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Optimization of the performance of the hydrodynamic parameters on the flotation performance of coarse coal particles using design expert (DX8) software

A. Dashti [a], M. Eskandari Nasab [b,*]

[a] The student of Mineral Processing Engineering, P.O. Box 51587335983, Tabriz, Iran
[b] Mineral Processing Engineering, Zarand Collage, Bahonar University, P. O. Box 14579-73869, Kerman 7616914111, Iran

HIGHLIGHTS

- ▶ The effects of some key hydrodynamic factors on coarse coal particles were investigated using DX8 software.
- ▶ For the first time, the effect of impeller off-bottom clearance on the flotation was investigated.
- ▶ Impeller rotational speed showed the optimum efficiency on the flotation of coarse coal flotation.

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ABSTRACT

Hydrodynamic parameters play an important role in flotation efficiency. In the present work, the effects of some key hydrodynamic factors such as impeller speed (600, 700 rpm), impeller off-bottom clearance (0.3H, 0.4H), solids percent (12%, 14%), frother type (Pine oil and methyl isobutyl carbinol (MIBC)) and their concentrations (140, 170 ppm) on the flotation performance of coarse coal particles were investigated using factorial experimental design. The DX8 software was used to analyze the results of the experiments. According to DX8 software, it is concluded that until 700 rpm, the effects of the studied parameters follow the order: impeller off-bottom clearance > impeller rotational speed > frother concentration > the interaction between impeller off-bottom clearance and impeller speed. But for higher impeller speeds, the impeller rotational speed has the most effects. The positive effect of impeller speed before 700 rpm (i.e. $97397.38 < Re < 119589.22$, $1.21 < Fr < 1.53$ and $0.0035 < C_a < 0.0038$ for $0.01226 < \mu_p < 0.01299$) and its negative effect beyond (i.e. $Re > 113609.61$, $Fr > 1.53$ and $0.0033 < C_a < 0.0035$ for $\mu_p = 0.01299$) concluded that the optimum value for impeller speed is 700 rpm. Also, it was concluded that the recovery of coarse coal particles is increased by increasing pulp solids percent because of increasing medium viscosity.

1. Introduction

Coal washing plants use flotation technology to beneficiate coal particles smaller than 1 mm. It has been observed in several mechanical cell installations that the recovery of coal particles greater than 0.5 mm is much less than that of finer material. Fig. 1 shows the inverted U-shape curve obtained from averaged industrial data describing the combustible recovery vs. particle size [1]. Inefficient recovery of the >0.5 mm fraction directs vast amount of valuable coal to tailings.

Klassen and Mokrousov reviewed the conditions necessary for flotation of coarse particles and established that several factors could increase the recovery of coarse coal including [2]:

- Increasing the hydrophobicity of the surface using an appropriate collector.
- Flotation by clusters of air bubbles.
- Increased aeration.
- Lowering of intensity of agitation.

Three of these factors have been addressed by developments within the industry. The following items show the use of these factors in the industry:

- The use of collectors in coal flotation is commonplace with most installations employing diesel due to its low cost and adequate performance.
- The high intensity zone within the downcomer of a Jameson cell allows for high probabilities of collection and flotation by clusters of bubbles and operation at high volume of induced air.
- The final point regards lowering the intensity of agitation.

* Corresponding author.
E-mail address: Mahmoodeskandari2010@yahoo.com (M. Eskandari Nasab).

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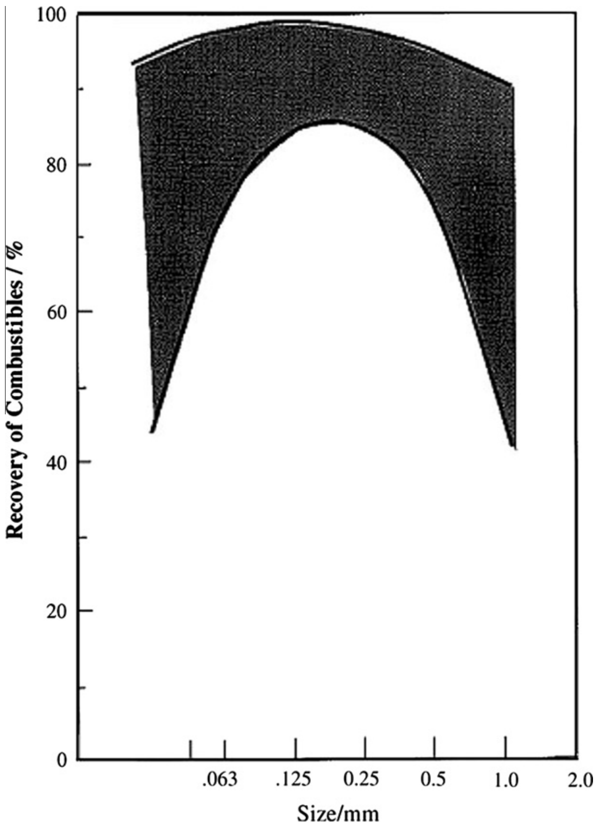

Fig. 1. Example of combustibles recovery vs. size fraction for coal (Nicol, 2001).

