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Column flotation cell design by drift flux and axial dispersion models

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ABSTRACT

A common problem in column flotation research is designing the appropriate cell which provides all the requirements of the desired tests. The drift flux model and the axial dispersion model were used in this paper for designing a column flotation cell for research purposes. To validate the approach, a column with required values of axial mixing coefficient (E), vessel dispersion number (N_d), bubble diameter (d_b), column height (H_c) and gas holdup (ε_g) equal to 0.003 (m^2/s), 0.32, 1.7 (mm), 1.15 (m) and 7.2 (%) were assumed respectively and the column diameter was calculated as 5.42 (cm) by the developed methodology. The flotation column was constructed based on the calculated value of column diameter and required values of above-mentioned variables. Residence time distribution (RTD) of the liquid phase was measured for the column using the tracer impulse response method. Vessel dispersion number (N_d) was measured from the RTD statistics equal to 0.32, which was completely similar to its required value. One other set of information from the literature was also used for validation and it was found that the methodology is capable of designing of columns with required specifications.

1. Introduction

Flotation columns for industrial application are selected from the available brochures of manufacturing companies, while laboratory flotation columns are constructed based on the relevant requirements. Dispersion and mixing are the most important characteristics being implemented by researchers for designing and scaling up of the flotation columns (Dobby and Finch, 1985; Mankosa et al., 1992). It is well known that dispersion and mixing depend on the flotation column geometry and flows (aeration flow rate and pulp feeding flow rate). Such dependencies have been investigated by modeling approaches too (Mavros, 1993a; Xu and Finch, 1991, 1992; Yianatos et al., 2005). Although several flotation columns with different geometrical parameters have been constructed to build these models (Mavros, 1993a), to the knowledge of the authors, nothing has been reported on design procedure of those flotation columns. The question is still unanswered if these models are consistent for calculating the flotation column geometrical parameters with given values of mixing, dispersion and flows or not. This paper describes the implementation of axial dispersion model and drift flux model for designing the laboratory column flotation cells with specific requirements.

2. Theory

In flotation columns, mixing process could be characterized by axial mixing coefficient, E, (m^2/s) which is related to the column geometry and aeration (Cruz, 1997). Eq. (1) correlates E to superficial gas velocity (J_g)(cm/s), and the column diameter (d_c)(m).

$$E = 0.063 d_c \left(\frac{J_g}{1.6}\right)^{0.3} \quad (1)$$

For a column with required values of E and J_g, the diameter can be calculated based on Eq. (1) which is derived from axial dispersion model. J_g can be estimated from the drift flux model as it would be described later. Therefore, combination of drift flux model and axial dispersion model leads to a methodology to design columns with specific requirements.

2.1. Drift flux model

Theory of dispersed multiphase flows provides the fundamental information to study the column hydrodynamic conditions by applying the modeling approach known as the drift-flux. This model is derived from the momentum conservation equation for multiphase mixtures based on the relative velocity between the phases. Hence, the bubble hindered rise velocity (U_{sg}) in column flotation could be explained by the drift flux theory (Cruz, 1997). Bubble hindered rise velocity, U_{sg} (cm/s), (i.e., slip velocity of gas phase relative to liquid or slurry phase) has been expressed by two equations (Finch and Dobby, 1990):

$$U_{sg} = \frac{J_g}{\varepsilon_g} + \frac{J_{sl}}{(1-\varepsilon_g)}. \quad (2)$$

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This equation is used for correlating the bubble hindered rise velocity to superficial gas velocity, J_g (cm/s), and superficial liquid velocity, J_{sl} (cm/s), where ε_g is the fractional gas holdup. Alternative equation for calculating bubble hindered rise velocity is based on hydrodynamic parameters such as, bubble-particle Reynolds number (Re_s) and fractional liquid holdup function ($F(\varepsilon_f)$) (Cruz, 1997).

$$U_{sg} = \frac{g d_b^2 F(\varepsilon_f)\left(\rho_{sl} - \rho_{susp}\right)}{18\mu_f\left(1 + 0.15\mathrm{Re}_s^{0.687}\right)} \tag{3}$$

where ρ_{susp} is the density of suspension of slurry and gas (g/cm^3), ρ_{sl} is the slurry density (g/cm^3), d_b is the bubble diameter (cm), μ_f is the fluid dynamic viscosity (cP) and g is the gravitational acceleration (m/s^2). Other variables of Eq. (3) are defined as:

$$\mathrm{Re}_s = \frac{d_b U_{sg} \rho_f \varepsilon_f}{\mu_f} \tag{4}$$

$$F(\varepsilon_f) = (1-\varepsilon_g)^{m-1} \tag{5}$$

$$m = 4.45\mathrm{Re}^{-0.1} \tag{6}$$

where Re is the single bubble Reynolds number that is calculated as follows:

$$\mathrm{Re} = \frac{d_b U_b \rho_f}{\mu_f}. \tag{7}$$

U_b is the single bubble terminal rise velocity which is related to the bubble hindered rise velocity (U_{sg}) by the following equation (Cruz, 1997):

$$U_b = \frac{U_{sg}(1-\varepsilon_g)^{(5/3)}}{(1-\varepsilon_g)}. \tag{8}$$

According to above equations, U_{sg} is calculated by Eq. (3) via iterative solution with initial values of $F(\varepsilon_f)$ and Re_s as shown in Fig. 1. The initial values of $F(\varepsilon_f)$ and Re_s could be obtained from literatures. U_{sg} is substituted in Eq. (2) in order to calculate the J_g. However J_{sl} is required for calculating the J_g, which could be calculated by axial dispersion model.

