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Technical note

# Measuring gas dispersion parameters: Selection of sampling points

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ABSTRACT

Bubble surface area flux has proven to be a key operational variable in flotation machines not only for diagnosis but also for optimization purposes. It is calculated as a combination of two gas dispersion properties, superficial gas velocity and bubble Sauter mean diameter. Since gas is not necessarily distributed evenly over the cross sectional area of a cell the sampling point where gas dispersion properties are measured must be carefully selected. This article illustrates that a radial parabolic gas velocity profile exists in mechanical cells, in some cases with significant variation in gas velocity as a function of radial distance from the center. An optimal sampling location for single point gas dispersion measurements in mechanical flotation machines is proposed.



## 1. Introduction

Flotation is a separation process where hydrophobic particles are recovered by attachment to rising air bubbles. Efficiency of the process is strongly influenced by the characteristics of the bubble population. These characteristics are referred to as the machine gas dispersion properties, which include the following: bubble size (Sauter mean diameter, $D_{32}$), gas holdup ($\varepsilon_g$), superficial gas velocity ($J_g$) and bubble surface area flux ($S_b$) (Gomez and Finch, 2007).

Over the last decade, $S_b$ has proven to be a key operating variable being directly related to the flotation kinetic (rate) constant and consequently to flotation performance (Gorain et al., 1997; Hernandez et al., 2003). It is defined as the amount of available surface area for collecting hydrophobic particles per unit of time and effective machine cross-sectional area. It can be mathematically expressed as follows:

$$S_b = 6 \cdot \frac{J_g}{D_{32}} \left[s^{-1}\right] \quad (1)$$

As can be seen in Eq. (1) calculation of $S_b$ depends on measurement of $J_g$ and $D_{32}$.

The literature concerning geometrical considerations for measuring gas dispersion parameters in flotation machines considers the axial sampling position (Yianatos et al., 2001; Grau and Heiskanen, 2003; Schwarz and Alexander, 2006). A representative measurement requires careful selection of both axial and radial positions. Without agreement on the measurement (sensor) location it will be difficult to compare data from different sources. The limited plant measurements support that cylindrical symmetry is developed in the cell; i.e., gas distribution is parabolic with the larger proportion of air flowing through the center of the cell (Dahlke et al., 2001; Gomez et al., 2003). In this paper, the argument is advanced that the ideal position for gas dispersion measurements is at the average of the radial parabolic profile.

## 2. Theoretical considerations

Mechanical flotation machines use a centrally located rotor–stator mechanism both to suspend particles and disperse the air delivered via a hollow shaft. Generation of bubbles occurs in the low pressure air cavity region at the trailing edge of the impeller blades (Harris, 1976; Schubert and Bischofberger, 1998). Bubbles form by vortex shedding from the tail of the cavity and are distributed throughout the cell cross-sectional area by the action of the rotor–stator mechanism. A consequence of the central location is that air tends to adopt a radial parabolic distribution.

One implication of a parabolic air profile is that gas dispersion measurements depend on the location (from the center) of the sampling point. An additional complication is that flotation cells often have geometries (internal launders, froth crowders, shaft shroud) that incur significant changes in cross sectional area along the vertical axis, which must be considered in selecting the sampling point(s).

Gas superficial velocity is defined as the volumetric gas flow rate ($Q_g$) per unit of effective cross sectional area of the cell ($A$):

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**Nomenclature**

| | | | |
|---|---|---|---|
| $A$ | cross-sectional area, $cm^2$ | $r$ | radial distance from the machine center to a point in the cell cross-sectional area, cm |
| $H_L$ | total length of the "sensor" tube, cm | $r_0$ | radius of the machine's center hollow shaft, cm |
| $H_0$ | distance from the top of the "sensor" tube to the cell lip, cm | $r_1$ | internal radius of an annular region, cm |
| $H_{BD}$ | distance between the bottoms of tubes "sensor" and "bubbler", cm | $r_2$ | external radius of an annular region, cm |
| $J_g$ | superficial gas velocity, cm/s | $r$ | radial distance at which the average superficial gas velocity is obtained, cm |
| $J_{g(av)}$ | average superficial gas velocity, cm/s | $R$ | radius of the flotation cell, cm |
| $P_{atm}$ | atmospheric pressure, $cmH_2O$ | $\alpha$ | empiric constant linked with parabola width |
| $P_1$ | pressure signal from the "sensor" tube, $cmH_2O$ | $\beta$ | empiric constant that estimates maximum $J_g$ |
| $P_2$ | pressure signal from the "bubbler" tube, $cmH_2O$ | $\rho_b$ | bulk density, $g/cm^3$ |
| $Q_g$ | gas flow rate, $cm^3/s$ | | |

$$J_g = \frac{Q_g}{A}[\mathrm{cm/s}] \tag{2}$$

At a particular depth gas distribution can be established by measuring the gas velocity at several radial distances from the center of the cell (radial $J_g$ profile) (Dahlke et al. 2001; Gomez et al., 2003). The $J_g$ profiles have been found to be parabolic and well represented by the following function (Araya et al., 2009):

$$J_g = \begin{cases} 0, & r \leqslant r_0 \\ \beta - \alpha \cdot r^2, & r_0 < r \leqslant R \end{cases} \tag{3}$$

where $r$ is radial distance from the center of the cross-sectional area, $r_0$ the radius of the machine's center shaft and $R$ the radius of the vessel (Fig. 1). Parameters $\alpha$ and $\beta$ are empirical constants to be determined.

