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The utilization of sewage sludge by blending with coal water slurry

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ABSTRACT

The effects of blending sewage sludge on the properties of coal–sludge slurry (CSS), such as solid loading, apparent viscosity, rheological behaviour and stability, were systematically investigated. The size and morphology of particles, and grinding efficiency were analyzed. The experimental results showed that adding sewage sludge can improve the grinding efficiency and stability of slurry. CSSs prepared from Yanzhou coal, Jiangxinzhou sewage sludge and Yangzi sewage sludge exhibit pseudo-plastic behaviour with an apparent viscosity decreasing with increasing shear rate. Both CSSs, containing 10 wt% Jiangxinzhou sewage sludge and 15 wt% Yangzi sewage sludge, with about 60 wt% solid loading and 1200 mPa s apparent viscosity, are suitable for theirs handling in preparation, transport, storage, atomization, and combustion processes.

1. Introduction

The sewage sludge production from wastewater treatment plants is increasing rapidly all over the world. The sewage sludge usually concentrates not only high contents of moisture, but also high contents of volatile matters, heavy metals, poorly biodegradable trace organic compounds, and potentially pathogenic organisms, which are hazardous to the environment. The treatment and disposal of sewage sludge is becoming an urgent problem on a global scale [1–3].

At present, various options are available for sludge handling, such as recycling in agriculture, landfill, incineration and pyrolysis [4–7]. However, these methods either cause the secondary pollution, or need a large amount of cost in the process [8]. Therefore, it is important to develop a suitable treatment technology to reduce environmental problems and treatment costs.

The sewage sludge can be used as an energy resource. In order to utilize caloric value sufficiently in the sewage sludge, it is more and more frequently combined with various types of fuels to yield blends which are adjusted, both from the viewpoint of their energy potentials and physical properties, to the intended utilization processes [9,10].

As an energy-containing material, sludge can be made into slurry-based fuel by blending with coal powders [11–14]. This coal–sludge slurry (CSS), much like coal–water slurry (CWS), can be pumped, transported in pipelines and combusted in industrial boilers and furnaces with an environmentally benign manner [15–20]. Using this method, heavy metals in the sewage sludge are trapped in ash during the fusion of coal ash, avoiding secondary pollution. At the same time, some metals in the sewage sludge may reduce the coal ash fusion temperature [21–24]. This process does not require pre-dried sewage sludge because a certain quantity of water is needed for CSS. Since the main solids in CSS are coal, effective gasification also meets the industrial criterion. Preparation of CSS is the most important point for gasification technology, because only if a certain quantity of sewage sludge is mixed with CWS will the method be useful for sludge disposal [25].

As a special CWS, it is necessary for CSS to display excellent fluidity and stability suitable for its handling in preparation, transport, storage, atomization, and combustion processes. High solid loading and low viscosity are desirable properties for CSS [26,27]. The solid loading of coal–sludge slurry should be increased as possible to reach a high level of heat value. Meanwhile, the viscosity should be low enough to facilitate preparation, pumping, and atomization of the slurry. However, rich interstices and fluffy structures endow sludge with a strong water-bonding ability. The viscosity of slurry exhibits an increase after sludge is added [28,29].

This paper provides a suggested route for the use of the sewage sludge. The CSS samples were prepared by mixing the raw sewage sludge with CWS according to different mass proportion. The apparent viscosity, particle size distribution, morphology, rheology behaviour and stability of CSS were investigated.

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2. Experimental

2.1. Materials

Coal taken from Yanzhou mine and sewage sludge samples supplied by Jiangxinzhou wastewater treatment plant and Sinopec Yangzi petrochemical company Ltd., respectively, were chosen for the study. The proximate and ultimate analyses of coal and sewage sludge samples are given in Table 1.

An anionic surfactant, naphthalene sulfonate formaldehyde condensate (NSF), was selected as a dispersant. The dispersant (dry basis) was fixed at a constant dosage of 0.8 wt% based on dry coal basis.

2.2. Coal–sludge slurry preparation

The slurryability of the sewage sludge pretreated by alkali could be improved [12]. In this study, a 2 mol/L NaOH solution was added to sewage sludge and thoroughly mixed by stirring. The mass ratio of NaOH solution to sewage sludge was 10 wt%. The raw coal was crushed in jaw and roll type crushers to obtain particles of sizes less than 3 mm. The crushed coal particles, dispersant, distilled water and treated sewage sludge were comminuted in a ball mill to obtain coal–sludge slurry samples.

