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Automatic control of bubble size in a laboratory flotation column

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A B S T R A C T

Gas dispersion properties play an important role on determining the metallurgical performance of flotation processes. Indeed, bubble surface area flux (S_b) has been found to correlate with the collection zone flotation rate constant and is therefore a potential variable to regulate in order to achieve a target performance. S_b can be calculated as a combination of two other gas dispersion properties, namely, gas superficial velocity and the Sauter bubble mean diameter. This communication describes the design and implementation of a feedback control system for the Sauter bubble mean diameter in an attempt towards controlling S_b. In order to track changes on bubble size, the Sauter bubble mean diameter was derived from an adaptive bubble size probability density function (PDF). A Gaussian mixture model was used to represent the bubble size PDF and its parameters were updated on-line and in real-time by a dedicated computer from sequentially incoming images. To improve bubble size controllability, a frit-and-sleeve sparging device was installed. This device allows modifying bubble size by manipulating the water flow rate circulating through a sleeve surrounding a porous ring (shear water). A Wiener model is used to represent the dynamic relationship between the shear water flow rate and the Sauter bubble mean diameter. A nonlinear control, based on the internal model control (IMC) structure, was designed and implemented. Tracking and regulation performance against gas velocity and unmeasured frother concentration variations were then successfully evaluated in a two-phase system.

1. Introduction

Flotation is a process commonly used for separating valuable minerals from useless minerals (gangue). Metallurgical performance can be determined through the valuable-mineral concentrate grade and recovery. Whereas the first of these two variables can be measured online using an X-ray on-stream analyzer (XRA), the latter is commonly calculated from the feed, concentrate and tails grade using a steady-state material balance, an assumption that strongly limits its use for control purposes. Moreover, the long sampling times of these XRA devices, usually multiplexed, favor the use of a hierarchical control structure where secondary variables are kept under control to indirectly optimize the process.

Experimental studies have shown that the collection zone flotation rate constant can be expressed as the product of the bubble surface area flux and a factor that accounts for particle related properties called particle *floatability* P (Gorain et al., 1997; Hernandez-Aguilar et al., 2003). The model can be extended to the overall flotation rate constant by introducing the froth recovery (i. e., $k_{overall} = PS_bR_f$). This suggests that for a given particle floatability, recovery can be modified by varying froth recovery and/or bubble surface area flux. While some control approaches have focused on controlling froth characteristics, such as froth speed (Barria and Valdebenito, 2008; Cortes et al., 2008), or froth appearance (Liu and MacGregor, 2008), others aimed at controlling some gas dispersion properties, such as gas hold-up and superficial gas velocity (Bergh and Yianatos, 1993; Carvalho and Durão, 2002; Persechini et al., 2004; Maldonado et al., 2009). This approach has been motivated by the recent availability of industrial gas-dispersion sensors (Gomez and Finch, 2007; O'keefe et al., 2007). Nevertheless, to the author's knowledge no attempt has been made to automatically controlling bubble size in flotation columns which is an important step towards controlling S_b. This latter is normally expressed mathematically as follows:

$$S_b = \frac{6 \cdot J_g}{d_{32}} \quad (1)$$

where J_g is the gas superficial velocity in (cm/s) and d_{32} is the Sauter bubble mean diameter in (mm). In flotation column operation, bubble size is mainly affected by frother type and concentration, gas rate and the type of gas sparging device. Superficial gas velocity modifies S_b directly through the numerator of Eq. (1) and indirectly by affecting bubble size (denominator) (Finch and Dobby, 1990; Nesset et al., 2006). Whenever feasible, the sparger system adds another control degree of freedom to modify bubble size in flotation columns. In this work, a 'frit-and-sleeve' sparger was implemented (Kracht et al., 2008). By

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mean of the shear water rate, this type of sparger allows the modification of bubble size independently from gas velocity, thus improving controllability of S_b.

This article extends previous works on the control of gas dispersion properties, to the control of bubble size represented by the Sauter bubble mean diameter. Section 2 describes the laboratory column and its instrumentation. Bubble size density estimation is presented in Section 3 and the nonlinear Wiener model identification is detailed in Section 4. The Wiener based IMC design and implementation is presented in Section 5. Finally experimental results and discussion are respectively found in Sections 6 and 7.

2. Flotation column set-up

The flotation column used in this work has three sections made of polycarbonate tubes for a total height of 5 m. The internal diameters of the bottom, intermediate and upper sections are respectively 15.24 cm, 10.16 cm, and 5.08 cm and their respective heights are 42 cm, 58 cm and 400 cm. Three frit-and-sleeve sparging devices were mounted at the bottom of the column although only one was used in this work, as illustrated in Fig. 1.

