The Second International Symposium on Multiphase, Non-Newtonian and Reacting Flows'04, September 10 -12, 2004,
Hangzhou, China

PRESSURE DROP STUDIES OF GAS-LIQUID BUBBLY FLOWS IN A VERTICAL UPWARD PIPELINE

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ABSTRACT

This paper describes the experimental and theoretical studies of gas-liquid bubbly flow in vertical upward pipeline carried out at Institute of Mechanics, Chinese Academy of Sciences. Bubbly flow in a vertical pipe with a 3 m long and 5 cm inner diameter plexiglass pipe was experimentally investigated, and studies carried out on the relationship between superficial velocities of the liquid and gas phases and pressure gradient is described. The developed drift-flux model applied to gas-liquid bubbly flow is presented, and the results are compared against the experimental data measured by ours in air/water vertical pipes.

Key words : bubbly flow; pressure gradient; vertical upward pipe flow; drift-flux model

INTRODUCTION

The bubbly flow pattern is characterized by a suspension of discrete bubbles in a continuous liquid. There are numerous regimes of bubbly flow. Void fractions rang from the extreme case of a single isolated bubble in a large container to the quasi-continuum flow of foam, containing less than one percent of liquid by volume. Interactions between the forces that are due to surface tension, viscosity, inertia, and buoyancy produce a variety of effects which are quite often evidenced by different bubble shapes and trajectories.

The objective of the work described in this chapter is to investigate more fully the relationship between superficial velocities of the liquid and gas phases and frictional pressure gradient on the bubbly flow in vertical upward pipelines and to compare the measurements with the theories of the developed drift-flux model.

In what follows, Section 2 gives a detail description of the experiment setup. The experiment results are presented in Section 3 and comparisons with the theories of the drift-flux model are presented in Section 4. The paper closes with a summary of the main conclusions in Section 5.

EXPERIMENTAL SETUP

The experiments reported in this paper were performed in the multiphase flow facilities at Institute of Mechanics, Chinese Academy of Sciences shown in Fig.1. Air and water were pumped separately from their storage tanks and were joined at the beginning of the test section via a modified T-joined which ensures minimum mixing. The main pipe, and also the test section, was a 3 m long and 5 cm inner diameter plexiglass pipe through which the flow could be observed. After the section, the mixture flowed to a separator tank and the separated water was then returned to its storage tank.

The sampling frequency of the pressure gradient was 8,000 Hz and a total of 960,000 samples which corresponds to 2 minute sampling time were collected at sampling point. Flow patterns were recorded using a high speed video camera, and the flow patterns for each test condition were recorded and could be observed later in slow motion.

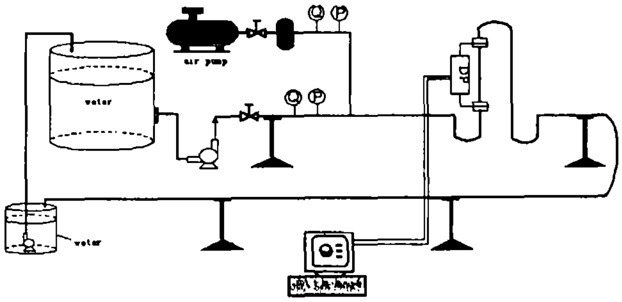

Fig.1 Schematic diagram of experimental facility of gas-liquid flow
DP—pressure transducer; Q—centrifugal pump; P—pressure gauge

EXPERIMENTAL RESULTS

Over one hundred and fifty gas and liquid rates points of the bubble flow pattern were observed in the test section. Experiment covered a range of superficial liquid velocity from 0.21 m/sec to 2.48m/sec and of superficial gas velocity from 0.06 m/sec to 3.40 m/sec. From Fig.2 the feature of pressure fluctuating signal which has very good periodicity could be obtained for bubbly flow. For a given low superficial liquid velocity, the pressure gradient was observed to decline sharply with superficial gas velocity increasing as is shown in Fig.3.

