Heat Transfer Experiments under Pressure Transient near the Critical Pressure on 5x5 Bundle with Unheated Rods

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1. Introduction

The supercritical water-cooled reactor (SCWR) is under consideration as fourth generation nuclear reactors, mainly because of their high thermal efficiency and considerable plant simplification. The SCWRs are operating at critical pressure to eliminate coolant boiling, so the coolant remains single-phase throughout the system [1]. A number of detailed reviews of work on heat transfer to fluids at supercritical pressure can be found in the literatures [2].

The abnormal pressure transients such as loss of coolant accidents require the comprehensive apprehension for reactor safety. In the internally-heated vertical annular channel cooled by R-134a fluid, Hong et al.[3] showed that the wall temperature rise rapidly up to very high values as soon as the pressure passes below the critical pressure from the supercritical pressure in the pressure reduction transients. They suggest that the wall temperature rise rapidly due to the departure from nucleate boiling.

The main objectives of this experiment are to investigate heat transfer characteristics on 5x5 rod bundle with four unheated rods geometry for the pressure transient condition and to supplement the database of heat transfer near critical pressure for rod bundles.

2. Experimental Apparatus and Procedure

In the FTHEL facility using R-134a as a coolant, the main components of the loop are non-seal canned motor pump, mass flowmeter, preheater, inlet valve, test section, condenser, and cooler. System pressure is controlled by accumulator. The heated rods of the 5x5 bundle are electrically heated directly with a DC power.

The wall temperatures are obtained from 52 thermocouples installed in the 21 heated rods which have a uniform axial power shape. The four unheated rods made of fiber glass are replaced with rod number 17, 19, 21, and 23 in 5x5 bundle. The geometries of test section and 5x5 bundles are listed in Table 1. Radial power distributions are shown in Fig. 1.

Table 1. Parameters of the 5x5 bundle test section

Parameter	5x5 Bundle
Total number of heated rods	25
Rod pitch (mm)	12.85
Rod diameter (mm)	9.5
Heated length (mm)	2000
Rod to wall gap (mm)	3.0
Corner radius (mm)	3.0
Flow area (mm^2)	2695.8
Axial power distribution	Uniform
Distance between spacer grids (mm)	565

The following system conditions keep constant in the experiments : initial outlet pressure, inlet temperature, total power, and mass flow rate. After maintain the steady state condition during some minutes, the system pressure was increased until the outlet pressure reached over the critical pressure enough by accumulator which was pressurized by compressed nitrogen gas. The nitrogen gas in the accumulator is released to the atmosphere for the pressure decrease experiment of the same condition.

This experiments were performed in ranges of mass flux, G = 150 ~ 1000 kg/m^2s, and limited total power decided by the maximum wall temperature to conserve the heated rods. Inlet temperature was fixed in 91 ^oC.

3. Results and Discussion

3.1 Pressure increase experiments

To estimate the time dependency in pressure increase ratios, two ratios are compared; dP/dt = 0.52 and 1.39 kPa/sec. Figure 2 shows the averaged wall temperature behavior of the center rod #25 for the outlet pressure of two ratios. It is interesting to note that the wall temperature behavior is very similar despite the about 2.5 times difference of the pressure increase ratio. The temperature jump which may be defined as CHF from a viewpoint of a sharp reduction of the local heat transfer is observed in similar outlet pressure, p = 3945 kPa. Increased temperature is decreased when the outlet temperature has gone up to the critical temperature approximately. The wall temperature maintains stability afterward. For the pressure increased transient

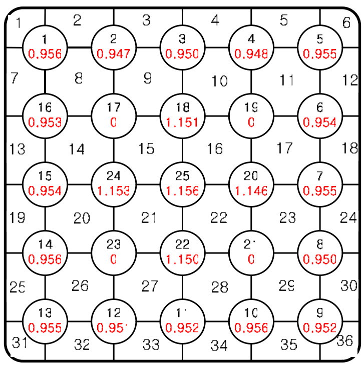

Fig. 1 Radial power distribution of 5x5 bundle

condition, the wall temperature depends on the fluid pressure and temperature rather than the transient time in the present experiments.

Fig. 3 shows the effect of total power on the pressure transient condition. CHF is observed at lower pressure with increasing input power. Temperature jump in the lowest power in this test disappears. The decrease of temperature after the critical pressure appears in the higher power of which outlet temperature is over the critical temperature.

3.2 Pressure decrease experiments

The ratio of the pressure decrease is controlled by amount of released nitrogen gas easily; the difference of the ratio is higher than increase test. Figure 4 shows the wall temperature for the ratio of pressure transient. The wall temperature has two increase gradients in the case of decrease gradually. For the rapid decrease of pressure, however, the high temperature on the wall is maintained although the outlet pressure decreased to sub-critical pressure adequately. The more time is required to recover the sub-critical condition.

