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Bubble shape in horizontal and near horizontal intermittent flow

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ABSTRACT

This paper presents an experimental study of the shape of isolated bubbles in horizontal and near horizontal intermittent flows. It is found that the shapes of the nose and body of bubble depend on the Froude number defined by gas/liquid mixture velocity in a pipe, whereas the shape of the back of bubble region depends on both the Froude number and bubble length. The photographic studies show that the transition from plug to slug flow occurs when the back of the bubble changes from staircase pattern to hydraulic jump with the increase of the Froude number and bubble length. The effect of pipe inclination on characteristics of bubble is significant: The bubble is inversely located in a downwardly inclined pipe when the Froude number is low, and the transition from plug flow to slug flow in an upward inclined pipe is more ready to occur compared with that in a downwardly inclined pipe.

1. Introduction

Horizontal and near horizontal intermittent flow is frequently encountered in many two-phase flow engineering applications, such as power generation units, two phase pipelines and other process industries. The intermittent flow can be viewed by the succession of aerated liquid pistons followed by elongated gas bubbles which are not periodic in time and space. The unsteady and nondeterministic nature of the intermittent flow makes the modeling complicated.

The first comprehensive model to predict the intermittent hydrodynamic parameters was developed (Dukler and Hubbard, 1975) based on the unit cell concept by neglecting its nondeterministic nature and considering the alternating liquid pistons and gas bubbles in an orderly periodic way. More researchers, such as Nicholson et al. (1978), Kokal and Stanislav (1989), Taitel and Barnea (1990) improved the steady state slug flow models by employing the unit cell concept. It is assumed that liquid slugs and gas bubbles have constant lengths. The gas volume fraction in the bubble region is usually determined based on the assumption that the liquid film has a constant thickness like that in a fully developed stratified flow. In reality, the slug structure is never periodic. The bubble and slug lengths are widely distributed about the average values. Many experimental works by Grenier (1997), Cook et al. (2000), Lev Shemer (2003) provided a statistical description of slug flow. Slug-tracking method is widely employed to predict the evolution of the slug structure (Cook et al., 2000). Most slug tracking models assume the all bubbles are fully developed with a uniform liquid film thickness. From various experiments carried out in horizontal and near horizontal intermittent flows, the liquid film thickness in any section of the bubble region depends on the distance to the bubble nose (Fagundes et al., 1999).The assumption of fully developed liquid film in bubble region tends to overestimate the hold-up in bubble region.

Moreover, the intermittent flows in horizontal and inclined pipes are usually classified by two subregimes: the plug flow, in which liquid slugs do not entrain gas, and the slug flow, in which slugs entrain many small gas bubbles. Although these two subregimes show similar appearance, their fluid dynamic characteristics in such areas as pressure drops and slug velocity are distinctively different. Many studies have been performed to define the transition from plug flow to slug flow in a horizontal pipe. There is a history of uncertainty over the correct location of the plug to slug boundary as it can be seen from the examination of different flow maps and transition criteria. To date, it still remains unclear whether the transition occurs at constant superficial gas velocity or at constant mixture superficial velocity. Barnea and Brauner (1985) proposed a theoretical model assuming that gas bubbles were entrained into the liquid slug when turbulence overcame gravity, and the transition from plug flow to slug flow depended on mixture superficial velocity. More recently, Bontozoglu and Hanratty (1990) and Fan et al. (1993) proposed different mechanisms of slug flow initiation according to different superficial gas velocities. Ruder and Hanratty (1990) studied the characteristics of the gas bubble in the whole region of

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Nomenclature

D	tube diameter (mm)
Fr	Froude number (–)
g	gravity force (N/kg)
H	liquid height (mm)
L	bubble length (m)
U	velocity (m/s)
V	voltage (v)

Greek symbols

θ	tube inclination (°)
λ	wavelength (mm)

Subscripts

B	bubble
L	liquid
SL	superficial liquid velocity
SG	superficial gas velocity

intermittent flow using photographic techniques. They concluded that the existence of a staircase-like shape of the gas bubble tail was an indicator of the plug flow regime. The later studies of Fagundes et al. (1999) and Fossa (2001) verified this conclusion. Hence, the knowledge of the shape of the gas region in intermittent flow is very important to improve the knowledge of the flow structure and flow pattern transition.

