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Pressure Characteristics in a Flotation Column

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Abstract: An exclusive study was performed on experimental investigation of axial pressure characteristics with slurry-gas system in countercurrent flotation column. The effects of gas and slurry flow rate on axial pressure were presented in this paper. An attempt was also made to show the effect of experimental gas holdup on the pressure drop. Coal and sphalerite were used in the present experiment as solid. The experiments were conducted in the bubbly flow regime because of its uniformity that was used in flotation process.
Keywords: Pressure drop; gas holdup; flotation column; solid.

Introduction

Slurry bubble columns are generally used in industries as multiphase contactors. Flotation column is one such equipment where solid-solid separation is achieved by the rising air bubbles in a slurry medium. Flotation column offers several advantages over conventional mechanical flotation cells like: recovery of fines, less power consumption, less floor area, flexibility to shift the bubble size distribution, ease in operation and low maintenance cost. It is currently providing its widespread application to many industrial as well as environmental problems like enrichment of minerals, soil remediation, purification of coal, de-inking of paper pulp, industrial wastewater treatment, bio-leaching of mineral ores and recovery of talc. The salient features of flotation column are drawing the attention of researchers towards its improvement. ignificant work in the flotation column has been carried out but most of the reported works are with gas- liquid systems[1-,9] and gas slurry system[10,11,4]. Major studies focus on the estimation of bubble size distribution and gas holdup in gas-liquid/slurry system. Gas flow rate, liquid flow rate, frother concentration are the main parameters for these studies. Mixing characteristics of flotation column has also been made by some authors[12]. Lopez-Saucedo et al.[13] and Uribe-Salas[14] have studied the metallurgical performance (grade and recovery) of the flotation column.

Besides gas-holdup and metallurgical performance, frictional pressure drop is an important parameter for designing a flotation column. Knowledge of axial pressure characteristics inside the column is also essential in controlling the bubble size. But limited research works are available in the published literature. Gomez et al.[15] have studied on axial pressure profiles in a laboratory flotation column with air water only. They have reported that increase in gas holdup with column's height is a direct function of the hydrostatic expansion of gas bubble. Yianatos et al.[19] have performed an experiment in large size industrial flotation column to measure axial pressure profile and derived a hydrodynamic model to describe the pressure and gas holdup profile in flotation column. Jiong-tian et al.[16] have made their investigations on pressure drop performance of the packed flotation column. They have developed correlations between dry plate/wet plate pressure drop and gas velocity. Pressure drop characteristics have been studied in a modified gas-liquid down flow column and correlation for pressure drop have been developed[17,18]. No other major literature is available. Also, study on the frictional pressure drop in flotation column still has not been made. Therefore, the aim of the present investigation is to study the characteristics of frictional pressure drop of a laboratory flotation column with slurry containing sphalerite or coal. Experiments have also been conducted to observe the effect of process variables on column's axial pressure profile. The experimental results have been analyzed by a newly developed correlation. Analysis of relationship between gas holdup and axial pressure characteristics has also been made.

