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Heat Transfer Characteristics of the Supercritical CO_2 Flowing in a Vertical Annular Channel

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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 characteristics of supercritical CO_2 at several test sections with a different geometry. The loop uses CO_2 because it has much lower critical pressure and temperature than those of water [1].

Experimental study of heat transfer to supercritical CO_2 in a vertical annular channel with and hydraulic diameter of 4.5 mm has been performed. CO_2 flows downward through the annular channel simulating the downward-flowing coolant in a multi-pass reactor or water rod moderator in a single pass reactor. The heat transfer characteristics in a downward flow were analyzed and compared with the upward flow test results performed previously with the same test section at KAERI [2].

2. Description of the Test

2.1 Test section

Fig. 1 shows the locations of the measuring points and dimensions of the test section. The wall heat flux over the heated length of about 1800 mm was maintained as uniform as possible. The estimated heat loss to ambient was negligibly small. The bulk fluid temperatures in the channel were estimated by from the inlet temperature of the fluid and the imposed heat flux by using a heat balancing formula. The thermocouples were embedded under the surface of the heater rod. The phase angle of the thermocouple was increased by 60^o along the flow direction.

2.2 Test conditions

The tests were conducted with a change of the mass flux and the heat flux at a given pressure selected at 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 250 ℃. 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 an observance of heat transfer deteriorations. The mass flux ranged over 400 ~ 1200 kg/m^2s. The maximum heat flux was $130kW/m^2$.

3. Results and Discussion

3.1 Wall temperature and heat transfer coefficient

Fig. 2 shows the measured wall temperatures and the heat transfer coefficients. The solid lines in the upper and lower box are the heat transfer coefficient and the wall temperature calculated from the Dittus-Boelter correlation [4].

The wall temperature increases as the heat flux increases. The heat transfer coefficient increases as the heat flux decreases. Under the test conditions, heat transfer deterioration did 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.

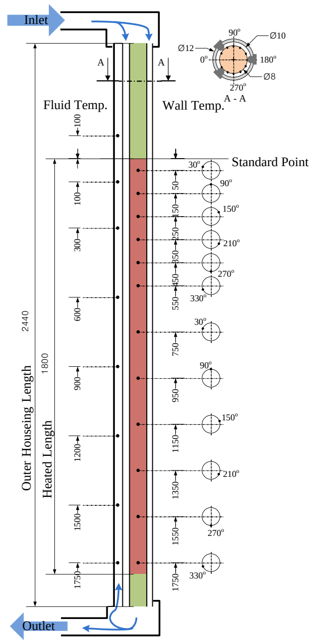

Fig. 1. The locations of the measuring points and dimensions of the test section

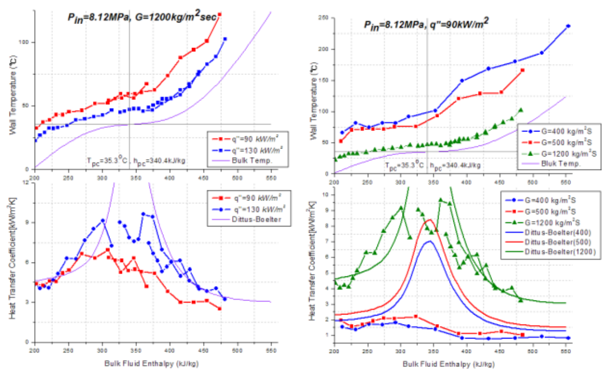

Fig. 2. Heat transfer coefficient and wall temperature versus bulk fluid enthalpy in a downward flowing CO_2

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 [2, 3]. In the upward flow test, a heat transfer deterioration occurred at a low mass flux (G=400 kg/m^{2}s). On the other hand, for the same test conditions, heat transfer deterioration did not occur in the downward flow test below pseudo-critical enthalpy. However, in the high enthalpy region, the sudden increase of the wall temperature probably indicates an occurrence of deterioration. This phenomenon was more conspicuous at the low mass flux and was not observed test sections of tube.

