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Bubble size estimation for flotation processes

Bao Lin [a,*], Bodil Recke [b], Jørgen K.H. Knudsen [b], Sten Bay Jørgensen [a]

[a] *Department of Chemical Engineering, Technical University of Denmark, Lyngby 2800, Denmark*
[b] *FLSmidth Automation, Valby 2500, Denmark*

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Abstract

This paper presents a real-time image analysis system that was installed at a phosphorus oxide flotation process. The focus of the image analysis system is to effectively estimate bubble size. Flotation is one of the most challenging processes for modelling and control in mineral processing industry due to the inherently chaotic nature of the underlying microscopic phenomena and the lack of sufficiently accurate process measurements. Digital image processing is a promising technology for obtaining process related information that can potentially be used to improve the control of flotation processes. Traditional bubble size estimation techniques based on morphological operators and the concept of texture spectrum perform unsatisfactorily on froth images from the phosphorus oxide flotation process. A modified texture spectrum approach and a method based on binary images are proposed and implemented. The reliability of the proposed bubble size estimation approach is demonstrated on phosphorus oxide flotation processes.

Keywords: Flotation bubbles; Sizing; On-line analysis

1. Introduction

Froth flotation is a selective separation process that is widely used in mining industry to extract valuable minerals. Modelling and effective control of flotation processes are challenging tasks, due to the complicated dynamics and chaotic nature of the underlying microscopic phenomena. The lack of sufficiently accurate and reliable process measurements poses additional difficulties. Experiences have shown that process conditions are highly correlated to the appearance of the flotation froth (Moolman et al., 1996a; Aldrich et al., 1997). Advances in digital image processing techniques enable the quantification of froth properties, which is a prerequisite step for automatic control of flotation processes.

There are several conventional process measurements on flotation processes, including the flow-rate of feed and chemical additives, pH, fluid level in the flotation machine, etc. But, "measurements" related to the type and movement of the flotation froth are based on human visual inspection in most plants. In fact, many flotation processes are manually controlled by operators looking at the appearance of the froth (Moolman et al., 1996b). The performance thus depends on the operator's experience and is limited by the absence of physical, quantitative methods for measurement and characterization of the froth.

Vision-based methods have been developed recently for observation and analysis of froth images. Applications include the classification of froth and the extraction of physical features, such as color, average bubble size and size distribution. Statistical techniques (Nguyen and Thornton, 1995), neural network (Moolman et al., 1995) and fuzzy logic (Chuk et al., 2005) are also integrated to enhance the performance of image analysis systems.

Duchesne et al. (2003) report the investigation of flotation froth images analysis using the multivariate image analysis (MIA) concept. The MIA approach is based on multivariate statistical analysis approaches, such as Principal

* Corresponding author. Present address: FLSmidth Automation, Bethlehem, PA 18017, United States. Tel.: +1 610 2646529.
E-mail address: bao.lin@flsmidth.com (B. Lin).

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components analysis (PCA) and partial least squares (PLS) regression. The most relevant information of the highly correlated data is efficiently extracted through the projection of the original image data onto a reduced dimensional space. The applicability of the MIA approach to flotation systems is described with several industrial case studies. Bartolacci et al. (2006) present applications of image analysis systems to control flotation processes. Several image analysis approaches are described, including MIA, grey-level co-occurrence matrix (GLCM) and wavelet transform analysis (WTA) methods. A feedback control strategy based on a froth structure indicator is described and implemented on an industrial zinc flotation circuit. A hybrid control scheme using a froth/concentrate grade is also proposed to stabilize the froth structure.

Several image analysis systems have been developed during recent years, including FrothMaster™ (Outokumpu), VisioFroth™ (Metso), PlantVision™ (KnowledgeScape), WipFroth™ (Wipware). COREM (Bartolacci et al., 2006) develops the iFroth™ system that predicts the froth grade concentrate. This paper reports an image analysis system for flotation processes that was developed using the image analysis toolbox of MATLAB.

