The Ohio State University Research

The following report from Ohio State University for the period contains these brief chapters:

Highlights

Work Performed
1. Development of Fiber Optic Probe System
2. Effect of Pressure on the Gas Holdup of Slurry Bubble Column

INTRINSIC FLOW BEHAVIOR IN A SLURRY BUBBLE COLUMN UNDER HIGH PRESSURE AND HIGH TEMPERATURE CONDITIONS

(**Reporting Period:** October 1 to December 31, 1997)

Highlights

1. A computer code was developed to process the light intensity signals from a fiber optic probe. The computer code can calculate the bubble rise velocity and bubble chord length distribution from the signals.

2. It was proven in experiments that the probe system and the computer code can be used to measure the bubble size distribution in a slurry bubble column under high-pressure, high-temperature, and high-gas velocity conditions.

3. A new technique was established to measure gas holdup in slurry bubble columns. The new technique has two major advantages over other techniques: elimination of uncertain particle density from the measurement and the capability to determine if the particles are completely suspended.

Work Performed

1. Development of Fiber Optic Probe System

In the last quarter, a dual-tip optical fiber probe was developed to measure bubble size distribution in high-pressure slurry bubble columns. Calibration of the probe proved that the probe system can satisfactorily measure the bubble rise velocity and bubble chord length, provided that the signal from the probe is processed appropriately.

A computer code was developed during this quarter to analyze light intensity signals. The computer code first normalizes the signals based on the following formula:

$$\begin{cases} I_n(t) = 0 & \text{if } I(t) \leq T \\ I_n(t) = 1 & \text{if } I(t) \geq T \end{cases} \tag{1}$$

where $I_n(t)$ is the normalized light intensity; $I(t)$ is the original light intensity; and T is a threshold value. T is taken as the maximum value in signals from a gas-free liquid-solid suspension. Then a peak in the lower tip signal is used as a trigger to match a peak in the upper tip signal. The $\Delta\tau_2$ of these two peaks, shown in Figure 1, should be smaller than 0.018 second, since the detectable minimum bubble rise velocity is 8 cm/s. Also, the ratio of the width of peak (τ) in the upper tip signal to that in the lower tip signal is between 0.7 and 1, based on a calibration. After the peaks are matched, the bubble rise velocity is:

$$U_b = \frac{\Delta L}{\Delta \tau_2} \qquad (2)$$

where ΔL is the vertical distance between the two measuring tips. The bubble chord length is then

$$l = \tau U_b \qquad (3)$$

The computer code was used to analyze the signal when the probe was placed in a chain of bubbles. The result from the computer program matched well that from visualization.

The computer code was then used to analyze the signals obtained from slurry bubble columns. Figure 2 shows a typical signal obtained in a slurry bubble column. The probability density function of the bubble chord length is shown in Figure 3. It can be seen from Figure 3 that the bubble size distribution at the ambient pressure was wide, with a maximum bubble chord length of 6 cm which was more than half of the column size (10.16 cm). This result proves that the bubble column is in the slugging regime at a gas velocity of 34.6 cm/s and at 0.1 MPa pressure.

The computer code will be used to analyze the bubble size distribution and operating regime in slurry bubble columns under high-pressure and high-gas velocity conditions.

2. Effect of Pressure on the Gas Holdup of Slurry Bubble Column

With the probe system developed during the past two quarters, attention has shifted to investigating the effect of pressure on the hydrodynamics, including gas holdup and bubble size distribution, in high-pressure slurry bubble columns at high gas velocities.

The measurement of the gas holdup is based on the bed collapse technique described in the quarterly report of July 1997. Efforts were made to further improve that technique, which involves the simultaneous shutoff of both the inlet and outlet of the slurry bubble column after it reaches a steady state. The dynamic pressure gradient signal was recorded with a computer data acquisition system during the entire bed collapse process. The ratio of solids holdup to liquid holdup, K, in a slurry bubble column at steady state can be calculated from the dynamic pressure drop in the gas-free suspension stage:

$$K = \frac{\varepsilon_s^0}{\varepsilon_l^0} = \frac{(\Delta P / \Delta z)_d^0}{(\rho_s - \rho_l)g - (\Delta P / \Delta z)_d^0} \qquad (4)$$

where ε_s^0, ε_l^0, and $(\Delta P / \Delta z)_d^0$ are the solids holdup, liquid holdup, and dynamic pressure gradient at the gas-free suspension stage, respectively. At a steady state, the gas holdup can be related to the dynamic pressure gradient, phase densities, and the constant K by

$$\left(\frac{\Delta P}{\Delta z}\right)_d = \left(\rho_g \varepsilon_g + \rho_l \varepsilon_l + \rho_s \varepsilon_s - \rho_l\right) g$$
$$= \left\{ \frac{K\left(\rho_s - \rho_l\right)}{1+K} + \left[\frac{\left(1+K\right)\rho_g - \left(\rho_l + K\rho_s\right)}{1+K} \right] \varepsilon_g \right\} g \qquad (5)$$

where ε_s, ε_l, ε_g, and $(\Delta P/\Delta z)_d$ are the solids holdup, liquid holdup, gas holdup, and dynamic pressure gradient at the steady state, respectively. Substituting Eq.(4) into Eq.(5), the gas holdup at the steady state can be derived as

$$\varepsilon_g = \frac{\left[(\Delta P/\Delta z)_d - (\Delta P/\Delta z)_d^0\right]/g}{\left(\rho_g - \rho_l\right) - (\Delta P/\Delta z)_d^0/g} \qquad (6)$$