The solid loading was accurately determined from the weight loss measured after drying in an oven at 105 °C for 2 h. Before testing, a slurry sample was always thoroughly mixed by stirring to ensure homogeneity.

2.3. Particle size distribution measurements

The particle size distribution (PSD) of slurry sample was determined by Mastersizer 2000 (Malvern Ltd., Britain).

2.4. Scanning electron microscopy measurements

The morphology of the solid particles of slurry was studied with a Shimadzu Superscan SSX-550 scanning electron microscopy (SEM). The slurry sample was dried, and the solid was dispersed in ethyl alcohol by ultrasonic vibration for 30 min before measure.

2.5. Viscosity and rheology measurements

The apparent viscosity of slurry was measured using Brookfield DV-II + Pro rotary viscometer made in America. The principle of operation of the rotary viscometer is to drive a spindle which is immersed in the test fluid through a calibrated spring. The viscous drag of the fluid against the spindle is measured by the spring deflection. Spring deflection is measured with a rotary transducer. At a constant temperature of 25 °C, measures were performed using the standard LV-4 spindle.

The shear-dependent rheological properties of the samples were determined by changing the shear rate from 0 s^{-1} to 100 s^{-1} then acquiring the resulting apparent viscosity as a function of shear rate.

2.6. Static and dynamic stability measurements

The evaluation of stability was based on the CWM Quality Testing Methods (GB/T 18856.5-2008 Test methods for coal water mixture China, 2008) [30]. The static stability of slurry could be estimated after the slurry sample statically held for 7 days. The static stability could be determined according to the mass ratio of the supernatant to the total water in the sample.

The dynamic stability of slurry could be estimated after the slurry sample was continuously vibrated for 24 h on a vibrating platform with 2 mm horizontal amplitude and 200 times per minute frequency. Likewise, the dynamic stability could be determined according to the mass ratio of the supernatant to the total water in the sample.

3. Results and discussion

3.1. Study of CSS slurryability

CSSs were comminuted and prepared in the ball mill by blending sewage sludge with coal, water and dispersant in different mass proportions (the mass ratio of raw sewage sludge to total slurry). When the blending proportions were adopted, the solid loading was varied and the viscosity data at shear rate 100 s^{-1} was recorded. The results are presented in Figs. 1 and 2.

It is seen in Figs. 1 and 2 that the apparent viscosity of CSS increases when the solid loading increases. Sludge flocs have fluffy structures and rich interstices, resulting in a strong water-bonding ability. Therefore, CSS exhibits an increase in viscosity after sludge is added.

The characteristics of slurries with different sewage sludge blending proportions are given in Table 2. As is observed in

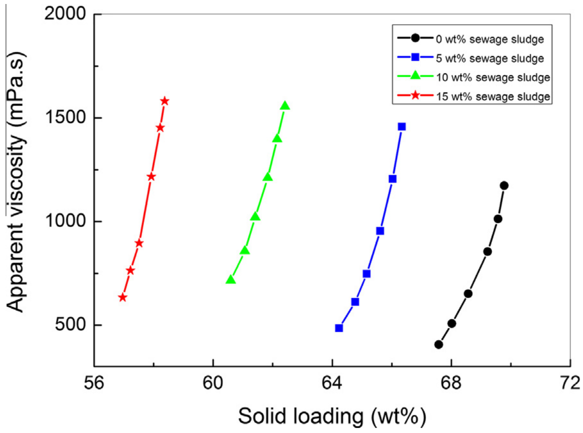

Fig. 1. Effect of Jiangxinzhou sewage sludge blending proportion on the apparent viscosity and solid loading of CSS.

Table 1
Proximate and ultimate analyses of coal and sewage sludge samples.

Sample	Proximate analysis (wt%)				Ultimate analysis (wt%)				Q_d (MJ/kg)
	M_{ar}	A_d	V_d	FC_d	C_d	H_d	N_d	S_d	
Yanzhou coal	7.81	14.05	27.35	58.60	68.85	3.97	2.35	0.66	29.05
Jiangxinzhou sewage sludge	84.74	58.46	35.53	6.01	17.85	4.04	2.26	0.85	8.70
Yangzi sewage sludge	81.20	43.46	45.84	10.70	32.08	3.82	2.54	1.91	12.89

M_{ar} refers to moisture on received basis; A_d, V_d and FC_d refer to ash, volatile and fixed carbon on dried basis; ultimate analysis is also on dried basis; Q_d refers to higher heating value.