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RESEARCH NOTES

Local Gas Phase Flow Characteristics of a Gas-Liquid-Solid Three-Phase Reversed Flow Jet Loop Reactor*

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Abstract The local gas-phase flow characteristics such as local gas holdup (ε_g), local bubble velocity (V_b) and local bubble mean diameter (d_b) at a specified point in a gas-liquid-solid three-phase reversed flow jet loop reactor was experimentally investigated by a five-point conductivity probe. The effects of gas jet flow rate, liquid jet flow rate, solid loading, nozzle diameter and axial position on the local ε_g, V_b and d_b profiles were discussed. The presence of solids at low solid concentrations not only increased the local ε_g and V_b, but also decreased the local d_b. The optimum solid loading for the maximum local ε_g and V_b together with the minimum local d_b was $0.16 \times 10^{-3}\,m^3$, corresponding to a solid volume fraction, $\varepsilon_S = 2.5\%$.
Keywords local gas holdup, local bubble velocity, local bubble mean diameter, gas-liquid-solid three-phase, reversed flow jet loop reactor

1 INTRODUCTION

Gas-liquid-solid three-phase flow jet loop reactors have been widely used in chemical and petrochemical processes, especially in biochemical technology because of their advantages in simple construction and operation, low investment and operational costs, very fine gas dispersion, definitely directed circulation flow, high mixing and mass transfer performance and relatively low power consumption. In gas-liquid-solid three-phase reversed flow jet loop reactors, the gas phase local parameters such as ε_g , V_b and d_b distributions, play an important role in the performance of these reactors. Meanwhile, studies on the local gas-phase flow characteristics are necessary for the design and evaluation strategy.

In recent years a number of studies have been reported in the literature investigating local gas-phase flow parameters in gas-liquid-solid three-phase fluidized beds and bubble column reactors[1–4]. Some research reports on the overall gas-phase flow characteristics for the gas-liquid two-phase and the gas-liquid-solid three-phase reversed flow jet loop reactors have been published[5–7]. A study on the local gas-phase flow characteristics of gas-liquid two-phase reversed flow jet loop reactor has been reported[8,9]. However, very little has been known about the local gas-phase flow characteristics in the gas-liquid-solid three-phase reversed flow jet loop reactors.

The objective of this study is to observe the influences of the operational variables (gas jet flow rates, liquid jet flow rates, solid loading, axial position) and the design parameter (nozzle diameter) on the local gas-phase flow parameters such as the local ε_g, V_b and d_b for the gas-liquid-solid three-phase reversed flow jet loop reactors at different axial and radial positions.

2 EXPERIMENTAL

The experimental setup is shown in Fig. 1. A 0.55 m high Perspex draft tube of 0.06 m in diameter was fixed concentrically inside the main 0.82 m high Perspex reactor tube of 0.102 m in diameter. Three concentric gas-liquid two-fluid nozzles of 0.0054 m, 0.0062 m, 0.0068 m were designed, respectively. They were located 0.075 m above the draft tube. One outlet was provided at the top (0.68 m from the bottom) of this reactor. A circular baffle of 0.102 m in diameter was fixed 0.01 m below the outlet to prevent the direct outflow of the solid particles along with the liquid. All experiments were performed at atmospheric pressure and the temperature of the liquid was maintained at (25 ± 0.1)℃ by circulating tap water through a copper coil heat exchanger immersed in a water tank. Tap water was used as the liquid phase in all experiments. Air was used as the gas phase. Spherical glass beads of 0.001 m in average diameter were used as the solid media. A five-point conductivity probe was used to characterize the local ε_g, V_b and d_b profiles of the gas-liquid-solid three-phase reversed flow jet loop reactor.

