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Invited Article

EFFECTS OF GRID SPACER WITH MIXING VANE ON ENTRAINMENTS AND DEPOSITIONS IN TWO-PHASE ANNULAR FLOWS

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ABSTRACT

The effects of mixing vanes (MVs) attached to a grid spacer on the characteristics of air–water annular flows were experimentally investigated. To know the effects, a grid spacer with or without MV was inserted in a vertical circular pipe of 16-mm internal diameter. For three cases (i.e., no spacer, spacer without MV, and spacer with MV), the liquid film thickness, liquid entrainment fraction, and deposition rate were measured by the constant current method, single liquid film extraction method, and double liquid film extraction method, respectively. The MVs significantly promote the re-deposition of liquid droplets in the gas core flow into the liquid film on the channel walls. The deposition mass transfer coefficient is three times higher for the spacer with MV than for the spacer without MV, even for cases 0.3-m downstream from the spacer. The liquid film thickness becomes thicker upstream and downstream for the spacer with MV, compared with the thickness for the spacer without MV and for the case with no spacer.

1. Introduction

The critical power in a boiling water nuclear reactor (BWR) fuel rod bundle depends on the spacer geometries, because they affect the axial distribution of the liquid film and the liquid droplets in two-phase annular flow. Several studies [1,2] have demonstrated the method of liquid film thickness recovery to deposit liquid droplets in a gas core in two-phase annular flow to fuel rod by mixing vanes (MVs) attached on a spacer. Computational fluid dynamics (CFD) codes, which can analyze flows in detail based on CFD, have been developed to treat the droplet transfer, that is, the entrainment and deposition of the

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droplet for steam-water annular flow in the rod bundle. For example, Onishi et al. [3] developed a CFD code with a droplet-tracking model for analyzing the vapor-phase turbulent flow in which droplets are transported in subchannels of a BWR fuel rod bundle. It is thus necessary to verify whether the code can evaluate the effect of a spacer with MV. However, published data on spacers with MV in gas–liquid two-phase flow are limited.

Therefore, the purpose of this study is to know the effect of a grid spacer with MV on flow characteristics of two-phase annular flows. An experimental program was proposed to obtain 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 a fuel bundle. To understand the effects of MVs, grid spacers with or without MV were inserted in the test channel. In the two-phase flow experiment, the liquid film thickness, liquid entrainment fraction, and deposition rate were measured by the constant current method, liquid film extraction method, and double liquid film extraction method, respectively. In the analysis, data on entrainment and deposition rates were compared with the calculations performed based on existing correlations in the literature. From the experiments and the analysis, the effects of the test spacers on liquid film thickness, entrainment, and deposition were clarified. The results of the experiments and the analysis are described in this paper.

2. Experiments

2.1. Test apparatus

Fig. 1 shows a schematic diagram of the test apparatus. A vertical circular pipe [internal diameter (i.d.) = 16 mm] was used as the test channel. Air and water at room temperature were used as test fluids. The water was fed from a reservoir to an air–water mixer by a pump. 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 the air stream supplied by a compressor. The air–water mixture so made flowed upward through a 2.2-m entry section, a 0.3-m test section, and a 0.5-m discharge section, before flowing into an air–water separator. The separated water was returned to the reservoir, while the air was released into the atmosphere. The volume flow rate of air was measured using an ultrasonic flowmeter with an accuracy of ±5%, whereas that of the water was measured using an electromagnetic flowmeter with an accuracy of ±2%. One of the test spacers was inserted in the test section, and liquid film thickness, liquid droplet entrainment, and deposition were measured upstream and downstream of the spacer.

Fig. 2A and B show the two kinds of gird spacer tested. Fig. 2A is the grid spacer without an MV. Two plates made of polyethylene terephthalate were orthogonally connected to each other as shown in the photo to the right in Fig. 2A. The thickness of the plate is 0.5 mm. Fig. 2B is the grid spacer with MVs. Four vanes were attached to the end of the grid spacer. The vanes were inclined separately at a 60-degree angle to create swirling flow in the gas core for annular flow.

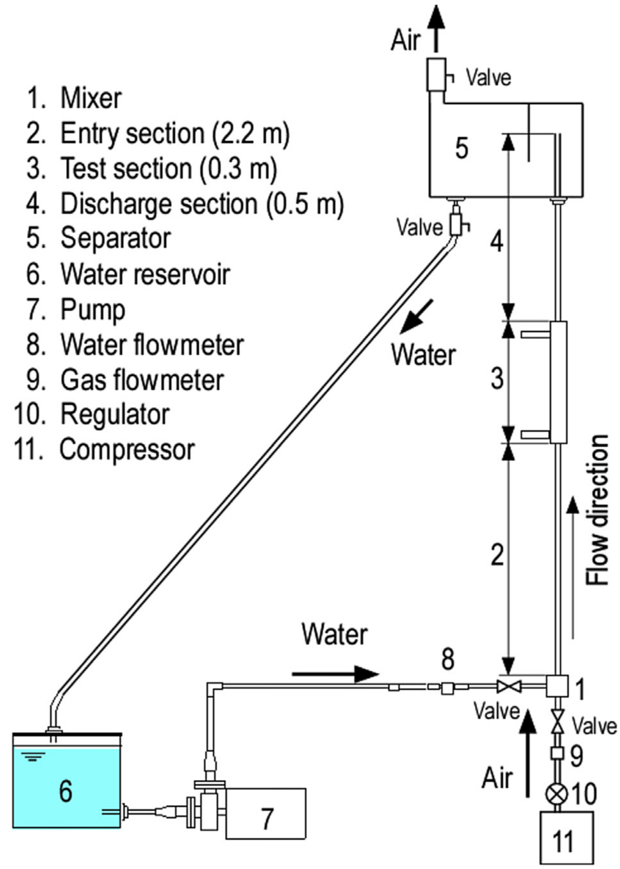

Fig. 1 – Test apparatus.

2.2. Measurement of liquid film thickness

In the test section, the liquid film thickness was measured using the constant current method developed by Fukano [4]. Fig. 3 shows the locations of electric probes for measuring the liquid film thickness. A series of six probes were arranged upstream and downstream of the test spacer. Each probe was composed of two brass rings (height of each ring, 2 mm) 3 mm apart embedded in the inner surface of the test pipe made of acrylic resin. The output voltage signals from each probe were substituted to a calibration curve expressing the relationship between the voltage and the film thickness for converting them to time-varying liquid film thickness signals. These signals were then fed to a personal computer through an A/D converter to compute the time-averaged liquid film thickness. The liquid film thickness, therefore, was a circumferentially averaged value over 3 mm in axial length. Details about the calibration are presented in a previous study [5]. According to the calibration, the maximum relative uncertainty in the measurement of the film thickness was 10%.

2.3. Measurements of entrainment and deposition

In gas–liquid annular flow, part of the liquid flows as droplets in the gas core flow and part as liquid film on the channel walls. The liquid droplets would entrain from liquid film to the gas core, and the liquid droplets re-deposit into the liquid film. In the present experiments, the liquid droplet entrainment