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Research article

The effect of water addition on the surface energy, bulk and flow properties of lignite

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ABSTRACT

In this paper, the relationship between angle of repose, surface energy and bulk and shear properties of different particle size distribution lignite pulverized coal with different moisture content was experimentally investigated. The dry sample and wet sample were prepared under relative humidity 0% and 90%. The interactions between coal samples and polar or non-polar gaseous probes were investigated by the surface energy test with an inverse gas chromatography (IGC) technique. The compressibility test and shear test were taken by the FT4 Powder Rheometer. The changes in bulk and flow properties of different particle size distribution samples were collected as a function of water content. The results show that water content plays a significant role on the packing and flow behaviors and surface energy of the dry and wet different particle size lignite pulverized coal. The IGC tests results showed that for the relative humidity 90% samples, the water was the interior water, which played a role of improving the flowability. In the end, a model was proposed to study the relationship between angle of repose and surface energy and flowability. The model could easily predict the relationship between angle of repose with wet and dry particles. This research will provide a better understanding on how water content affects surface characteristic and the flow properties of lignite particles and will benefit to optimize the relevant unit operations.

1. Introduction

Entrained-flow pressurized gasification process, including the storage, discharge and pneumatic conveying of pulverized coals, is one of the best contemporary carbon gasification technologies [1,2]. There are various gasification materials, involving in coal, biomass, pet coke and etc. [3] Because of limitation of the energy structure and the storage of coal, lignite coal is the most widely used in the entrained-flow pressurized gasification process [3–5]. During the entrained-flow pulverized coal gasification process, moisture content of the coal is usually controlled below 2 wt% for the smooth and reliable feeding system, which needs huge amount of heating resources [6]. If the moisture content of lignite pulverized coal, rich in water, is reduced to a smaller level where the flowability will not be influenced greatly, it will make significant potential economic benefits [7]. Therefore, the study of water addition on the lignite coal is very important.

The reliable handling of wet particles is a requisite for a successful industrial application, but it still represents a scientific and technological challenge. The handling and processing of wet powders require a good understanding of their bulk mechanical behavior such as cohesiveness, flowability and aggregation [8–10]. For the particulate material, many bulk mechanical properties are related to inter-particle forces, such as van der Waals, capillary and electrostatics forces. Suitable powder conditioning may minimize the influence of capillary and electrostatic forces. However, without altering the powder composition and particle size distribution, it is not possible to change the effect of van der Waals forces in dry powders. Van der Waals force depends on the material surface free energy [11–13].

In this paper, the methodology of shear test, angle of repose test, compressibility test and surface energy test are taken to analysis the influence of moisture content on different particle size distribution. The surface energy of particles is the analogue of surface tension of liquids and determines several chemical and physical properties of materials. For example, a high surface energy means a more reactive surface [14,15]. Surface energy has also important implications in interfacial interaction processes, such as wetting, coating, mixing, compaction, cohesion and adhesion [16–18]. The surface energy determines the interactions between particles themselves as well as with other surfaces [19]. These properties require a better understanding on particles, which have not been well understood. Measurements of surface energy

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Nomenclature

AN	acceptor number
AOR	angle of repose
BET	Brunauer, Emmett and Teller
C	cohesive strength
d	particle size
d_e	equivalent mean particle size
d_s	mean surface diameter of the particles
DN	donor number
F_{ad}	inter-particle force
g	gravity
$\triangle G$	free energy
$\triangle G^d$	adsorption free energy
ΔG^{sp}	specific free energy
K	model parameter
$k_{1,2,3,4}$	coefficient of proportionality
K_A	Gutmann acid numbers
K_D	Gutmann base numbers
n	the spread of particle sizes
n/n_m	surface converge
N_A	the number of Avogadro
n_c	contacts per unit fracture area
n_{cp}	the number of micro scopic interparticle contacts per unit fracture surface area
n_{pp}	the number of macroscopic interparticle contacts per unit fracture surface area
m_1	model parameter
M_t	moisture content
R	the gas constant
R(d)	particle size distribution function
T	the temperature of measurement (*K*)
p	model parameter
V_N	the retention volume
a	the cross sectional area of the probe
γ	surface energy
γ^D	dispersive surface energy
γ_l^d	liquid dispersive surface energy
γ_s^d	solid dispersive surface energy
ρ_p	true density
$\rho_{b,0}$	bulk density
φ	the bed compactness
φ_i	angle of internal friction

