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Fast-transient Flow Boiling Heat Transfer due to Abrupt Power Excursion on a Tube Flow within 10-50 bar Pressure Ranges

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1. Introduction

Reactivity initiated accident (RIA) can be caused by an accidental insertion of reactivity to reactor core, resulting sudden excursions in fission rate and reactor power [1]. Recently, test results from NSRR (Nuclear Safety Research Reactor, Japan) and Cabri research reactor (Cadarache, France) reveal that high burn-up nuclear fuels could fail even at lower enthalpy than the previously accepted safety limit in case of a RIA, due to the effect of burnup-related and cladding corrosion-related phenomena on fuel rod performance. However, most studies are focused on pre-DNB (Departure from Nucleate Boiling) failure mechanisms such as the PCMI (pellet-clad mechanical interaction) rather than the post-DNB phenomena. These result in a lack of knowledge related to the thermal hydraulic phenomena during the RIA [5].

In this paper, we introduce a recently constructed thermal hydraulic experimental facility for RIA safety study. The objective of this study is to characterize the fast-transient flow boiling phenomena for forced convection flow in a vertical tube due to abrupt power excursions within 10 to 50 bar pressure ranges. Current experimental designs and major specifications of the constructed test loop are introduced. Finally the test results are presented and discussed.

2. Description of the Test Facility

2.1 Test Loop

The principal operating conditions of the transient flow boiling test facility for RIA are as followings:

- Operating pressure: 0.5~16.0 MPa
- Test section flow rate: 0~0.3 kg/s
- Maximum water temperature: 340 ℃
- Available pulse power: 450 kW

Fig. 1 shows the schematic diagram of the RIA thermal-hydraulic test facility, THERA (Thermal-Hydraulic Experimental facility for RIA Applications). It consists of a circulation pump, preheater, RIA test section, steam/water separator, pressurizer, cooling lines, and feed water lines. Measuring variables are also indicated in the figure. The inlet flow rate, inlet/outlet fluid temperatures and pressures, tube surface temperatures, and voltage and current for analyzing the applied power are measured. Especially to measure the very fast transient surface temperature responses, high-speed infrared pyrometers having minimum response time of 0.5 ms are adopted. The applied voltage and current are also measured for every 1 ms using a high speed data acquisition system to analyze the fast variations in the applied power from the DC (Direct Current) pulsed power supply.

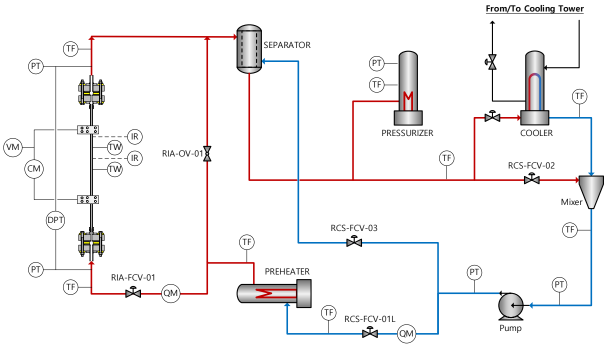

Fig. 1. Schematic diagram of the test facility

2.2 DC Power Supply

A conventional DC power supply is modified to apply a step-wise pulse power on the test section. The power supply has maximum capacity of 450 kW with adjustable voltage and current up to 80 V and 6000 A. The pulse width is also adjustable within 20~330 ms.

2.3 RIA Test Section

Vertical tube flow is adopted to simulate a bundle flow in the reactor core since its heated and hydraulic perimeters are the same. Inconel-600 tube of 8 mm in inner and 10 mm in outer diameters is used for the tube. The bus-bars are spaced out 0.5 m apart considering the electrical resistance of the tube. Tube outer surfaces are thermally insulated and the tube wall temperature is measured through a small hole in the insulation at 0.48 m from the beginning of the heated region.

3. Methods

3.1 Estimation of Heat Flux to Coolant

The heat flux from the tube inner wall to the coolant is estimated by inverse heat conduction calculation. The calculation is achieved in three steps: (1) frequency filtering of the measured signals to remove unavoidable noises, (2) inverse heat conduction calculation to get the temperature profile in the tube wall, and (3) extraction of heat flux to the water using the temperature gradient at the inner wall.

3.2 Test Conditions

Tube inlet pressures are within 10-50 bar. Mass flow rate and subcooling temperature are around 3500 kg/s-m^2 and 50 K. Applied powers to the tube are within 98-198 kW/ft. Pulse widths are within 87 ms to 154 ms.

4. Results and Discussions

Fig. 2 shows the tube outer wall temperature measured by IR-pyrometer and the tube inner wall temperature extracted from the inverse heat conduction calculation for 10-50 bar. The temperature rise rates on the outer wall are from 1000 to 4000 K/s according to the applied power. Fig. 3 shows the applied power and the extracted heat flux at the tube inner wall. Occurrence of DNB is identified by the existence of peak heat flux. The DNB temperature is the inner wall temperature at the time of DNB.

As the pressure increases, the peak heat flux decreases and occurs earlier. The wall superheat temperature at the DNB also seems to decrease as the system pressure increases. The DNB temperatures are about 20 to 70 K higher than the saturation temperature.

5. Conclusions

Fast-transient flow boiling heat transfer due to abrupt power excursion are experimented using a vertical tube flow in a pressure range of 10-50 bar. The flow conditions are adjusted to match the PWR operational conditions except the pressures. Experimental methodology is not fully established yet due to the unstable nature of the inverse heat conduction calculation. Fine tuning is still necessary on the analysis code to obtain concrete results.

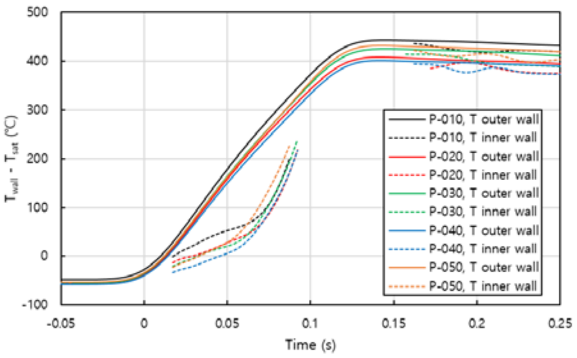

Fig. 2. Effect of pressure on the wall temperature

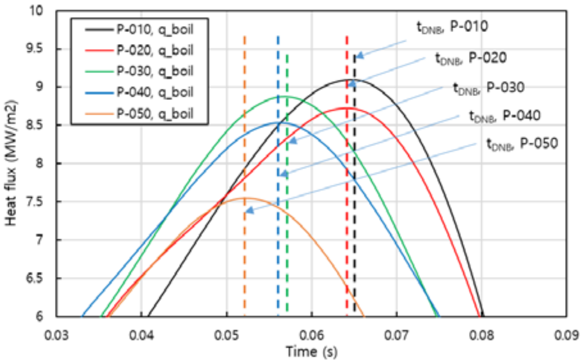

Fig. 3. Effect of pressure on the heat flux peak

ACKNOWLEDGEMENT

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