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A two-stage process for fine coal flotation intensification

Xiahui Gui [a,*], Yijun Cao [a,*], Yaowen Xing [b], Zili Yang [b], Dongyue Wang [b], Chenwei Li [b]

[a] Chinese National Engineering Research Center of Coal Preparation and Purification, China University of Mining and Technology, Xuzhou 221116, Jiangsu, China
[b] School of Chemical Engineering and Technology, China University of Mining and Technology, Xuzhou 221116, Jiangsu, China

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ABSTRACT

Power input and flotation time are the two key factors influencing the efficiency of the fine coal flotation process. A new two-stage process is proposed in this investigation for intensifying fine coal flotation. The flotation process is divided into two parts: lowering energy input in the first stage and raising energy input in the second stage. Easily floated materials are recycled with low energy in the rapid floating section (first stage), and hard-to-float materials are compulsorily recycled using higher energy in the recycling section (second stage). A flotation energy consumption test system is established. Flotation tests were conducted in an XFD 0.75-L laboratory-scale flotation machine. The effects of energy input on the flotation rate constant in instantaneous flotation or flotation over a period of time were investigated. The results indicate that higher combustible matter recovery or lower concentrate ash content could be obtained using a two-stage process compared with a single-stage flotation process with the same energy consumption. Compared with energy input in the first stage of the flotation process, the energy added in the second stage of the flotation process would increase with flotation processing owing to the decreased rate of fine coal floatability in the first stage. The larger the floatability difference in the flotation process, the more energy must be used in the second stage of the flotation process. With the same energy input, the flotation tests indicate that lower ash content or higher combustible matter recovery could be obtained using the proposed two-stage flotation process.

1. Introduction

With the improvement in the proportion of mechanical coal mining and the rapid development of heavy-medium coal preparation, China's fine coal is characterized by size reduction, ash increase, and rising intergrowth content. The fine coal separation problem has become prominent. The degree optimality of the fine coal separation process directly affects the quality and quantity of resulting clean coal products, dewatering operations for clean coal and tailings, and the washing water balance of the entire coal preparation plant. However, there are still many defects such as poor recovery, limited flexibility, and contradiction between recovery and productivity in existing fine coal separation processes in China. It is well-known that the selective recovery of hard-to-separate fine coal particles is the key factor in coal flotation efficiency [1–4]. Inhomogeneous changes in fine coal floatability impose stricter requirements on fine coal separation process design. Actual production raises the demand for upsizing, refinement, and improving the adaptability of separation devices. In view of the above-mentioned problems, process intensification for fine coal flotation was conducted and a number of important conclusions were obtained.

A number of studies have been performed regarding flotation kinetics and energy input in the flotation process. The energy input and material floatability were both considered to design a fine coal flotation process [5–7]. The floatability of materials degraded and the flotation rate was reduced gradually with continuation of the flotation process [8–11]. A small amount of energy was inputted early in the flotation process to recover easy-to-float materials, whereas a large amount of energy was inputted late in the flotation process to recover difficult-to-float materials [6,12]. Heinrich [13] found that flotation energy input has an important effect on the collision and adhesion of fine particles and microbubbles. Duan et al. found that a larger flotation rate constant for particles with good surface hydrophobicity exhibited more rapid floating into the froth [14–17]. Mohanty and Honaker [18] studied the effect of stirring intensity in the flotation process, and found that a suitable mixing intensity can promote the suspension of mineral particles as well as the uniform dispersion of air and particles. The rate constants for coarse composites follow the rate for fully liberated particles of the same size [19]. Changunda et al. [20–22] found that the effect of energy input on kinetics was a near linear increase in the rate of flotation with increasing power intensity.

Numerous studies have focused on working process optimization of flotation cells and flotation columns. The observation of a linear k-Sb relationship by Gorain et al. had important implications for optimization, scale-up, and design of mechanical flotation cells, where k is the

* Corresponding authors.
E-mail addresses: guixiahui1985@163.com (X. Gui), yijuncao@126.com (Y. Cao).

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flotation rate constant and Sb is the flux of the bubble surface area throughout the cell [23–24]. Li et al. [12] optimized the energy input in slime flotation under the same or similar total energy input, wherein clean coal with high combustible matter recovery and good quality can be obtained when energy input is low in the early stage of flotation and high in the later stage. However, the majority of these studies have concentrated on normal mechanical flotation cells, and few studies focused on the effect of energy input on cyclonic-static micro-bubble flotation columns (FCSMC). Multi-stream steps strengthen the separation method, achieving a flotation process concept adapted to changes in the physical properties of the slime flotation process, improved micro-fine slime separation selectivity, and combustible material recovery. FCSMC has been used widely in fine-particle separation [25] of coal, metal ore (nickel, copper, iron, gold, aluminum, molybdenum, zinc, etc.), non-metallic minerals (phosphorus, fluorite, etc.) and other materials, and has achieved good economic and technical indicators. On this basis, FCSMC 3000 × 6000 (large, two-stage column separation) equipment was developed with the basic characteristic of fast flotation and mandatory recycling and significantly improved capacity and adaptability compared with the single-stage process [26].

