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

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The past three months of research has been focused on three major areas of bubble column hydrodynamics. The three major areas consist of (1) a comparison of the LaPorte Unit with the two-inch high pressure high temperature three-phase fluidization column, (2) single bubble rise velocity of nitrogen in Paratherm NF heat transfer fluid, and (3) the combined effect of pressure, temperature, and gas distributor on bubble column hydrodynamics, i.e., gas holdup, bubble regime transition, and bubble size distribution.

1. LaPorte Unit vs. High Pressure/High Temperature Bubble Column.

A comparison is made between the LaPorte Unit and our two-inch high pressure and high temperature three-phase fluidization column. This comparison includes comparisons between the variation of the gas holdup, the deviation of gas holdup, and the dominant frequency versus the superficial gas velocity.

The two-inch column is operated at a pressure of 780 psig and a temperature of 78 °C. The pressure is chosen to match the LaPorte Unit pressure and the temperature is chosen to match the liquid viscosity of the LaPorte Column. The major differences between the Laporte unit and the high pressure and high temperature column are as follows. The LaPorte Unit has an internal diameter of 18 inches and it is operated as a slurry bubble column. The high pressure and high temperature column has an internal diameter of two inches and it is operated using two phases, Paratherm NF heat transfer fluid and nitrogen gas. A porous plate and a cylindrical perforated pipeline (sparger) are used as the gas distributors. The average pore diameter of the porous plate is 60 microns. The hole diameter of the sparger is three millimeters.

Figure 1 shows a comparison of gas holdup between the two-inch unit with a porous plate and sparger as gas distributor and the LaPorte Unit. The gas holdup decreases in the following order of gas distributors: porous plate > sparger > LaPorte Unit. The porous plate exhibits a higher gas holdup due to the smaller primary bubbles which emerge from the distributor. Also for the porous plate distributor, the bubble regime transitions is apparent due to the occurrence a local maximum and a local minimum. The maximum gas holdup for the dispersed bubble regime is 40 percent and it occurs with a gas velocity of 4 cm/s. The maximum gas holdup for the churned turbulent regime (bubble clustering) is 45 percent and it occurs at a gas velocity of 10 cm/s. The turbulent bubble regime (bubble coalescence) exists beyond the gas velocity of 10 cm/s. The gas holdup of the sparger closely resembles that of the LaPorte Unit. Based on inspection of the figure, it is difficult to determine the bubble regime transitions. More data is necessary to accurately determine the occurrence of the regime transitions. The greater holdup of the two-inch unit versus the LaPorte Unit is explained as follows. Since the LaPorte Unit is operated with three phases, bubbles that are rising through the column tend to aggregate in the center of the column. These bubbles collide and coalesce forming larger bubbles which have a higher bubble rise velocity than that of the two phase column. A higher bubble rise velocity coincides to lower gas holdup because of the decrease in the residence time of the bubble in the column. Also, because the LaPorte Unit contains solid, the apparent viscosity created by the solid and liquid phases is greater than the viscosity of the liquid phase of the high pressure and high temperature unit. This higher viscosity aids in the coalescence of bubbles as they rise through the column. Another factor which explains the lower gas holdup of the LaPorte Unit is its larger internal diameter.

In comparing the deviation of gas holdup for the LaPorte and the sparger (See Figure 2), the deviation in gas holdup, obtained by determining the gas holdup for the difference of the maximum and minimum pressure fluctuation across the pressure transducer, for the sparger is greater by approximately two percent for all gas velocities. Also, the deviation in gas holdup increases with gas velocity for both types of gas distributors. One of the important factors which influences this deviation, is the column diameter. The LaPorte Unit experiences less pressure fluctuation because of its large size relative to the two inch column. The small deviation in gas holdup is directly proportional to small deviation of pressure fluctuations as bubbles rise past the pressure transducer. Because the LaPorte unit is a slurry bubble column, the solid phase will dampen out the pressure fluctuations in the column. These results are very reasonable.

