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Experimental Study of Critical Heat Flux Under Rolling Condition

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1. Introduction

The most prominent characteristic of a marine reactor is that it is operated during voyage over the ocean. Furthermore the ocean has the most dynamic motion such as rolling, heaving and yawing. The thermal-hydraulic behavior of marine reactor can be influenced by rolling (kind of rotation which gives the system a time-dependent inclination together with a centrifugal and a tangential force) and heaving (time-dependent linear vertical gravity acceleration variation) motions, especially. Variation of flow patterns and instability, heat transfer and critical heat flux (CHF) in coolant channel are affected by rolling and heaving motions. Among them, a prediction of the CHF characteristic is an important factor to marine reactor safety and thus its design. The studies of single-phase natural circulation characteristics [1], two-phase flow instability [2] and heat transfer [3-5] under rolling motion have been carried out using experimental research and numerical calculation. However, no one has approached CHF under rolling condition. Therefore, experimental study of CHF under rolling condition is needed. To understand the effect of rolling motion on CHF better, tests using a CHF loop mounted on rolling equipment, were performed. During rolling motion, tangential and centrifugal forces imparted are imposed on the coolant channel of marine reactor. It is extremely difficult to draw any plausible flow patterns without relying on the experimental data. Experiment conditions were converted into R-134a condition, which are pressure, inlet subcooling and mass flux as independent variables, corresponding to water condition using fluid-to-fluid scaling. The main purpose of the study is to understand the characteristics of CHF under rolling motion through the experiment.

2. Experimental Apparatus

The three-dimensional MArine Reactor Moving Simulator (MARMS) is shown in Fig. 1. It is composed of a Freon circulation loop and rolling system. The Freon (R-134a) circulation loop consists of the following components: a test section, a non-sealed canned motor pump, a mass flowmeter, a preheater, a pressurizer (accumulator type), a cooler (brazed type heat exchanger), control valve and a chilling system with water. The loop is filled with R-134a by vacuum system. The test loop is designed for pressure of 40 bar and temperature of 200 ^{o}C. Temperatures and pressures are measured at various locations. The rolling device consists of the loop stand, support, gear and motor to control the rolling motion. The loop stand is a 1m×1m square plane. Rolling axis located at the top of the device and the height is 1.5m between axis and stand. The rolling device is driven by motor and gear from controller. The heater as test section is stainless steel (SUS316) tube with upward flow. The tube is directly heated with a direct current (DC) power supply, which controls the power by a silicon controlled rectifiers (SCRs) with the maximum power capacity of 40V and 1200A. The heated length of test section is 1000 mm and the inside diameter and thickness are 9.5 mm and 1.65 mm, respectively. These geometric dimensions are selected to reflect the hydraulic diameter of a marine reactor core.

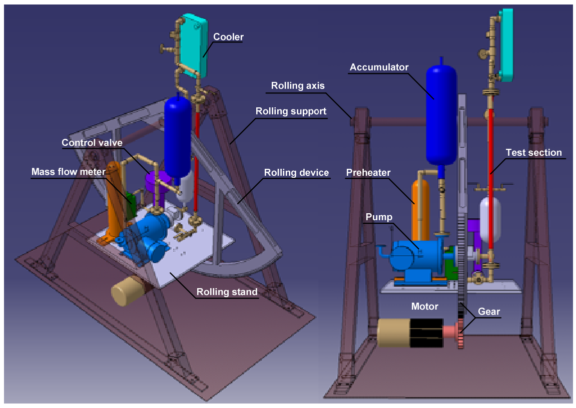

Fig. 1. Isometric and lateral view of MARMS.

2. Experimental Results

2.1 Effect of Rolling Amplitude on CHF

Figures 10 and 11 show the effect of the rolling amplitude on CHF ratio at different pressure conditions. There are clear differences trend of CHF ratio between intermediate (13, 16 bar) and high pressure (24 bar) region. At intermediate pressure, the CHF ratio decreases as the rolling amplitude increases. In the cases of higher mass flux region, the CHF under rolling condition tends to become higher than the stationary value. In higher quality (i.e. low subcooling), reduction rate of CHF ratio decreases with increasing the rolling amplitude. As mass flux increase, CHF ratio becomes independent on the effect of rolling amplitude. Furthermore, above certain mass flux, the CHF ratio almost never changes. However, every CHF is enhanced compared to the stationary CHF in the high pressure (24 bar) as shown in Fig. 11. CHF ratios in high pressure region increase as rolling amplitude increase.