Massey et al. [27–29] showed that the effect of power intensity on flotation kinetics is strongly dependent on both particle and bubble size in an oscillating grid flotation cell. Tao et al. [30] reported that the Ken-Flote-type flotation column was inferior compared with mechanical flotation for coal particles with poor natural floatability. Meanwhile, Tao claimed that these conclusions may only be applied to Ken-Flote-type flotation columns with quiescent flow conditions. With a flotation column such as a Jameson cell using a turbulent collection mechanism, the results of the flotation column may be close to or even better than those of mechanical flotation machines. Therefore, Han et al. [31] used a coal flotation column developed by Canadian Process Technologies (CPT) with high turbulent mineralization for low-rank coal location. The performance and separation efficiency of the column were clearly superior compared with those of a conventional cell.

Coal preparation plant process optimization has also been conducted to improve fine coal combustible recovery. For coking coal, fat coal, and other scarce coals in which the slime is high in ash and difficult to float, workers at the China University of Mining Technology [26] developed a corresponding efficient separation process based on secondary resource recycling. From the aspect of improving the quality of coal, the proposed process involves coarse-particle settling and filtering, centrifuge dewatering, and filtrate re-cleaning processes, reducing the quantity of cleaning material and circulation in these systems. To improve combustible coal recovery, they proposed roughing tailings thickened and classified in a cyclone, for which a spigot was used to dewater with a high-frequency sieve. Oversized material was re-cleaned after being liberated in a ball mill, and process systems handling a pulp capacity of 400 m^3/h have been established in the Kailuan Coal Mine Group Qianjiaying plant. Industrial application results indicate that, compared with rougher-cleaner flowsheets, the intensification and efficient flotation separation process can increase combustible coal recovery by 5–10% in the case of different middling content and the same ash content.

High-efficiency flotation of fine coal has attracted substantial attention from researchers in the field. However, most studies insist on increasing flotation time. It is difficult to enhance flotation efficiency while maintaining low energy consumption. Among numerous enhancement methods, increasing the flotation rate constant in different flotation stages could have strong efficacy compared with other methods because of its high efficiency and practicability.

With continuation of the flotation process, the flotation rate of materials decreases in line with the exponential function rules. The flotation rate increases constantly as the power input increases at any time during the flotation process. However, the trend of increasing flotation rate declines as the power input continues to increase. The maximum value of the flotation rate constant can be obtained with an increase in power input at a certain value. There are some relationships between fine coal flotation consumption and floatability, and the most important factors in these are flotation time and energy input [5–7].

Using several stirring tanks to recycle minerals of interest in flotation cells shows good potential; however, the energy input of each stirring tank is at the same level. It is difficult for the energy input to adjust coal surface hydrophobic characteristics changes tank by tank with the flotation process. Compared with flotation cells, more cleaner coals can be obtained by thick froth layer, static separation environments in flotation columns. However, the disadvantages of poor recycling ability gradually emerge. There are three manners of mineralization in cyclonic-static micro-bubble flotation columns: counter-current mineralization, cyclonic mineralization, and pipe flow mineralization. The dynamic turbulence intensity of multiple mineralization increases step by step to compensate for the decrease in the floatability of mineral particles. However, further improvement of FCSMC separation efficiency would be limited for a single-stage flotation process.

In this paper, energy input and coal floatability were combined to design a two-stage flotation process. With a fixed total energy input, the fine coal separation process was divided into a fast float section and a recycling section. Easily floated materials were recycled with low energy input in the fast float section, and hard-to-float materials were compulsorily recycled by using higher energy in the recycling section.

2. Experiment

2.1. Flotation energy consumption test system

The flotation energy consumption test system consisted of an XFD 0.75-L flotation machine and a torque sensor for shaft power measurement along with ancillary data acquisition, data conversion, and data processing equipment. A TQ-662-type dynamic resistance strain torque sensor was used to measure agitation power in the flotation tests. The torque was converted into flotation power by the data conversion equipment. The torque value of the shaft was determined by a strain bridge sensor when strain gauges were attached to the shaft. The torque value was converted into a frequency value according to the voltage/frequency conversion. The torque sensor was fixed between the power and the load using two couplings (Fig. 1).

For the flotation cells, power input was performed by an agitator shaft. Eq. (1) shows the formula for power consumption of the agitator shaft in the flotation process:

$$P = \frac{2\pi Mn}{60} \quad (1)$$

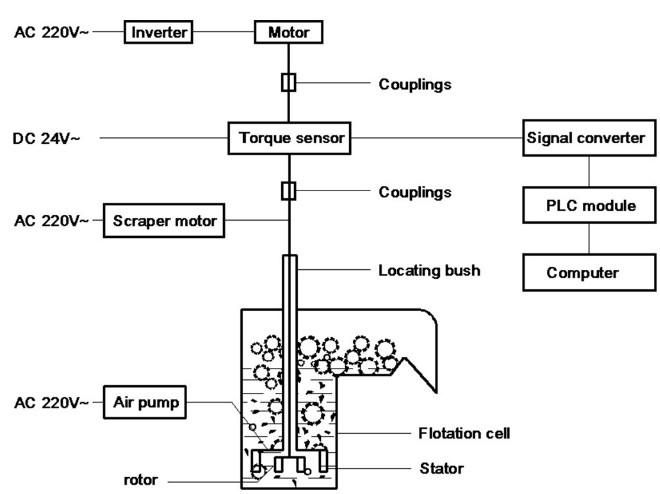

Fig. 1. Schematic diagram of the flotation energy input measurement system.