Powder Technology 325 (2018) 333–339

Contents lists available at ScienceDirect

Powder Technology

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

Flotation intensification of the coal slime using a new compound collector and the interaction mechanism between the reagent and coal surface

Jingfeng He [a,b,*], Chengguo Liu [b], Yake Yao [b]

[a] Key Laboratory of Coal Processing and Efficient Utilization of Ministry of Education, China University of Mining and Technology, Xuzhou 221116, China
[b] School of Chemical Engineering and Technology, China University of Mining and Technology, Xuzhou 221116, China

ARTICLE INFO

Article history:
Received 29 September 2017
Received in revised form 3 November 2017
Accepted 11 November 2017
Available online 14 November 2017

Keywords:
Flotation intensification
Flotation collector
Coal slime
Interaction mechanism
Fourier transform infrared spectroscopy (FTIR)
Contact angle measurement

ABSTRACT

Flotation reagents in particular the flotation collector plays a significant role in the cleaning efficiency of coal slimes in the coal preparation and utilization industry. A new collector (NC) was used to achieve the efficient cleaning of coal slimes. Comparing with the conventional flotation collector of diesel oil (DO), the higher yields and lower ash contents of clean coal with the higher combustible material recoveries could be obtained using the NC in flotation. The optimum NC dosage of 500 g/t was acquired through the unit flotation tests. Fourier transform infrared spectroscopy (FTIR) and contact angle measurement were used to study the interaction mechanism between the flotation collector and coal surface. The results indicated that the stronger electron-attracting ability of the ester groups than that of the carbon-carbon double bond resulted in the more stable interaction between the NC and coal surface than that between the DO and coal surface. The contact angle of the coal slime wetting with the NC of 67.1° was larger than that with the DO of 62.6°, suggesting the stronger hydrophobicity of the coal slime with the NC than that with the DO. The chemical composition analysis results suggest that the NC belongs to a compound flotation reagent, which provides an alternative high-efficient collector for coal flotation industry.

1. Introduction

Froth flotation is a conventional method to efficiently separate the concentrate and gangue from the raw mineral fines, which depends on the differences of the surface hydrophobicity of concentrate and gangue [1,2]. Froth flotation has been widely used in the field of mineral processing, particularly in the field of coal slime cleaning [3]. The flotation reagents play an important role in the coal slime flotation. Normally, the conventional collector (diesel oil and kerosene) was added to the flotation pulp to make the surface of the coal concentrate more hydrophobic. Then, the collectors were attached to the coal slime and plenty of micro air bubbles were formed, the coal concentrate was carried up by the air bubbles to be separated from the pulp [4–6]. However, the efficiency and cost of conventional collectors are not satisfactory for coal slime cleaning, particularly for the high-ash and superfine coal slime. In order to improve the flotation efficiency of coal slime, it is an urgent to develop new collectors with low cost and dosage. The new collectors are usually added with a small amount of surfactant, which is used to improve the surface hydrophobicity of coal slime and strengthen the absorbability between the coal slime and air bubbles [7–10]. Thus, the development of efficient flotation collectors for coal slime cleaning has become a focused subject.

Jia et al. used different non-ionic oxygenated surfactants as the collectors to separate a high-sulfur coal in the flotation. The results suggested that the lower dosage of non-ionic oxygenated surfactants was required than that of dodecane or nonyl-benzene with the similar flotation selectivity in terms of ash rejection and pyrite sulfur rejection [11]. Erol et al. used the non-ionic reagent, including the mixture of methyl isobuthyl carbinol (MIBC) with Triton x-100 or Brij-35 as the collector in the froth flotation of coal slime. The combustible material recovery was remarkably increased using the non-ionic collector [12]. Sis et al. found that the oleic acids of ionic collectors were significantly better at reducing the ash content down to 16.0% from fine coal samples containing 46.1% ash in despite of their lower flotation yield and higher consumptions [13]. Das and Reddy used Polanga and Mahua oil as the collector, and the ash level could be reduced to 22% with 60% yield from a non-coking coal containing 40.2% ash [14]. Chaudhuri et al. found an improved collector derived from coal tar. The concentrate with a yield of 83% and a low-ash content of 16% were obtained in the flotation using the specific coal tar, while the yields with the diesel oil and *N*-dodecane as the collectors were only 71.4% and 66.7%, respectively [15]. In addition, utilizing the bacteria as the biological alternative to the collectors for coal flotation enhanced the floatability of fine particles of bio-modified coal [16]. Ramos-Escobedo et al. used a bio-collector