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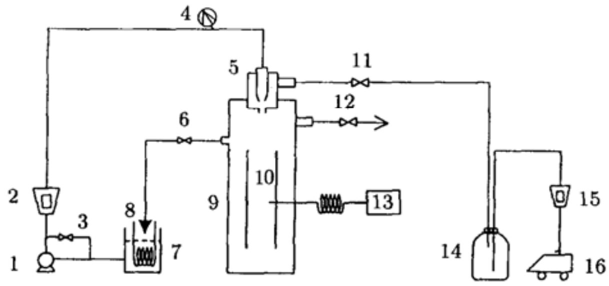


Figure 1 Schematic of experimental apparatus
1—water pump; 2,15—rotameter; 3—by-pass control valve; 4—pressure gauge; 5—nozzle; 6,11,12—drain valve; 7—tank; 8—heat exchanger; 9—reactor; 10—draft tube; 13—measuring system of the five-point conductivity probe; 14—air buffer; 16—air compressor

3 EXPERIMENTAL RESULTS AND DISCUSSION

3.1 Effect of gas jet flow rate

The influences of gas jet flow rate on the radial profiles of the local gas ε_g, V_b and d_b at the same liquid jet flow rate, nozzle diameter, solid loading and axial position are shown in Figs. 2(a)—2(c), respectively. It is observed that the local ε_g, V_b and d_b increase with an increase in gas jet flow rate.

3.2 Effect of liquid jet flow rate

Typical results for the local values of ε_g, V_b and d_b as a function of the liquid jet flow rate are illustrated in Figs. 3(a)—3(c). It is seen that the local values of ε_g and V_b increase with increase of liquid jet flow rate, but the local d_b decreases.

3.3 Effect of nozzle diameter

Figures 4(a)—4(c) show that the nozzle diameter has influence on the local ε_g, V_b and d_b profiles. It is found that the local ε_g and V_b decrease with the increase in the nozzle diameter in the range of the nozzle diameters studied, however the local d_b increases. It is attributed to the fact that the decrease in nozzle diameter resultes in the increase in the liquid jet velocity.

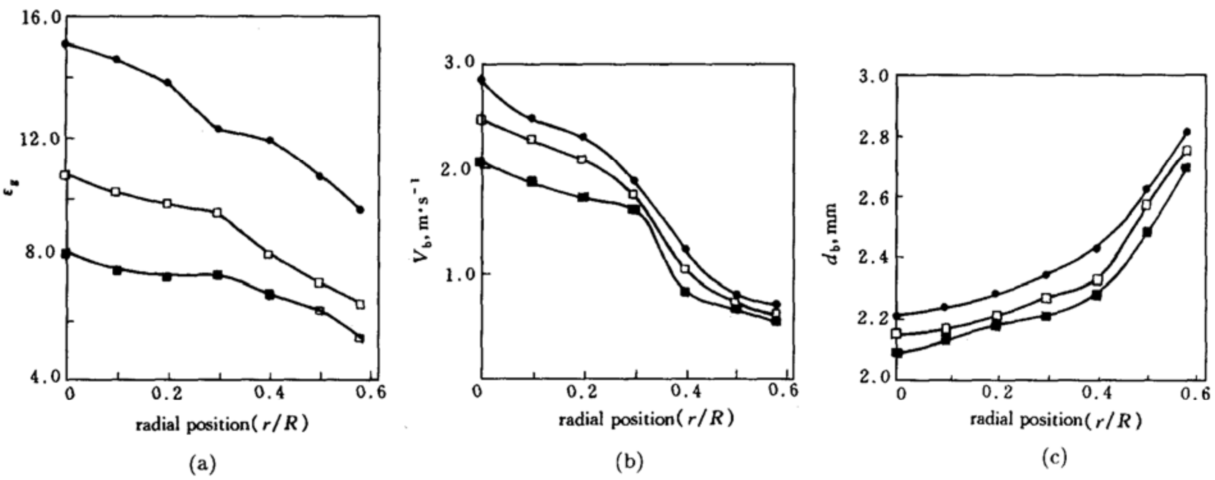


Figure 2 Influences of gas jet flow rate on the local profiles ε_g, V_b and d_b
($Q_L = 1.6\,m^3{\cdot}h^{-1}$, $d_n = 6.2 \times 10^{-3}\,m$, $V_S = 0.14 \times 10^{-3}\,m^3$, $L = 0.18\,m$)
Q_G, $m^3{\cdot}h^{-1}$: ■ 0.5; □ 1.0; ● 1.5