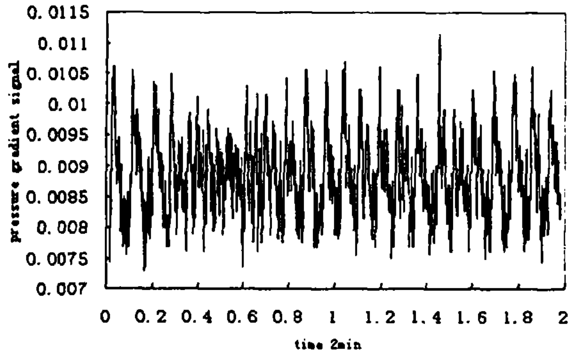

Fig.2 Pressure gradient signal from the pressure transducer for gas superficial velocity 0.85m/s and liquid superficial velocity 1.59m/s in the pipe

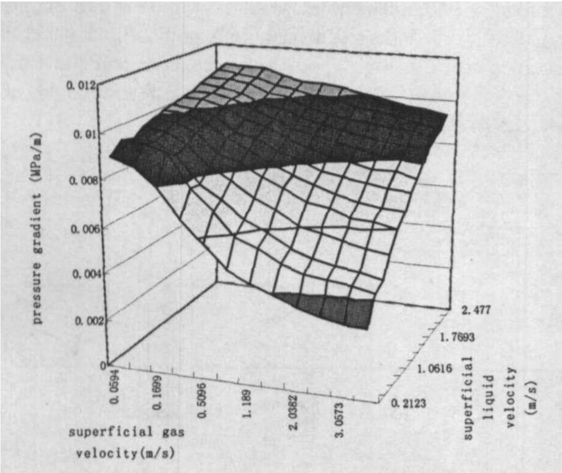

Fig. 3 Pressure gradient in the vertical upward pipelines for different superficial velocities

THEORETICAL ANALYSIS WITH DFM

The drift-flux model proposed by Zuber & Findlay (1965) can be used to calculate the gas volume fraction and interpret holdup data. It correlates the actual gas velocity V_g and the mixture velocity V_m, using two parameters C_0 and V_d :

$$V_g = \frac{V_{sg}}{\alpha_g} = C_0 V_m + V_d \qquad (1)$$

$$V_m = V_{sl} + V_{sg} \qquad (2)$$

where V_m is the mixture velocity as defined in Eq.2. C_0 is referred to as the distribution parameter or profile parameter. It accounts for the effects of the non-uniform distribution of both velocity and concentration profiles (see Fig.4. for typical gas concentration and velocity distributions). If the two phases are uniformly mixed, the concentration profile will be flat and C_0 should be equal to one. V_d is called the drift velocity of gas, and accounts for the local relative velocity between the two phases. If the liquid is stationary, V_d corresponds to the gas rise velocity in the stagnant liquid.

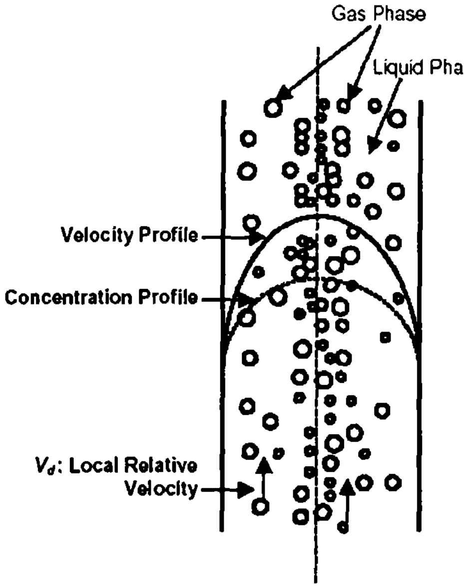

Fig. 4 Schematic diagram of velocity and concentration profiles

Flow pattern determination

Bubbly flow is encountered in steeply inclined pipes and is characterized by a continuous liquid phase containing a dispersed phase of mostly spherical gas bubbles. It can exist if both of the following conditions are satisfied:

(1). The Taylor bubble velocity exceeds the bubble velocity. This is satisfied in large diameter pipes (Taitel et al.[1]) when

$$D > 19\left[\frac{(\rho_l - \rho_g)\sigma}{\rho_l^2 g}\right]^{\frac{1}{2}} \qquad (3)$$

(2). The angle of inclination is large enough to prevent migration of bubbles to the top wall of the pipe (Barnea et al.[2]):

$$\cos\theta \le \frac{3}{4\sqrt{2}} V_d \left(\frac{C_l \gamma^2}{g d_b}\right) \qquad (4)$$