This paper investigates the issue of bubble size estimation using images collected from a chamber and a column of a phosphorus oxide flotation process. Initial results demonstrate that the reported approaches are infeasible for the specific process. A modified texture spectrum approach and a method based on binary images are proposed and described in detail. Case studies reveal the reliability of these methodologies.

The next section describes the mechanism of the flotation process, as well as the introduction of two types of flotation equipment: the chamber and the column. Section 3 reviews reported approaches of characterizing the flotation froth. The infeasibility of these approaches is illustrated with case studies. Based on preliminary results, two novel approaches are described in Section 4. Section 5 presents the hardware and software of image analysis system that was installed on-site, followed by the conclusions and a list of future research activities.

2. Flotation process

Flotation process is commonly used in mineral industry for concentrating valuable minerals from raw ore, such as gold, silver, zinc and phosphor. Ground ore powder, mixed with water, frothing reagents and collecting reagents, is fed into the flotation machine, where air is continuously injected into the pulp through a sparger at the bottom of the container, forming a large number of air bubbles (see Fig. 1).

Chemical reagents are added to modify the surface hydrophobicity of the solid particles. The valuable mineral particles are made to be hydrophobic in order to attach easily to bubbles. Air bubbles float to the top and form the froth layer on the surface; while gangue materials are hydrophilic and settle to the bottom. Thus, the concentrated product is readily collected from the top. The bottom flow is recycled for further treatment.

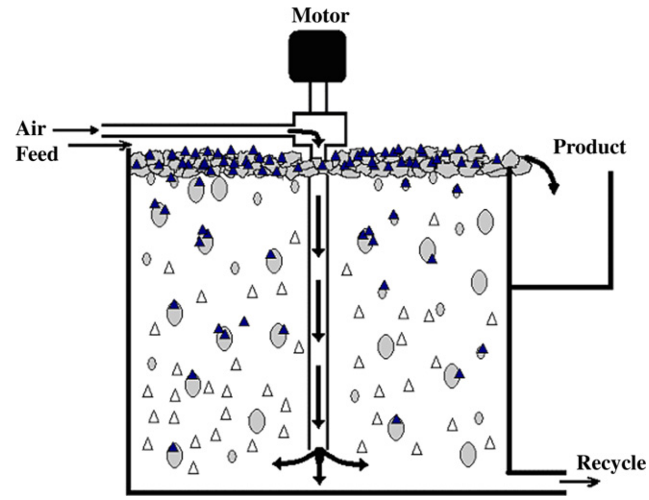

Fig. 1. Scheme of a flotation process.

There are two main types of flotation machines: the chamber and the column. Flotation chambers are shallow tanks (usually 3–4 m in depth), which concentrate minerals that are easily separated. The columns are long vertical vessels (might be more than 10 m high) that are now used worldwide.

The objective of flotation process control is to achieve the target mineral grade recovered from the feed of varying compositions. The separation efficiency of flotation processes depends significantly on the chemical and hydrodynamic conditions. In many plants, chemical reagents that are used to increase the efficiency of flotation are controlled by human operators, who determine adjustments to the addition rates based on empirical analysis of visual appearance of the froth. Consequently, the operation of flotation processes depends essentially on the experience of operators. Therefore, a reliable and consistent approach to quantify the froth characteristics is essential for automatic monitoring and control of flotation processes.

3. Reported bubble size estimation approaches

The fast development of digital image processing renders the possibility to automatically acquire and interpret images of the froth in real-time, resembling the more or less heuristic features used by the operators. It is widely accepted that mineral concentrations and process status are closely related to the color and morphological features of the froth (Moolman et al., 1996b). Color indicates the type and concentration of mineral carried by the froth. The operational status of the flotation process can be characterized from the features of froth bubbles, especially the size, which determines the froth load, collision and attachment efficiency. The investigations of the relationship between bubble size and the separation efficiency have received considerable attention. A number of methods were reported for determining the size of bubbles, including