A frequency spectrum analysis of fluctuation in differential pressure is conducted on the two inch unit to compare with that of the LaPorte Unit. It was found that the dominant frequency, which corresponds to the maximum power on the power spectrum, exhibits the same trend for both the LaPorte Unit and the two- inch unit with the sparger as the gas distributor (See Figure 3). At lower gas velocities, the dominant frequency is greater for the two-inch unit. At higher gas velocities, the opposite is true. The two-inch unit has a lower dominant frequency at lower gas velocity because the fluid flow is very uniform in the dispersed bubble regime. At higher gas velocities, the two inch unit exhibits a higher dominant frequency due to small internal diameter (wall effect), and because it is operated as a bubble column. Because of the small column diameter, slugging can occur at higher gas velocities.

2. Single Bubble Rise Velocity of N_2 in Paratherm NF Heat Transfer Fluid

The single bubble rise velocity is an important variable which affects gas holdup in a bubble column. It is affected by bubble shape, bubble size, and liquid and interfacial physical properties of the system. The purpose of this area of research is to determine the effect of pressure and temperature, which in turn affects the liquid and interfacial properties of the system, on single bubble rise velocity. The results are shown in Figure 4 and Figure 5.

In general, an increase in pressure will decrease the single bubble rise velocity, while an increase in temperature will increase the single bubble rise velocity. The pressure effect is greater for higher temperatures and it is also greater for bubble sizes greater than one centimeter. The obtained results can be predicted well using two correlations: the Fan-Tsuchiya equation (Fan and Tsuchiya, 1989) and the modified Mendelson equation (Mendelson, 1967). The Fan-Tsuchiya equation

$$U_b = \left(U_{b1}^{-n} + U_{b2}^{-n}\right)^{-1/n} \qquad (1)$$

$$U_{b1} = \frac{\rho_l g d_e^2}{K_b \mu_l} \qquad (2)$$

$$U_{b2} = \sqrt{\frac{2c\sigma}{\rho_l d_e} + \frac{g d_e}{2}} \qquad (3)$$

accurately predicts single bubble rise velocity for the Stokes/Levich bubble size regime and spherical cap bubble regime. The modified Mendelson equation, given by equation (3), better predicts the transition from small to large bubbles. By combining both of these results, the single bubble rise velocity can be predicted well using any system of various gas, liquid, and interfacial physical properties and various compositions. The constant, K_b, is a function of the Morton number and the liquid composition; the constant, c, is dependent on the purity and number of components of the system; and n is determined over the entire range of the obtained data.

The plot of Reynolds number versus Eotvos number for various pressures and temperatures of 27 and 78 °C shows a comparison of single bubble rise characteristics of N_2 in Paratherm NF heat transfer fluid with that in an infinite Newtonian liquid.

3. Effect of Pressure, Temperature, and Gas Distributor on Bubble Column Hydrodynamics

Pressure and temperature indirectly affect bubble column hydrodynamics. Pressure and temperature affect the gas, liquid, and interfacial properties of the system. These properties affect bubble formation, shear layer instability (maximum stable bubble size) and liquid layer thinning and rupturing which affect bubble collisions, bubble breakup and bubble coalescence, respectively. These combined effects affect the bubble size distribution. The bubble size distribution and the single bubble rise velocity, which is a function of the maximum stable bubble size, affect the most important macroscopic variable: gas holdup.

Below, is a description of the effect of pressure and temperature on bubble column hydrodynamics using a porous plate as the gas distributor. Under a temperature of 27 °C (See Figure 6), pressure has no effect on gas holdup for the dispersed bubble regime (low superficial gas velocity). But as the pressure is increased, the dispersed regime is prolonged with respect to the gas holdup. Beyond the transition from the dispersed bubble regime to the turbulent regime, the effect of pressure is more distinct. For a superficial gas velocity of 6 cm/s, the gas holdup values are 12, 15, 17, and 20 percent for pressures of 0, 500, 1000, and 2200 psig, respectively.