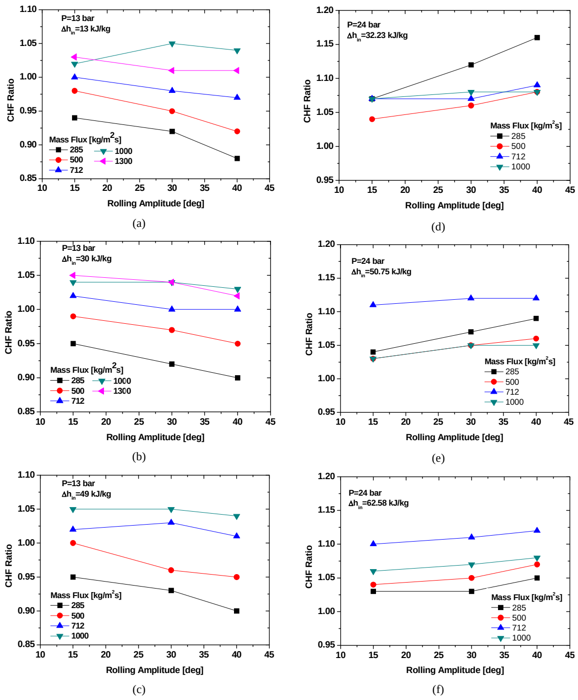

Fig. 2. Effects of rolling amplitude on CHF ratio as inlet subcooling and mass flux (a-c: 13 bar, d-f: 24 bar)

2.2 Effect of Mass Flux on CHF

Ranges of mass flux are 285 through 1300 kg/m2s at 13, 16 and 24 bar of pressure. At intermediate pressure (13 and 16 bar), trend of CHF ratio changes according to certain range of mass flux is observed as shown in Fig. 12 (a) and (b). Rolling CHF above certain mass flux seems similar to stationary CHF or slightly higher. However, when the mass flux is smaller than certain value it gradually decreases. Also, it depends on the mass flux in lower subcooling. This tendency is significant for 16 bar of pressure. The CHF is not strongly dependent on mass flux than intermediate pressure region in higher pressure region (24 bar), as shown in Fig. 12 (c). In higher mass flux region, change in CHF ratio is not significant than in lower mass flux region. CHF ratio is increased as inlet subcooling increased in low mass flux region. In other words, CHF ratio is affected by inlet subcooling in low mass flux region.

2.3 Variation of the inlet flow rate

The observed amplitude of flow oscillation is shown in Fig. 13 as a function of rolling amplitude. Over the range investigated, the amplitude of flow oscillation is proportional to the rolling amplitude. As expected, the amount of flow oscillation strongly depends on the inlet subcooling, it decreases with increasing inlet subcooling. No variation of flow rate is detected in the cases where the inlet subcooling is high. The fluctuations of the inlet flow were inherent in flow and were observed in the stationary case.

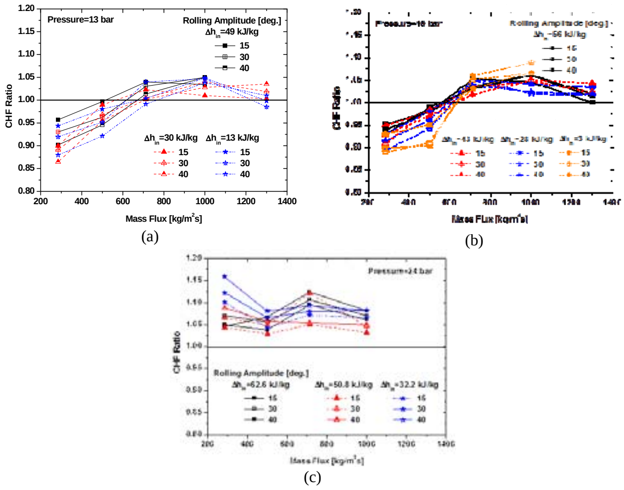

Fig. 3. Effects of mass flux on CHF ratio as inlet subcooling and rolling amplitude.

3. Conclusions

The CHF characteristics under rolling motion can be summarized as follow:

- The CHF enhancement is dependent on the mass flux, pressure and rolling amplitude.
- The CHF ratio decreases with decreasing mass flux (below certain mass flux) at intermediate pressures (13 and 16 bar).
- At intermediate pressure, with increasing mass flux (over certain mass flux), the CHF is enhanced or similar to the stationary CHF.
- At high pressure (24 bar), the CHF is enhanced at all mass flux regions and inlet subcooling.

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