When the wall temperature approaches the pseudo-critical condition, the interaction between a shear stress and a buoyancy force affects a cross-sectional velocity profile and consequently results in an altered turbulent shear stress (or turbulent Prandtl number) distribution, which is considered to be a major factor for the heat transfer deterioration [5].

However, the phenomenon occurred in the present experiment may not be explained by the above argument. A low-density buoyant layer, grown from the wall by high heat flux, might have been built up over the wall and inhibited heat transfer resulting an abnormal increase of temperature. At an increased mass flux of 1200 kg/m^{2}s and the same heat flux such an abnormal temperature increase was not observed. The high velocity at 1200 kg/m^{2}s effectively swept the low-density buoyant layer, while the velocity at 400 kg/m^{2}s was not sufficiently high. Fig. 4 shows a comparison of buoyancy parameter of Eqs. (1) and ratio of downward to upward. At the above figure, criterion of deteration at 4.57 mm tube (*B=1E-5*) is satisfied at upward flow, but it do not apply to downward flow.

$$B = \frac{\overline{Gr}_b}{Re_b^{2.7}\overline{Pr}_b^{0.5}} \qquad (1)$$

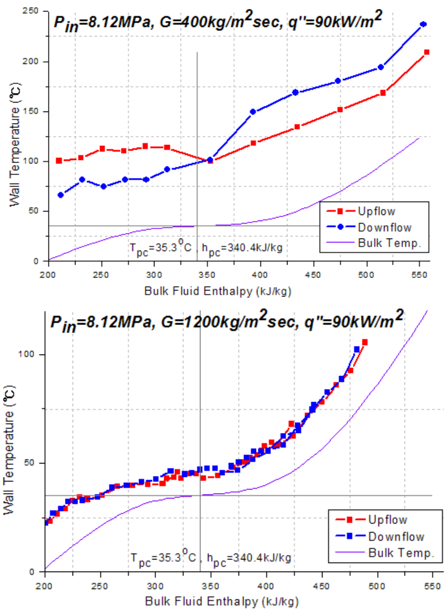

Fig. 3. Comparison of wall temperature between the upward and downward flow tests at the heat flux of 90 kW/m^2

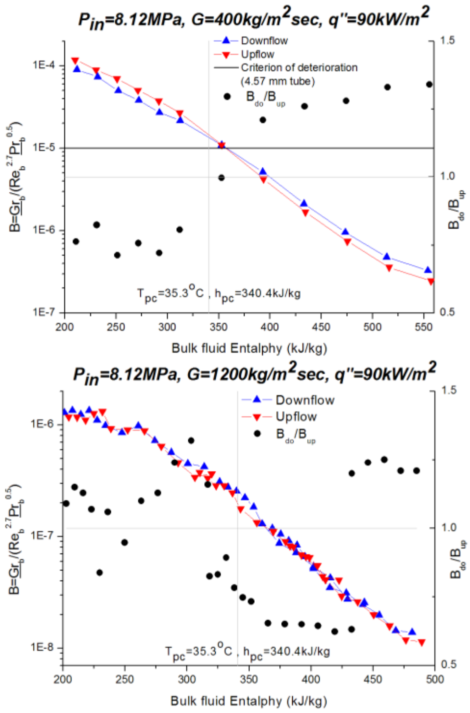

Fig. 4. Comparison of buoyancy parameter and ratio of downward to upward

4. Conclusions

Heat transfer characteristics of supercritical pressure CO_2 flowing downward through an annular channel with an hydraulic diameter of 4.5 mm was experimentally investigated. At the same heat flux, the heat transfer coefficient increases as the mass flux increases. The heat transfer coefficient increases as the heat flux decreases at the same mass flux.

In the region above the pseudo-critical condition, a deterioration like phenomenon - sudden increase of wall temperature - was observed. It may have been caused by a large scale buoyant layer built up on the wall by a sufficiently high heat flux.

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