For a temperature of 27 °C, there are three flow regimes: the dispersed bubble regime, the churned-turbulent (bubble clustering) regime, and the turbulent regime where coalescence takes place for ambient pressure and where high density bubble clusters form under high pressure. The regime transitions were determined by examining the change in the slope of the standard deviation of pressure fluctuation versus the superficial gas velocity (See Figure 7). The regime transitions occurred at points where the slope changed. For ambient pressure, 500 psig, and 1000 psig, there are three distinct regimes. For 2200 psig, it was not possible to obtain data for the third regime, due to the limited maximum gas velocity for this pressure. These results were verified using the drift flux model for the determination of the regime transitions. The drift flux is defined as the relative velocity of the gas phase with respect to the liquid phase. For a temperature of 27 °C, the regime transition gas velocity was virtually constant for all operating pressures at 1.25 cm/s. However, the regime transition was delayed with respect to the gas holdup when the pressure was increased from ambient pressure to 500 psig. Increasing the pressure beyond 500 psig had no further affect on the bubble regime transition with respect to gas holdup.

References

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Mendelson, H. D., "The Prediction of Terminal Velocity Equations for Bubbles and Drops as Intermediate and High Reynolds Numbers," *AIChE J.* **13**, 250-253 (1967).

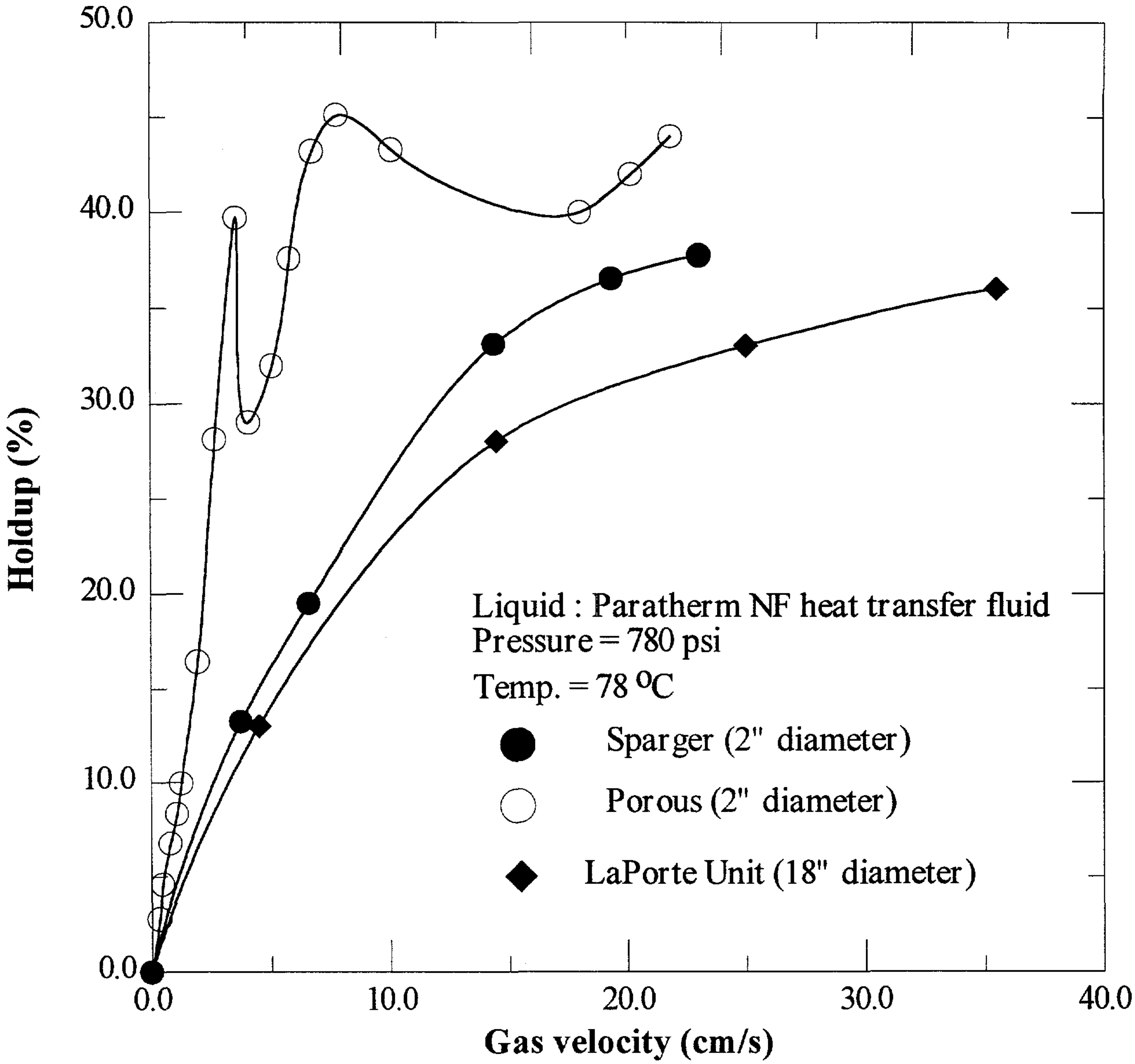

Figure 1. Comparison of gas holdup between two-inch column and LaPorte unit

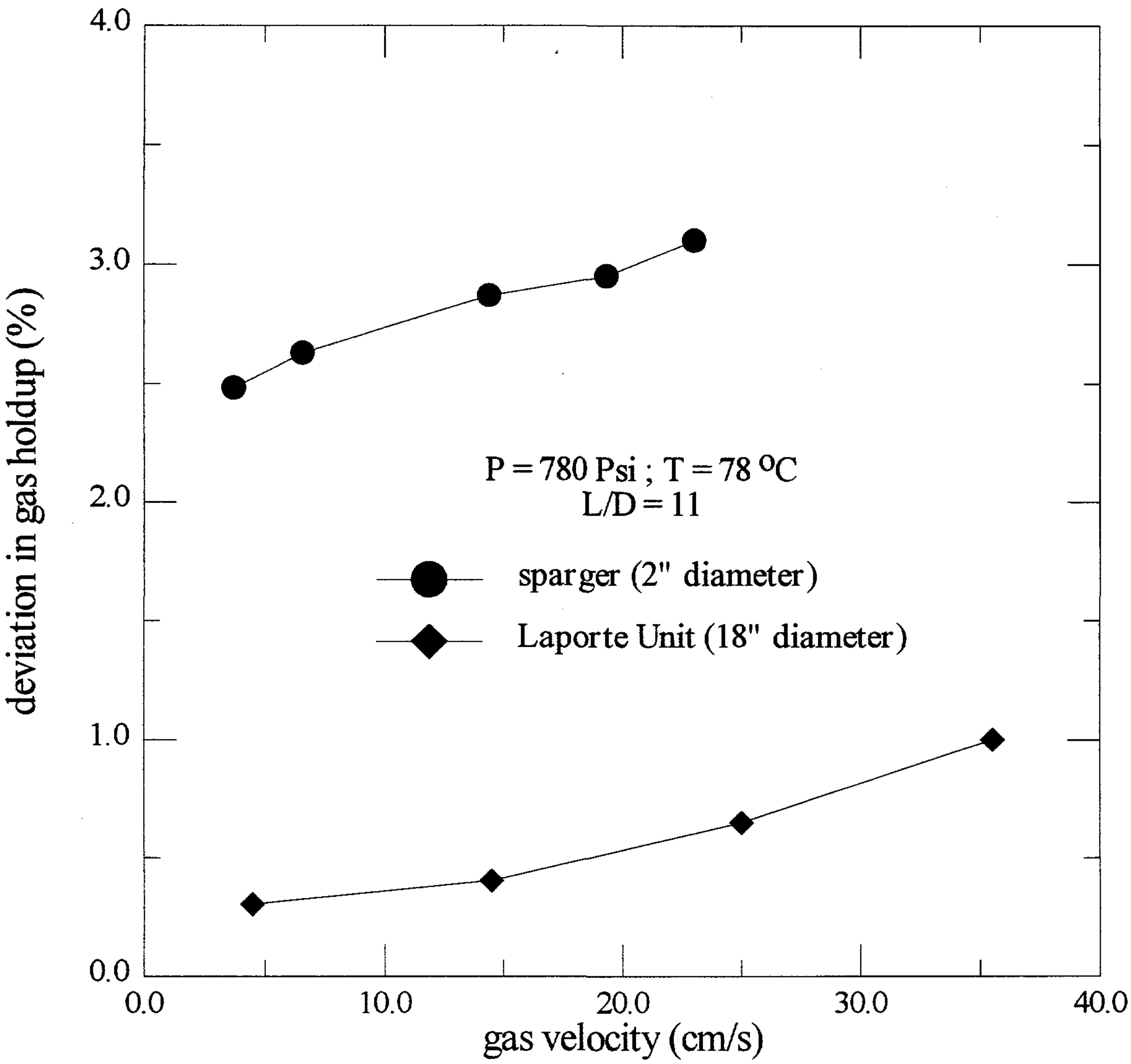

Figure 2. Comparison of deviation in gas holdup between two-inch column and LaPorte Unit.

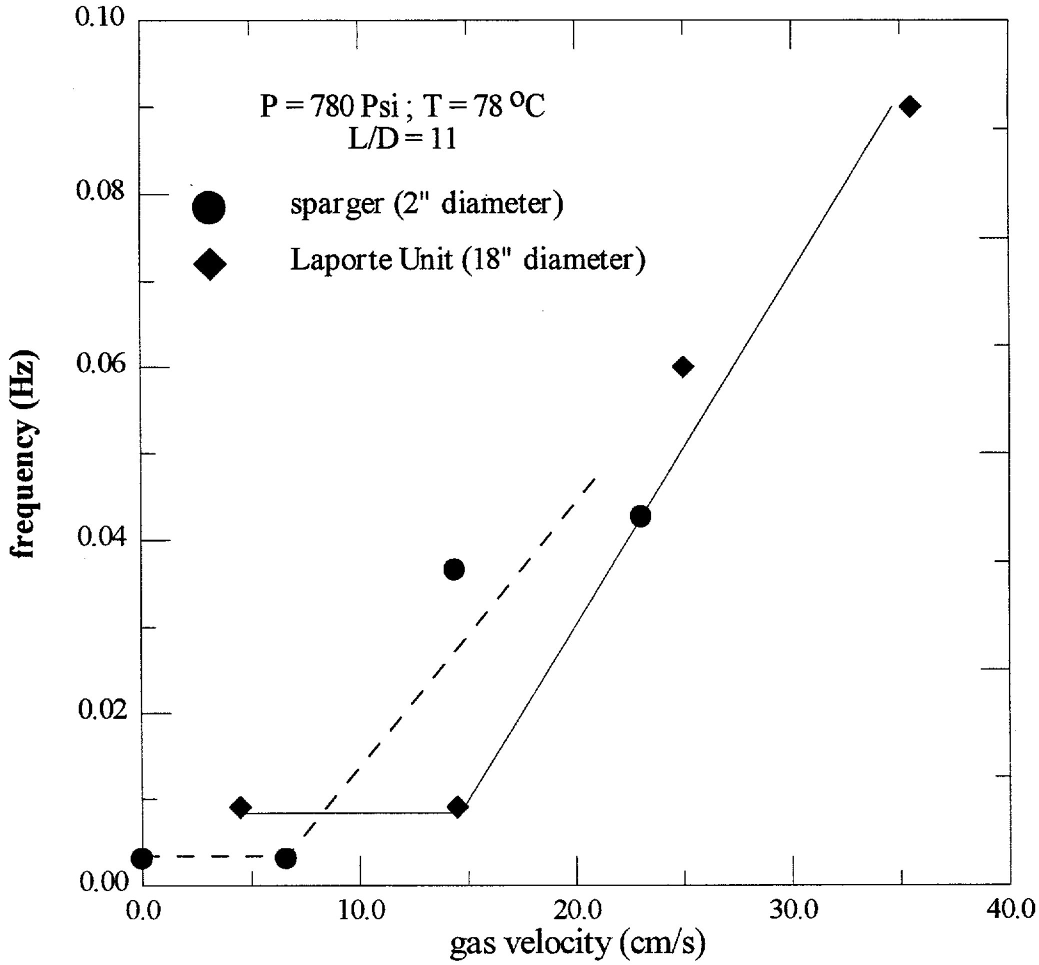

Figure 3. Power spectrum analysis of differential pressure fluctuation for two-inch column and LaPorte unit

