Minerals Engineering 98 (2016) 52–59

Contents lists available at ScienceDirect

Minerals Engineering

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

Textural image classification of foams based on variographic analysis

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ARTICLE INFO

Article history:
Received 12 February 2016
Revised 22 May 2016
Accepted 27 July 2016

Keywords:
Foam
Frothers
Foam texture
Classification

ABSTRACT

Froths can be characterised according to several features, such as colour, bubble size distribution, velocity, mobility or texture. In the case of texture, there are some alternatives that can be used to analyse and classify them, like the texture spectrum analysis, the grey-level co-occurrence matrix, or the wavelet texture analysis. In this work, a variogram-based technique is introduced. Variograms are a widely used geostatistical technique to describe the degree of spatial dependence between sample values as separation between them increases, and have been used before to analyse textures in applications that range from microscopy to satellite images. The purpose of the current work is to introduce the variogram-based technique to compare and classify foams (water-air froths) according to their texture, and studying the effect of frother type on the texture of foams generated in a quasi-2D cell and in a laboratory column. In the case of the quasi-2D foams, the variogram-based textural classification algorithm was able to classify foam images according to the frother used, with an accuracy of 88.9%. In the case of the foam images generated in the laboratory column, the results suggest that foam texture is mainly defined by froth type, with some effect of foam height. The column foam images did not show similar characteristics when grouped by foam gas holdup, which was confirmed with the variogram-based textural analysis.

1. Introduction

It is well known that froth behaviour has a strong impact on flotation (Barbian et al., 2005; Tsatouhas et al., 2006; Hadler and Cilliers, 2009). Froth features such as froth colour, bubble size, froth velocity and froth texture can be used to classify froths in order to develop appropriate flotation control strategies for each type. The froth classification, which may appear simple for an experienced operator, may be difficult for automated systems, and requires good imaging instruments and adequate image analysis techniques.

There are different ways of characterising froth images. They can be characterised by colour and/or by applying morphological algorithms to determine bubble size and shape (Bonifazi et al., 2001), which can be considered physically meaningful features (Aldrich et al., 2010); however, this information may not be descriptive enough to consider the possible spatial distribution of the image components, and froth texture.

1.1. Texture

Texture is usually perceived as related to the properties that a certain area has, usually associated with perceptions such as roughness, smoothness, directionality, among others. Extrapolating to image processing, this concept is related to the perception of an object, or surface, and its description of local variability (Tuceryan and Jain, 1998). Since texture is a local feature that describes the arrangement or structure in a specific area, it can be considered as an important characteristic that could be used to compare and classify froths or foams, which is the objective of this work.

Some alternatives to analyse and classify froth texture are the textures spectrum analysis (Holtham and Nguyen, 2002), the Grey-Level Co-occurrence Matrix (GLCM) (Moolman et al., 1995b,a) and the Wavelet Texture Analysis (WTA) (Bartolacci et al., 2006). In the current work, the use of a variogram-based technique is introduced, which is an alternative method to the co-occurrence matrix for classifying image textures (Carr and De Miranda, 1998).

1.2. Geostatistics and image analysis

The variogram, a widely used geostatistcal technique, is a two-point statistical function that describes the degree of spatial

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http://dx.doi.org/10.1016/j.mineng.2016.07.012
0892-6875/

dependence between sample values as separation between them increases. It characterises the spatial continuity or roughness of a data set, elements in an image for instance, and allows identifying differences that common descriptive statistics and histograms cannot (Barnes, 2003). The variogram in particular, and geostatistics in general, are nowadays frequently applied image processing techniques.

This is not the first time that two-point statistics is used to characterise images related to flotation. Previously, Emery et al. (2012) and Kracht et al. (2013) had used a geostatistical approach to estimate the bubble size distribution of bubbles generated at a laboratory flotation cell, which proved to be a good solution to the problem of sizing bubbles that appear touching each other or overlapping (clusters) in the images.

As shown by Woodcock et al. (1988a,b), variogram characteristics such as height, range and shape, relate to the spatial variation in images. This spatial information can provide data on texture that can be used for classification (Atkinson and Lewis, 2000). Different uses of variogram-based texture analysis are reported in the literature, ranging from microscope to satellite images. Bonetto and Ladaga (1998), for instance, used the variogram method to characterise the texture of scanning electron microscope (SEM) images; Chica-Olmo and Abarca-Hernandez (2000) used geostatistical texture analysis to classify lithologies; Wu et al. (2006) used variogram-based texture analysis to classify urban land-use from aerial images; Jakomulska and Clarke (2001) used variogram-based measures to discriminate between vegetation classes from aerial images; and Fotsing et al. (2013) used variograms to characterise and classify satellite images.