Equation (6) was used to evaluate the gas holdup of high-pressure slurry bubble columns because of its two advantages. The solids density, ρ_s, cannot be easily be measured for porous particles in liquids, as hydrocarbon liquids can partially fill the pores of particles. Eq.(6) eliminates the particle density from the calculation. This technique can also determine if the particles in the column are completely suspended by comparing the dynamic pressure gradient at the gas-free suspension stage, $(\Delta P/\Delta z)_d^0$, obtained at different gas velocities. $(\Delta P/\Delta z)_d^0$ remains a constant when all the particles are suspended. In the literature, sampling of the liquid-solid mixture has been used for the same purpose. However, the sampling technique at high pressures is tedious and inconvenient to conduct. Also, the amount of liquid and particles cannot be maintained constant.

Figure 4 shows the gas holdup in a slurry bubble column with a solids concentration of 20 wt % at 28°C and various pressures. It can be seen that the gas holdup increases with an increase in pressure. The difference between this result and that obtained by sampling of liquid-solid mixture is negligible.

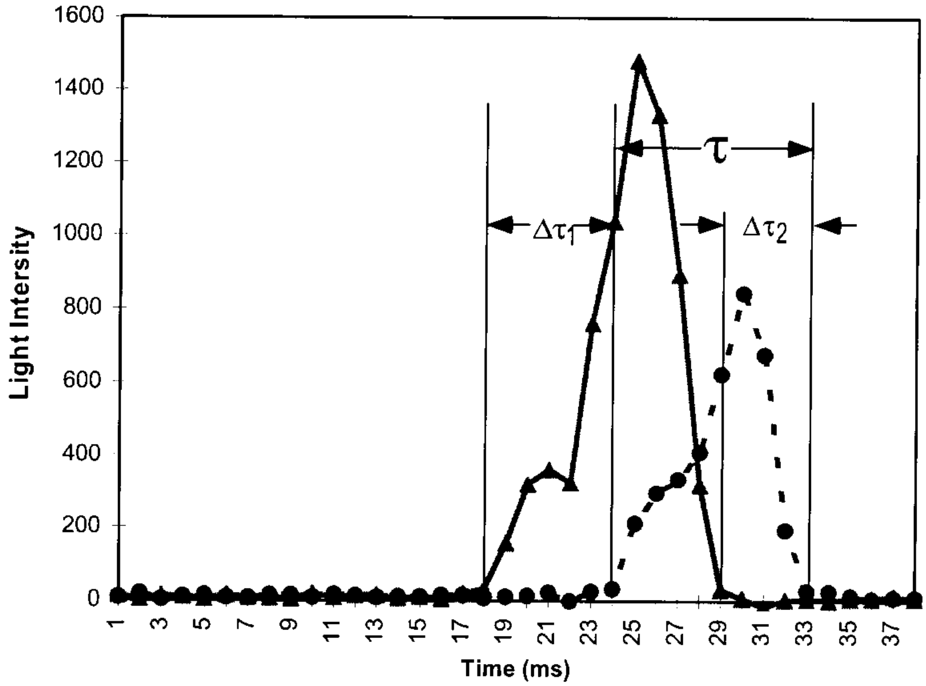

Figure 1. Characteristics and Notations of Peaks of Light Intensity Signals

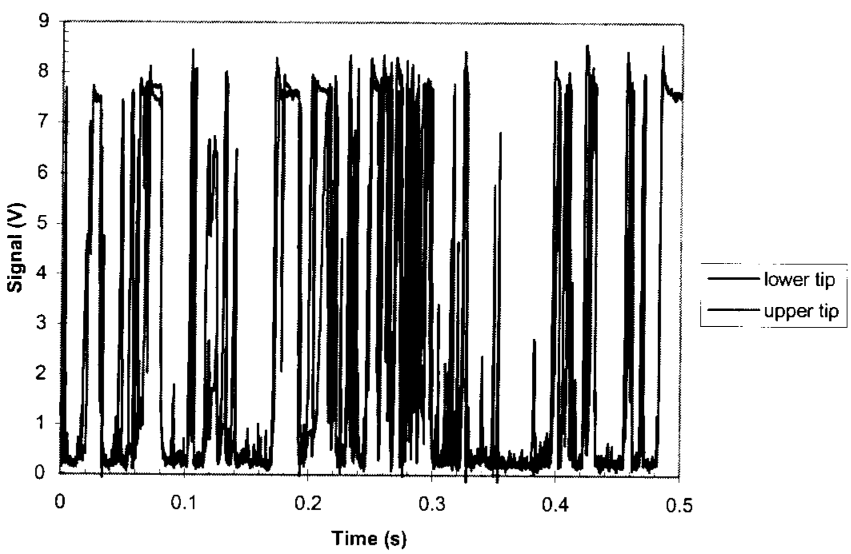

Figure 2. Typical Signals Obtained in Slurry Bubble Column

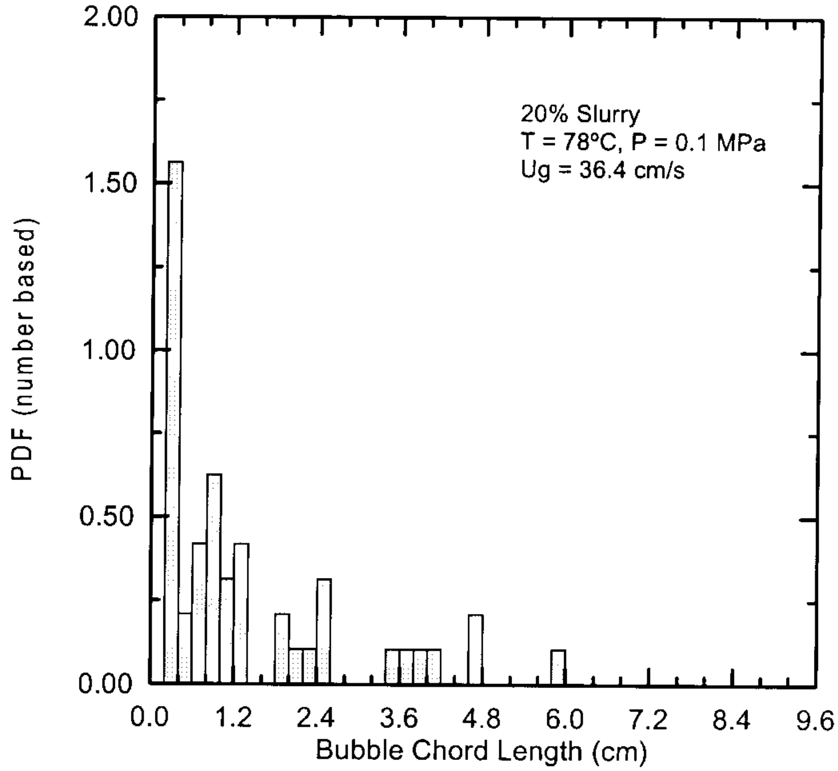

Figure 3. A Typical Bubble Chord Length Distribution from the Computer Code

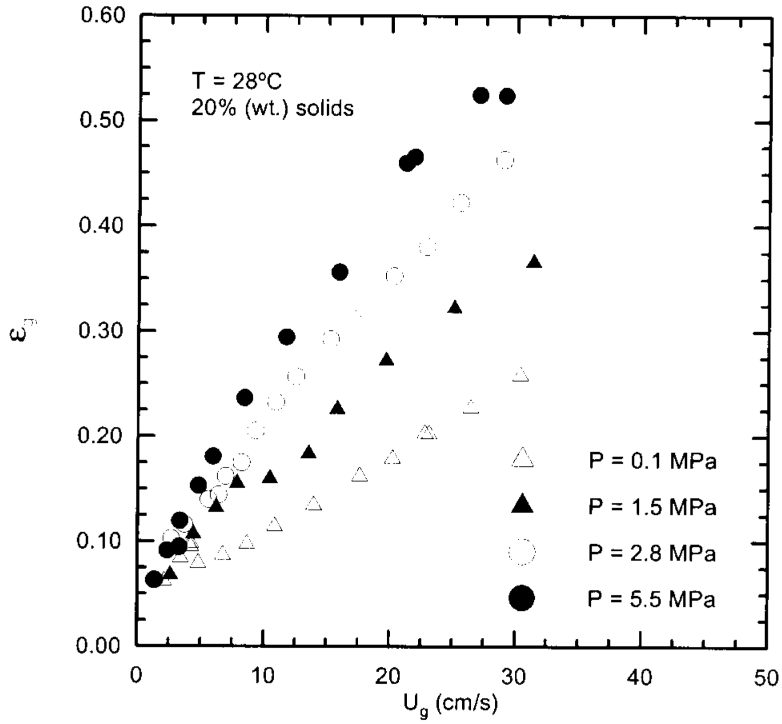

Figure 4. Gas Holdup in a Slurry Bubble Column at 28°C and Various Pressures