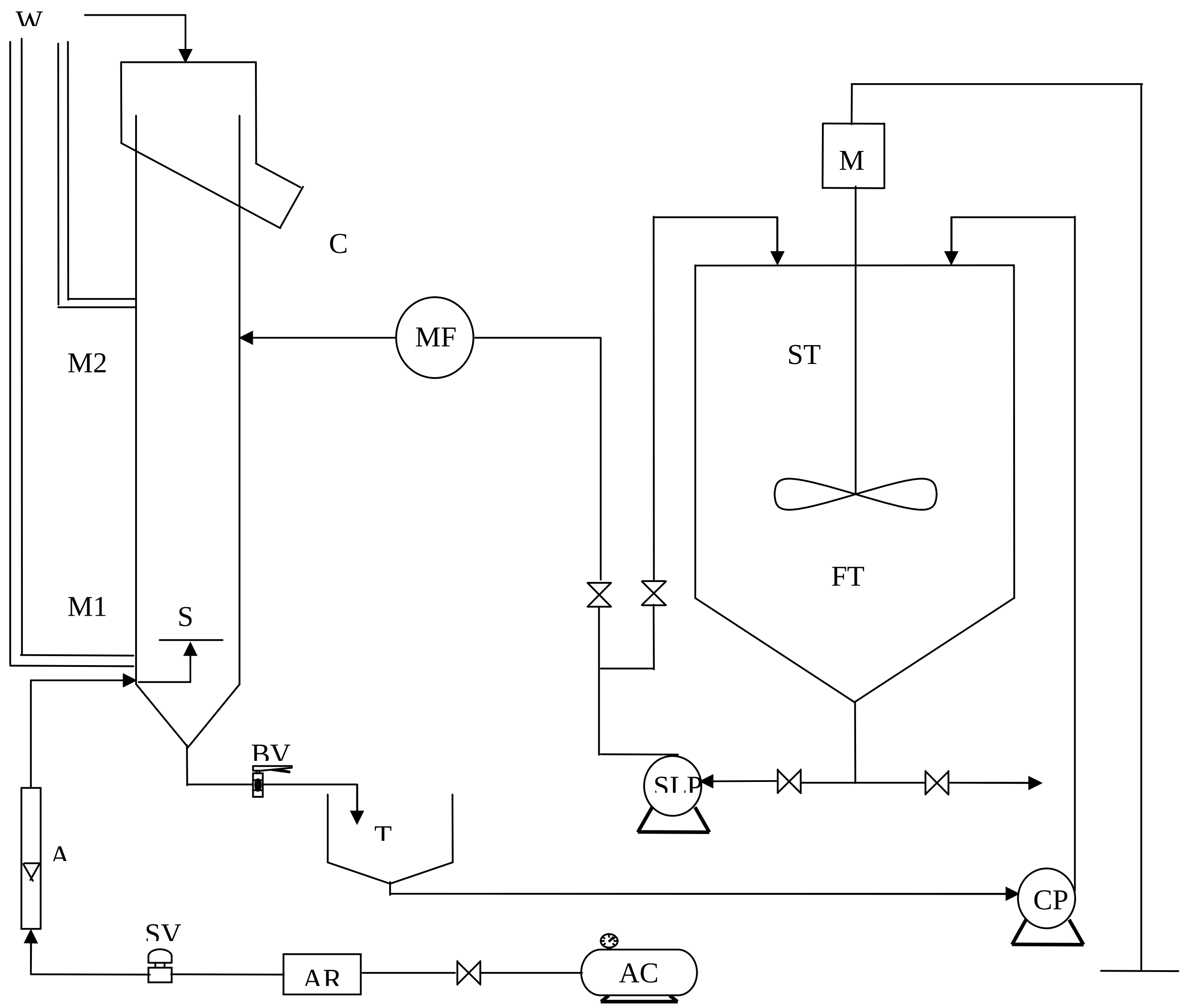
Experimental Setup, Materials and Methods

The schematic diagram of the experimental set-up is presented in Fig. 1. It consists of a flotation column, feed preparation tank, a tailing and concentrate collector tank, and other accessories e.g. slurry pump, magnetic flowmeter, air compressor, gas controller, gas rotameter, ceramic porous sparger, piezometer, butterfly valve, solenoid valves etc. The detailed specifications of the experimental column are given in Table 1. In the present study, sphalerite from Hindustan Zinc Ltd. (India) and coal have been used as solid.

