	3.76	8.16	36.70	55.14	70.55	4.15	0.94	0.45	15.75
JS	1.24	14.42	8.86	76.71	81.39	1.98	1.00	0.67	0.54
WS	9.67	6.4	85.08	8.52	44.04	4.92	0.35	0.28	44.01
SD	9.69	1.34	90.92	7.74	42.39	5.64	0.79	0.44	49.40
RS	7.75	10.09	78.93	10.98	43.07	5.13	0.35	0.3	41.06

[a] M_{ar} refers to moisture as received.
[b] O was calculated by difference.