Minerals Engineering 84 (2015) 130–144

Contents lists available at ScienceDirect

Minerals Engineering

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

A review of the modern characterization techniques for flocs in mineral processing

Long Liang [a], Yaoli Peng [a,b], Jiakun Tan [a], Guangyuan Xie [a,b,*]

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

ARTICLE INFO

Article history:
Received 5 June 2015
Revised 13 October 2015
Accepted 15 October 2015
Available online 24 October 2015

Keywords:
Floc property
Flocculation
Mineral processing
Characterization technique

ABSTRACT

The paper reviews the modern characterization techniques for flocs. Flocculation is playing an integral role in mineral processing. In the solid liquid separation processes, flocculation can speed up particle settling and dewatering. Also, flocculation can increase concentrate recovery or reduce gangue mineral entrainment in the flotation processes. The effect of flocculation is highly related to floc property. The characterization techniques for three kinds of floc property, namely floc size, floc shape and structure and floc strength, are reviewed in this paper.

Contents

* Corresponding author at: School of Chemical Engineering and Technology, China University of Mining and Technology, Xuzhou 221116, China.
E-mail address: xieguangyuan1962@sina.com (G. Xie).

http://dx.doi.org/10.1016/j.mineng.2015.10.011
0892-6875/

1. Introduction

Flocculation is widely used in many industries including pharmaceuticals, papermaking, sewage treatment and mineral processing. In mineral processing plants, flocculation is generally applied to hasten the settling of tailings. It is usually achieved by the addition of flocculants. The floc property to a very large extent determines the effect of subsequent concentrating and dewatering processes. Extensive research (Mpofu et al., 2003, 2004; Franks et al., 2004; Franks, 2005; Nasser and James, 2006; Pal et al., 2008; Zbik et al., 2008; Oliveira and Rubio, 2012a,b) has been conducted on the relationship between floc property and slurry settling and dewatering effects. Large and compact flocs are wanted both in concentrating and dewatering processes (Mpofu et al., 2004; Kaya et al., 2006; Sabah and Erkan, 2006; Lemanowicz et al., 2011; Wang et al., 2011). However, the two requirements of floc size and floc strength are difficult to achieve at the same time. It was found that in dilute slurries, aggregates caused by strong attractive forces are characterized as large and loose structured. The diffusion of particles to aggregates is the main limitation of aggregate growth. This kind of aggregate growth is named diffusion-limited cluster aggregation (DLCA). On the other hand, aggregates induced by weak attraction are usually small and compact. The limitation of aggregate growth is the reaction of particles. This is called reaction-limited cluster aggregation (RLCA) (Lin et al., 1989, 1990).

Flocculation of particular minerals is also applied in the flotation processes, which have been reviewed by Forbes (2011) and Yang and Song (2014). The aim of the flocculation of particular minerals can be divided into two opposite directions, according to the flocculated objectives. One is to flocculate hydrophobic valuable minerals so as to increase their collision and attachment efficiency with bubbles. As a result, the concentrate recovery and quality are improved. This kind of flocculation can be achieved by the addition of polymers or nonpolar oil (Laskowski, 1992; Song and Trass, 1997; Song et al., 2004, 2012; Song, 2008; Ozkan et al., 2005; Duzyol et al., 2012; Ozkan and Duzyol, 2014). Hydrophobic interaction is the main driving force for flocculation. Proper shearing is implemented to increase the collision efficiency and improve the hydrophobic flocculation by providing kinetics to overcome the energy barrier. Polymers or nonpolar oil can significantly increase the flocculation. This kind of flocculation is mainly applied in the flotation of natural hydrophobic minerals, such as coal (Song and Trass, 1997; Song et al., 2004; Ozkan et al., 2005; Song, 2008) and molybdenite (Song et al., 2012).

The other direction is to flocculate hydrophilic gangue minerals so as to reduce their entrainment (Song et al., 2000, 2001a,b; Cao and Liu, 2006; Liu et al., 2006; Huang et al., 2012a,b, 2014; Wang et al., 2012; Liu and Peng, 2014). For example, polyethylene oxide could selectively flocculate quartz particles in the flotation of chalcopyrite via hydrogen bonding (Gong et al., 2010). Polyacrylamide and chitosan could flocculate chalcopyrite via chemical adsorption so sphalerite was selectively floated (Huang et al., 2012a,b, 2014; Wang et al., 2012). It is also proposed that even without high molecular polymers, inorganic depressants such as zinc sulfate could also increase the size of gangue minerals via precipitate enmeshment (Cao and Liu, 2006). Depressants have dual functions of increasing the hydrophilicity and enlarging the particle size of gangue minerals (Cao and Liu, 2006; Liu et al., 2006). However, the research in this direction, which might as well be called hydrophilic coagulation/flocculation, is very scarce compared to hydrophobic flocculation.

It can be concluded that the purpose of flocculation varies in different processes. The necessary floc properties also vary. In the concentrating and dewatering process, large and compact flocs are wanted. The floc hydrophobicity is less important. In the flotation process, however, the requirement of flocculation is strict. Selective flocculation of aimed minerals should be achieved, so the hydrophobicity and strength of flocs should be controlled. The hydrophobicity of flocs determines whether the flocs are floated as concentrate or discharged as tailings. The interaction between particle and flocculant should not be too strong, because strong interaction usually brings the non-selective flocculation. Proper breakage of flocs by shearing or desorption of polymers on valuable minerals by the addition of collector can help to achieve selective flocculation (Ding and Laskowski, 2007; Gong et al., 2010). The floc size and floc shape and structure should also be considered because they can influence the slurry rheology (Liu and Peng, 2014) and the interaction between flocs and bubbles (Forbes, 2011). The interaction between flocculants and flotation reagents and bubbles also plays an important role. Unfortunately, scarce research has been conducted in this area.

Therefore, it is very important to comprehensively understand the floc property so as to know whether the flocs are proper for the particular purposes. There are various characterization techniques for flocs. In this paper, they are divided into three parts, namely the characterization techniques for floc size, floc shape and structure and floc strength.

2. Characterization techniques for floc size

There are numerous techniques to measure particle size and size distribution and a lot of reviews (Li et al., 2005; Hogg, 2008; Abbireddy and Clayton, 2009) can be found. Flocs usually form in liquid and they can be destroyed when they are filtered and dried, or even when poured from a container to another, so the size measurement of flocs is usually conducted in liquid. There are two types of floc size characterization techniques, the in-situ and sampled techniques. In the sampled techniques, the flocs may be sheared or diluted, which causes measurement errors. But the in-situ techniques do not suffer from the potential problems associated with the sampled techniques. In this paper, the floc size characterization techniques are classified by the different working principles. These techniques include laser particle size analyzer, focused beam reflectance measurement (FBRM), microscope,

Table 1
Summary of floc size characterization techniques.

Technique	Particle size definition	Applicable size range (μm)	Solid concentration (%)
Laser particle size analyzer	Spherical equivalent diameter	0.1–2000	<0.1
FBRM	Chord length	1–2000	<20
Microscope	Geometric equivalent diameter	0.01–10,000	<0.5
DIA		1–2000	
PVM		0.5–2000	