Heat Transfer Experiments with Supercritical CO_2 in a Vertical Circular Tube (9.0 mm)

Tae Ho YOO[ab*], Hwan Yeol KIM[a], Woo Gun SIM[b] and Yoon Yeong BAE[a]
[a]*Korea Atomic Energy Research Institute, Yusung, Daejeon 305-600, Korea*
[b]*Hannam University, Ojeong-dong, 133 Daedeok-Gu, Daejeon 306-791, Korea*
[*]*Corresponding author: thyoo82@kaeri.re.kr*

1. Introduction

Heat transfer test facility, SPHINX(Supercritical Pressure Heat transfer Investigation for NeXt generation), has been operated at KAERI for an investigation of the thermal-hydraulic behaviors of supercritical CO_2 at several test sections with a different geometry. The loop uses CO_2 because it has critical pressure and temperature which is much lower than water [1].

Experimental study of heat transfer to supercritical CO_2 in a vertical circular tube with and inner diameter of 9.0mm has been performed. CO_2 flows downward through the vertical circular tube for the simulation of the water rod which may be used for a moderation of the reactor. The heat transfer characteristics were analyzed and compared with the upward flow test results previously performed at the same test section at KAERI [2].

2. Description of the Test

2.1 Test Loop and Test Section

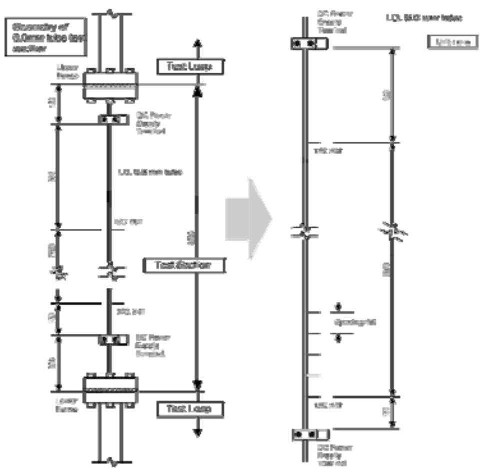

Fig. 1. The test section and measuring locations

Fig. 1 shows the locations of the measuring points and dimensions of the test section. The test section is made of Inconel 625 and is directly heated by a DC power supply. 41 K-type thermocouples, each apart by 5 cm, are soldered on the external surface of the tube to measure the wall temperatures. The length of the heated section is 2.65 m. The supercritical CO_2 flows downward inside the test section and the fluid temperatures are measured in the mixing chambers at the inlet and outlet of the test section.

2.2 Test Conditions

Tests were conducted with a change of the mass flux and the heat flux at a given pressure selected at 1.05(7.75 MPa) and 1.10(8.12 MPa) times the critical pressure. The inlet temperature of the test section was in the range of 5 ~ 38 ℃ and the outlet temperature of the test section was maintained below 100 ℃. For each test, the mass flux and the heat flux were selected such that the pseudo-critical conditions are met inside the test section for the investigation of heat transfer deteriorations. The mass flux was in the range of 400 ~ 1000 kg/m^2 s. The heat flux was up to $90kW/m^2$.

3. Results and Discussion

3.1 Wall temperature and heat transfer coefficient

Fig. 2 shows the measured wall temperatures and the heat transfer coefficients about the bulk fluid enthalpy. The black solid line is the heat transfer coefficient calculated from the following Dittus-Boelter correlation [3].

The wall temperature increases as the heat flux increases. It is clearly shown that the heat transfer coefficient increases as the heat flux decreases. Under the test conditions, a heat transfer deterioration does not occur. It is noted that the maximum heat transfer coefficient is obtained where the bulk fluid enthalpy is slightly lower than the pseudo-critical enthalpy.

3.2 Comparison with the upward flow test results

Fig. 3 shows a comparison of the current test results with the previous ones for an upward flow [4]. In the upward flow test, a heat transfer deterioration occurred at a low mass flow($G=400kg/m^2$ s). On the other hand, for the same test conditions, a heat transfer deterioration did not occur in the downward flow test. So, the heat transfer coefficient is larger than that of the upward flow test at the region where the heat transfer deterioration occurs. It is known that an interaction of a shear stress and a buoyancy force affects a cross-sectional velocity profile which is considered to be the major factor for the heat transfer deterioration. In the upward flow, the velocity profile is distorted to a M-shape due to the combined effect of a flow acceleration force and a buoyancy force when the fluid is near the pseudo critical condition. In the M-shape velocity profile, the eddy conductivity and diffusivity become so small that the heat transfer to the fluid is suppressed, which causes a heat transfer deterioration [5]. But, in the downward flow, the M-shape velocity profile never happens because the buoyancy force is exerted in the opposite direction to the flow acceleration force. For a normal heat transfer, the general trend of the heat transfer coefficient is similar to that of the upward flow test. But, at a high bulk fluid enthalpy region the heat transfer coefficient is slightly lower.