The lift coefficient, C_l, ranges from 0.4 to 1.2, the bubble distortion (from spherical) coefficient, γ, ranges from 1.1 to 1.5 and a bubble size, d_b, between 4 and 10mm is recommended. The bubbly swarm rise velocity in a stagnant liquid, V_d is given by[3]:

$$V_d = K \cdot [\frac{g(\rho_l - \rho_g)\sigma}{\rho_l^2}]^{\frac{1}{4}} \sin\theta \tag{5}$$

When both of the above conditions are satisfied, bubbly flow is observed even at low liquid rates where turbulence does not cause bubble breakup.

Calculation of pressure gradient

The volumetric gas fraction during bubbly flow is obtained from Eq.6.

$$\alpha_g = \frac{V_{sg}}{C_0 V_m + V_d} \tag{6}$$

Zuber and Findlay[4] have shown that the distribution parameter, C_0, for dispersed systems can range from 1.0 to 1.5, the higher values being associated with high bubbly concentrations and high velocities at the center line (laminar flow). When the flow is turbulent and the velocity and concentration profiles are flat C_0 approaches 1.0. The bubbly swarm rise velocity in a stagnant liquid, V_d, is given by Eq.5. The value of V_g thus obtained, is limited to the range:

$$0 \le \alpha_g \le \frac{V_{sg}}{V_m} \tag{7}$$

The pressure gradient is given by:

$$-\frac{dp}{dz} = \frac{2 f_{ml} V_m^2 \rho_m}{D} + \rho_m g \sin\theta \tag{8}$$

The friction factor, f_{ml}, is obtained from standard methods using the pipe roughness and the following Reynolds number (turbulent flow) [5]:

$$\mathrm{Re}_{ml} = \frac{D \rho_l V_m}{\mu_l} \tag{9}$$

$$f_M = 0.1067\mathrm{Re}^{-0.3629} + \frac{13.98\mathrm{Re}^{-0.9501} - 0.1067\mathrm{Re}^{-0.2629}}{\left(1 + \left(\frac{\mathrm{Re}}{304}\right)^{2.948}\right)^{0.2236}} \tag{10}$$

THEORETICAL RESULTS COMPARED AGAINST THE EXPERIMENTAL DATA

Results of gas volume fraction and pressure gradient predicted by the developed model are shown in Fig.5 and Fig.6, where it may be observed that Results have coincident trend with the experiment data (Fig.3) and new model performs better in predicting the pressure gradient.

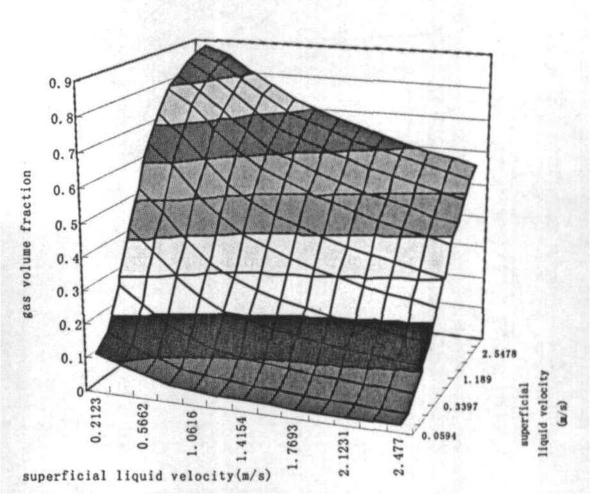

Fig.5 Gas volume fraction in the vertical upward pipelines for different superficial velocities (DFM)

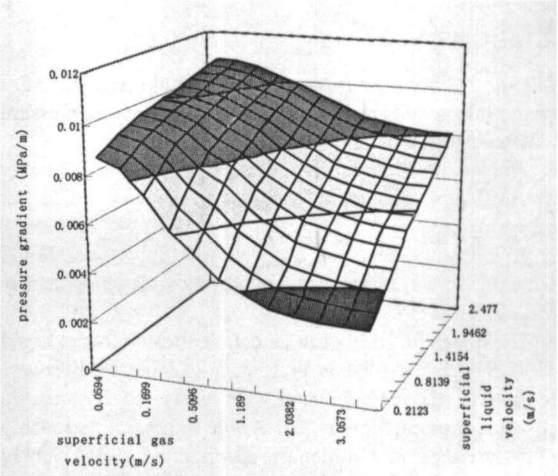

Fig.6 Pressure gradient in the vertical upward pipelines for different superficial (DFM)

The error percentage of the model prediction for pressure gradient is shown in Fig.7. The developed drift-flux model is able to predict the pressure gradient within an accuracy of 10% in low superficial gas velocity, as shown in Fig. 7, and all calculation errors can be limited in 20 percent.