Initially feed tank FT was filled with some amount of water. Slurry was prepared by adding known amount of solids for each case. This was then properly stirred and additional water was added to reduce the solid concentration to the desired level. This prepared feed slurry was fed using the slurry pump (Bornemann India, Faridabad, India) to the flotation column at desired feed flow rate. Air was supplied to the sparger by switching on the air compressor before sending the feed to the column. Feed/slurry flow rate was measured using a magnetic flow meter. The flow rate of air was measured using air rotameter. The column was operated continuously for about 30 min to reach steady state, which was confirmed by constant flow of tailings and froth. Wash water was not used to avoid dilution of the slurry. Moreover, the objective of the work was focused on the phenomena occurring in the collection zone, hence the role and performance of the cleaning zone was not of particular interest. Therefore, froth depth was kept low. For this reason during steady state the interface level was maintained such that it prevented the overflow of feed slurry from the top of the column with minimum froth depth. This froth product was returned to the feed tank to maintain a constant solid concentration of slurry. All the tests were performed at room temperature (25 - 30^{o}C). The ranges of operating variables utilized in experiment are listed in Table 2.

The mean gas holdup for the present system has been measured by "phase separation technique" as reported in literature[10]. When a steady state condition of the system was attained, the total height of gas slurry mixture in the column was noted. Then the feed pump and the solenoid valve were switched off by a common switch and the butterfly valve for tailings was closed simultaneously (Fig. 1). This ensured stoppage of all flows at the same time i.e., an immediate termination of slurry and gas flow. The gas slurry mixture inside the column got arrested and was allowed to settle for some time whereby all gases got separated. The clear liquid height inside the column was then noted. The difference between the gas slurry mixing height and the corresponding clear liquid height gave the overall gas holdup in the column. This was repeated twice for same operating condition to measure mean gas holdup.

At similar conditions of gas holdup measurement, the axial pressure characteristic of the column was evaluated using piezometers (Fig. 2). The column was divided into four zones. The total pressure difference of each zone was obtained from the difference of pressure readings of corresponding piezometers. The length of these zones was selected in increasing order to improve accuracy in experimental results. The operating conditions of the present study are given in Table 2.



Legends:
A: Air rotameter, AC: Air compressor, AR: Air regulator, BV: Butterfly valve, C: Concentrate, CP: Centrifugal pump, FT: Feed tank, MF: Magnetic flow meter, M: Motor, M1, M2: Manometer, S: Sparger, SLP: Slurry pump, ST: Stirrer, SV: Solenoid valve T: Tailings, W: Wash water

Fig. 1. Experimental setup

Table 1: Laboratory columns specifications

Parameters	*Column*
Diameter (m)	0.1
Height (m)	1.68
Gas sparger type	Internal-porous ceramic candle
Feed point from sparger (m)	1.3

Table 2: Operating variables of column experiments

Parameters	*Range*
Solids	Coal, Sphalerite
Superficial gas velocity (cm/s)	1.91
Superficial feed/slurry velocity (cm/s)	0.64 – 2.76
Slurry concentration (Kg /m^3) (mass of solid/liquid volume)	0-30

