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Hydrodynamic effects of mixing vane attached to grid spacer on two-phase annular flows

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HIGHLIGHTS

- The effects of a grid spacer with mixing vane (MV) on annular flows in a 16 mm I.D pipe was investigated.
- Pressures upstream and downstream from the spacer, entrainment fraction and deposition rate downstream the spacer were measured.
- The deposition mass transfer coefficient was much higher for the spacer with mixing vanes than that without mixing vanes.

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ABSTRACT

This paper investigates the effect of a grid spacer with mixing vane (MV) on flow characteristics of two-phase annular flows in a test channel, which was a circular pipe with 16 mm I.D. To know the effects of spacers, a grid spacers with and without MV were installed in the test channel. Furthermore, two kinds of inclination angle of MV were tested to be 20° (MV-20) and 30° (MV-30). In the experiment, pressures upstream and downstream from the spacer were measured with a pressure transducer. Entrainment fraction and deposition rate were measured respectively with liquid film extraction method. Experimental data revealed that the deposition mass transfer coefficient was much higher for the spacer with mixing vanes than that without mixing vanes. No effects of the vane inclination angle on the mass transfer coefficient were seen. Therefore, the spacer with MV-20 was enough to re-deposit effectively liquid droplet to the channel wall downstream of the spacer, because pressure drop due to the spacer is smaller for MV-20 than MV-30.

1. Introduction

Two-phase annular flow is the most prevalent flow patterns in a fuel rod bundle in a boiling water nuclear reactor (BWR). In the annular flow, part of the liquid flows as a liquid film on the fuel rod and the rest flows as droplets in gas core. The liquid droplets would entrain from liquid film to the gas core, and the liquid droplets re-deposit to the liquid film. If the liquid film thickness reduces to zero, the heat transfer coefficient from the rod surface to gas core flow decreases significantly with consequent increasing of the rod temperature. This will cause damage to the fuel rod. In order to prevent from the damage, it is therefore necessary for water to always cover the fuel rods.

Grid spacers, which keep the fuel rod in position, are being designed to force the liquid droplets to re-deposit onto liquid film on the fuel rod to keep a covering of water on the rods. Several researches (Kraemer et al., 1995; Feldhaus et al., 2002; Damsohn and Prasser, 2010), for example, the method of liquid film thickness recovery to deposit liquid droplets onto fuel rod by mixing-vanes (MV) attached on the spacer, have been conducted. A CFD-code, which can analyze flows in detail based on Computational Fluid Dynamics, has been developed to treat the droplet transfer, i.e., the entrainment and deposition of the droplet for steam-water annular flow in the rod bundle (Onishi et al., 2011). It is thus necessary to verify whether the code can evaluate the effect of the spacer with MV. However, the published data of the spacer with MV in gas-liquid two-phase flow are limited.

In our previous study (Kawahara et al., 2014), an experimental program was proposed to get the validation data for single-phase gas flows and two-phase annular flows in a test channel, which was a circular pipe simplified center subchannel as seen in fuel bundle. To know the effects of mixing vanes, a grid spacers with or without MV were inserted in the test channel. The inclination angle of the mixing vane was set to be 30° which was determined by reference to the mixing vane in a pressurized water nuclear

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reactor (PWR). The experiments cleared that the mixing vanes promoted significantly to re-deposit liquid droplets onto liquid film on the channel walls, and deposition mass transfer coefficient is three times higher for the spacer with MV than that without MV even at 0.3 m downstream from the spacer. In consequent, liquid film thickness becomes thicker downstream of the spacer with MV, compared to the thickness for the spacer without MV.

In this connection, the purpose of this study is to know the effects of inclination angle of mixing vane on liquid droplets deposition and pressure drop performances. Both of these performances must be balanced with the need to minimize the additional pressure drop caused by the mixing vane. Thus, two inclination angle, i.e., 20° and 30°, were tested. In the experiment, liquid entrainment fraction and deposition rate were measured respectively by liquid film extraction method and double liquid film extraction method. In addition, axial pressure distribution upstream and downstream of the test spacer was measured to determine the additional pressure drop by the spacer. From analyzing the experimental data, the effects of the MV inclination angle on the entrainment, the deposition and the pressure drop were clarified.

2. Experiments

2.1. Experimental setup

Fig. 1 shows schematic diagram of the test apparatus. A vertical circular pipe of D = 16 mm i.d. was used as the test channel. The diameter tested is a little bit larger than the hydraulic diameter of center subchannel in BWR, and the lager diameter facilitates the measurement of deposition, entrainment, liquid film and gas velocity profile, etc. (Kawahara et al., 2014). Air and water at room temperature were used as test fluids. The water was fed from a reservoir (#6) to an air-water mixer (#1) by a pump (#7). In the mixer, the pipe wall had 12 holes of 2 mm i.d. drilled to introduce the water as a liquid film from the periphery of the pipe to air stream supplied by a compressor (#11). The air-water mixture so made flowed upwards through 2.2 m entry section (#2), a 0.8 m test section (#3) and a 0.5 m discharge section (#4), and flowed into an air-water separator (#5). The water separated was returned to the reservoir, while the air was released to the atmosphere. Volume flow rate of air was measured with an ultrasonic flowmeter (#9) within the accuracy of ±5%, while that of the water with electromagnetic flowmeter (#8) within ±2%. In the test section, one of test spacers was inserted, and liquid droplet entrainment fraction, deposition rate and gauge pressure were measured downstream of the spacer.