of particles involve determination of long and short-range intermolecular forces, which are commonly described as London dispersive and acid/base interactions respectively [20]. Unlike flat surfaces of materials, such as the biomass particles, whose surface energy can be easily determined by contact angle measurements, the powder materials are hard to perform such measurements [21]. In this research, we used a Surface Energy Analyzer (SEA) to determine the surface energy of the lignite. Many people have studied the influence of particle size distribution and moisture content on the particle system from the stand point of flowability [22–27] and surface energy [28–31]. Sometimes the addition of moisture content is carried out by the change of relative humidity. And many researchers also studied the effect of humidity on powders [32–39]. They have concluded that with the increase of moisture content, the flowability of the particle system would be poorer [6]. Among these studies, the study of the addition of moisture content in the lignite pulverized coal by the humidity, like our system, there are few studies. Through our study, the addition of this kind of moisture content will improve the flowability. The flowability of the particle system is influenced by the particle contacts. The particle contacts can be determined by the Rumpf equation or the modified Rumpf equations to study the relationship between tensile strength and interparticle forces [32–34]. This method can provide people a quantitative description of the relative strength among particles.

To better guide the industrial process, this study also investigates the relationship between particle-scale interactions dominated by the cohesive van der Waals force and powder flow performance. For the experiment materials, the surface energy was determined from the particle scale. The compressibility test and angle of repose test was carried out from the bulk scale. In the last part of the paper, the relationship between the bulk and surface properties was established by using a model to predict the angle of repose. These results will be helpful to gain process control on unit operation such as storage, discharge and pneumatic conveying.

2. Materials and methods

2.1. Materials

The lignite pulverized coal was obtained from Yangzi Petrochemical Company limited in China and used without any modifications. The raw sample was sieved by air classifier (Retsch AS200 Jet Air). The particle size distribution of the particles was measured with a particle size analyzer (Malvern Mastersizer 2000MU) (Fig. 1). The particle size

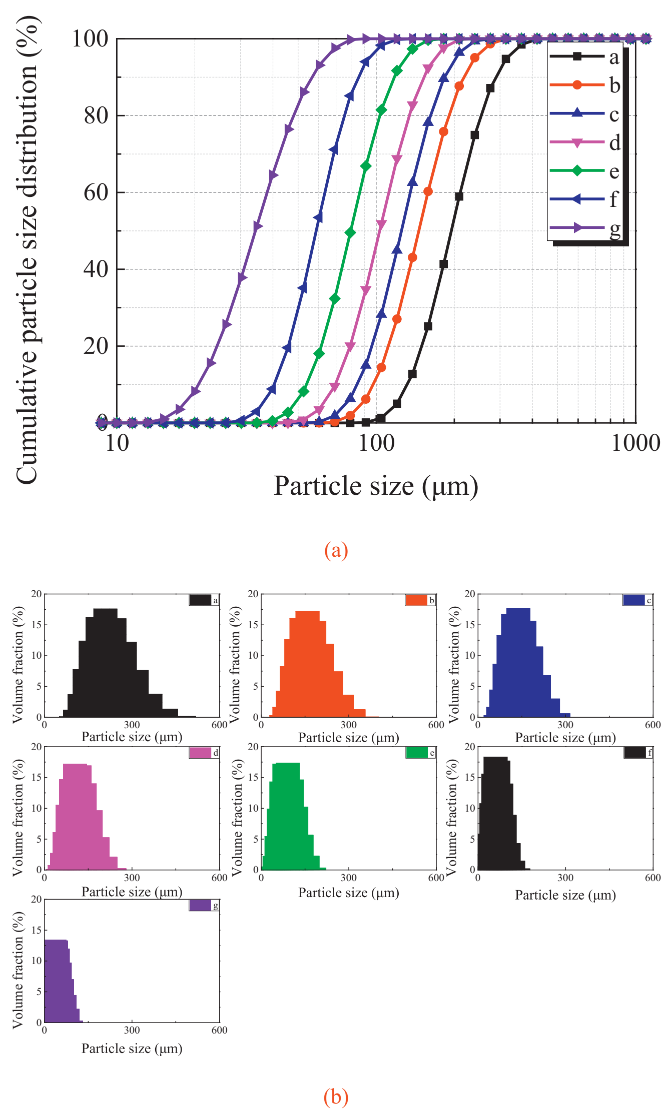

Fig. 1. The Mastersizer 2000 particle size distribution for the lignite pulverized coal particle. (a) cumulative particle size distribution; (b) histograms of particle size distribution.