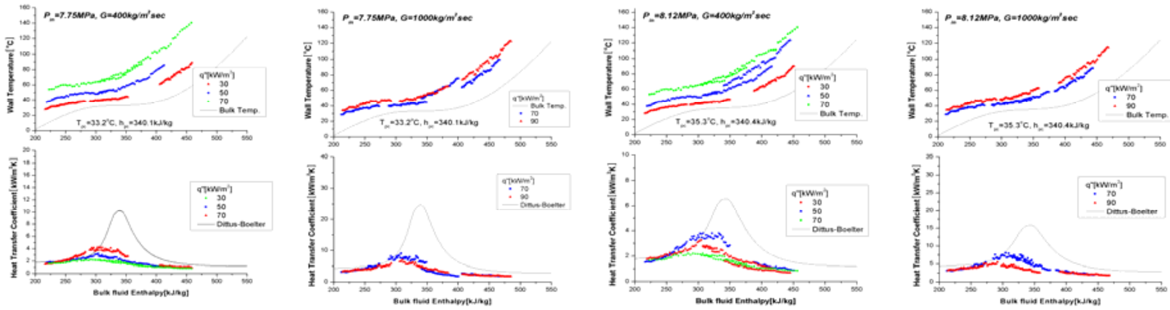

Fig. 2. Heat transfer coefficient and wall temperature versus bulk fluid temperature

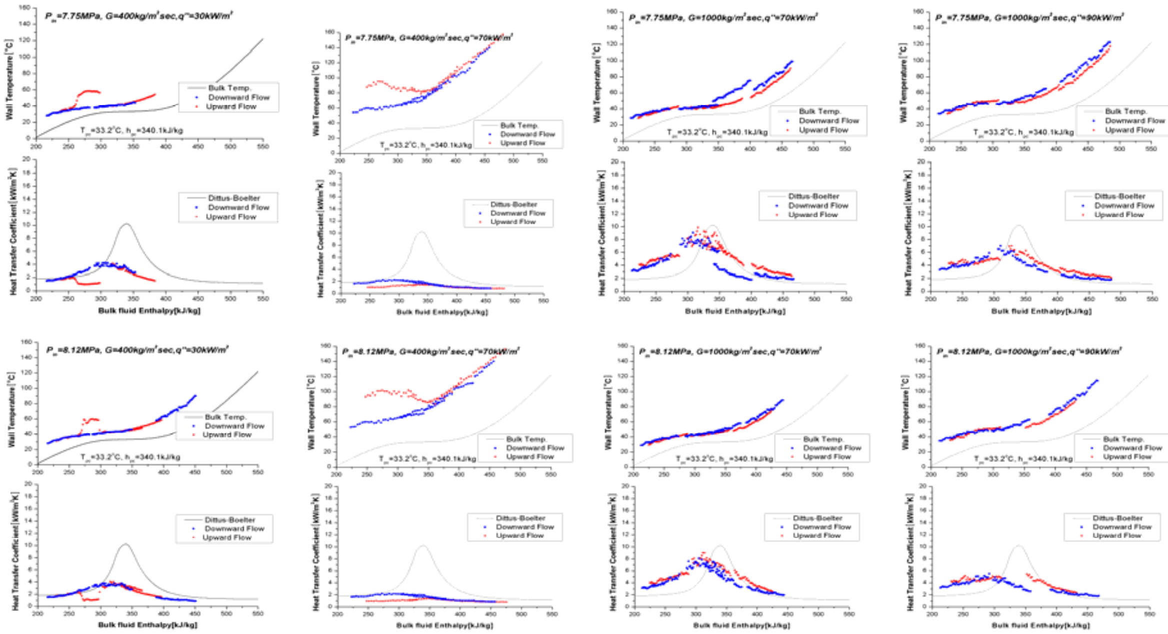

Fig. 3. Comparison with the upward flow test at inlet pressure of 7.75MPa and 8.12MPa

4. Conclusions

Heat transfer experiments were performed to investigate the characteristics of a heat transfer to supercritical pressure CO_2 which flows downward through a vertical circular tube with an inner diameter of 9.0 mm. At the same heat flux, the heat transfer coefficient increases as the mass flux increases. It seems that the heat transfer coefficient increases as the heat flux decreases at the same mass flux. Comparison with the upward flow test results showed that similar heat transfer characteristics were observed except that a heat transfer deterioration did not occur under the experimental conditions.

REFERENCES

[1] H. Y. Kim et al., State of the Art on the Heat Transfer Experiments Under Supercritical Pressure Condition, KAERI / AR-681 / 2003,(2003).

[2] H. Y. Kim et al., "Heat Transfer Test in a Vertical Tube Using CO_2 at Supercritical Pressures," *J. of Nuc. Sci. Tech.*, Vol. 44, No. 3, pp.285-293, (2007).

[3] F. P. Incropera and D.P. De Witt, Introduction to Heat Transfer, 2^{nd} Ed., p.456, John Wiley & Sons, 1990.

[4] Y. Y. Bae et al., Investigation of Heat Transfer in Supercritical Fluids for Application to the Generation IV Supercritical Water Cooled Reactor (SCWR), I-NERI Final Technical Report, (2007).

[5] V. A. Kurganov and A. G. Kaptil'nyi, "Velocity and enthalpy fields and eddy diffusivities in a heated supercritical fluid flow," *Experimental Thermal and Fluid Science*, 5 (4), pp. 465-4788, (1992).