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CHF Characteristics near the Critical Pressure in a 5x5 Heater Rod Bundle Cooled by R-134a Fluid: Effects of Spacer Grid and Unheated Rods

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1. Introduction

Research and development efforts for realizing a SuperCritical pressure Water cooled Reactor system (SCWR) are being made at the present time in a number of research institutes [1,2]. The SCWRs are operated at pressure conditions higher than the thermodynamic critical point of water (374 ^{o}C, 22.1 MPa). When the SCWRs are operated with a sliding pressure start-up mode, that is, the nuclear heating starts at sub-critical pressures, the CHF should be avoided during the power-increasing phase under sub-critical pressure conditions. Moreover, in order to ensure the reliability of safety analyses with the computer codes for abnormal pressure decreasing transients including a loss of coolant accident, it is necessary to understand the CHF characteristics near the critical pressure.

Experimental studies in which the CHF has been carefully measured near the critical pressure have not been carried out yet, as far as the authors know. The authors have recently conducted the CHF experiments with a 5x5 heater rod bundle cooled by R-134a fluid. In his paper, the characteristics of the CHF under sub-critical pressure conditions close to the critical pressure are presented, and the effects of the spacer grid with mixing vane and with the unheated rods on the CHF are discussed.

2. Test Section

The experimental work has been performed in the Freon Thermal-Hydraulic Experimental Loop at the Korea Atomic Energy Research Institute. This loop uses R-134a (P_c=4.059 MPa, T_c=101 ^{o}C) as a working fluid and can be operated up to 4.50 MPa. The cross-sectional view of the 5x5 heater rod bundle and the spacer grids used in the present work is shown in Figure 1. The heater rods are made of Inconel 601 tube with an outer diameter of 9.5 mm and a heated length of 2000 mm. Three kinds of heater rod bundle have been used in the present experiments;

TB-1: all heated rod bundle with the plain spacer grids
TB-2: all heated rod bundle with the mixing vane spacer grids,
TB-3: bundle with four unheated rods (rod No. 17, 19, 21 and 23) and with the plain spacer grids.

For measuring the heater rod wall temperatures and detecting the CHF occurrence, K-type thermocouples are located at 10 mm below the top end of the heated section.

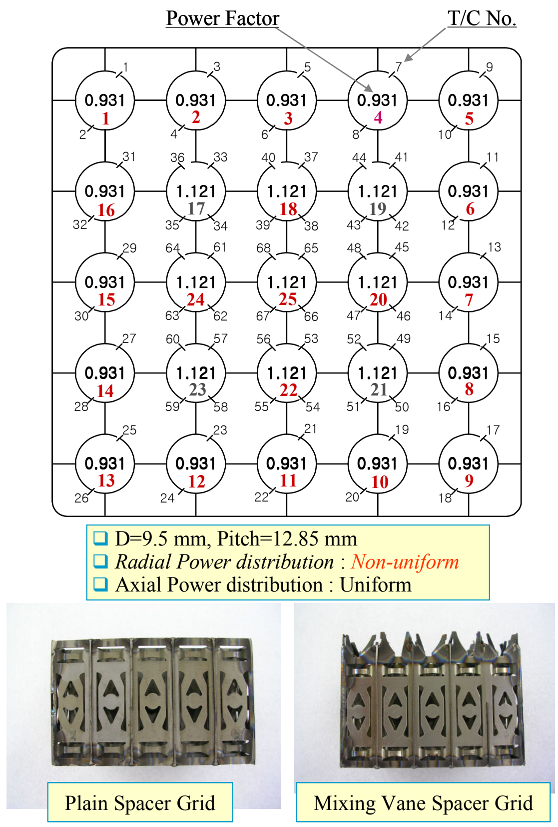

Figure 1. Cross-sectional view of the 5x5 heater rod bundle and spacer grids

3. Experimental Results and Discussions

Figure 2 shows the difference in the wall temperature variations depending on the pressure at CHF conditions. For the pressures of 3.95-4.00 MPa, the behavior of the temperatures at T/C52 and T/C30 implies that the CHF phenomenon near the critical pressure no longer leads to an inordinate increase in the heated wall temperature. Furthermore, at the pressures of 3.98-4.03 MPa very close to the critical pressure, the wall temperature does not indicate the features of the CHF phenomenon. The wall temperatures designated by A, B and C increase monotonously without CHF occurrence according to the applied power level.

