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Void fraction of dispersed bubbly flow in a narrow rectangular channel under rolling conditions

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ABSTRACT

Rolling motion, as a typical ocean condition, can induce additional force and change the states of a two-phase flow system. Visualized experiments was carried out on void fraction of air–water flow in a narrow rectangular channel (40 × 3 mm^2) under ambient temperature and pressure as well as rolling conditions of 5°-8s, 10°-8s, 15°-8s, 15°-12s, 15°-16s (rolling amplitude-rolling period). The results showed that the void fraction oscillates periodically in rolling motions due to the induced changes in phase distribution and the slip of the interface. In addition, rolling motion gives rise to the reduction of the time-averaged void fraction. The fluctuation amplitude of the void fraction increased with the increase in rolling amplitude and the decrease in rolling period. The distribution parameter under rolling condition was obtained and compared with that under steady state. The influence coefficient K was defined by taking the rolling Reynolds number and gas Reynolds number into consideration. A new correlation for predicting the void fraction was given based on the experimental data.

1. Introduction

As is commonly encountered in the nuclear reactor safety applications, heat exchangers, refrigeration and air condition systems, the void fraction is of importance in view of hydrodynamics and thermodynamics in two-phase flow. Defined as the cross-sectional area occupied by the vapor in relation to the area of the flow channel, void fraction is one of the key parameters to determine the flow pattern transition, heat transfer coefficient and two-phase pressure drop.

Because of remarkable frictional resistance and the effects of surface tension, characteristics of two-phase flow in rectangular ducts differ from that in conventional round pipes. A number of previous studies regarding the void fraction in rectangular channels have been performed in recent years (Fujita et al., 1995; Ide et al., 2007; Mishima et al., 1993; Sowinski et al., 2009; Xu, 1999). Distribution of void fraction was investigated by using the measurement of probe sensor, constant electric current, neutron radiography and photograph. In recent years, it has become of importance to research the characteristics of bubbly flow in rectangular channel. Kim et al. (2009) focused on obtaining detailed local two-phase flow parameters in the air–water adiabatic bubbly flow in a vertical rectangular duct using the double-sensor conductivity probe. The 'wall peak' was observed in the profiles of the interfacial area concentration and the void fraction. Flow measurements of vertical upward air–water flows in a narrow rectangular channel were performed by Shen et al. (2012) at seven axial locations. The predictions by drift-flux models with the correlation of Ishii (1977) for calculating the distribution parameter in rectangular channel and several existing drift velocity correlations of Ishii (1977), Hibiki and Ishii (2003) and Jones and Zuber (1979) agreed well with the measured void fractions and gas velocities from Shen et al. (2012). All the above-mentioned literature concerning the void fraction in bubbly flow were under steady conditions, but not unsteady conditions.

In recent years, effects of ocean conditions (rolling, heaving, pitching, and inclination conditions) on the flowing and heat transfer characteristics have been attracted growing interests. The main difference between land-based and barge-mounted equipments is in that the latter ones cannot avoid from the influence of sea wave oscillations. Numbers of previous studies regarding thermal hydraulic characteristics under rolling conditions have been performed in recent years. Gao et al. (1997), Tan et al. (2009a, b) and Yan and Yu (2009) indicated that the flow rate of a natural circulation system will oscillate periodically in rolling motion. The effects of rolling parameters, flow rate and tube radius on forced single-phase circulation in vertical and horizontal pipes were investigated by Cao et al. (2006), Xing et al. (2012) and Zhang et al. (2009). Some numerical simulations in terms of the effect of rolling on the single-phase flow in ducts were investigated by Yan et al. (2011)

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Nomenclature

T	rolling period (s)
t	time (s)
L	length between the pressure taps (m)
D	hydraulic diameter of test sections (m)
Re	the two-phase Reynolds number
v_{gj}	drift velocity (m/s)
C	distribution parameter (−)
j	superficial velocity (m/s)
g	gravitational acceleration
w	the height of the channel (m)
s	the width of the channel (m)
l	the distance between the test section and rolling axis (m)
z_2', z_1', y_1'	relative coordinates fixed on rolling platform (m)
K	influence coefficient
S	the slip ratio (−)

Greek letters

θ	rolling angle (rad)
ω	angular velocity (rad/s)
β	angular acceleration (rad/s^2)
ρ	the mixture density (kg/m^3)
α	void fraction (−)
σ	surface tension (−)

