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Preparation and improving stability of bubble petroleum coke water slurry

Fuyan Gao [a,*], Jianzhong Liu [b], Junhu Zhou [b], Kefa Cen [b]

[a] Ningbo Institute of Technology, Zhejiang University, Ningbo 315100, PR China
[b] State Key Laboratory of Clean Energy Utilization, Zhejiang University, 38 Zheda Road, Hangzhou 310027, PR China

HIGHLIGHTS

- Petroleum coke water slurry (PCWS) may become a favorable substitute for fuel–oil.
- The development and application of PCWS are restricted by its inferior stability.
- Existence of air bubbles helps the pour rate increase by about 80 percentage points.
- The bubble-PCWS can greatly improve the stability of the slurry.

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ABSTRACT

To improve the stability of petroleum coke water slurry (PCWS), bubble-PCWS has been researched in this paper. The presence of bubbles in the slurry helps to decrease its apparent viscosity and enhance its slurryability. The three-dimensional network structures based on the bubble–particle complexes make the bubble-PCWS show pseudoplastic characteristics. Effects of the operational parameters such as aeration time, frother dosage, aperture size of air distribution plate and solid concentration of the slurry on its stability were investigated. The results showed that the stability of the bubble-PCWS increased as aeration time increased moderately and as the solid concentration decreased. Stability increased rapidly at first and then gradually decreased when increasing the frother dosage, and that the stability remained practically unchanged as the aperture size of air distribution plate varied within the experimental range. With aeration time of 30 min, frother dosage of 0.03 wt% and solid concentration of 65 wt%, the bubble-PCWS could achieve an increase of about 80 percentage points in pour rate over PCWS without bubbles under the same conditions.

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1. Introduction

Petroleum coke with high carbon content, an end product of the petroleum refining process, shows good slurryability [1,2]. As a new-type of liquid fuel, petroleum coke water slurry (PCWS) generally has high calorific value and similar flow characteristics to oil, and may become a favorable substitute for fuel–oil [3,4]. But the development and application of PCWS are restricted by its inferior stability [1,5–7]. At present, research specifically on the stability of PCWS is still not much. Wang et al. [1] worked on co-slurry ability of petrochemical sludge and petroleum coke and found that stability of PCWS improved after petrochemical sludge was added. Zhan et al. [5] found that stability of PCWS increased by using black liquor as an additive. However, all these methods had a common negative effect that mass concentration of the slurry was reduced at the same time. A new method, which can make PCWS obtain both a high mass concentration and a good stability, is desired.

There are two main reasons leading to instability of PCWS [8]. On one hand, Van der Waals forces and hydrophobic interactions between particles cause large coagulates. On the other hand, gravity sedimentation also causes agglomeration of particles, which is usually the main reason.

To overcome agglomeration of particles in slurry, this paper describes a bubble-PCWS, which produces a stable suspension of particles in slurry through buoyancy and steric hindrance of bubbles. Adsorption is one of the main forms of interaction at the phase boundary of the bubble-particle, and bubble–particle complexes can be formed because of this adsorptive action

* Corresponding author. Address: Ningbo Institute of Technology, Zhejiang University, 1 Qianhunan Road, Ningbo 315100, Zhejiang, PR China. Tel./fax: +86 574 88130123.

E-mail address: gaofuyan@nit.zju.edu.cn (F. Gao).

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[9–13]. Moreover, both air bubbles and petroleum coke particles have strong hydrophobic surfaces, which increase the stability of bubble–particle complexes [14–16]. The stable bubble–particle complexes can effectively hinder the agglomeration of particles in a slurry. In this paper, the effects of several factors (i.e. aeration time, dosage of frothers, aperture size of air distribution plate and solid concentration of slurry) while preparing bubble-PCWS on stability of the slurry were studied, and the internal mechanism involved in obtaining good stability was analyzed.

2. Experimental

2.1. Materials

A petroleum coke from Jinshan Petrochemical Co., Ltd. was used in the experiments. The proximate and ultimate analysis results of the petroleum coke sample are shown in Table 1.

The dispersing agent used was sodium lignosulfonate at a concentration of 0.8 wt% of the air-dried pulverized petroleum coke. Two kinds of anionic surface active agents, sodium lauryl sulfate (K12) and α-olefin sulfonate (AOS), were used as frothers. Frothers with amphiphilics molecular structure are adsorbed and aligned at the liquid–vapor interface. This produces a reduction in the liquid–gas surface tension and system energy, which causes air disperse in the slurry to form bubbles of smaller diameter [17].