Figure 3 shows the critical power as a function of the pressure. The critical power falls sharply at about 3.8-3.9 MPa as if the values of the critical power converge to zero at the critical pressure (4.059 MPa). The authors have found the existence of a pressure

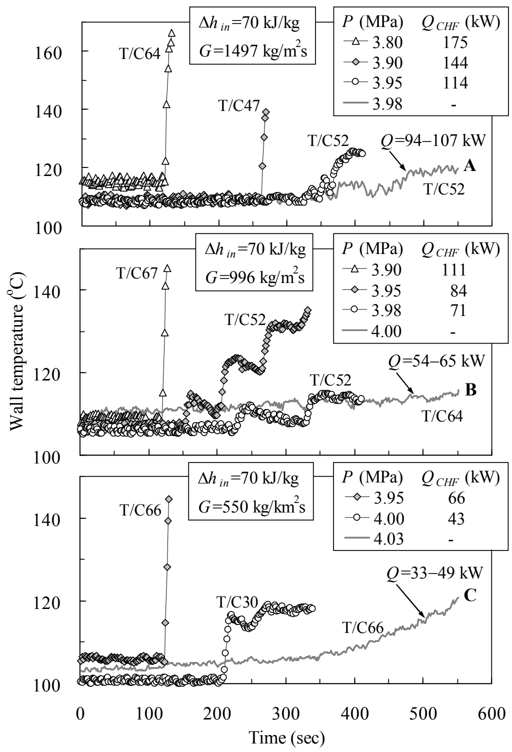

Figure 2. Difference in the wall temperature variations depending on the pressure (TB-1)

region in which the CHF phenomenon does not occur. The dotted lines indicate a threshold pressure at which the CHF phenomenon disappears. When the pressure passes through the Threshold Pressure Line (TPL), the CHF phenomenon cannot be identified. The solid data points A, B and C correspond to the wall temperature variations of A, B and C in Figure 2, respectively.

Figure 4 shows the comparison of the critical power data in TB-1 and TB-2. The critical power of the heater rod bundle with the mixing vane spacer grids shows larger values compared to that for the spacer grids without mixing vanes (the plain spacer grids). This trend is maintained up to a pressure of 3.95 MPa (P/Pc =0.97) very close to the critical pressure. Figure 5 shows the comparison of the critical power data in

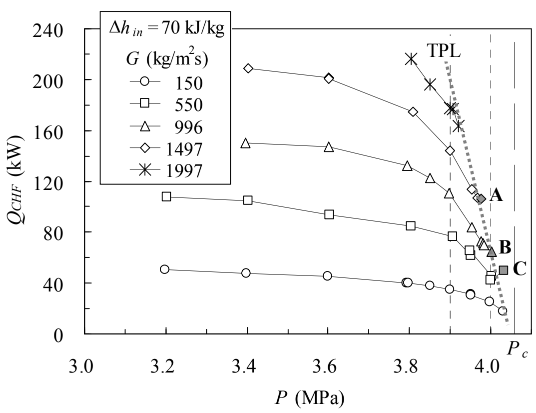

Figure 3. Critical power as a function of the pressure (TB-1)

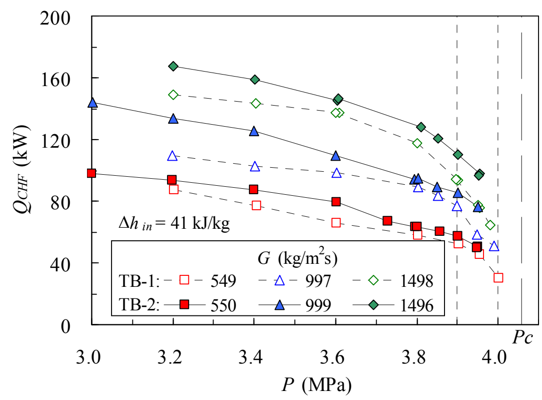

Figure 4. Effect of the spacer grid

TB-1 and TB-3. The effect of the unheated rods in the heater rod bundle on the critical power becomes smaller as the pressure approaches the critical pressure, and when the pressure exceeds 3.9 MPa, the unheated rods have little effect on the critical power.

4. Conclusions

As the pressure approaches the critical pressure, the critical power falls sharply at about 3.9 MPa. The existence of a threshold pressure at which the CHF phenomenon disappears has been observed in the sub-critical pressure region near the critical pressure. The turbulence effect by the mixing vane of the spacer grid on the critical power is maintained up to a pressure of 3.95 MPa (P/Pc=0.97). The effect of the unheated rods on the critical power becomes smaller as the pressure approaches the critical pressure.

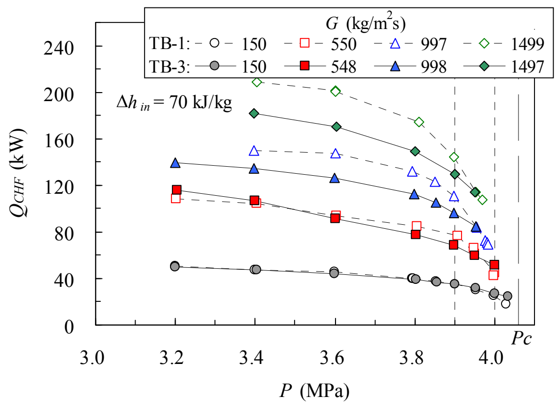

Figure 5. Effect of the unheated rods

References

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