A New Method for the Measurement of Gas Holdup in Solid-Suspended Bubble Columns

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Abstract

A method for the measurement for gas holdup in gas-liquid-solid multiphase devices is developed. The method depends on measurements of hydrostatic pressuress in the three-phase dispersion followed by interruption of gas flow and solids and liquid holdups without gas flow.

Introduction

The solid-suspended bubble columns in widely used as a three-phase slurry reactor in industrial chemical processes (Shah, 1979), in bio-processing, and in environmental pollution abatement devices (Wenge *et al.*, 1995). Gas holdup and interfacial area obtained by gas holdup and size of bubbles are important parameters necessary for practical design of three-phase systems.

In the present paper, a method for the measurement of gas holdup is developed theoretically to study flow phonomena in solid-suspended bubble columns. The method depends on measurements of hydrostatic pressures in three-phase dispersion followed by interruption of gas flow and solids and liquid holdups without gas flow. The proposed method is very simple compared with the usual ones: the visual obsevation of static slurry height and the height of the aerated slurry, and the method based on measurements of electroconductivity requiring complex setups (Uribe-Salas *et al.*, 1994; Hills, 1993). Hence, the proposed method could be considered as the useful method for the study on flow phenomena in solid-suspended bubble columns.

Theoretical Development

The theoretical treatment of the new technique of the determination of gas holdup is detailed here. The proposed method depends on measurements of hydrostatic pressures in the solid-suspended bubble column. **Figure 1** shows schematically the arrangement for manometric measurement of hydrostatic pressure in solid-suspended bubble column.

The volumetric ratio of solids holdup to liquid holdup without gas flow can be expressed as follows:

$$K = \frac{\varepsilon_{sf}}{1-\varepsilon_{sf}} = \frac{\varepsilon_{sf}}{\varepsilon_{sl}} \tag{1}$$

The K value is identical with that in case of blowing gas into the reactor column. Then, the following relationship can stand up.

$$\varepsilon_s = K\varepsilon_l \tag{2}$$

Now, for the pressure at points 1 and 2, we have

$$P_1 = P_M + \rho_l g h_1 + \rho_g g h_3 \tag{3}$$

$$P_2 = P_M + \rho_l g h_2 + \rho_g g (h_3 + \varDelta h) \tag{4}$$

Where P_M is the pressure of the enclosed gas space. From Eqs. (3) and (4)

$$\begin{aligned} \varDelta P = P_2 - P_1 &= \rho_l g (h_2 - h_1) + \rho_g g \varDelta h \\ &= \rho_l g (z - \varDelta h) + \rho_g g \varDelta h \end{aligned} \tag{5}$$

where $\varDelta h$ is the manometer reading. Furthermore

$$\varDelta P = P_2 - P_1 = \rho_M g z \tag{6}$$

where ρ_M is the density of the multiphase dispersion. The density ρ_M is related to the densities and fractional holdups of individual phases as follows :

$$\rho_M = \rho_l \varepsilon_l + \rho_s \varepsilon_s + \rho_g \varepsilon_g \tag{7}$$

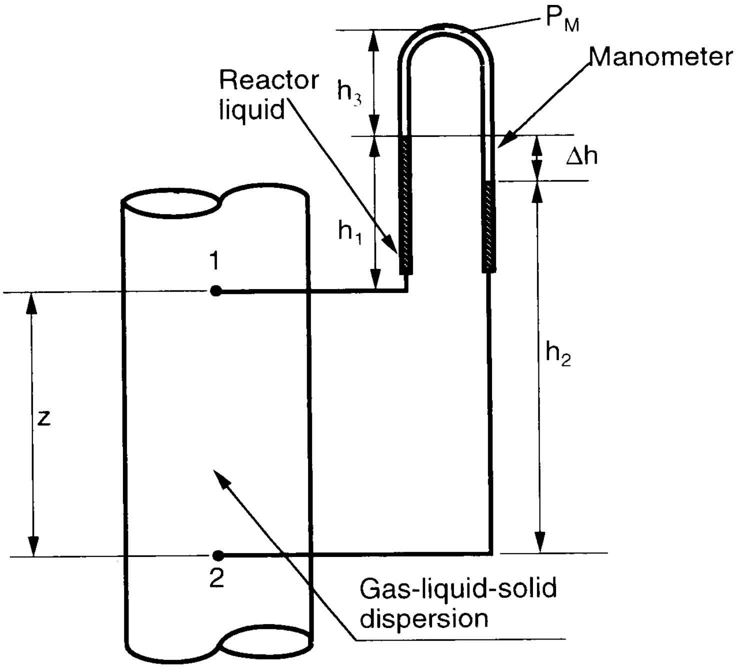

Fig. 1 Schematic drawing of inverted U-tube manometer

Moreover, the sum of the volume fractions of the individual phases in unity; thus

$$\varepsilon_l + \varepsilon_s + \varepsilon_g = 1 \tag{8}$$

From Eqs. (2) and (8)

$$(1+K)\varepsilon_l + \varepsilon_g = 1 \tag{9}$$

From Fqs. (8) and (9)

$$\varepsilon_l = \frac{1-\varepsilon_g}{1+K},\ \varepsilon_s = \frac{K(1-\varepsilon_g)}{1+K} \tag{10}$$

From Eqs. (5), (6), (7) and (10)

$$\rho_l g(z-\Delta h) + \rho_g g \Delta h = \left(\varepsilon_g \rho_s + \frac{1-\varepsilon_g}{1+K}\rho_l + \frac{1-\varepsilon_g}{1+K}K\rho_s\right)gz \tag{11}$$

From Eq. (11)

$$\varepsilon_g = \frac{K(\rho_l-\rho_s) - (1+K)(\rho_l-\rho_g)\dfrac{\Delta h}{z}}{(1+K)\rho_g - \rho_l - K\rho_s} \tag{12}$$

Concluding remarks

Eq. (12) is the basis of the manometric determination of gas holdup in multiphase reactors, such as the solid-suspended bubble column and/or in the riser of the solid-suspended airlift reactor, using the following approach.

1) Initially, with no gas flowing into the system, we can determine the K value from volumes of solids and liquid.Then, the solids settle to the bottom of the reactor, and the manometer fills with the same liquid as the reactor; the manometer reads zero.

2) When a gas is blown into the reactor, the system is allowed to establish a hydrodynamic steady state, and the manometer reading, Δh, is noted.

3) The gas holdup in the three-phase system, ε_g, is obtained using Eq. (12)

Nomenclature

g = gravitational acceleration [m/s^2]
h_1 = height of the liquid leg in Figure 1 [m]
h_2 = height of the liquid leg in Figure 1 [m]
h_3 = height of the gas leg in Figure 1 [m]
Δh = manometer reading [m]
K = volumetric ratio of solids holdup to liquid holdup without gas flow [−]
P_M = pressure of the air space in manometer [Pa]
P_1 = hydrostatic pressure at location 1 [Pa]
P_2 = hydrostatic pressure at location 2 [Pa]
$\Delta P = P_2 - P_1$ [Pa]
z = vertical distance between measuring points 1 and 2 [m]

ε_g = gas holdup [−]
ε_l = liquid holdup [−]
ε_{lf} = liquid holdup without gas flow [−]
ε_s = solids holdup [−]
ε_{sf} = solids holdup without gas flow [−]
ρ_g = density of gas [kg/m^3]
ρ_l = density of manometric fluid [kg/m^3]
ρ_M = density of gas-liquid-solid dispersion [kg/m^3]
ρ_s = density of solids [kg/m^3]

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