The volumetric gas flow rate rising in a flotation cell can be estimated by integrating the $J_g$ profile through infinitesimal annular regions with differential area $dA = 2\pi r dr$ (White, 2006).

$$Q_g = \int_{r1}^{r2} (\beta - \alpha \cdot r^2) \cdot 2\pi r dr \tag{4}$$

with the solution,

$$Q_g = \pi \cdot \beta \cdot (r_2^2 - r_1^2) - 0.5 \cdot \pi \cdot \alpha (r_2^4 - r_1^4) \tag{5}$$

where $r_1$ and $r_2$ are the internal and external radius of the circular annular region where the gas flow rate is being calculated. Evaluating Eq. (5) with the integration limits, $r_1 = r_0$ and $r_2 = R$ (Fig. 1) and dividing by the effective cross-sectional area ($A = \pi(R^2 - r_0^2)$) gives the average gas velocity ($J_{g(av)}$),

$$J_{g(av)} = \beta - 0.5 \cdot \alpha \cdot (R^2 + r_0^2) \tag{6}$$

Comparing Eqs. (6)–(10) the radial distance ($r_{av}$) at which the average superficial gas velocity is obtained is given by:

$$r_{av} = \sqrt{0.5 \cdot (R^2 + r_0^2)} \tag{7}$$

Note, when $r_0 = 0$, $J_{g(av)}$ is found at the following radial distance for any parabolic distribution,

$$r_{av} \approx 0.71 \cdot R \tag{8}$$

The result can be confirmed graphically by comparing the gas flow rate resulting from a parabolic profile to a uniform profile.

## 3. Experimental part

### 3.1. $J_g$ measurement

The Mineral Processing group at McGill University has developed a device for measuring local gas superficial velocity in industrial flotation machines. It comprises two tubes both closed by a top which houses a connection to a valve and pressure transmitter (Fig. 2). The pressure transmitter is connected to an electronic board that acquires, digitizes and transmits pressure signals to a laptop for analysis. The tube labeled "sensor" collects air bubbles when the valve is closed and records the rate of pressure increase which is related to $J_g$ (Gomez and Finch, 2007). The expression to calculate $J_g$ requires the density of the mixture pulp-air (bulk density) which is calculated from the pressure difference between the two tubes (the second labeled "bubbler") when both are full of air (the bubbler tube is normally maintained in that condition, i.e., valve $B$ remains closed, see Fig. 2 left hand side).

The tubes, typically 10 cm in diameter, are inserted into the flotation machine with the open-ends below the froth and at different

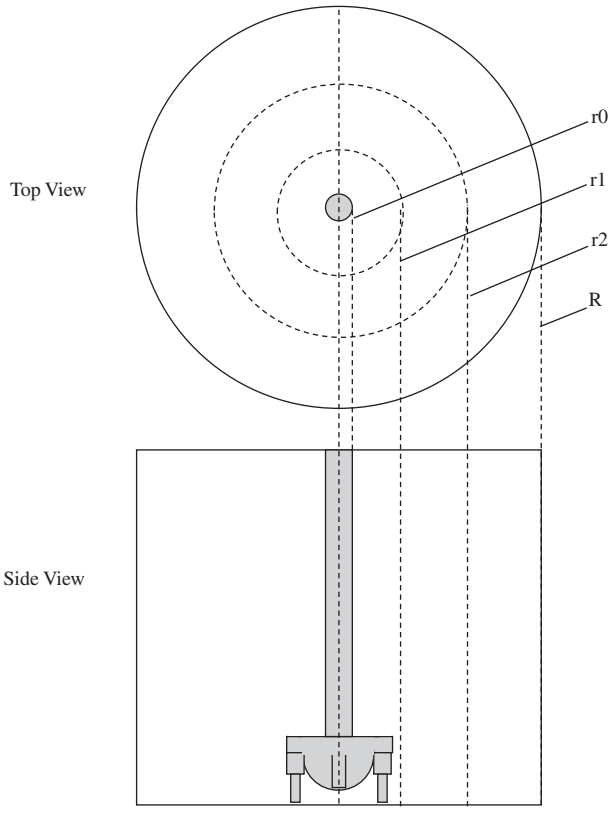


**Fig. 1.** Illustration of the cross-sectional area of a circular flotation (tank) cell.