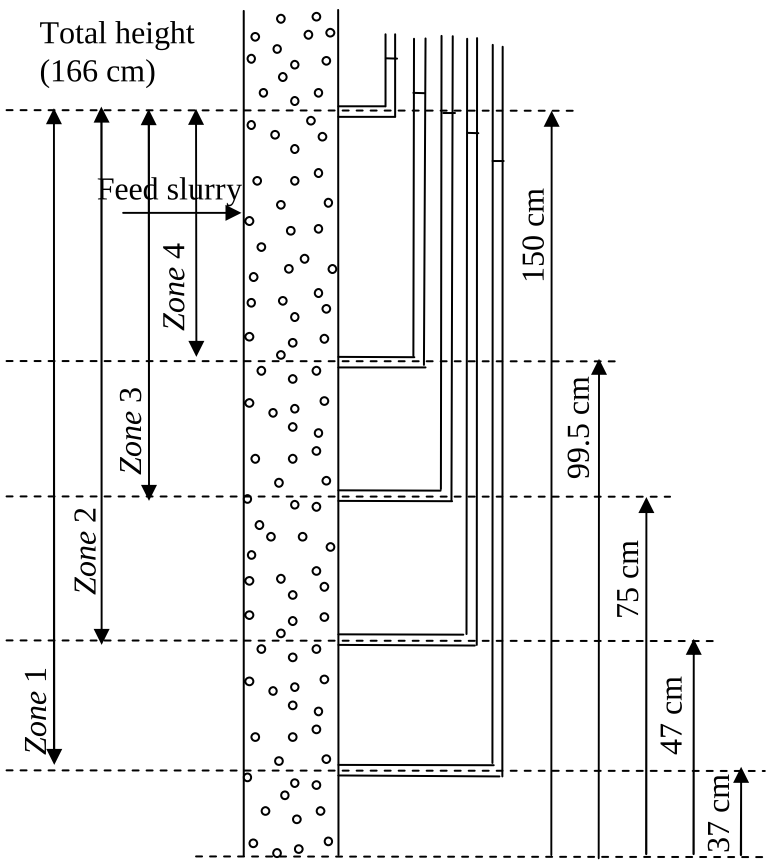


Fig. 2. Axial pressure measurement scheme

Results and Discussions

Axial Pressure Profile in Flotation Column

The measured axial gauge pressure profiles of the column operating with coal slurry without frother have been presented in Fig. 3. This plot also compares pressure profiles at different gas velocities. Fig. 3 shows decreasing in local pressure with increasing in gas velocity at all measurement points. It is also found that local pressure at lower height (higher depth) decreases rapidly with gas velocity.

Effect of Gas Velocity and Solid Property on Pressure at Particular Point

Fig. 4 illustrates the effect of gas velocity on pressure variation at a particular point at constant slurry flow rate. The pressure has been measured at a height of 37 cm from bottom of the column. It can be observed from this plot that the pressure decreases with an increase in gas flow rate. This decrease in pressure can be explained by the fact that an increase of gas velocity causes higher population of gas bubbles in column, which in turn decreases the static pressure head. It can also be attributed to lower pressure zone due to high gas velocity according to Bernoulli's principle. Fig. 4 also depicts the variation of pressure with gas velocity at constant slurry flow rate for different solid. Sphalerite (sp. gr. 3.16) and coal (sp. gr. 1.6) have been used as solid. It can be found from Fig. 4 that higher pressure has been observed for sphalerite slurry at the same gas velocity. The reason can be explained by considering the increasing slurry density. Slurry containing sphalerite has higher density than that containing coal at the same solid concentration as higher specific gravity of sphalerite.

Effect of Gas Velocity and Solid Concentration on Axial Pressure difference

Fig. 5 shows the pressure difference with gas velocity at various zones using coal and sphalerite slurry. The pressure difference between two locations of the column has been obtained by subtracting the corresponding piezometer tube readings. This pressure difference in cm of water has been plotted against gas velocity in Fig. 5 for various zones. Increase in gas velocity decreases pressure difference almost linearly in each zone due to increase in gas holdup. The pressure difference against gas holdup at constant slurry flow rate has been presented in Fig. 6, from which it is clear that pressure difference decreases with increase in gas holdup. The relationship between gas holdup and gas velocity using coal has been shown in Fig. 7, from which it can be concluded that the gas holdup increases with gas velocity.

Effect of Solid Property and Slurry Concentration on Axial Pressure profile

Variations of pressure difference per unit length of column with gas velocity has been graphically presented in Fig. 8 and compared with different solids. It may be observed from the plot that the pressure difference is higher for sphalerite slurry due to higher specific gravity. The variation of pressure difference due to slurry concentration with gas velocity has been shown in Fig. 9 using sphalerite as solid. From Fig. 9, it can also be seen that pressure difference per unit column length decreases with increase in slurry concentration at constant gas velocity.

