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Study of flow characteristics of biomass and biomass–coal blends

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HIGHLIGHTS

- A model on the angle of internal friction has been proposed for biomass–coal blend.
- The blend's best flow for aerated and discharge was obtained at 10 wt% of biomass.
- The effect of aeration on the flow behavior of materials was studied in detail.

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ABSTRACT

The flow characteristics of biomass and biomass–coal blends were demonstrated experimentally by investigating the shear properties, flow energy and aeration with a FT4 Powder Rheometer. The results show that the addition of biomass into coal has no effect cohesion strength but significantly increases the angle of internal friction. We propose an improved empirical correlation to describe the quantitative relationship between angle of internal friction and particle shape factor, which agrees well with the experimental data. With the increase of biomass mass fraction, the flow energy was found to exponentially increase and the flow of blends became unstable, which produce a critical mass fraction to obtain an optimum flow performance of biomass–coal, i.e., 10 wt%. It is apparent that the flow behavior of biomass–coal blends is very sensitive to aeration, but torpid for biomass particles due to its high permeability. It indicates that biomass is not suitable for dense-phase pneumatic conveying.

1. Introduction

Gasification of biomass and co-gasification of biomass–coal blends are good approaches to make full use of biomass in energy applications. Mostly previous studies [1–5] have been focused on thermo-chemical conversions of biomass–coal blends and biomass due to its economic and environmental benefits, but few researches pay attention on the flowability of biomass–coal blends. Understanding the flow properties of biomass–coal blends and biomass have a significant impact for blends trouble-free flow in dense phase pneumatic conveying system. The characterization of the flow properties of biomass–coal blends is especially important for the design of reliable storage devices and composition of the product gas during co-gasification process [6–8]. Therefore, it is essential to investigate the flow ability of biomass and biomass–coal blends.

Traditional approaches for demonstrating granular flow behavior have largely depended on the investigation of angle of repose [9,10], bulk density [11] and angle of internal friction [12], etc. In recent years, there have been many researches on characterizing biomass flowability [13–17] due to the increasing interest on biomass fuels. Since the first step of utilization of biomass is grind into a certain particle size [18,19], the breakup model of biomass particle was proposed, and it has been proved to possess universal application. Owing to biomass substance construction and anisotropic in spatial structure, mostly biomass particles has needle-shaped after breakup. The biomass particle shape and particle size distributions of four kinds of biomass samples have been explored quantitatively by images analysis [20–22]. Some studies [23–25] indicated that the biomass particle flowability is closely linked with its shape and its moisture content in the utilization process. In addition, Dai and Grace [26] proposed a comprehensive presentation what is the mechanism of biomass particle blockage in screw feeding and how biomass physical properties (particle mean size, shape, moisture content and density) affect its feeding.

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Nomenclature

R	blade radius (mm)	Φ_{IC}	angle of internal friction of coal (°)
F	axial force on the blade (N)	Φ_I	angle of internal friction of mixture (°)
T	torque acting on blade (Nm)	σ	the normal stress (kPa)
d_s	small particles diameter (μm)	τ	the shear strength (kPa)
d_b	large particles diameter (μm)	w	biomass particles mass fraction (%)
A	average aspect ratio of biomass particles	ρ_b	bulk density of granular materials (kg/m^3)
C	cohesion of powders (kPa)		
R	roundness of granules		

Greek letters

α	helical path angle (°)
μ	gas viscosity (Pa s)

The flowabilty of pulverized coal has been extensively researched due to the dominate status in China. Numerous experimental studies [27,28] have found that its flow behavior highly depends on material properties such as particle size, shape and surface roughness of particle material. For biomass–coal blends, since the flowability is multidimensional, its quantification is a burdensome issue. A pioneering work [29] presented a model to propose a quantitative expression about the angle of repose of mixed granular system, so as to estimate succinctly the flowability of binary mixture, which gives a qualitative understanding of the influence of physical parameters on mixed granular flow behavior. Conventional wisdom would insist that the presence of biomass particles in a binary solids mixture would negatively affect the flowability of the blend because its irregular shape generates large resistance to inception of flow. However, from other viewpoint, adding biomass particles into pulverized coal may significantly improve the flowability of the cohesive pulverized coal particles due to the reduced cohesive strength [30]. While it is well known that aeration can improve flowability of cohesive powders [31–33], so far there are still few reports on the biomass–coal blends and more work is needed.

Motivated by the studies cited above, we carried out a further study to present the flow behavior of biomass and biomass–coal blends, which provides new insights for us to understand and analyze the flow problems. The paper is to systematical study the flow characteristics of biomass and biomass–coal blends with a FT4 Powder Rheometer, aiming to provide the essential data for the success of biomass–coal blends in dense phase pneumatic conveying system.

2. Materials and methods

2.1. Materials

Shenfu bituminous coal and two representative biomass particles (rice straw and sawdust) were chosen, and whose physical properties were listed in Table 1. Fig. 1a shows the cumulative particle size distribution functions of Shenfu bituminous coal, which is

Table 1
Material properties.

Material	Sample number	Moisture content (wt%)	ρ_b (kg/m^3)	Average length (μm)	Average width (μm)	Average aspect ratio	Average surface roughness
Coal	a	1.92	517				
Rice straw	I	1.28	222	206	97	2.25	0.612
	II	1.36	200	465	145	3.64	0.584
	III	1.06	190	2415	384	8.22	0.552
Sawdust	I	1.81	219	187	94	2.07	0.586
	II	1.47	186	425	138	3.34	0.563
	III	1.25	166	1375	337	5.61	0.511

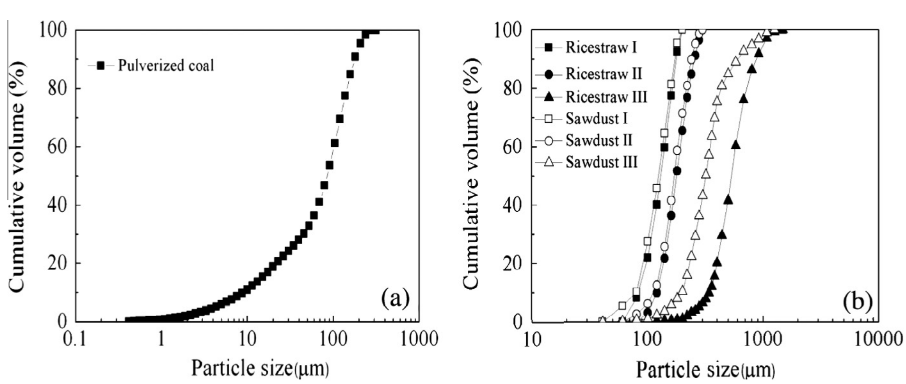

Fig. 1. The cumulative distribution functions of experimental materials. (a) Measured by a particle size analyzer of Malvern Mastersizer 2000. (b) Measured by a particle image analyzer of BT-2900.