Fuel 141 (2015) 214–221

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Rheological properties and stability of lignite washery tailing suspensions

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HIGHLIGHTS

- Rheological properties and stability of LWTS were studied.
- LWTS has good stability and is suitable for long-term storage and transportation.
- Rheological properties were studied by rotational viscometer and pipeline system.
- The two rheological methods were compared and a rheological model was proposed.
- Dispersant NDF has no effect on stability but improves the rheological properties.

ARTICLE INFO

Article history:
Received 12 June 2014
Received in revised form 20 October 2014
Accepted 22 October 2014
Available online 4 November 2014

Keywords:
Lignite washery tailings
Rheological properties
Rotational viscometer
Pipeline test system
Rheological model

ABSTRACT

The rheological properties and stability of lignite washery tailing suspensions (LWTS) were studied as a special type of coal water slurry (CWS). The properties of LWTS in these aspects are all shown to meet the requirement of a CWS. Two test methods, i.e., a rotational viscometer and a pipeline test system, were used to study the rheological properties of the LWTS and to distinguish between theory and practice. Furthermore, a rheological model of LWTS transfer in the pipeline test system was proposed and proved to be suitable and useful in designing commercial pipeline systems. Moreover, the influence of an anionic dispersant NDF (a co-polymer of methylene naphthalene sulfonate, styrene sulfonate and maleate) on the stability and rheological properties of LWTS was studied. The dispersant NDF proved to have no effect on the stability of the LWTS, while it significantly improved the rheological properties of the LWTS.

1. Introduction

The lignite washery tailing (LWT) used in this study is a solid waste obtained from a power plant in Indonesia. Lignite from South Sumatra was first dried in a steam tube rotary dryer and subsequently combusted at the power plant. Pulverized lignite fines formed during drying were collected by wet scrubbing, and thus, a wastewater containing powdered lignite was produced. The LWT proper were obtained from this wastewater through precipitation (output of approximately 10–15 t/h). This LWT flow represents a great threat to the environment if it is disposed of incorrectly. However, the LWT is also hard to utilize, with its high water content, low calorific value and difficulties in transportation. Therefore, the disposal of LWTs is of great concern.

Coal water slurry (CWS) in China is commonly used as in clean energy applications. Considering its fine particle and high water contents, LWT is suitable for use as a CWS. Therefore, in this article, suspensions of LWTs (LWTS) were prepared for study as a CWS. Until now, the feedstock for preparing slurry has been widened from traditional bituminous coal to include biomass [1–4], petroleum coke [5–7] and lignite [7–11]. However, no research has been reported until now on the use of LWTs as a CWS. The physicochemical properties of LWTs are different from those of common coal washery tailings: it has a volatile matter content higher than common coal washery tailings, which may be because it derives from lignite. Therefore, it is necessary to study the characteristics of LWTs in all respects to evaluate if LWTs are suitable for use as a CWS. The rheological properties are always the most important

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http://dx.doi.org/10.1016/j.fuel.2014.10.067
0016-2361/

parameters of a CWS, and in this article, the rheological properties of the LWTS were first studied.

Researchers from all over the world, e.g., Boylu, Atesok and Dincer from Istanbul Technical University as well as Goudoulas et al. from Aristotle University of Thessaloniki, have extensively studied the rheological properties of CWS. The first group [12–17] considered the effect of the addition of various chemicals on the viscosity and stability of a CWS. Goudoulas et al. [8,10,18] reviewed the rheological properties of lignite–water slurries as well as the solid-loading effects. Moreover, He et al. [19] summarized the methods used for studying slurry rheology, the empirical equations modeling rheological behavior. All of these studies indicated that the slurry rheology models need to be studied further and that a more fundamental approach is desirable to develop models that can be applied to the design of commercial units.

In this study, the stability and rheological properties of LWTS were studied to determine if LWTs are suitable for use as a CWS. Two test methods, i.e., a rotational viscometer and a pipeline test system, were used to study the rheological properties of the LWTS and to distinguish between theory and practice. A fundamental rheological model suitable for the LWTS that could be useful in designing a commercial LWTS reuse system for energy recovery and environment protection was proposed. In addition, the effects of dispersant NDF on the stability and rheological properties of the LWTS were studied.

2. Experimental

2.1. Materials

The lignite washery tailings were collected from a power plant in Indonesia. The proximate and ultimate analysis results of the LWTs are presented in Table 1. The particle size distribution of the LWTs (Fig. 1) was measured by a Malvern MasterSizer 2000. Most particles were found to be between 1 and 100 μm, in accordance with the usual particle size requirements for a CWS. Therefore, the LWTS is suitable for further processing as a type of CWS.