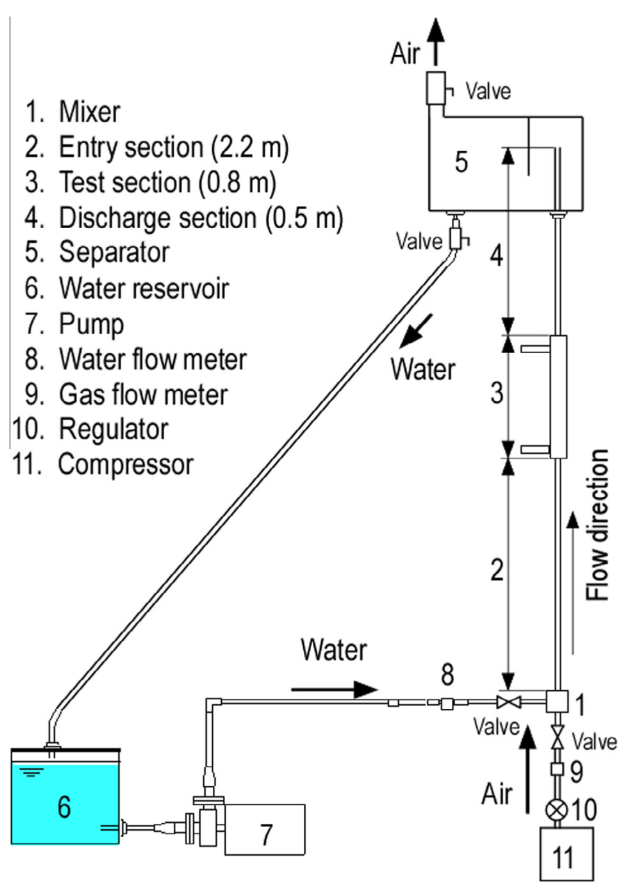

Fig. 1. Test apparatus.

Fig. 2 shows two kinds of gird spacer tested. Fig. 2(a) is the grid spacer without mixing vanes. Two plates were made of PET (polyethylene terephthalate), and the thickness of the plate is 0.5 mm. Each plate has a 19 mm slit with its width of 0.5 mm. And then, two plates were orthogonally connected through the each slit as shown in right photo in Fig. 2(a). The thickness of the plate is 0.5 mm. Fig. 2(b) is the grid spacer with mixing vanes. Four vanes were attached on the end of the grid spacer. The vanes were inclined separately at θ = 20 or 30 degree angle to create swirling flow in gas core for annular flow. Hereafter, the mixing vane with the inclination angle of θ = 20° and θ = 30° are called as MV-20 and MV-30, respectively.

2.2. Determination of pressure drop due to spacer

Fig. 3 shows pressure tap positions due to measure pressure distribution along the channel axis. Eight pressure taps were located at the positions as shown in Fig. 3. Each pressure tap was connected to gauge type pressure transducer calibrated with accuracy ±5%. The pressure at #4 tap was used to evaluate the air density needed for the determination of the air volume flow rate, Q_G. Thus, gas volumetric flux, j_G, was specified as the value of the Q_G divided by channel flow area.

Fig. 4 shows typical pressure distribution data for two-phase flow at liquid and gas volumetric fluxes, j_L = 0.07 m/s and j_G = 35 m/s in the test channel with the spacer with MV-30. The ordinate is the gauge pressure, while the abscissa is the distance from upstream end of the spacer. The pressure drop at the spacer, Δp_S, was determined by the pressure difference at upstream and downstream ends of the spacer extrapolated from linear pressure distributions upstream and downstream from the spacer, as shown in Fig. 4.

2.3. Measurements of entrainment and deposition

In the present experiments, liquid droplet entrainment fraction and deposition rate were measured with liquid film extraction method. Fig. 5 shows the film extraction units implemented in the test section as shown in Fig. 1. Two film extraction units were installed downstream of the test spacer. The distance between the gas-liquid mixer and the spacer was ca. 130 pipe diameters. According to Ishii and Mishima's correlation (1989), 120 pipe diameters are enough for flow to attain fully developed annular flow, in which the entrainment rate might be balanced with the deposition rate.

The local entrainment flow fraction, $E(Z)$, at Z which is the distance from upstream end of the test spacer to the first extraction unit was determined by

$$E(Z) = \frac{G_L - G_{LF1}}{G_L}, \quad (1)$$

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