Gas flow rate is measured through a mass flow sensor/controller (Aalborg model GFC17). The mass flow sensor also provides an estimate of the volumetric flow based on a reference or standard condition provided by the vendor (i.e., 21.1 °C and 101.3 kPa). Its readings must then be converted to the actual tests conditions of temperature and pressure which were respectively measured by sensors PT and TT, as depicted in Fig. 1, using the following equation:

$$J_g = J_g^{std} \cdot \left[\frac{1033.23}{1033.23 + P_g}\right] \cdot \left[\frac{T + 273.15}{294.16}\right] \quad (2)$$

where P_g is the gauge pressure in cm H_2O measured by sensor PT, T is the temperature in degrees Celsius measured by sensor TT and J_g^{std} is the gas superficial velocity, calculated from the air mass flow meter readings at standard conditions. A differential pressure transmitter DP (model ABB 264DS) was tapped between 250 cm and 320 cm above the sparger to measure collection zone gas hold-up. For a two-phase system (air–water), this latter can be accurately measured using the following relationship:

$$\varepsilon_g(\%) = 100 \cdot \frac{\Delta P}{L} \quad (3)$$

where ΔP is the pressure differential in cm H_2O and L is the distance between taps, in this case 70 cm. Supervision was performed by a HMI/SCADA software (iFIX®) working under Windows XP® operating system. An Opto 22 I/O system is used to centralize sensor and actuator signals. A modified version of the McGill's bubble viewer (Gomez and Finch, 2007) was implemented to continuously measure bubble size as shown in Fig. 2.

Images of the bubbles were captured by a digital camera (SONY DFW-X710) and continuously retrieved by a dedicated computer

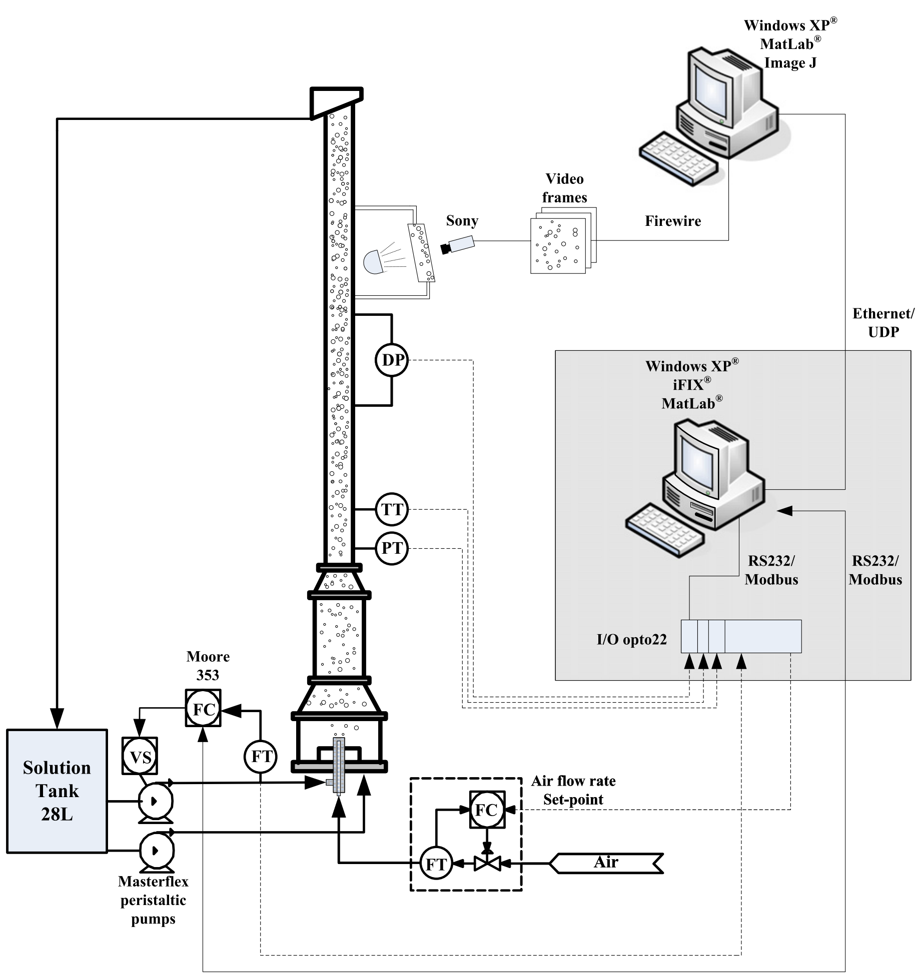

Fig. 1. Instrumented flotation column.