An anionic dispersant NDF was selected for use in this study. It is a co-polymer of methylene naphthalene sulfonate, styrene sulfonate and maleate and was first proposed by Ran of Nanjing University [20]. The same dispersant NDF was also used in our previous work, and its chemical structure is shown in Fig. 2 [21]. The LWTS was prepared by mixing the LWT powder in a pot containing a known quantity of dispersant (0, 0.5, 0.8, and 1.0 wt.% of the dried LWT sample) and deionized water. The mixture was continuously stirred by an electric stirrer during the addition of LWT powder. The stirring of the slurry was then continued for another 20 min at 800–1000 rpm to ensure the homogenization of the LWTS. The solid concentration of the LWTS in this study is defined as the mass of the dry pulverized LWTs divided by the total mass of the LWTS.

2.2. Methods

2.2.1. Measuring stability

The stability of a slurry is comprised of static stability and dynamic stability. Because LWTS is usually directly transported to the furnace for combustion, its storage is more important than its transportation. Therefore, only static stability was studied. This stability was evaluated by establishing the separated water ratio after seven days of static retaining. A certain amount of LWTS (50 mL) was put into a mixing cylinder with a stopper; its weight was predetermined, and the cylinder was kept static for seven days. The weight (m_0) of the water in the slurry sample could be calculated by weighing the cylinder with the slurry sample as well as the known solid concentrations in the sample. After seven days, the water that was separated above the slurry was removed using a pipette and weighed (m_1). The stability of the LWTS was calculated according to Eq. (1).

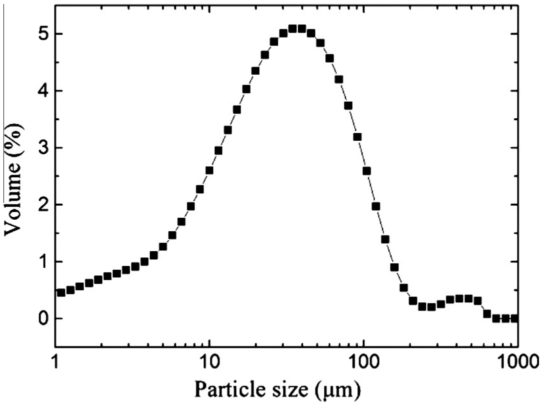

Fig. 1. Particle size distribution curve of the LWT.

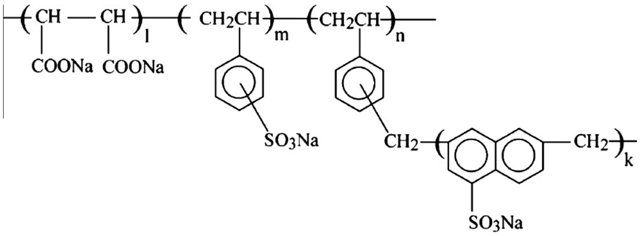

Fig. 2. Chemical structure of dispersant NDF [21,22].

Table 1
Proximate and ultimate analysis (wt.%) of the LWT.

Proximate analysis			Ultimate analysis (daf)				$S_{t,d}$
M_{ad}	A_d	V_{daf}	C	H	N	O	
10.12	18.84	55.34	66.95	5.41	1.45	>25.89	0.21

daf = Dry and ash-free base; M_{ad} is the moisture (air dried base); A_d is the ash (dry base, i.e., moisture-free base); and V_{daf} is the volatile matter (dry and ash-free base).

$$SW_{sta} = \frac{m_1}{m_0} \times 100 \tag{1}$$

where SW_{sta} (%) is the separated water ratio of the LWTS, which is directly related to the static stability of the LWTS. The higher the value of SW_{sta}, the more unstable the LWTS is. Therefore, the parameter SW_{sta} was used to evaluate the static stability of the LWTS.

2.2.2. Measuring rheological properties

2.2.2.1. Rotational viscometer. The rheological measurements were performed with a Chinese rotational viscometer (NXS-4C). This is a Couette-type rotational viscometer. The inner diameter of the outer cylinder was 40 mm, and the outer diameter of the inner cylinder was 31.8 mm. Therefore, the gap size was 4.1 mm. The LWTs were sieved (0.28-mm mesh) before the experiment was performed. Therefore, the gap size was greater than 10 times the maximum size of the particles. Moreover, the discontinuous medium problem caused by coarse particles could be ignored when using this rotational viscometer. During the experimental process, the shear rate (S) was first controlled in ascending order, i.e., at 10, 20, 40, 60, 80, and 100 s^{-1}. The measurement was then conducted six times while S was 100 s^{-1}. Finally, the shear rate (S) was controlled and decreased, following the order 80, 60, 40, 20, and 10 s^{-1}.