* Corresponding author at: School of Chemical Engineering and Technology, China University of Mining and Technology, Xuzhou 221116, China.
E-mail address: jfhe@cumt.edu.cn (J. He).

https://doi.org/10.1016/j.powtec.2017.11.034
0032-5910/

named *S. carnosus* as the collector. The experimental results showed that the recovery was approximate 50% in the absence of microorganism, while the recovery reached close to 90% by using the bio-collector in both samples of coal for a time of 12 h and a pH of 9. Although using the bio-collector in the flotation can achieve the higher recovery of clean coal, however it takes too long to be appropriate for industrial production [17]. A new collector was evaluated and compared with diesel oil to its effect on coal flotation. The contact angles were measured to study the kinetics of collector spreading on the hydrophobic and hydrophilic coal surfaces. Both flotation recovery and selectivity were improved with the adoption of the new collector. The lower interfacial tension of the latter resulted in the faster spreading of collector on coal surface [18]. Moreover, the flotation mechanism between the coal surface and the collector named ZFC was studied by measuring the wetting heat and Zeta potential. The higher wetting heat with ZFC proved more stable adsorption between ZFC and coal. The higher Iso-electric Point (IEP) of ZFC contained lots of polar group of anionic surfactants, which formed the chemical bond with the oxygen-containing functional groups on coal surface [19].

Despite some new findings concerned on the preparation and utilization of the efficient flotation collectors, the researches on the interaction mechanism of the collector and coal surface are not sufficient and require to be in-depth investigated. Therefore, the conventional collector named diesel oil (DO) and a new collector (NC) were used as the collectors in this work to investigate the effects of collectors on the flotation efficiency of coal slimes through the unit flotation tests and stepwise release experiments. The intensified interaction mechanism between the collectors and coal surface was analyzed using the Fourier transform infrared spectroscopy (FTIR) and contact angle measurements. Afterwards, the gas chromatograph/mass spectrometer (GC/MS) was used to determine the chemical composition of NC. Finally, a new compound collector was proposed and proved efficient in the flotation of coal slimes, which provides an alternative flotation reagent in the coal flotation industry.

2. Experimental

2.1. Coal slime sample

A coal slime sample from Henan province, China was collected as the flotation feed in this experimental study. The proximate analysis results of the coal slime sample are summarized in Table 1. The coal slime has an air-dried moisture (M_{ad}) of 1.09%, an ash content (A_d) of 20.46%, a dry ash-free volatile matter (V_{daf}) of 9.85%, and an air-dried fixed carbon (FC_{ad}) of 71.71%, respectively. The results indicated that the coal slime belonged to an anthracite with a low volatile content and a moderate ash content.

The relationship between the yields and size fractions of the coal slime is shown in Fig. 1(a). The dominant size fractions of the coal slime were −45 μm, 250–500 μm and +500 μm with the yields of 22.55%, 24.20%, and 21.02%, respectively, with a total yield of 67.77%. The results indicated that the coal slime was mainly distributed in the finer and coarser particle size fractions, while the yields of the moderate size fractions were relatively lower. In addition, the size fraction of +500 μm coal slime accounted for more than 20%, which indicated that a portion of coarse coal slime particles over the upper flotation limit was entrained in the coal slime feed. The relationship between the ash content and size fractions of the coal slime is shown in Fig. 1(b). The ash content of the coal slime decreased from 32.40% to 12.51% with the size fraction increasing from −45 to +500 μm. The results indicated that the coal slime was mainly consisted of the fine-sized components with the high-ash contents. The coal slime with the coarse-sized fractions and low-ash contents had more probability to be enriched into the clean coal products through the flotation.

