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Experimental study on the effect of angles and positions of mixing vanes on CHF in a 2 × 2 rod bundle with working fluid R-134a

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Abstract

In this paper, the CHF experiment on the effect of angles and position of mixing vanes was performed in a 2 × 2 rod bundle. The test section had rectangular geometry in which four rod, each with a diameter of 9.5 mm, were inserted. The rod-to-rod gap was 3.15 mm, and the rod-to-wall gap was 1.575 mm. It was vertically installed in the test loop and was uniformly heated by electricity. The heating length was 1.125 m. The working fluid was R-134a. The mass flux ranged from 1000 to 1800 kg/m^2. The test pressure ranged from 14.67 to 25.67 bar. CHF data in the 2 × 2 rod bundle without a mixing vane were compared to the Bowring correlation and a CHF look-up table at equivalent hydraulic diameter. For this comparison, Katto's fluid-to-fluid model is applied. The results had a good agreement with error rates of 16 and 20%. In the CHF experiment with the mixing vanes with various angles, the angles of the mixing vanes were 20–40°. The CHF enhancement ratio (CER) was largest at 30°. CHF was enhanced up to 19%. A CHF experiment on the position of the mixing vane was also performed. In the experiment on the position of mixing vane, CER was reduced with increasing distance between grid and CHF location because swirl flow decayed. We also performed the CHF experiment on mixing vane developed by KAIST.

1. Introduction

In PWR, the boiling crisis of DNB (departure from nucleate boiling) can occur at non-normal condition. Because DNB-type boiling crises mainly occur at high temperatures and pressures and high heat fluxes, if it occurs, the integrity of nuclear fuel could be damaged severely. In order to achieve higher fuel cycle economy, enhancement of the CHF, which we attempt in this paper, is one of major objectives in nuclear fuel development. To achieve this enhancement, we must first design and optimize the mixing vane.

Nowadays, most mixing vanes for commercial nuclear fuel are shaped to reduce enthalpy difference between subchannels and to create a swirl flow inside the subchannel. Fig. 1 shows the shape of the representative mixing vane for commercial nuclear fuel. It prevents the peak enthalpy in any subchannel by forced mixing, so boiling crisis does not occur ahead in any subchannel. Forced mixing of the CHF is effective at a

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Nomenclature

c_p	specific heat [J kg^{-1} K^{-1}]
D	hydraulic diameter [m]
G	mass flux [kg m^{-2} s^{-1}]
h	Enthalpy [kJ kg^{-1}]
P	Pressure [kPa]
q_c	Critical Heat Flux [kW m^{-2}]
q_{ij}	heat transported between subchannels i and j per unit length [W m^{-1}]
q''_{MV}	critical heat flux in rod bundle with mixing vane [kWm^{-2}]
q''_{bare}	critical heat flux in rod bundle without mixing vane [kWm^{-2}]
S	gap width [m]
T	bulk temperature [K]
w'_{ij}	mixing rate between subchannels i and j [kg m^{-1} s^{-1}]
w'_{eff}	effective mixing velocity [m s^{-1}]

Greek symbols

φ	modeling parameter
ρ	density [kg m^{-3}]
σ	surface tension [Nm^{-1}]

Subscript

f	liquid
g	vapor
fg	difference between saturated liquid and saturated vapor
i	subchannel i
j	subchannel j

high mixing rate. Many researchers have estimated the mixing rate between subchannels (Cheng and Muller, 1998; Shen et al., 1991; Silin et al., 2004). Rehme (1992) proposed these equations for the estimation of a single-phase flow mixing rate between subchannels from experimental works in rod bundle geometry.

$$w'_{ij} = \rho w_{ett} S \tag{1}$$

$$q_{ij} = \rho c_p w_{eff} S (T_i - T_j) \tag{2}$$

$$q_{ij} = \rho c_p \bar{\varepsilon} S Y \frac{T_i - T_j}{\delta_{ij}} \tag{3}$$

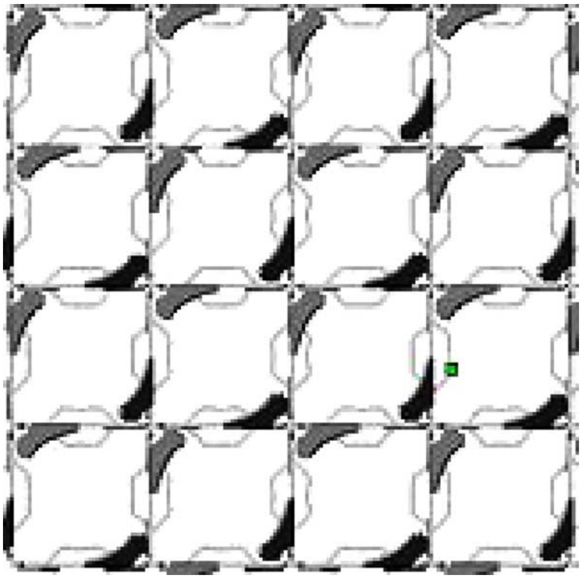

Fig. 1. Representative mixing vane in commercial nuclear fuel (Vantage-5H^{TM}).

The idea is applied to flow mixing in a rod bundle with a mixing vane. Also, there are some researches in which the idea is applied to two-phase flow. Carlucci et al. (2004) developed the generalized relationships for single- and two-phase intersubchannel turbulent mixing in vertical and horizontal flows, and lateral buoyancy drift in horizontal flows. Kawahara et al. (1997) insists that turbulent mixing rate between adjacent subchannels in two-phase flow has been known to be strongly dependent on the flow pattern through visualization. He suggested a close relationship between the liquid phase turbulent mixing rate and the magnitude of the pressure difference fluctuations; however, predictions of the CHF in a rod bundle from the results of this research are limited. Therefore, there is a great deal of work involved in CHF experiments in rod bundles with and without mixing vanes, and many researchers developed CHF correlations for bundle geometry from CHF experimental data. The CHF correlations for bundle geometry consider the heating type (uniform or non-uniform), spacer grid and mixing vane effect, location of guide thimble and non-heating area (EPRI correlation, CE correlation, B&W correlation, etc.). In addition to these works, some researchers developed the CHF correlation in bundle geometry from CHF data in circular tube using a correction factor (Fortini and