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Investigation of Rayleigh-Taylor Instability Wavelength under Pressure Effect using High Speed Video and Particle Image Velocimetry

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1. Introduction

The analysis of minimum heat flux based on unstable wavelength (RT instability wavelength) has been studied [1-2] to quantify the available experimental data. The experiments were studied using different inorganic fluids. To quantify the data, the dimensionless terms such as radius and minimum heat flux were considered.

Nowadays, nanofluids and depositions of nano-particle on heater surface have been used to enhance of thermal margin in terms of critical heat flux (CHF) and boiling heat transfer. The enhancement of thermal margin is described as surface wettability, thermal activity (effusivity), and the change Rayleigh-Taylor (RT) instability wavelength due to deposition of nanoparticles which could make the surface as porous structure [3-5]. In our research group, the change of RT instability wavelength using a simple condensation method was studied because the graphene-oxide deposition layer did not show the surface wettability improvement [4]. Based on the enhancement of CHF studies, Lee et al. [5] proposed the change of Rayleigh-Taylor instability wavelength could explain all the methods of CHF enhancement on pool boiling experiment. Therefore, the analysis of RT instability wavelength is needed to explain the effect of wavelength to the CHF enhancement.

In the present study, the observation of RT instability wavelength with one-dimensional horizontal wire surface is studied in the pressurized wire pool boiling facility to show the relation between RT instability wavelength and CHF or MHF. The pressure effect is considered instead of using different working fluids.

2. Experimental Setup

2.1 Pressurized Wire Pool Boiling Facility

A pressurized wire pool boiling facility is schematically illustrated in Fig. 1. The experiment is conducted in the boiling vessel and the N_2 gas is connected to the pressurizer to control the desired system pressure during the experiment. The maximum pressure and temperature limit in the facility is 20 bar and 200 ^oC, respectively. The temperature of working fluid is heated up to saturation state using cartridge heaters in the boiling vessel and the pressurizer. To maintain the desired system pressure, two back pressure regulators are utilized. The wire used in the experiment is connected to DC power supply and the standard resistor is equipped in the facility. There are four sight glasses for visualization of the experiment to find nucleate boiling, CHF, and minimum heat flux (MHF) regions. The high speed video and particle image velocimetry (PIV) technique are used to visualize the flow pattern.

2.2 Experimental Procedure

R-123 refrigerant is used as working fluid. The saturation state at desired system pressure is controlled by cartridge heaters before the experiment. Ni-Cr (80/20) wire having 0.5 mm diameter is used in the experiment. Heat loaded on the wire is controlled by power supply and the heat flux on the wire surface is step-wise increased until CHF. After the CHF occurred, the heat flux is step-wise decreased until the phase change appeared from film boiling to transition state. The images are recorded at this state using high speed video. The scaling plate is attached at the sight glasses to measure the RT instability wavelength.

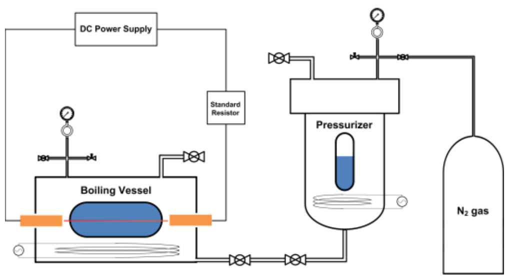

Fig. 1. Schematic diagram of pressurized wire pool boiling facility.

3. Results and Discussion

Five different system pressures were conducted in the experiment; 1, 3, 5, 7, and 9 bar. Table I shows the CHF, MHF, and RT instability wavelength at different system pressure. Figure 2 illustrates the boiling curve obtained in the experiment. Figure 3 shows the images of wavelength observation at MHF region with different system pressure. The wavelength and departure diameter tends to decrease with high pressure. Figure 5 indicates the flow visualization at the film boiling region by using PIV.

The RT instability wavelength at horizontal surface (1-dimensional) is followed as [2]:

$$\lambda_{d1} = \frac{2\pi\sqrt{3}}{\sqrt{\frac{g(\rho_f - \rho_g)}{\sigma} + \frac{1}{2R^2}}} \qquad (1)$$

where, σ is surface tension (N/m), R is heater radius (m), ρ_f and ρ_g are liquid and vapor density (kg/m^3), respectively. Figure 5 shows the comparison between the experimental data and the equation (1). The critical wavelengths observed in the experiment were underpredicted.

Table I. Experimental results

	CHF (kW/m^2)	MHF (kW/m^2)	Wavelength (mm)
1 bar	160.51	82.5	5.33
3 bar	446.38	181.2	4.26
5 bar	492.93	175.2	5.42
7 bar	629.04	183.5	4.04
9 bar	644	230.1	4.12

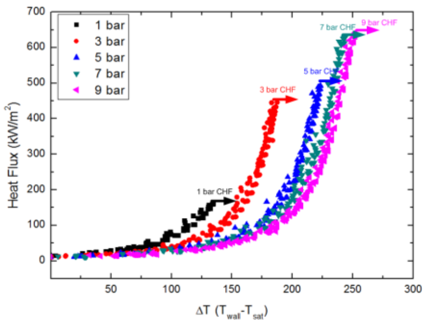

Fig. 3. Boiling curve obtained at 1, 3, 5, 7, and 9 bar (Temperature coefficient of resistance formula is used).

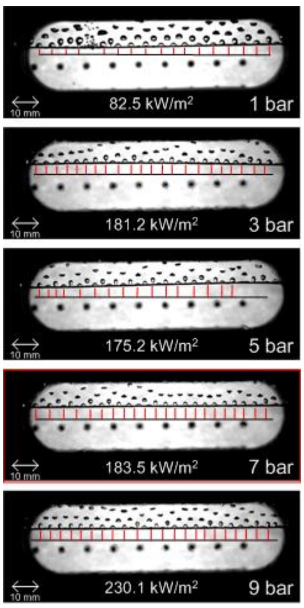

Fig. 2. Rayleigh-Taylor instability wavelength at different system pressure (obtained at minimum heat flux region).

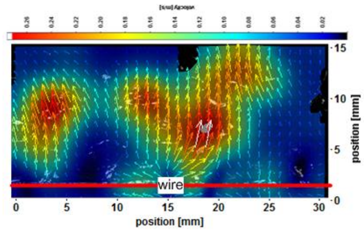

Fig. 4. Flow pattern at film boiling state (PIV observation)

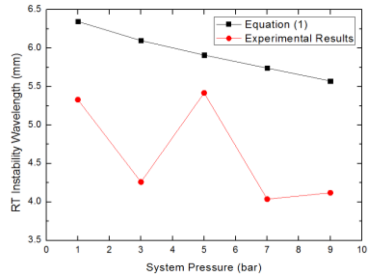

Fig. 5. Rayleigh-Taylor instability wavelength according with system pressure.

3. Conclusions

The observation of RT instability wavelength at different system pressure with bare Ni-Cr wire (0.5 mm dia) was studied. The CHF using R-123 refrigerant was enhanced according with higher system pressure.

There was a tendency that RT instability wavelength was decreased when CHF and MHF is increased. The measurement value of wavelength in the experiment is less than the predicted wavelength equation.

Different wire radius and system pressures should be conducted with bare wire surface to establish the fundamental data for the experiment of nano-coated wire.

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