2.2. Axial dispersion model

Plug flow pattern has been considered by some literatures for mixing inside the column flotation cell; while some others suggest that the collection zone in a column is a mixed zone (Grau, 2006). In reality, the extent of departure from ideal plug flow that is called the axial mixing can characterize the mixing in flotation column. Axial mixing is represented by axial mixing coefficient (E). The deviation from plug flow pattern could also be expressed by back flow zones in series model (Mavros, 1993b). Axial dispersion model applies parameters such as Peclet number and vessel dispersion number to justify the residence time distribution profiles in the flotation columns, while mixed zones in series model uses parameters such as zones number (N) and back flow coefficient (λ) (Mavros, 1993b).

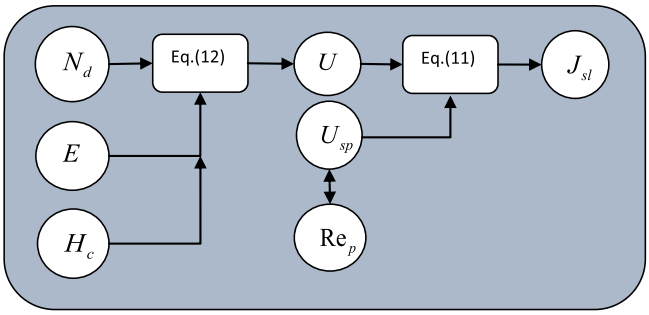

Fig. 2. Iteration procedure for calculation of J_{sl} by Eqs. (11) and (12). N_d, E and H_c are constants based on the desired design.

Mixing intensity, presented by axial mixing coefficient is related to the residence time distribution, superficial gas velocity and the column diameter (Mankosa et al., 1992). The axial mixing in column flotation cell refers to solid particles axial mixing. It has been reported that for fine and low density particles, solid axial mixing is the same as fluid axial mixing (Finch and Dobby, 1990). Non ideal plug flow dispersion model in the vertical axis of the column is as follow (Mavros, 1993a):

$$\frac{\partial C}{\partial t} = E\left(\frac{\partial^2 C}{\partial x^2}\right) - u\left(\frac{\partial C}{\partial x}\right) \tag{9}$$

where C is the tracer concentration, x is the length in which the variation of concentration is studied, t is time and E is the axial mixing coefficient. Eq. (9) can be rewritten using dimensionless parameters (Mavros, 1993a):

$$\frac{\partial C}{\partial \theta} = \left(\frac{1}{Pe}\right)\left(\frac{\partial^2 C}{\partial z^2}\right) - \left(\frac{\partial C}{\partial z}\right) \tag{10}$$

where Pe is defined as Peclet number ($Pe = (u \cdot H_c)/E$), H_c is vessel total length (in flotation column it is the distance between froth-pulp interface and the sparger outlet), z is a dimensionless parameter representing the length x to the total length, $\theta = t/\tau$ where τ is fluid mean residence time ($\tau = H_c/u$) and u is the interstitial velocity:

$$u = \frac{J_{sl}}{(1-\varepsilon_g)} + U_{sp} \tag{11}$$

where J_{sl} s the superficial slurry velocity and U_{sp} is the slip velocity of solid phase to fluid phase (Mankosa et al., 1992; Quinn and Finch,

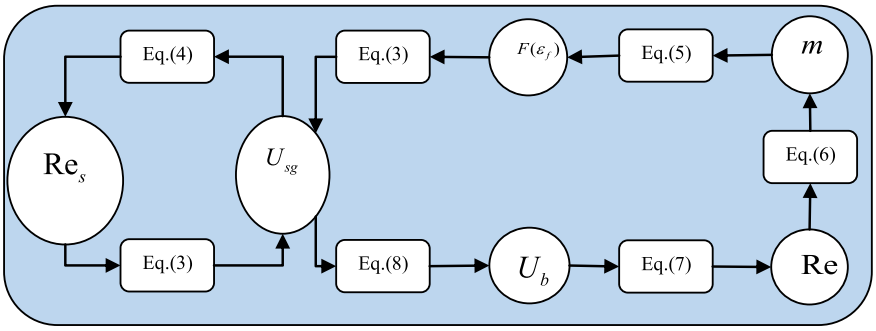

Fig. 1. Iterative calculation of U_{sg} with initial values of Re_s and $F(\varepsilon_f)$.