Investigations concludes that the most important reason for the loss of coarse particles is detachment of particles from the bubbles [3,4] and all the trends to increase the flotation performance of coarse particles tend to decrease detachment rate. Bubble–particle detachment can be occurred either in the collection zone [5,6], where the bubble–particle interaction takes place, or in the froth layer [7–10]. A particle that has been attached to the surface of a bubble would be detached when the forces that hold it at the surface are dominated by the detachment forces [11,12]. In the collection zone, turbulence has the most important role in detachment process [6,12,13]. In the flotation cells, turbulence is characterized by dimensionless hydrodynamic numbers such as Reynolds (Re), Froude (Fr) and Weber (We) numbers. These numerical values are defined by some hydrodynamic variables including impeller speed, pulp density and the surface tension of air–water interface. The particle detachment in the froth layer is mainly originated from reduction in the overall specific surface area of the bubbles. As bubbles move from liquid-froth interface to the top of the froth layer, their expansion and finally coalescence would cause particles detachment. Previous studies show that the coarser particles are more sensitive to bubbles coalescence and are detached more easily [14]. Frothers decrease the surface tension of air–water interface which prevents bubbles coalescence and stabilize froth phase and would increase the recovery of coarse particle. Other hydrodynamic variables such as impeller speed would also change froth stability. Girgin et al. [15] found that the increasing of impeller rotational speed in self-aerating Denver laboratory flotation cells increases bubbles size. Bigger bubbles with more surface energy would result in more bubble coalescence and this would increase particles detachment. Rodrigues et al. [16] studied the effect of hydrodynamic dimensionless parameters on the microflotation response of coarse glass spheres and quartz particles. A plateau of maximum recovery was observed at $3000 < Re < 8000$, $10 < We < 100$ and $0.l < Fr < l$. Their visual observations concluded that in more quiescent conditions (i.e. $Re < 3000$ or $Fr < 0.1$), where the impeller was not capable of keeping particles in suspension and promoting particle/bubble collision, thus the recovery was decreased steadily. On the other hand, under more turbulent conditions (i.e. $Re > 10,000$ or $Fr > 1.0$), the disruption of particle/bubble decreases the flotation recovery. Pyke [17] studied the effect of impeller rotational speed and energy dissipation on the size dependent flotation rate of hydrophobic quartz, chalcopyrite and galena in a Rushton turbine flotation cell. The work was also extended to the flotation of chalcopyrite from a copper ore [18]. Laser Doppler Velocimetry (LDV) determined the local dissipation of turbulent energy at the different impeller rotational speeds. For hydrophobic quartz (advancing contact angle of 73°), increasing the mean dissipation of energy to 4.5 W/kg increased the flotation rate constant across the particle size range (−80 μm). However, increases in dissipation of energy above this value decreased the flotation rate, initially for particles above 30 μm [17]. At still higher dissipation of energy, a decrease in the flotation rate was reported for particles greater than 10 μm. Grano [19] studied the effect of impeller rotational speeds on the dependence of the flotation rate of galena to the particle size in industrial cells. He found that the increasing of impeller rotational speed from 137 rpm to 157 rpm enhances the flotation rate constant of fine particles (3–9 μm) due to increase in collision rate but adversely decreases coarse particles flotation rate constant by increasing detachment rate.

Frothers have important roles in flotation and the most import one is their effect on bubble size. It was found that the effect of frothers on bubble size results from their ability to prevent bubble coalescence [20–23]. Gupta et al. [24] studied the effect of different types and concentrations of frothers on foam stability, bubble size and coal flotation and found that different types and concentrations of frothers produce different bubble size distributions and foam stabilities. Also, they concluded that different types of frothers produce flotation concentrates with different characteristics. For the oversize fraction (−1 + 0.5 mm) and the intermediate size fraction (−0.05 + 0.075 mm), the frother DF-1012 was efficient while alcohol frother MIBC for the ultrafine fraction (−0.075 mm).

There have been limited studies on the effect of impeller off-bottom clearance on flotation efficiency and most of them are restricted to its effect on agitation in chemical reactors but the findings can be used for three phase systems such as floatation cells. The impeller clearance has the substantial effects on the suspension of solid. Momentum transfer from the impeller to the particles is maximized in configurations where the impeller operates close to the cell base [25]. By increasing impeller off-bottom clearance, the stagnant zone underneath the impeller increases and more solid particles are trapped in that region. Also, the momentum transfer to solid particle decreases, therefore the higher impeller speed is required to force particles to move toward the tank corner from where they are suspended.

Scientists no longer can afford to experiment in a trial-and-error manner, changing one factor at a time, the way Edison did in developing the light bulb. A far more effective method is to apply a systematic approach to experimentation, one that considers all factors simultaneously. That approach is called design of experiments (DOEs). DOE provides information about the interaction of factors and the way the total system works, something not obtainable through testing one factor at a time (OFAT) while holding other factors constant. Recently different methods of DOE are used for modeling process parameters and optimization in mineral processing. Central composite design has been successfully used to design an experimental program to provide data to model the effects of operating factors and the cyclone geometry on the operational performance of a three-product cyclone [26]. Factorial experimental design has been used to investigate the effect of pH, depressant