Level control loop design for a test-rig flotation column

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Abstract. During the last years, there has been a great advance in the instrumentation to improve the performance of industrial processes, this has allowed important advances in the control processes. In this work, we analysed the control of the froth layer height (level) of a flotation column to improve its performance. A level control loop was designed, selected and assembled, finally it was adjusted through NB Omron Designer interface that allows the communication between the measure element, controller and control valve, establishing a pressure (Set Point) to control froth layer height (level) and make sure it is stable operating.

Tests were carried out with water, water-air and water-air-frother. This was done to analyse the behaviour of the column and subsequently verify the results using drift flux analysis. Once the results were obtained, the parameters that showed the optimal performance of the column were analysed. An overshoot was obtained in the range of 1 % to 12 %, stabilization time in the range of 90 s to 97 s and the tailing velocity which was maintained between 0.72 cm/s - 0.76 cm/s. Analysing the results, the experimental error was in the range of 0 % to 6 %.

1. Introduction

Flotation is a solid-solid separation process, in which air bubbles separate solid particles, in an aqueous medium. For the flotation phenomenon to occur, the particle surface is required to be water repellent, air is introduced into the slurry so that the hydrophobic particles can adhere to the air bubbles, the hydrophilic particles do not adhere to the air bubbles and remain in slurry, this process is known as flotation [1,2].

Pierre Boutin, Remy Tremblay and Don Wheeler introduced the concept of flotation column in the early years of the 1960s with the objective to process fine mineral, offering a solution to problems encountered in conventional flotation. A flotation column differs from a conventional cell in its design and operating philosophy, because a flotation column can replace multiple flotation cells, generating a simpler and easier to control circuit. One of the advantages of columns flotation over conventional flotation cells is the improved capacity for modeling and automation [3-5].

One of the control objectives in a flotation column is to maintain the froth layer height (level) at the desired values through manipulation the tailing flow rate. Some papers present results of control schemes applied to the column flotation process. Finch and Dobby (1990) [2] presented two simple control schemes for stabilize the process. In the first scheme; the froth layer height (level) is controlled through the manipulation of the tailing flow rate, the wash water flow rate is controlled manually. In the second scheme, wash water flow rate and the tailing flow rate are manipulated to respectively control the froth layer height (level) and the difference between the tailing flow rate and the feed flow rate, as an attempt to control the bias flow rate. Bergh, Yianatos and Leiva (1998) [6] describe the application of fuzzy logic techniques to evaluate a PID controller in a flotation column, where the
froth layer height (level) is controlled by the manipulation of the tailing flow rate. Muani, Clark and Gonçalves (2004) [7] applied the relative gain array (RGA) method to measure the degree of interaction between the process variables and obtain the best pairing of the controlled and manipulated variables, designing a control scheme multiloop PI, which was tested in a pilot scale flotation column. Yinfei, Jiongtian, Yongtian, and Yijun (2011) [8] applied fuzzy control methods to the flotation column and tested the performance of the design by Matlab/Simulink simulation, the simulations show that level control in the flotation column becomes smoother and more rapid with the fuzzy controller. Compared to PID control methods the overshoot in valve position, the adjustment time, and the robustness of the controller are all improved. The objective of this work was to evaluate a simple control scheme, which consists in maintaining the control of the froth layer height (level) by manipulation of the tailing flow rate using two pressure transducers in two points of the collection zone, which were processed by a programmable logic controller (PLC). The values of ΔP thrown by the PLC were used for calculated, the bubble diameter (Db), the Reynolds number of the bubbles (NRe), using drift flux analysis [9-11].

2. Experimental description
In this study, a flotation column 2 m high and 0.05 m in diameter was used. The feed flow rate was located at a height of 0.75 m, measured from the top of the column. The bubble generation system consists of a static mixer and a centrifugal pump of 1/2 HP to 110 V, which was placed in the lower part of the column, the air flow rate was located in the recirculation line of the bubble system [12]. For pressure drop measurements a NP620 Novus transducer was chosen, this is a relative pressure transmitter, operating in the range of 0 psi to 14.5 psi and a temperature in the range of -20 °C to 70 °C, with an output signal in the range of 4 mA to 20 mA. A Danfoss Ev-260B solenoid proportional valve with signal converter operating in the range of 0 VDC to 10 VDC was selected. A programmable logic controller (PLC) CP1HXA40DRA was chosen, finally, use the NB Omron Designer interface that allowed the communication between the controller and the control valve, this interface showed the pressure data taken through the transducers, the pressure drop inside the column, the valve opening percentage, the overshoot and the stabilization time of the control circuit in each test. Methyl Isobutyl Carbinol-MIBC (C₆H₁₄O) and Aerofroth 65 (H(PO)₆·½OH) were used as frother. Figure 1 shows the diagram of the flotation column.

![Figure 1. Schematic diagram of the flotation column and associated instrumentation.](image)

Frother – water was homogenized by recirculation in the same mix tank. Subsequently, the feeding valve opened up until obtaining the flow rate desired in the column flotation, when the mixture reaches 0.1 m (approximately) above the feeder position, air rotameter valve was opened until
obtained the air flow rate desired. Pressure drop measurements were made at two data collection points installed in the flotation column, as shown in Figure 1 (TP1 and TP2). With the ΔP measurements at different values of air velocity (Jg) and frother concentration (FC), air holdup, bubbles diameter and the Reynolds number of the bubbles were calculated using drift flux analysis [9, 10, 11]. Experimentally Jg was selected in the range of 0.68 cm/s to 2.04 cm/s and FC in the range of 20 ppm to 100 ppm. The adjusting process of the level control loop in the flotation column was started according to the pressure drop data obtained through the transducers. A set point was selected for the pressure transducers (1.01 psi) which sent a signal to the controller and this to the control valve that maintain froth layer height (level) inside the flotation column of 142 cm ± 3 % and a tail velocity (Jsl) of 0.76 cm/s ± 6 %, according to the column design [12]. The tests for the controller adjustment were made with water, MIBC and Aerofroth 65. During the tests of the control system, other variables such as overshoot and stabilization time were analysed, which were in the range of 10 % to 12 % and 90 s to 96 s respectively.

