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Classification and modeling of flooding in vertical narrow rectangular and annular channels according to channel-end geometries

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ABSTRACT

In this study, data classification and modeling of the flooding phenomenon were performed in a narrow channel with a gap thickness of several millimeters. To implement the conventional classification study to a narrow channel case, three key ideas for two-phase flow in a narrow channel were proposed; characteristic length, the flow path for each phase and a concept of unit-cell that can unify both narrow rectangular and annular channels including large outer diameter. Based on the ideas, 330 flooding data points for both narrow rectangular and annular channels including large outer diameter were classified into exit flooding and entrance flooding according to the geometries of the liquid inlet. In order to develop the prediction model for flooding in a narrow channel, the hyperbolicity breaking concept was introduced. The present flooding model was derived based on the hyperbolicity breaking of the two-fluid model and produced the Root Mean Square Errors (RMSE) of 30.02% in terms of the superficial gas velocity against the 330 flooding data points from narrow rectangular and annular channels with relatively small outer diameter. Moreover, the proposed model was applied to a case of narrow-large diameter annuli with the introduction of the number of the unit-cells producing the RMSE of 26.11% against 91 flooding data points. The RMSEs of the existing models for narrow rectangular and narrow large-diameter annuli were 38.25% and 31.10%, respectively. Different from the existing models, the proposed model turned out that it is applicable to various narrow channel-types; a rectangular, an annular and an annulus with a large diameter.

1. Introduction

To estimate the heat removal rate of overheated systems by gravity-driven water penetration through a narrow channel, flooding in a narrow channel is one of the important issues. Typical examples are heat pipes, cooling systems of an electronic device, and nuclear systems in a severe accident. In the severe accident of a nuclear system, overheated molten-fuel in a reactor vessel is quenched by the gravity-driven water penetration, which flows through a narrow gap. The water penetration rate is restricted by the rising vapor flow; the water penetration rate governs the heat removal rate of the overheated-molten fuel in the lower plenum (Christoph, 2006). The issue of flooding in a narrow channel has recently been studied to estimate critical heat flux in a narrow channel (Juarsa, 2014; Kim et al., 2019). Hence, several experimental studies and modeling for flooding in a narrow channel were carried out.

In the above experiment in narrow channels, the geometric type of a narrow channel can be divided into two categories. The first one is flooding in a rectangular narrow channel (Mishima, 1984; Sudo and Kaminaga, 1989; Osakabe and Kawasaki, 1989; Osakabe et al., 1994; Vlachos et al., 2001; Drosos et al, 2006; Li and Sun, 2010) Their ranges of gap thickness and width are 1.5 ~ 10 mm and 40 ~ 150 mm, respectively. The second one is flooding in a narrow annular channel, which a rod was inserted into a tube (Ueda and Suzuki, 1978; Regland et al., 1989; Osakabe and Futamata, 1996). The ranges of the gap thickness and the outer diameter are 5 mm ~ 17 mm and 50 ~ 101.6 mm, respectively. Moreover, there is cases of large-diameter annuli, whose outer diameters are 440 mm (Richter et al., 1979) and 500 mm (Jeong, 2008). The hydraulic parameters of channels of the former researcher's work are shown in Table 1.

In order to predict the flooding gas velocity, following equation and non-dimensional parameters are widely used (Wallis, 1969; Tien, 1977).

$$(j_g^*)^{1/2} + m(j_f^*)^{1/2} = c \tag{1}$$

$$j_k^* = C_k j_k \quad \text{k is f(liquid) or g(gas)} \tag{2}$$

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