In this present work, the shapes of bubble region in horizontal and near horizontal intermittent flows were studied experimentally. The Interface was assumed to be pane due to the gravity. Fig. 1 showed the bubble shapes indicated with dimensionless height of bubble interface H_L/D in the horizontal pipe at the same mixture velocity, where H_L was height of bubble interface and D was the tube inner diameter. The good agreement of the air–water interface indicated that the bubble shape depended on the air–liquid mixture velocity, and was independent on each phase velocity, which agreed with the observation of Grenier et al. (1997) and Woods et al. (1996). So the bubble shape under intermittent flow was studied by injecting isolated bubbles into a continuous fluid to ensure a better control on the bubble length and to avoid the overlap of different phenomena induced by a train of bubbles.

2. Experimental facility and measuring technique

The experiment was performed in an air–water two phase flow test system, as shown in Fig. 2. Air and water were used as the test fluids in this study. The water was measured by a mass flow meter with a precision high up to 0.1%. Water was introduced into the inlet of test section and formed a continuous liquid flow, and finally circulated to a water tank via a separator. The air, supplied from a compressor, was introduced into the pressure regulator. Individual bubbles were injected into the test section from the pressure regulator controlled by an injection valve. The length of the injected bubbles was controlled by the duration of the value

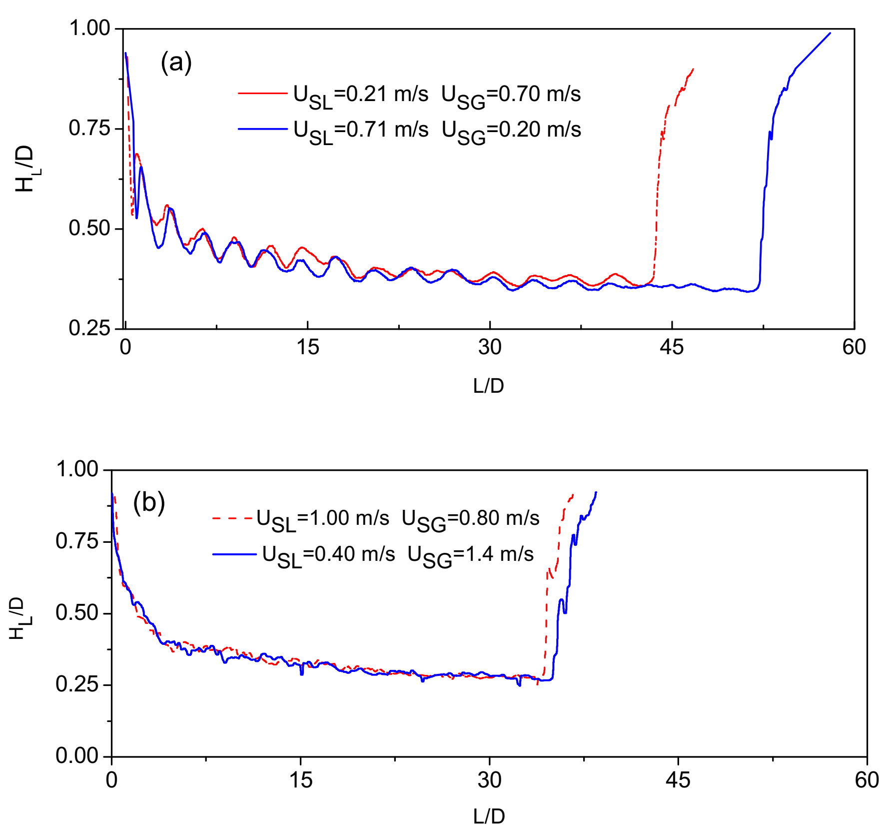

Fig. 1. Shape of two bubbles at the same mixture velocity.