The purpose of the current work is to introduce a variogram-based technique to compare and classify foams according to their texture, and studying the effect of frother type on the texture of foams generated in a quasi-2D cell and in a laboratory column.

2. Experimental

The foam images used in this work were generated from two separate, independent experimental campaigns, the first one performed in a quasi-2D cell, where the images generated correspond to vertical sections of the foam (Fig. 1, left); and the second one performed in a laboratory flotation column, where the foam images correspond to the top of the foam (Fig. 1, right).

2.1. Reagents

The reagents used in this study were: MIBC, Octanol, Oreprep F549, DF250 and PEG300. The composition and supplier of the reagents are summarised in Table 1.

Table 1
Reagents used.

Frother	Characteristics	
MIBC	Composition Supplier	4-Methyl 2-Pentanol ⩾ 98% Sigma Aldrich
Octanol	Composition Supplier	Octanol ⩾ 99% Sigma Aldrich
Oreprep F549	Composition Supplier	Polyglycols (DF250 simile) Cytec Chile
DF250	Composition Supplier	Polyglycols Dow Canada
PEG300	Composition Supplier	Polyethylene glycol ⩾ 99% Sigma Aldrich

2.2. Quasi-2D cell

A narrow quasi-2D cell was designed in order to study the foam structure. It consisted of an acrylic cell of 20 cm height, 15 cm wide and 1 cm depth, as shown in Fig. 2.

A slot sparger, similar to the one proposed by Li et al. (1994), was used for air dispersion. It consists of a system that injects air through a long and narrow slot located at the bottom of the cell, generating a discrete arrangement of equidistant bubble nodes. The slot sparger was built using acrylic and a 100 µm thick stainless steel strip. The gas flow rate was measured with an Omega mass flow meter, FMA1820, and controlled with a rotameter Dwyer, combined with a manometer Festo.

2.3. Laboratory column

The column tests were performed in a Plexiglass laboratory column of 4 m height and 10.16 cm internal diameter with a porous sparger for air dispersion. The column was equipped with a mass flow meter MKS (0–20 L/min) to measure and control the gas flow rate, a differential pressure cell (Bailey) that allows the gas holdup in the collection zone (ε_g) to be calculated, and a conductivity meter, to estimate the foam gas holdup ($\hat{\varepsilon}_{gf}$) at the top of the column. The foam height was controlled by adding water to the column with a pump. The foam images were captured at the top of the foam (foam surface) as represented schematically in Fig. 3.

2.4. Variogram-based textural classification

2.4.1. Image database

The images in both sets of experiments where taken with the same controlled light (two LED spotlights of 50 W each). This white light was significantly brilliant, in order to overcome any other difference in ambient light. Moreover, all the experiences were performed in a laboratory without direct sunlight.

The original pictures were centred cropped in order to avoid edge lighting variations. Original size of the images for the quasi-2D experiment was 4280 × 2840 pixels and they were cropped to 3250 × 1700. In the case of the column experiments, the original size of the images was 5180 × 3450 and they were cropped to 3900 × 2600.

Figs. 4 and 5 show sample images of these two databases.

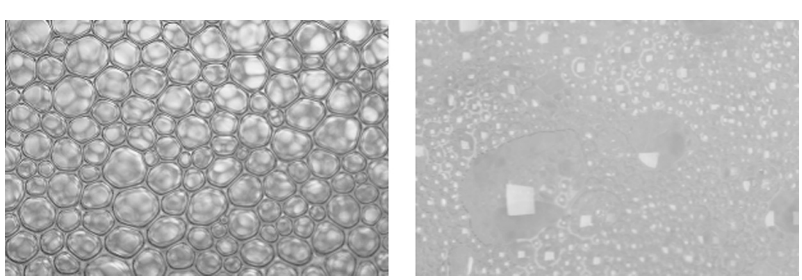

Fig. 1. Example of foam images generated in a quasi-2D cell (left) and in a laboratory flotation column (right). Images not at scale.