Fuel 190 (2017) 182–188

Contents lists available at ScienceDirect

Fuel

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

Full Length Article

The result of surfactants on froth flotation of unburned carbon from coal fly ash

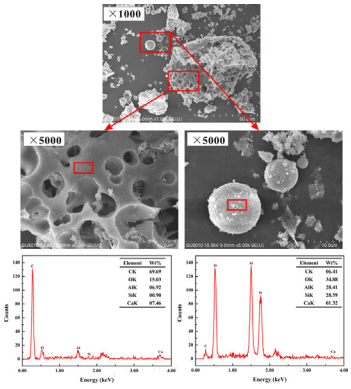
Feng Zhou [a,b], Chunjie Yan [a,b,*], Hongquan Wang [a,b], Sen Zhou [a,b], Huan Liang [c]

[a] Faculty of Materials Science and Chemical, China University of Geosciences, Wuhan 430074, China
[b] Engineering Research Center of Nano-Geomaterials of Education Ministry, China University of Geosciences, Wuhan 430074, China
[c] School of Resource and Civil Engineering, Wuhan Institute of Technology, Wuhan 430073, China

HIGHLIGHTS

- Surfactants significantly increased the recovery of unburned carbon in flotation.
- The tail length of the surfactants is important for the synergistic ability.
- The adsorption behaviour is determined by the steric effects of the surfactant.
- Unburned carbon is characterized with large porous sponge-like particles.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 24 June 2016
Received in revised form 4 November 2016
Accepted 8 November 2016
Available online 12 November 2016

Keywords:
Fly ash
Froth flotation
Carbon
Surfactants
Emulsions

ABSTRACT

The efficiency of the flotation of the fine unburned carbon from coal fly ash (CFA) is closely dependent on the dispersion of the collector on the carbon surface. In this work, we carried out the froth flotation tests of CFA using four different surfactants: Sodium Dodecyl Sulfate (SDS), Sodium Dodecyl Benzene Sulfonate (SDBS), Tween-80 (TW) and Triton X-100 (TX), to investigate the effect of surfactants on forth flotation. The surfactants were mixed with the collector kerosene at given ratios to produce the emulsions, and they were employed as promoters to increase the hydrophobicity of unburned carbon. The flotation results showed a strong relationship between the loss on ignition (LOI) and the type of the surfactants used. Flotation combustible recovery (CR) of 79.58% and LOI of 54.43% were obtained when TX was used as promoter. The removal mechanism was discussed according to the kinetic theory and surface-chemistry theory. The results of surface tension and zeta potential demonstrate that the tail length of the surfactants can affect the adsorption of kerosene significantly. Besides, the scanning electron microscopy energy dispersive spectroscopy (SEM-EDS) data indicate that the recovery of unburned carbon using TX as a synergist is apparently efficient, and reveal the microstructure of the unburned carbon and the gangue materials in CFA.

1. Introduction

CFA, as a by-product of solid fuels combustion, consist of mainly non-combustible unburned carbons and inorganic materials [1–7].

* Corresponding author at: Engineering Research Center of Nano-Geomaterials of Education Ministry, China University of Geosciences, Wuhan 430074, China.
E-mail address: chjyan@cug.edu.cn (C. Yan).

http://dx.doi.org/10.1016/j.fuel.2016.11.032
0016-2361/

The recovery and utilization of these fine unburned carbon from CFA as a significant energy source will have considerable environmental and economic benefits. The removal of unburned carbon could be achieved by physical or chemical processes such as gravitational separation [8], electrostatic separation [9] or froth flotation [10]. Among them, Flotation has been proven to be the most effective method for the recovery of unburned carbon [11].

Many researchers have investigated the recovery of unburned carbon from CFA by flotation. Bayat and Toraman [12] investigated the separation of coal Particles from soma fly ash by flotation and reported the effects of pH, kerosene dosage and temperature. Demir et al. [13] and Huang et al. [14] tested column flotation for the recovery of a municipal solid waste from the Tuncbilek power station and unburned carbon from CFA, respectively, and proposed a flowsheet for treatment.

However, common oily collectors such as kerosene and diesel oil are not capable of removing fine unburned carbon from CFA [15]. The use of oily collector alone is difficult to improve the flotation efficiency and the amount of adhesion of collector on CFA remain limited. The flotation of either coal particle or partially oxidized carbon requires the addition of surfactant to reduce the amount of oily collector, in order to yield a sufficiently high recovery of carbon and an effectively separation of CFA [16]. Molecular surfactants are preferentially adhered at the water-oil/air interface due to the non-polar (hydrophobic) chain tail and polar (hydrophilic) head group they contain [17]. This will produce an interface with high surface area to reduce the free energy, hence reducing the surface tension [18].