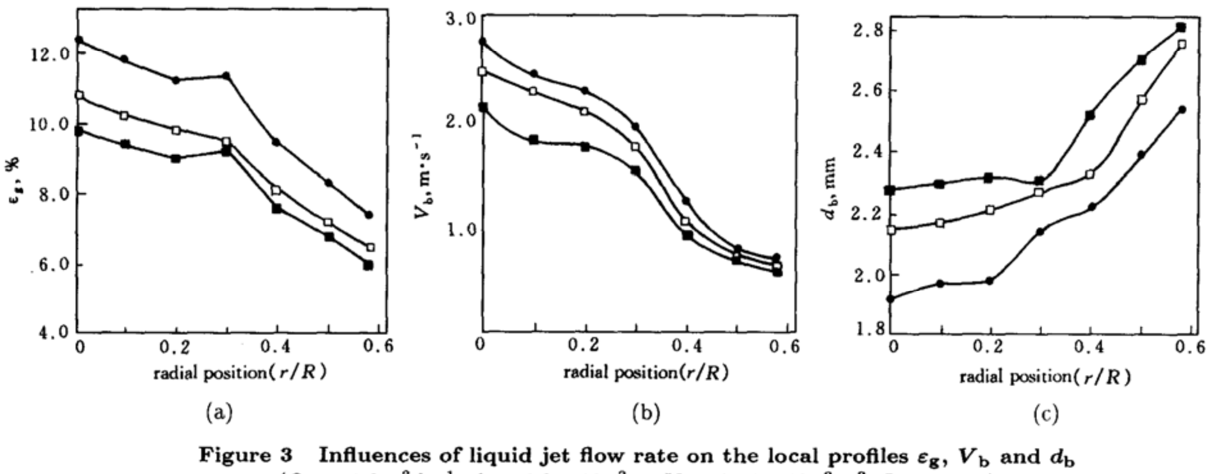
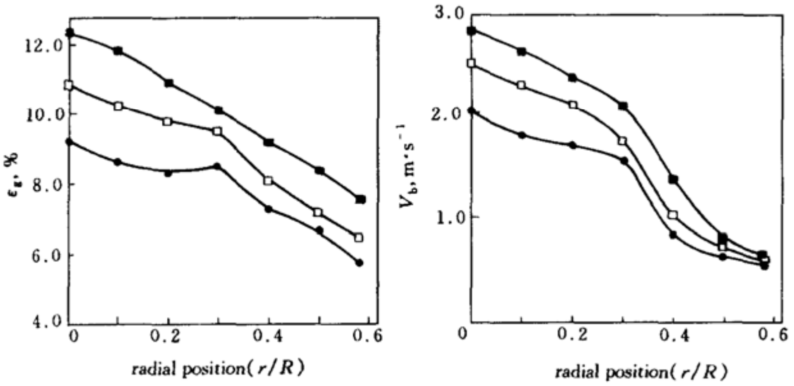


Figure 3 Influences of liquid jet flow rate on the local profiles ε_g, V_b and d_b
($Q_G = 1.6\,m^3{\cdot}h^{-1}$, $d_n = 6.2 \times 10^{-3}\,m$, $V_S = 0.14 \times 10^{-3}\,m^3$, $L = 0.18\,m$)
Q_L, $m^3{\cdot}h^{-1}$: ■ 1.2; □ 1.6; ● 1.8