3. Results and discussion

The initial measurements were made with water and air (without frother) in order to determine the Set Point for the pressure drop and in this way the control valve act for obtain the froth layer height (level) desired in the flotation column. The value found was 1.01 psi, which maintained a height of 142.5 cm, which is in accordance with the values determined in the flotation column design [12].

Figure 2 and Figure 3 show the interaction between air holdup (ε), bubble diameter (Db) and air velocity (Jg) respectively.

![Figure 2](image1.png)  
**Figure 2.** Air velocity vs air holdup for water-air system.

![Figure 3](image2.png)  
**Figure 3.** Air velocity vs bubble diameter for water-air system.

In these figures we can observe the increase in ε and Db with the increase in Jg. Figure 2 shown the increase in ε is in the range of Jg of 0.7 cm/s to 1.4 cm/s, for this range of Jg the bubble diameter is in the range of 0.7 mm to 0.9 mm (Figure 3). These results suggest that in this range of Jg is obtain a homogeneous bubble diameters distribution. Also shown in Figure 2 that ε remains constant above a Jg of 1.4 cm/s, while in Figure 3 can be seen that the bubble diameter increases from 0.94 mm (1.4 cm/s) to 1.20 mm (1.7 cm/s), showing us a great increase of Db as a consequence of the coalescence of the bubbles above of 1.4 cm/s.

Water-Air-Methyl Isobutyl Carbinol (MIBC): Figure 4 and Figure 5 show the interaction between ε, Db and Jg respectively using Methyl Isobutyl Carbinol. In these figures we can observe the increase in air holdup and bubble diameter with the increase in air velocity. From Figure 4 we can see that there is a strong increase in ε (15 % to 30 %, at 20 ppm of FC) in the Jg range of 0.7 cm/s to 1.0 cm/s, above this value shows a smooth increase until 2.04 cm/s (35% at 20 ppm of FC), this same trend is shown throughout the range of FC used. It is interesting to note in Figure 4 that with the increase in FC to Jg constant (0.7 cm/s) ε this increases from 14.87 % at 20 ppm to 17.62 % at 100 ppm. This same trend
was shown for different values of Jg and FC, it is noteworthy that the all values of ε with addition of frother at different concentrations are greater than without addition of frother. Figure 5 shows that Db is in the range of 0.54 mm to 0.96 mm for all values of FC used. Is observed than bubble diameter values are affected by the increase in air velocity and not by the frother concentration, however, bubble diameter values with addition of frother are lower than without addition of frother. From Figure 4 and Figure 5 we can see that for the Jg and FC used range, homogeneous bubble diameters distribution is obtained, and no evidence of coalescence is shown.

![Figure 4. Air velocity vs air holdup (MIBC).](image1)

![Figure 5. Air velocity vs bubble diameter (MIBC).](image2)

Water-Air-Aerofroth 65: Figure 6 and Figure 7 show the interaction between ε, Db and Jg respectively using Aerofroth 65. In these figures, we can observe the increase in air holdup and bubble diameter with the increase in the air velocity. From Figure 6 we can see that with the increase in the Jg range of 0.7 cm/s to 2.04 cm/s, the ε increases in the range of 13.5 % to 40 %. For an all range of FC (Jg constant) was observe the same trend, it is noteworthy that the all values of ε with addition of frother at different concentrations are higher than without addition of frother and are in the same range as those obtained with MIBC.

![Figure 6. Air velocity vs air holdup (Aerofroth 65).](image3)

![Figure 7. Air velocity vs bubble diameter (Aerofroth 65).](image4)
In Figure 7 it is observed that \( D_b \) is in the range of 0.6 mm to 0.96 mm for all the values of FC used. It should be noted that the bubble diameter values are affected by the increase in air velocity and not by the frother concentration, however, bubble diameter values with addition of frother are lower than without addition of this and they are in the same range as those obtained with MIBC.

As well as for the MIBC, with the Aerofroth 65 and the used range of \( J_g \) and FC homogeneous bubble diameter distribution is obtained, and no evidence of coalescence is shown. Based on the results of using drift flux analysis, Reynolds numbers in the range of 25.13 to 137.48 were obtained, which are within the required range [9-11]. Figure 8 shows the level height vs. the air velocity obtained with MIBC.

In Figure 8 it is observed that the values the froth layer height (level) are in accordance with those established in the flotation column design [12], which is 142 ± 5 cm showing a range of error of 0 % to 3 %, with a Jsl 0.76 cm/s ± 6 %. For the two frother used, overshoot ranges of less than 12 % and stabilization times in the range of 90 s to 97 s were obtained, these criteria being direct indicators of the good performance of the system. From these values it was experimentally demonstrated that the control loop designed and assembly on the flotation column worked successfully and complying with all the required parameters.

![Figure 8. Air velocity vs froth layer height (level).](image)

4. Conclusions
The tail velocity (Jsl) was maintained in the range of 0.72 cm/s to 0.79 cm/s with an error percentage in a range 0 % to 6 %, with values for the froth layer height (level) 142 cm ± 5 (error in the range of 0 % to 2.5%) according to the design. The Overshoot remained in the range of 1 % to 12 %. The stabilization time was maintained in the range of 90 s to 97 s.

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