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Construction of Transient Flow Boiling Test Facility for RIA Applications

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1. Introduction

An inadvertent insertion of reactivity to reactor core can cause a sudden increase in fission rate and reactor power leading to a reactivity initiated accident (RIA) [1]. In pressurized water reactors (PWRs), the control rod ejection accident can occur by mechanical failure of the control element assembly nozzle or control rod dive mechanism housing. In that case, the coolant pressure repels the control rod assembly completely out of the core. As a consequence, the reactivity of the core is rapidly increased and the power excursion is resulted in the reactor core with large localized relative power increase. In the worst possible scenario[1], the reactivity addition can occur within about 0.1 s which is shorter than the actuation time of safety systems such as the emergency core cooling system. Therefore present RIA safety criteria are focused on maintaining the fuel integrity and core coolability during and after the RIA[2-4].

Recently, test results from NSRR and CABRI 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, there is a huge lack of knowledge related to the thermal hydraulic phenomena during the RIA yet since it is difficult to realize the power excursion which simulates the RIA condition[5].

In this paper, we introduce current status of the ongoing thermal hydraulic RIA experiments by KAERI. The objective of these experiments is to characterize the transient flow boiling phenomena in a tube geometry with simulating the PWR RIA conditions. Current experimental designs and major specifications of the test loop under construction are presented and the experimental plan is exhibited.

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 DC pulse power: 450 kW

Fig. 1 shows the schematic diagram of the test facility. 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 flow rate, inlet/outlet 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 IR pyrometers are adopted. The applied voltage and current are also measured using a high speed data acquisition system to analyze the fast variations in the applied power from the DC pulsed power supply.

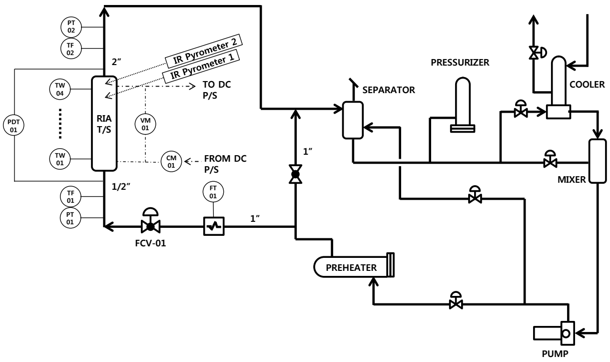

Fig. 1. Transient flow boiling test facility for RIA applications.

2.2 DC Power Supply

A conventional direct current (DC) power supply is modified to generate a DC pulse which simulates sudden power excursion on the RIA test section. The pulse makes abrupt heat flux on the test section by direct Joule heating. The power supply has maximum capacity of 450 kW with maximum voltage and current of about 80V and 6000A, respectively. To control the output voltage and the pulse width, the printed circuit board in the power supply is redesigned. The resulting pulse shape is similar to a step function and the pulse width is adjustable within 16~330 ms considering the actual RIA conditions. The step-wise waveform is originated from the inherent power supply design and the pulse width is adjusted by cutting the number of passing cycles in the input AC voltage.

Figure 2 shows typical pulse waveforms produced by the DC pulse power supply. The pulse corresponds to the shortest width case that can be made by this power supply. The small ripples are unavoidable due to the inherent original power supply design. The standard deviation of the ripples in the power plot is within 3%

of the mean value of the plateau. The resulting total injected energy is nearly linear due to the stepwise shape of the pulse. The rising time of the pulse is about 2 ms and the falling time is about 5 ms. The full width half maximum (FWHM) of the pulse is about 17 ms and the full width is about 21 ms. For a longer pulse, the pulse width can be adjustable by multiplication of the minimum FWHM.

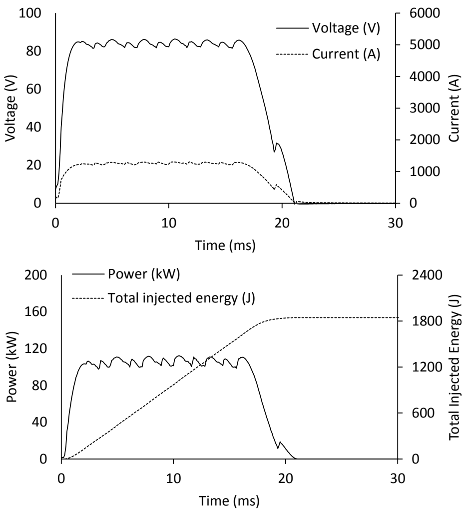

Fig. 2. Typical DC pulse wave form produced by the modified DC power supply.

2.3 RIA Test Section

Fig. 3 shows a schematic diagram of the RIA test section. Only single tube is applicable to reproduce RIA conditions due to the limit of the power supply capacity. In addition, tube internal flow are adopted to simplify the bundle flows in the reactor core since its heated and hydraulic perimeters are the same. Inconel-600 tube is used for the test section to eliminate oxidation effect during the experiments.

The temperature, pressure, and flow velocity of the hot zero power (HZP) state of the PWR (APR1400), which can be the most severe RIA case, are about 291℃, 15.5 Mpa, and 5 m/s, respectively[6]. These conditions constitutes the principal experimental conditions of this study. Hence the outer diameter and the wall thickness of the test tube are selected considering allowable tube internal pressure along with the temperature. On the other hand, the tube heating length is limited by the available voltage and current ranges of the power supply. The bus-bars are spaced out 0.3 to 0.5 m apart considering the electrical resistance of the tube. The heating length is adjusted regarding the flow velocity and the pulse width. The outer surface of the tube is thermally insulated to prevent the heat loss to air.

3. Experimental Plan

This study started from 2017 and planned to 2021. Aims of the study are to evaluate previous heat transfer models in RIA conditions and to make improvement in the models which are applicable in generalized RIA applications. From 2018, the transient flow boiling experimental facility for RIA conditions is under construction by modifying the previous RCS loop and power supply.

The flow boiling tests under RIA conditions are expected to start from the end of this year. The tests will be conducted under low pressure first and then the test pressure will be gradually increased to that of the HZP conditions. RIA flow boiling experimental data base for the low pressure conditions will be established at the end of 2019. The data base for the high pressure conditions are planned until 2021.

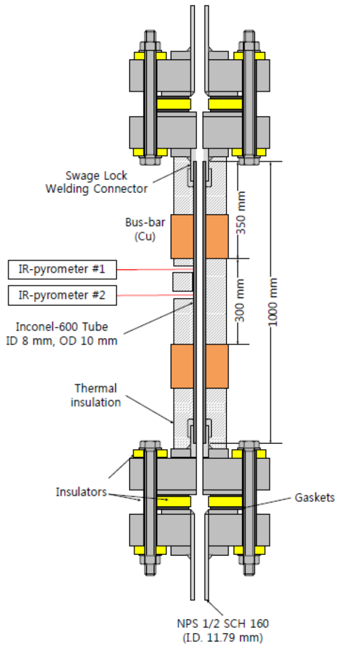

Fig. 3. Schematic diagram of the RIA test section.

4. Conclusions

RIA can result in disruption of the reactor due to a sudden increase in fission rate and reactor power. The current status of the KAERI's thermal hydraulic experiments on RIA are presented. Major facility design considerations, specifications, and test plan for this study are also described.

ACKNOWLEDGEMENT

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