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Numerical prediction of DNB in a rolling 2×2 rod bundle with tilted rotation axis

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1. Introduction

Ocean nuclear reactors may undergo various dynamic or inclined conditions. Therefore, it is necessary to investigate their effect on DNB. However, although a number of numerical studies have been conducted on DNB, they are limited to vertical, static rod bundles [1-3]. A few numerical studies reported the effect of rolling on DNB, but their applications were limited to single-heater or heating-tube configurations [4, 5].

This study presents numerical simulations of the DNB in a rod bundle under rolling conditions.

2. Numerical Methods and Conditions

2.1 Numerical Methods

Two-fluid simulations were conducted in the non-inertial frame of reference [6]. The numerical setup and physical models are described [5]. The DNB experimental data [7, 8] were simulated to validate the numerical setup and physical models.

2.2 Simulation Conditions

Figure 1 shows the schematic of a 2×2 rod bundle [8]. While the rod bundle was vertical and static in the experiment, it was assumed to be under rolling conditions in this study. The rolling axis is indicated in Fig. 2. The working fluid was water, the mass flow rate was 927 kg/m^{2}s, the pressure was 10.4 MPa, and the supercooling temperature was 50.3 K.

The rolling period and amplitude were set to $T = 6$ s and $\theta_{\max} = 30°$, respectively. The tilt angles of the rolling axis were $\phi = 0°$, 22.5° and 45°.

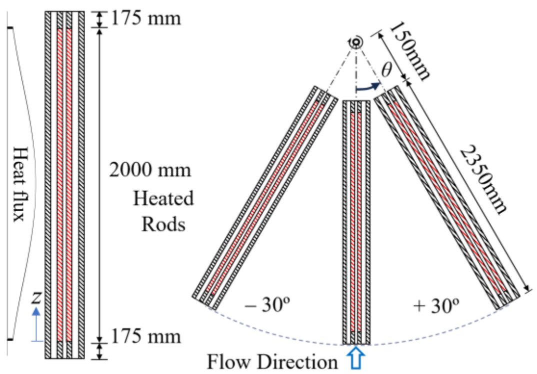

Fig. 1. A 2×2 rod bundle under rolling conditions

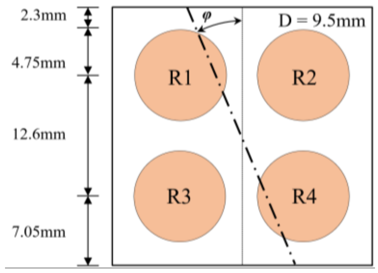

Fig. 2. 2×2 rod bundle

Table I: DNB predictions for the vertical rod bundle

Number of grids	DNB (kW/m^2) CFD	DNB (kW/m^2) Exp.
1,094,000	886.5	
1,217,000	919.0	
1,235,000	921.5	831
1,406,000	919.5	
1,632,000	915.5	
1,829,000	917.0	

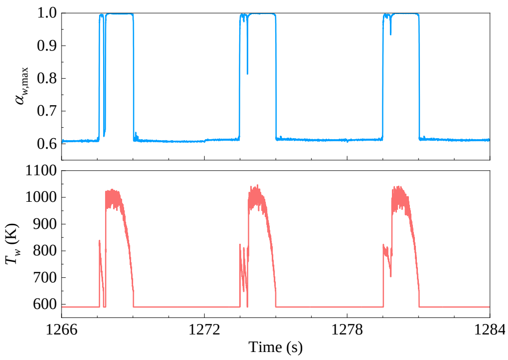

Fig. 3. Time histories of the maximum void fraction and wall temperature near DNB. ($T = 6$ s, $\theta_{\max} = 30°$, $\phi = 0°$)

3. Results and Discussion

Table I provides the DNB predictions for the vertical rod bundle. Based on this result, a grid system with 1.632 million grids was used. Figure 3 shows the maximum void fraction ($\alpha_{w,\max}$) and wall temperature ($T_{w,\max}$) for a heat flux near DNB. They temporarily rose and then fell.

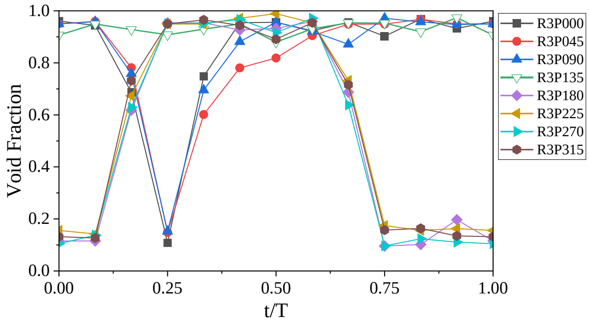

Fig. 4. Void fractions at 8 points around the heating rod R3 at 1.935 m location when the DNB occurred

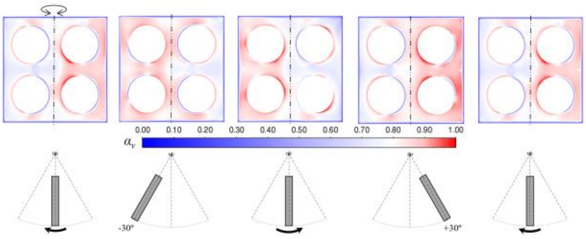

Fig. 5. Void fraction contour for one rolling cycle at 1.935 m location when the DNB occurred

Fig. 4 shows the void fractions at 8 points at the location of 1.935 m from the beginning of the heating section. It is seen that the void fraction at R3P135 point is maintained high during the rolling, that is, DNB. Fig. 5 shows the void fraction distributions for one rolling cycle after the DNB occurred. The void fraction distribution depends on the buoyance force and secondary flow directions.

In the vertical, static rod bundle, DNB occurred at the locations between rods. However, in the rolling rod bundle, DNB occurred at locations between the rod and the housing wall.

The effect of the tilted angle is provided in Table II. The DNB values under rolling conditions were higher than that in the vertical rod bundle (915.5 kW). However, an enhancement in DNB dampened as ϕ increased, due to the bubble concentration at a corner of the channel wall as shown as Fig. 5, making more vulnerable condition for DNB occurrence for specific heating rods.

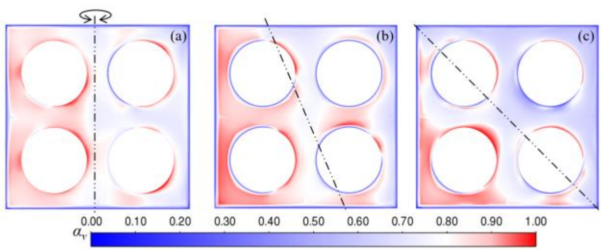

Fig. 5. Void fraction contour for one rolling cycle at 1.935 m location when the DNB occurred

Table II: Effect of the tile angle on DNB

ϕ	0°	22.5°	45°
DNB (kW/m^2)	1193.0	1144.9	995.5

4. Conclusions

Numerical simulations were conducted for DNB prediction in a rolling 2x2 rod bundle. The rolling motion increased the DNB. However, the enhancement in DNB decreased as the tilt angle of the rolling axis increased as the concentration of bubble at the corner of the channel wall creating a DNB vulnerable condition at specific heating rods. This result trend will be explained in detail at the conference.

Acknowledgment

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