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Analysis on Critical Heat Flux under Heaving Condition in Marine Reactor using RETRAN-3D/INT

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1. Introduction

The nuclear vessel has several advantages that it doesn't cause a marine pollution and provides long-term and large output of energy. These advantages are severely needed factors in the near future technology, so several countries have studied various marine reactors especially on nuclear-powered submarines or on ice breakers. In Korea, the integral type nuclear co-generation reactor, SMART is under development by KAERI. Japan also developed MRX and DRX.

The marine reactor experiences various ship motions due to the sea condition [1]. It is necessary to evaluate the effects of those motions on the thermal-hydraulics of the integral-type reactor. It is also important to be able to predict critical heat flux (CHF) in an oscillating acceleration field since CHF plays an important role in safety design and operating of nuclear reactor. CHF is directly related to the burnout of the reactor surface so an accurate expectation of the CHF is a significant factor.

Since the integral type marine reactor has typical three-dimensional characteristics, it requires analytical models for ship motions, such as rolling, pitching and heaving. These different conditions relative to existing reactors' make RETRAN-3D suitable to use. Several models in RETRAN-3D were modified and new models were added, and the code was named RETRAN-3D/INT [2]. Three-dimensional nodalization models for asymmetric flow in integral type reactors were developed using vector momentum equation in RETRAN-3D.

In this study, the analysis on CHF under heaving condition in RETRAN-3D/INT code for marine reactor is performed. Analytical results are used to compare with results from correlative equations.

2. Reviews on CHF correlation with a gravity term

There have been a lot of studies and experiments on CHF and the correlation between CHF and acceleration effect is proposed. When the marine heaves, the net of the coolant flow velocity would decrease, and bring down the CHF. Also, when the marine is in up-motion, the fluid acceleration in the direction of gravity would increase, and the lift pressure drop would increase, too.

Followings are a couple of results.

The ratio of CHF under oscillating to steady state CHF is proportional to the 1/4th level of the ratio of gravity acceleration to earth gravity and can be expressed as follows [3]:

$$q_{CHF} / q_{CHFO} = \left(g / g_o\right)^{1/4} \tag{1}$$

Isshiki conducted experiment under both natural and forced circulation with a void fraction of more than 1.5% at the exit [4]. The results are expressed as follows:

$$q_{CHF} / q_{CHFO} = 1 - \left(1 - y_{\min 0.8}\right) \Delta g / g_o \tag{2}$$

where is $y_{\min 0.8}$ the ratio of the minimum inlet velocity at $\Delta g = 0.8 g_o$ to the inlet velocity at $\Delta g = g_o$.

Otsuji et al. performed an experiment which shows that the CHF decreased quantitatively with oscillating gravity acceleration in a vertical direction [1]. As a result, the CHF values obtained by equation (1) were smaller than almost all of the experimental data, irrespective of quality and subcooling. Low limit of the CHF ratio was suggested as follows:

$$q_{CHF} / q_{CHFO} = \left(1 - \Delta g / g_o\right)^n \tag{3}$$

where is a constant which is dependent both on subcooling and the mass flow rate at the inlet.

3. RETRAN-3D/INT analysis

In this study, RETRAN-3D/INT analysis was carried out under Otsuji's experimental condition. Since the working fluid in Otsuji's experiment was Freon, the water properties should be found using fluid-to-fluid method for RETRAN-3D/INT analysis. According to Nam's study, the corresponding properties were obtained as given Table I [5].

Table I: Comparison to main properties

	Otsuji's experiment	RETRAN-3D/INT
Pressure [Bar]	3.0	24.4
Inlet mass flux [kg/m^{2}s]	980	2067

3.1 Nodalization for RETRAN-3D/INT analysis

The nodalization of Otsuji's experiment for RETRAN-3D/INT calculation is given in Fig. 1. The calculation model consisted of 20 single volumes, 1 time-dependent volume and 20 heat structures to describe the heater rod and simulate heat transfer phenomena along the heater rod. The inlet coolant was modeled using a fill junction model in RETRAN-3D/INT and the time dependent flow rate was given as a boundary condition using table data card.

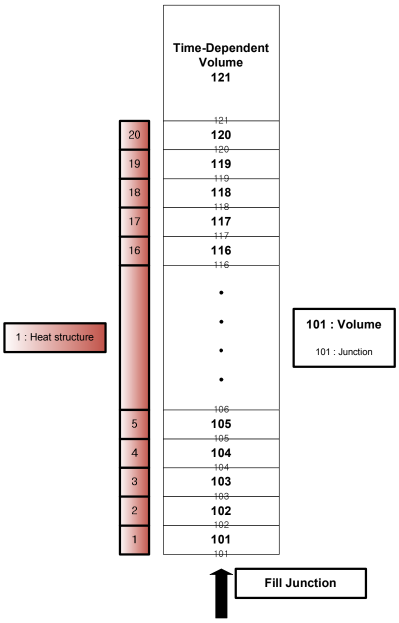

Fig. 1. Nodalization of RETRAN-3D/INT analysis.

3.2 RETRAN-3D/INT analysis

Figure 2 shows the results of comparison of RETRAN-3D/INT analysis to the existing correlations. The ratio of CHF under heaving condition to that at stationary state was compared.

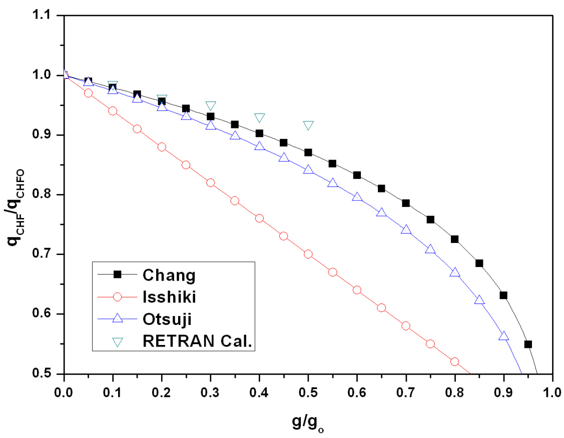

Fig. 2. Comparison of RETRAN-3D/INT analysis to other correlations.

As shown in Fig. 2, it can be found that the ratio of CHF decreases slightly with the change in heaving oscillation. This result agrees the previous research that ratio of CHF under oscillating to steady state CHF is proportional to the 1/4th level of the ratio of gravity acceleration to earth gravity. However, the results from RETRAN-3D/INT overestimated the ratio of CHF than those from any other correlation. Thus, it is needed to perform additional analysis and sensitivity test of CHF correlation in RETRAN-3D/INT.

4. Conclusion

In this study, the analysis on CHF under heaving condition in RETRAN-3D/INT code for marine reactor was performed. The analysis condition was determined by Otsuji's experiment. The nodalization for RETRAN-3D/INT analysis was modeled and the result of CHF ratio with acceleration can be obtained. As a result, it can be found that the ratio of CHF decreases slightly with the change in heaving oscillation.

In further studies, it is necessary to perform a sensitivity test on other correlative equations. There also will be needed more experiments and studies about CHF on different conditions since CHF is a significant safety factor in nuclear engineering. This study is expected to contribute a lot of outcome to future nuclear vessel industry.

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