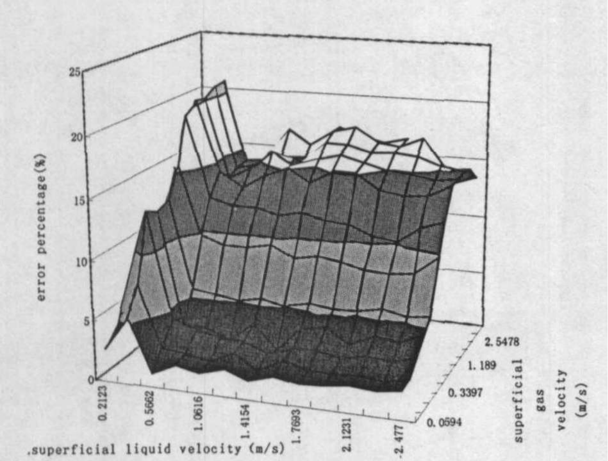

Fig. 7 The error percentage of the drift-flux model pressure gradient calculations compared with experimental data

Table1. System Properties

Pipe diameter (D)	0.05m
Gas Density (ρ_g)	1.205kg/m^3
Liquid Density(ρ_l)	1000 kg/m^3
Gas Viscosity(μ_g)	0.00001Pa·s
Liquid Viscosity(μ_f)	0.001Pa·s
Interfacial Tension (σ)	0.0728N/m
(Absolute)Pipe Roughness (ε)	0.001mm

CONCLUSIONS

Gas-liquid bubbly flow in vertical upward pipeline is studies in detail experimentally and theoretically, and the data on pressure gradient is obtained. These revealed the following:

(1) The feature of pressure fluctuating signal during bubbly flow in vertical pipe behaves in a characteristic way which has very good periodicity.

(2) It is shown that for a given low superficial liquid velocity, the pressure gradient of the bubbly flow declines sharply with superficial gas velocity increasing.

(3) The developed drift-flux model, applicable to gas-liquid bubbly flow in vertical pipe is presented, and the results were compared against the experimental data measured by ours in gas-liquid vertical pipes. New model is able to predict reasonably accurate pressure drop and volumetric gas fraction during bubbly flow in vertical pipe.

REFERENCES

1. Taitel, Y., Barnea, D. and Dukler, A. E. "Modeling Flow Pattern Transitions for Steady Upward Gas-Liquid Flow in Vertical Tubes," AIChe Journal, 26, pp. 345-354 ,1980.
2. Barnea, D., Shoham, O. et al., "Gas-Liquid Flow in Inclined Tubes: Flow Pattern Transitions for Upward Flow," Chem. Eng. Sci., 40, 1 pp. 131-136 ,1985.
3. Zuber, N., Staub, F.W., et al., "Steady State and Transient Void Fraction in Two-Phase Flow Systems," 1, Report EURAECGEAP-5417, General Electric Co., San Jose, California, January 1967.
4. Zuber, N., and Findlay, J.A., "Average Volumetric Concentration in Two-Phase Flow Systems," J. Heat. Transfer, Trans. ASME, Ser. C, 87, pp. 453-468 ,1965.
5. F. Garcia, R. Garcia, et al., "Power Law and Composite Power Law Friction Factor Correlations for Laminar and Turbulent Gas-Liquid Flow in Horizontal Pipelines," Int. J. Multiphase Flow, 29, pp 1605-1624 ,2003.
6. Petalas, N., and Aziz, K., "Development and Testing of a New Mechanistic Model for Multiphase Flow in Pipes," Proceedings of the ASME Fluids Division Summer Meeting, Volume 1, FED-Vol. 236, pp. 153-159, July, 1996.