2.2. Equipment and methods

Fig. 1 shows a flowchart of the process for preparing bubble-PCWS. The petroleum coke was ground in a ball mill to obtain pulverized samples, and particles below 100 mesh were selected by an electric sieve shaker. The petroleum coke particles, deionized water, dispersing agent and frother were mixed with an electric mixer at 1000 r/min for 10 min forming an initial bubble-PCWS. The initial bubble-PCWS was put into a container with an air distribution plate. Subsequently, compressed air (0.7 MPa, 1.5 m^3/h) was blown into the container from the bottom of the container through the air distribution plate. The samples of bubble-PCWS were obtained after a certain amount of compressed-air blow-time (0–40 min). The compressed air was produced by an air compressor, and was measured by a pressure gauge and a flow meter. In addition, thermostatic bath set to 20 °C was used to avoid the effect of variation of compressed air temperature on the nature of the slurry. Four different air distribution plate apertures were used in experiments, and aperture ranges were 40–80 μm, 15–40 μm, 5–15 μm and 2–5 μm, respectively.

The apparent viscosity and rheological properties of bubble-PCWS were measured on a rotary viscometer (NXS-4C, Thermo, China). A slurry sample was first loaded into the viscometer, and then the shear rate was increased from 10 s^{-1} to 100 s^{-1}. The relationship of the shear stress and the shear rate can be revealed in this process. Keeping the shear rate at 100 s^{-1} for 5 min, the apparent viscosity data were recorded every 30 s during a 5-minute period. The average apparent viscosity at 100 s^{-1} was calculated from the ten apparent viscosity values recorded. During the entire process, temperature was controlled at 20 ± 1 °C.

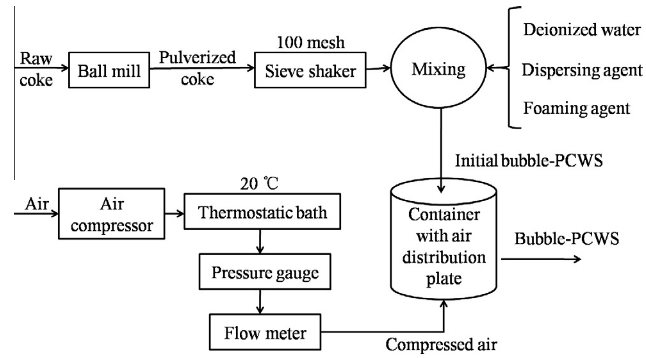

Fig. 1. Process flowchart for preparing bubble-PCWS.

The solid concentration of bubble-PCWS was determined by drying slurry in an oven at 105 °C for 2 h weighing the dried residue.

The stability of bubble-PCWS was measured by an visual method and inversion method separately. The visual method was done on the sample placed in a sealed container by observing the changes in slurry properties, such as separated water for 7 d. The rate of water separation and the ratio of separated water to the total mass of slurry, is normally used to evaluate the stability of slurry. A high water separation rate indicates poor stability. The inversion method starts by keeping the slurry in a sealed container for 7 d. Then the container is tilted for 30 s to make the slurry flow out freely, and then inverted vertically for 8 min. Finally, weigh and calculate the mass of poured slurry, and use pour rate, the ratio of poured mass to the total mass of slurry, as indicators to evaluate slurry stability. A higher pour rate indicates a more stable slurry.

3. Results and discussion

3.1. Apparent viscosity of bubble-PCWS

Fig. 2 shows the trends of apparent viscosity of the bubble-PCWSs with variations in frother dosage and aeration time when air distribution plate aperture is between 5 and 15 μm at solid concentration of 65 wt%. The apparent viscosity decreases with increasing dosage of frothers for all the bubble-PCWSs and both kinds of frothers have similar effects on the apparent viscosity, as shown in Fig. 2(a). It can be seen from Fig. 2(b) that the apparent viscosity decreases with increasing aeration time and is approximately constant when aeration time is longer than 20 min.

Therefore adding frothers and aeration decrease the apparent viscosity, which enhances slurryability. The frother itself is a surface active agent which can solely reduce viscous friction between the particles leading to much lower apparent viscosity of the slurry. Aeration helps tiny bubbles disperse evenly in slurry, which increases dispersion of the particles and reduces viscosity of the bubble-PCWS.

3.2. Rheological characteristics of bubble-PCWS

Rheological characteristics are key indicators of the quality of PCWS, which directly affects the storage, transport and

Table 1
Proximate and ultimate analysis results of the petroleum coke.

Proximate analysis/wt%				$Q_{b,ad}$/kJ kg^{-1}	Ultimate analysis/wt%				
M_{ad}	A_{ad}	V_{ad}	FC_{ad}		C_{ad}	H_{ad}	N_{ad}	St_{ad}	O_{ad}
1.07	0.73	10.0	88.2	35,461	88.77	3.55	1.01	2.22	2.65

Notes: Subscript ad stands for air-dried basis; M, A, V and FC stand for moisture, ash, volatile and fixed carbon, respectively; $Q_{b,ad}$ stands for the high heating value in air dried basis; C, H, N, St, O stands for carbon, hydrogen, nitrogen, total sulfur, and oxygen, respectively. The oxygen data are obtained by calculation.

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