Surfactant can modify the hydrophobicity of the unburned carbon by acting as surface modifier [19]. Therefore the addition of surfactant to the oily collector will enhances the flotation of lower carbon content CFA because of the polar part of the coal surface and the hydrogen bonding with the reagent [20]. Besides, the way of addition of non-ionic or anionic surfactant with collector impose a strong influence on the flotation effectiveness [21]. This technology enhanced dispersion of collectors through emulsifying the oily collector with the addition of synergist [22]. The number of adhesion of collector on CFA can be increased by the emulsification of an oily collector and therefore the flotation kinetics can be improved. The simple oily collector is known to have many disadvantages such as low selectivity, poor water solubility and large dosage. In order to overcome the above weaknesses, different type of surfactants is used in combination with kerosene.

Previous investigations have demonstrated that dissolving surfactants in collectors for reactive oily collector flotation could offer the following advantages: (a) reducing the distribution of oily collector molecules in aqueous phase and then the amount of oily collector required can be minimized [23]; (b) eliminating undesired activation of gangue particles by avoiding the addition of oily collectors in the aqueous phase then [19]; (c) eliminating of unnecessary interaction among the collector [24]; (d) a stronger collecting ability can be obtained by providing a high concentration of oil droplet at the water/oil interface [25]; (e) only the targeted particles can be floated by the reactive oil droplet leading to a better selectivity [26]. Taking into account of these features, investigation of surfactants becomes evident [27,28]. However, the effect of surfactants on flotation of unburned carbon from CFA has not been well researched.

In this study, four types of surfactants were selected in order to explore the relationship between the structure and synergistic ability of surfactants, so as to investigate the application potential of structure in the development of an effective surfactant to recover unburned carbon from CFA. The surfactants were anionic surfactants including sodium dodecyl sulfate (SDS), sodium dodecyl benzene sulfonate (SDBS), and non-ionic surfactants including Tween-80 (TW) and Triton X-100 (TX).

The mixture of surfactants and the collector kerosene was emulsified in water by using ultrasonication. The resultant material possessed enough froth so that an additional frother was not required. The collecting ability of collectors were evaluated in terms of the LOI and CR. Furthermore, surface tension, zeta potential and SEM-EDS techniques were used to discuss the CFA flotation mechanism. The objective was to develop surfactants with favorable synergistic ability on the flotation of unburned carbon and to explore the structure-activity relationship of surfactants.

2. Experimental

2.1. Materials used: CFA and reagents

CFA was obtained from Shenhua Junggar Energy Corporation in Junggar, Inner Mongolia, China. The as-received CFA was produced from Junggar thermal power station (Mongolia Erdos) by burning bituminous coal. The composition of CFA detected by X-ray fluorescence (XRF, AXIOS^{mAX}, PANalytical, Netherlands) was given in Table 1. The CFA is regarded as type F ($SiO_2 + Al_2O_3 + Fe_2O_3 \geqslant 70\%$) with a loss on ignition (LOI) from 9 to 12% by weight. Size distribution of the sample was as follows: +600 μm: 4.58%, −600 + 250 μm: 15.65%, −250 + 75 μm: 25.69%, −75 + 38 μm: 18.26%, −38 μm: 35.82%. Fig. 1 shows the contact angle of CFA decreases quickly with the increase of measurement time. The contact angle of CFA is about 0 while the measurement time is as short as 2 s. The low values of contact angle signify the difficulty of flotation. The surfactants used were SDBS, SDS, TW and TX. They were mixed with the collector kerosene at given ratios to produce the emulsions. Some physical properties of the surfactants are given in Table 2.

2.2. Flotation experiments and analysis

The CFA samples were ground to pass through a 200 mesh sieve and flotation tests were carried out in flotation machine (RK, XFD-0.5L, China). The pulp was conditioned at 20 wt.% solids (100 g) with a fixed impeller speed of 2000 r/pm. Analytical grade reagent Na_2CO_3 was used as a pH regulator by adjusting the pulp pH around 7 and was conditioned for 5 min. During this time, four different surfactants (0.02 g) were emulsified in 0.2 g kerosene respectively by employing an ultrasonic emulsification system. All the flotation experiments were performed with a freshly prepared emulsion. After the addition of the emulsion to the flotation cell, the pulp was stirred for another 5 min. The floated fraction was then gathered for 5 min. Flotation tailings and concentrates were filtered, dried at 120 °C for 24 h until they reached constant weight and cooled in a dry atmosphere. In order to analyze the ash, first of all, the dried sample of concentrates and tailings was ground to pass through a 200 mesh sieve and dried thoroughly at 105 °C in a laboratory furnace. After that, part of each of the ground samples was calcined in a muffle furnace at 800 °C for 2 h. Then, the remaining ash was weighed to calculate the LOI and the CR. CR% is calculated using the following formula

$$\mathrm{CR}\ (\%) = \frac{\text{Concentrate LOI}\% \times \text{Concentrate Weight}\%}{\text{Feed LOI}\% \times \text{Feed Weight}\%} \times 100 \qquad (1)$$

2.3. Surface tension measurement

The Wilhelmy plate method was used to determine the surface tension at room temperature using a JK99B Digital Tensionmeter with 0.2 wt.% emulsion. A thickness of d = 0.2 mm and length of w = 19.9 mm platinum plate was used. The measured interface was liquid-air interface. In the process of measurement, the