Subscripts

m	the maximum value
f	Liquid
g	Gas
0	non-rolling condition
tp	two phase flow
roll	under rolling condition
eff	efficient acceleration

Mathematical symbols

$< >$	area averaged value
$\langle\langle\rangle\rangle$	void fraction weighted mean value

recently. Regarding the two-phase flow, Cao et al. (2006) studied the flow resistance in vertical and horizontal pipes under rolling conditions, and provided the correlations for predicting the friction factor against the experimental data. The volume averaged void fraction under rolling condition was measured by Yan et al. (2007) in a circular tube by quick closing valves method and the result showed that rolling motion reduces the void fraction compared with that in vertical state. It is clear that rolling motion could change the effective forces acting on motional fluids, leading to the changes in interaction between the phases in a two-phase flow system.

Bubbly flow, as a typical flow pattern of gas–liquid flow, has been studied extensively in steady state, while its thermal hydraulic behavior in rolling motion are still under development, more work needs to be carried out in terms of the flow resistance and heat transfer. In this paper, aiming to illustrate the effect of rolling motion on void fraction in bubbly flow, experiments were performed with a rectangular duct having the cross section of 40 mm × 3 mm to obtain the distribution of local void fraction of bubbly flow in rolling motion.

2. Experimental setup

2.1. Rolling platform

The rolling platform, driven by a hydraulic system, is a rectangular plane which could roll around its middle shaft to generate different rolling periods and amplitudes. Fig. 1 shows the side view of the rolling platform, and a positive rolling angle is defined as counterclockwise seen from the direction perpendicular to the plane of *ZOY*. The rolling movement is simulated, following the discipline of trigonometric function. The rolling amplitude can be expressed as follow:

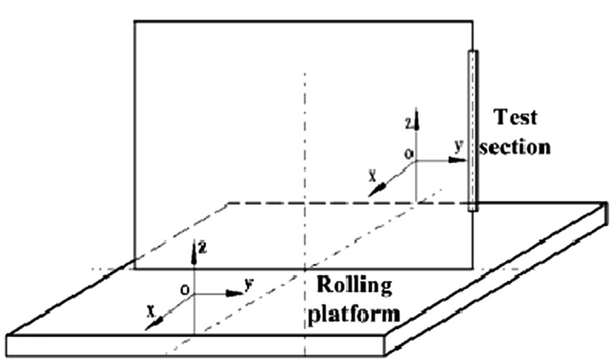

Fig. 1. Side view of rolling platform.

$$\theta = \theta_{\mathrm{m}}\sin(\omega_0 t) = \theta_{\mathrm{m}}\sin\left(\frac{2\pi}{T}t\right) \tag{1}$$

The angular velocity of the rolling motions is

$$\omega = \frac{\mathrm{d}\theta}{\mathrm{d}t} = \theta_{\mathrm{m}}\frac{2\pi}{T}\cos\left(\frac{2\pi}{T}t\right) \tag{2}$$

and the acceleration of the rolling motions is

$$\beta = \frac{\mathrm{d}\omega}{\mathrm{d}t} = -\theta_{\mathrm{m}}\left(\frac{2\pi}{T}\right)^2\sin\left(\frac{2\pi}{T}t\right) \tag{3}$$

Where θ_{m} and T denote the rolling amplitude and the rolling period, respectively, the chosen rolling conditions for comparison are as follows: θ_{m} 5°-T8s; θ_{m} 10°-T8s; θ_{m} 15°-T8s; θ_{m} 15°-T12s; θ_{m} 15°-T16s. (θ_{m} -rolling amplitude *T*-rolling period)

2.2. Test section and experimental loop

The test section is a 2000 mm long rectangular channel with the cross section of 40 mm × 3 mm (width × height), and the aspect ratio of the width to the height as well as the hydraulic diameter are 13.3 and 5.58 mm, respectively. The measurement uncertainties of the test section (width, height and length) are ±0.02 mm, ±0.02 mm and ±0.1 mm, respectively. The figures were got from different kinds of length measuring instruments, and the uncertainties were acquired from multi-measurement and the accuracy of these instruments. Two pressure taps are centered on one of the wide walls of the duct and with a separation of 1 m. To eliminate the effect of the entrance flow region, first pressure tap locates 0.5 m ($L/D = 89.6$) from the inlet of the test section.

The schematic diagram of the experimental loop is shown in Fig. 2. The test section and the mixing chamber are mounted on the rolling platform, while the water and air supply loops are placed on