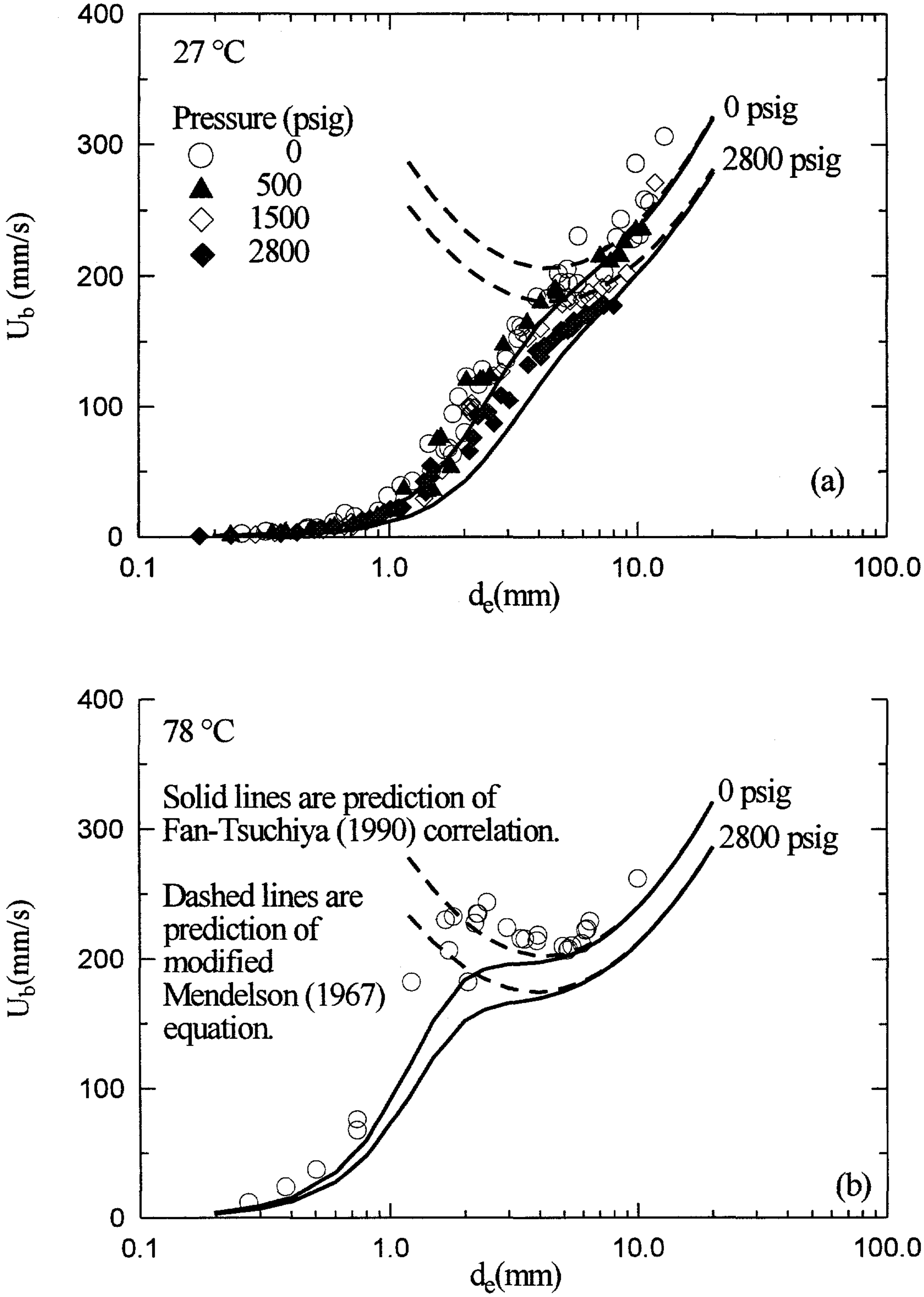

Figure 4. Effect of pressure on terminal rise velocity of single bubbles in Parather NF heat transfer fluid and its prediction at (a) 27 °C and (b) 78 °C.