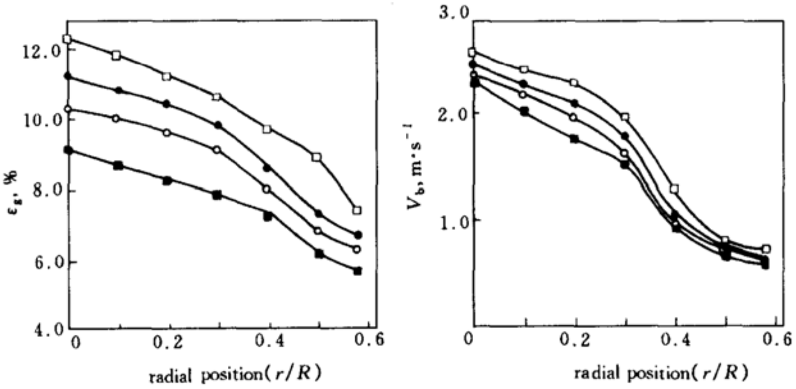
3.4 Effect of solid loading

The influences of solid loading on the local ε_g, V_b and d_b distributions are shown in Figs. 5(a)—5(c). The presence of solids not only enhanced the local ε_g and V_b, but also reduced the local d_b at low solid concentrations. An optimum value of the solid loading for the maximum local ε_g and V_b together with the minimum local d_b was $0.16 \times 10^{-3}\,m^3$, corresponding to a solid volume fraction of $\varepsilon_S = 2.5\%$. With a further increase in the solid concentration, the local ε_g and V_b decreased, but the local d_b profiles increased.



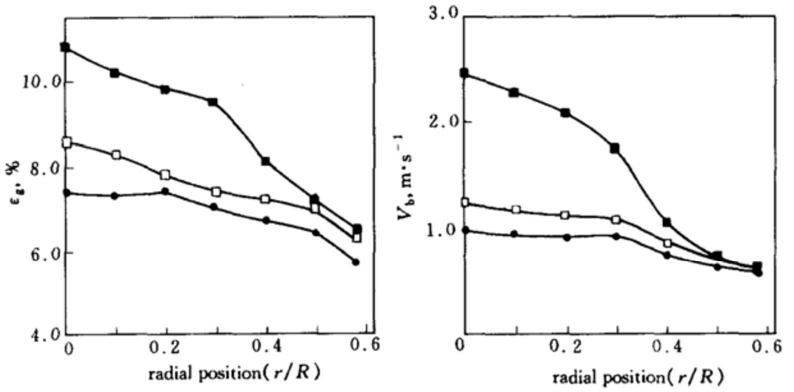
(a) (b) (c)

Figure 4 Influences of nozzle diameter on the local profiles ε_g, V_b and d_b
($Q_G = 1.0\,m^3{\cdot}h^{-1}$, $Q_L = 1.6\,m^3{\cdot}h^{-1}$, $V_S = 0.14 \times 10^{-3}\,m^3$, $L = 0.18\,m$)
d_n, m: ■ 5.4×10^{-3}; □ 6.2×10^{-3}; ● 6.8×10^{-3}



(a) (b) (c)

Figure 5 Influences of solid loading on the local profiles ε_g, V_b and d_b
($Q_G = 1.0\,m^3{\cdot}h^{-1}$, $Q_L = 1.6\,m^3{\cdot}h^{-1}$, $d_n = 6.2 \times 10^{-3}$ m $L = 0.18\,m$)
V_s, m^3: ■ 0.10×10^{-3}; □ 1.6×10^{-3}; ● 0.18×10^{-3}; ○ 0.20×10^{-3}



(a) (b) (c)

Figure 6 Influences of axial position on the local profiles ε_g, V_b and d_b
($Q_G = 1.0\,m^3{\cdot}h^{-1}$, $Q_L = 1.6\,m^3{\cdot}h^{-1}$, $d_n = 6.2 \times 10^{-3}$ m $V_S = 0.14 \times 10^{-3}\,m^3$)
L, m: ■ 0.18; □ 0.35; ● 0.58

3.5 Effect of axial position

As the axial distance from the jet entrance increased, the liquid velocity reduced and the profile became flat owing to the loss of liquid kinetic energy. This resulted to the bubble coalescence, the increase in the local d_b, and the decrease in the local ε_g and V_b as shown in Figs. 6(a)—6(c).

NOMENCLATURE

d_b	local bubble mean diameter, m
d_n	nozzle diameter, m
L	axial position from the jet entrance, m
Q_G	gas jet flow rate, $m^3 \cdot h^{-1}$
Q_L	liquid jet flow rate, $m^3 \cdot h^{-1}$
R	reactor radius, m
r	radial distance, m
V_b	local bubble velocity, $m \cdot s^{-1}$
V_S	solids loading, m^3
ε_g	local gas holdup
ε_S	solids volume fraction

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