Table 1
The proximate analysis results of coal slime.

M_{ad} (%)	A_d (%)	V_{daf} (%)	F_{cd} (%)	Coal rank
1.09	20.46	9.85	71.71	Anthracite

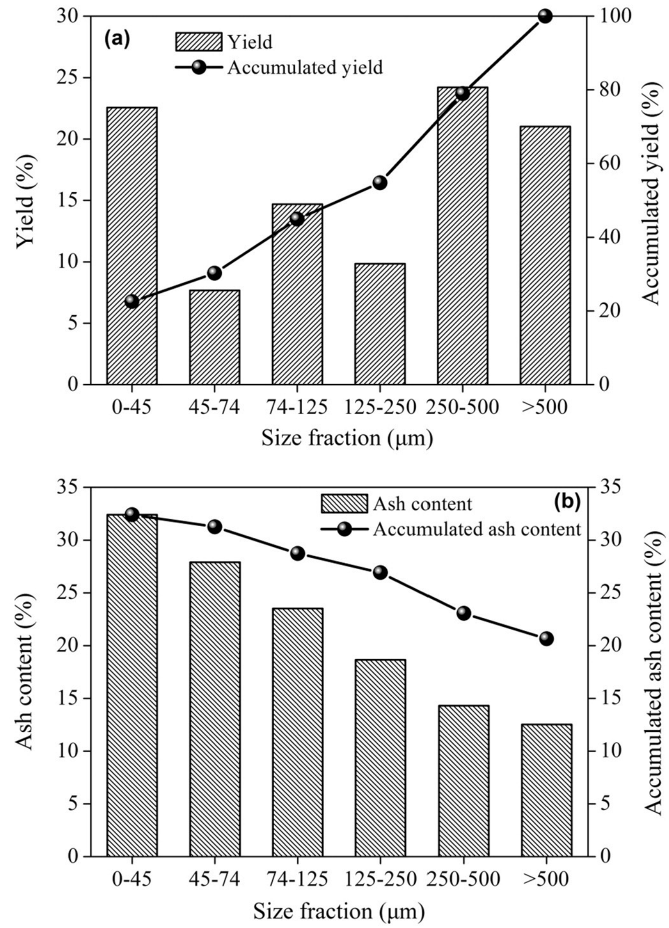

Fig. 1. The relationship between the yields and ash contents and the size fractions of coal slime.

2.2. Flotation tests

2.2.1. Unit flotation tests of coal slime

The mass concentration of the coal slime feed was set as 100 g/L. NC and DO were used as the collectors and the fusel was used as the foaming reagent in the flotation tests. The dosage of the foaming reagent was maintained as 350 g/t, and the dosage of NC and DO was set as 300, 350, 400, 450, 500 and 550 g/t, respectively. The lab-used single flotation cell of XFD with a capacity of 1.5 L was used in the unit flotation tests. The detailed operational parameters were set as: the prewetting time of 60s for coal slime sample, the agitation speed of 1800 r/min for the impeller, and the scraping foam time of 180 s for the products. The flotation products were treated by a vacuum filter and dried to a constant weight at 75 °C. The ash content of the products was obtained using a muffle furnace. Finally, the combustible material recovery ε of the coal slime can be calculated as Eq. (1).

$$\varepsilon(\%) = \frac{M_C(100-A_C)}{M_F(100-A_F)} \times 100 \tag{1}$$

where ε refers to the combustible material recovery, %; M_C and M_F refer to the weight of the concentrate and feed (%), respectively; A_C and A_F refer to the ash contents of the concentrate and feed by weight (%), respectively.