Figure 5 shows the effect of total power on the moderate pressure decrease test. For the high power, the rapid wall temperature increase before the recovery to sub-critical condition is observed. It is considered that the vapor generated on the wall rapidly formed vapor layer transitorily.

4. Conclusion

In this study, we investigate heat transfer characteristics on 5x5 rod bundle with four unheated rods geometry for the pressure transient condition near critical pressure.

For the pressure increased transient condition, the wall temperature depends on the fluid pressure and temperature rather than the transient time in the present experiments. The decrease of temperature after the critical pressure appears in the higher power of which outlet temperature was over the critical temperature.

For the rapid decrease of pressure, however, the high temperature on the wall was maintained although the outlet pressure decreased to sub-critical pressure adequately. For the high power, the rapid wall temperature increase before the recovery to sub-critical condition was observed.

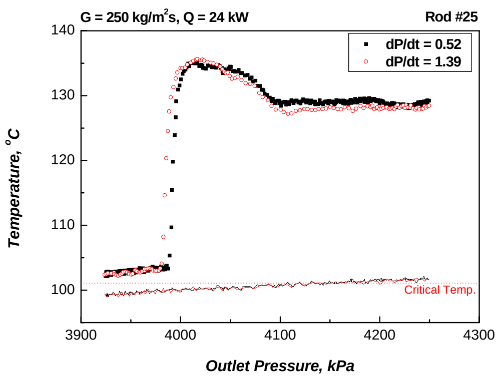

Fig. 2 The effect of pressure increase ratios

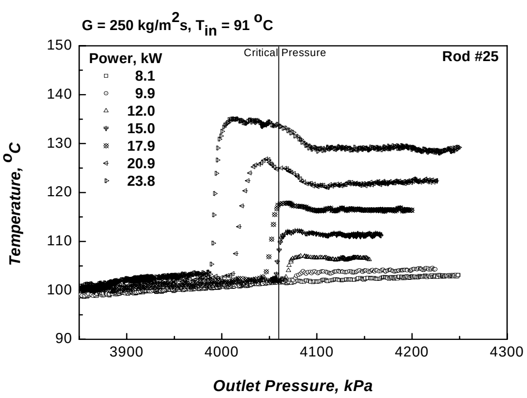

Fig. 3 The effect of power in pressure increase test

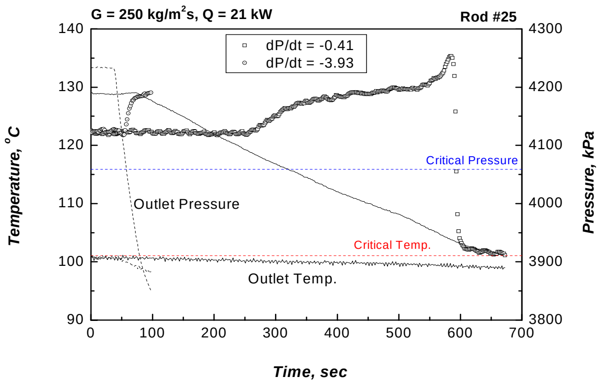

Fig. 4 The effect of pressure decrease ratios.

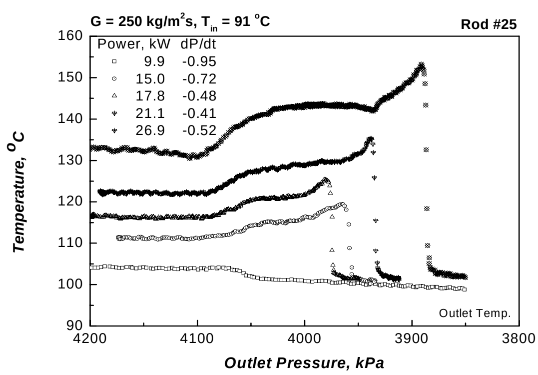

Fig. 5The effect of power in pressure decrease test

Acknowledgment

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REFERENCES

[1] J. Buongiorno, and P. E. MacDonald, Progress Report for the FY-03 Generation-IV R&D Activities for the Development of the SCWR in the U.S., INEEL/EXT-03-01210, 2003

[2] A. F. Polyakov, Heat Transfer under Supercritical Pressure., Advances in Heat Transfer, Vol. 21, pp 1-53, 1991

[3] S. D. Hong, S. Y. Chun, S. Y. Kim, and W. P. Baek, Heat Transfer Characteristics of an Internally-Heated Annulus Cooled with R-134a Near the Critical Pressure., J. Korean Nuclear Society, Vol. 36, pp. 403-414, 2004