Effect of Gas Velocity and Solid Property on Differential Piezometric Pressure Head

Piezometric head (h) at any point of the column is the sum of elevation head (L) and static pressure head ($P/\rho_w g$) at that point. Therefore the differential head (Δh) between two points of the column (A and B) can be defined as the following equation (Eq. 2).

$$h_B - h_A = (L_B + \frac{P_B}{\rho_w g}) - (L_A + \frac{P_A}{\rho_w g}) \qquad (1)$$

$$\begin{aligned}
\Delta h &= (L_B - L_A) - (\frac{P_A - P_B}{\rho_w g}) \\
&= (L_B - L_A) - \frac{(L - L_A)\rho_{gsl} g - (L - L_B)\rho_{gsl} g}{\rho_w g} \\
&= (L_B - L_A) - \frac{(L_B - L_A)\rho_{gsl} g}{\rho_w g} \qquad (2) \\
&= (L_B - L_A)(1 - \frac{\rho_{gsl}}{\rho_w}) \\
&= \Delta L(1 - \frac{\rho_{gsl}}{\rho_w})
\end{aligned}$$

Where L, ρ_{gsl}, ρ_w and g are total column length, density of gas-slurry mixture in column, water density and acceleration due to gravity respectively.

The effect of gas velocity on the differential head (Δh) is shown in Fig 10. Negative differential head has been observed for coal and sphalerite slurry. This may be explained by equation 2. It may be assumed that ρ_{gsl} is equal to the slurry density (ρ_{sl}) in absence of gas. But, slurry density is higher than water density, which indicates the negative value of differential head (Δh) in absence of gas. As superficial gas velocity increases the amount of gas in column increases, which in turn, decreases the density of gas slurry mixture. So the differential head (Δh) increases with gas velocity. Lower values of differential head for sphalerite have also been observed. A physical explanation of lowering effect of differential head for sphalerite can be related to the specific gravity of the solid. High specific gravity solid sphalerite increases gas slurry density, which in turn, decreases differential head, as shown in Fig 10.

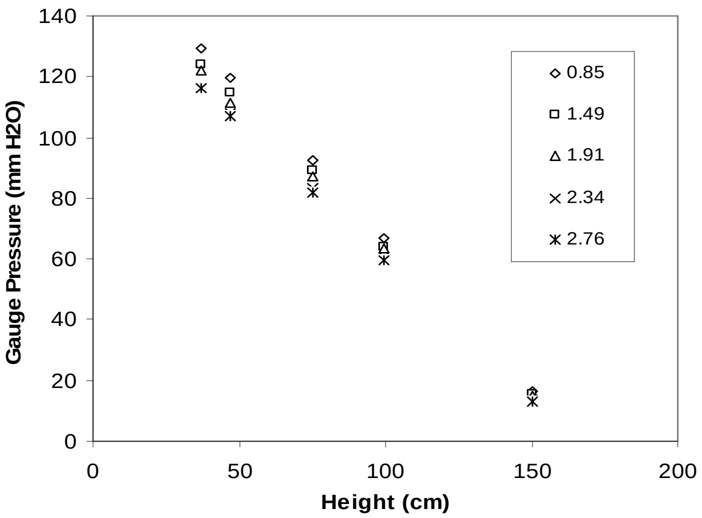


Fig. 3. Axial pressure profile

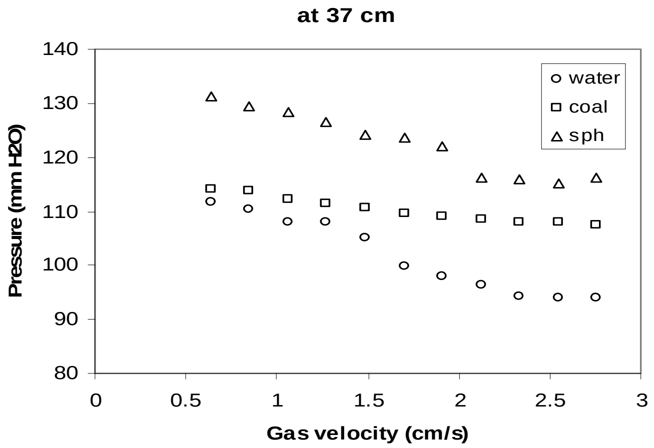


Fig. 4. Effect of gas velocity on pressure at particular point

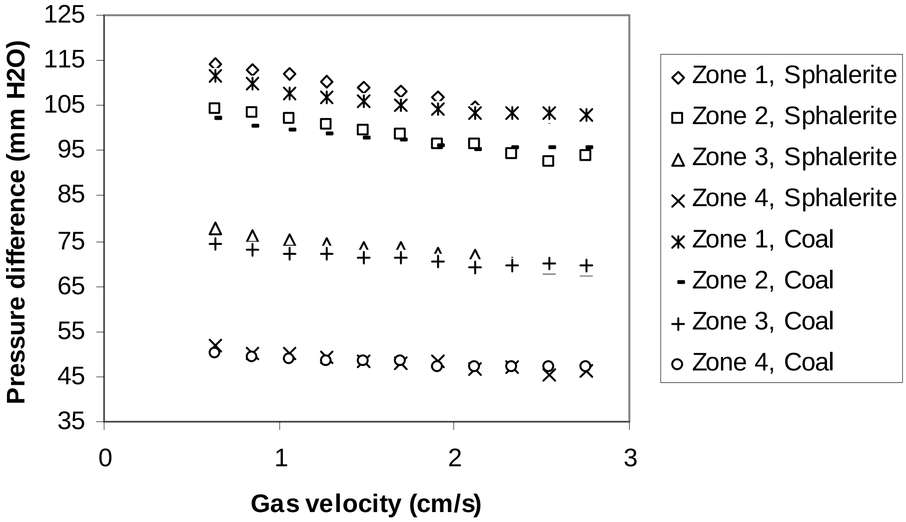


Fig. 5. Effect of gas velocity on axial pressure difference

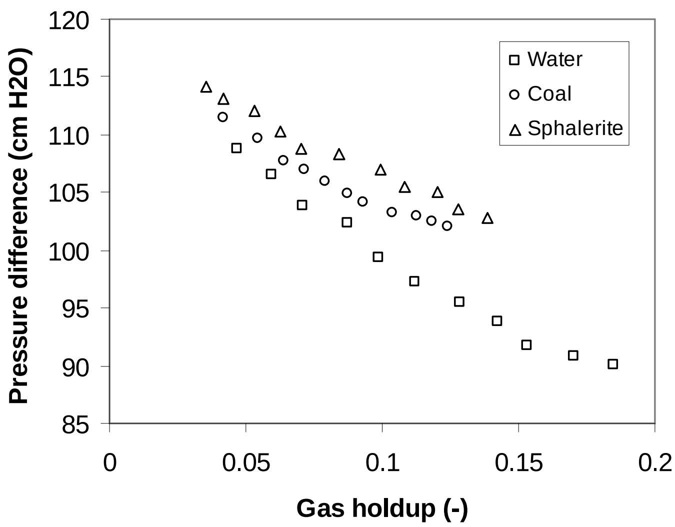


Fig. 6. Effect of gas holdup on pressure difference

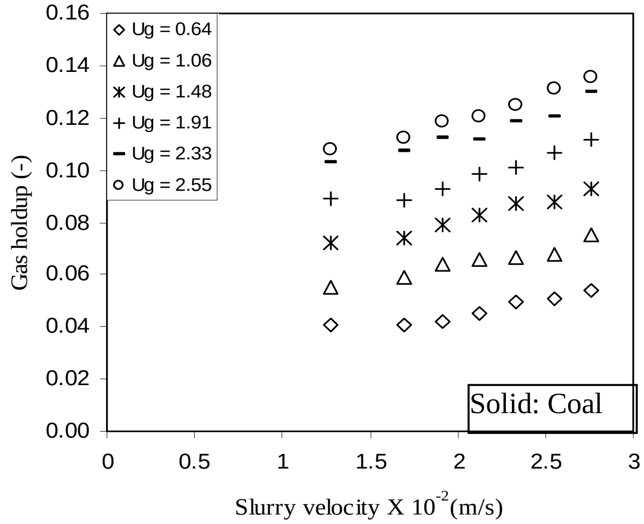


Fig. 7. Effect of superficial gas velocity and slurry velocity on gas hold-up

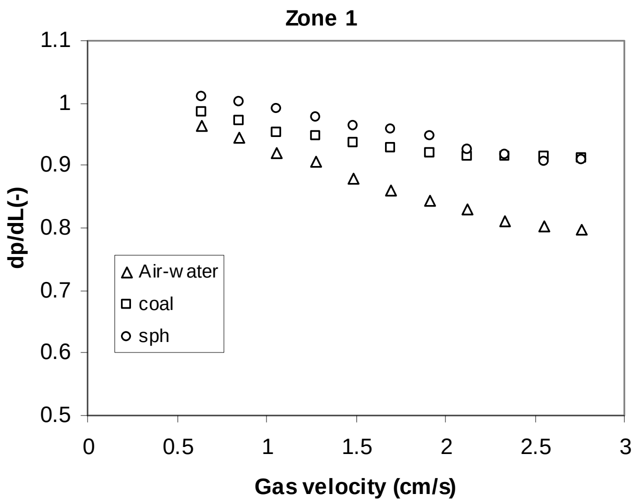


Fig. 8. Effect of solid property on axial pressure profile

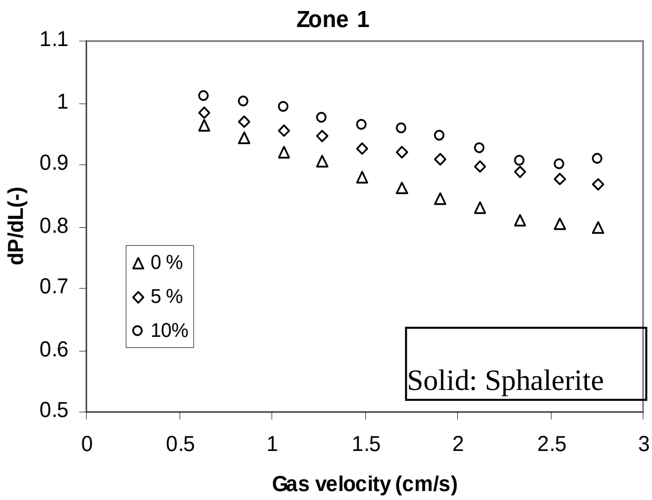


Fig. 9. Effect of solid concentration on axial pressure profile for sphalerite

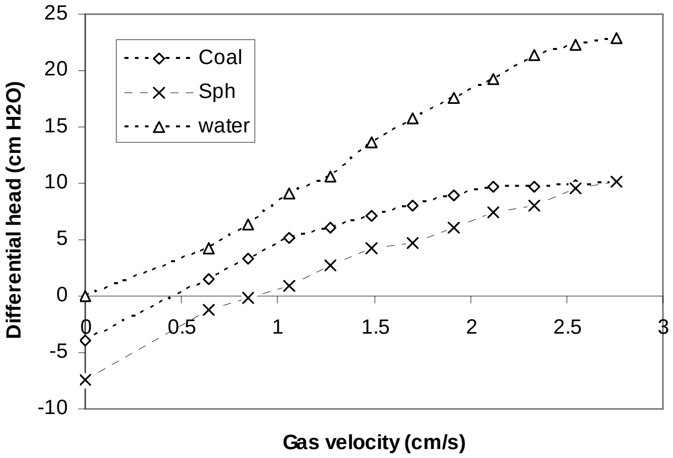


Fig. 10. Effect of gas velocity on differential head with different solid

Conclusions

The pressure drop characteristics of flotation column system have been studied in the present work. Effects of slurry concentration, gas flow rate, and solid type on axial pressure have been critically examined. Gas holdup and pressure difference relationship was presented for coal and sphalerite system. The analysis of experimental pressure data exhibits the frictional pressure drop. An empirical equation was derived to predict frictional pressure drop. The experimental results were found to be in good agreement with the predicted values obtained from the correlation.

Acknowledgement

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