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Heat Transfer Experiment with Supercritical CO_2 Flowing Upward in a Circular Tube

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1. Introduction

SCWR (SuperCritical Water-cooled Reactor) is one of the six reactor candidates selected in the Gen-IV project, which aims at the development of new reactors with enhanced economy and safety[1]. Heat transfer experiments under supercritical conditions are required in relevant geometries for the proper prediction of thermo-hydraulic phenomena in a reactor core. A heat transfer test loop, named as SPHINX (**S**upercritical **P**ressure **H**eat Transfer **I**nvestigation for **N**e**X**t generation), has been constructed in KAERI[2]. The loop uses carbon dioxide as a surrogate fluid for water since the critical pressure and temperature of CO_2 are much lower those of water.

As a first stage of heat transfer experiments, a single tube test is being performed in the test loop. Controlled parameters for the tests are operating pressure, mass flux, and heat flux. Wall temperatures are measured along the tube. Experimental data are compared with existing correlations.

2. Description of the Test

2.1 Test Loop and Test Section

Test facility is designed so that the heat transfer characteristics of supercritical CO_2 are investigated with varying heat and mass fluxes at a given pressure. The critical point of CO_2 is 7.38 MPa and 30.98 ^oC. For the details of the facility, refer to the previous publication [2].

Fig.1 shows the installed test section and the locations of measuring points. The test section is a circular tube with an inside diameter of 4.4 mm and heated by a direct current power supply to impose a uniform heat flux on the tube surface. 41 K-type thermocouples, each apart by 5 cm, are soldered on the external surface of the tube to measure the wall temperatures. The supercritical CO_2 flows upward 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 are conducted with the change of mass flux and heat flux at a given pressure. In order to investigate the effect of pressure on the heat transfer, the experiments are performed at three different pressures : 1.05, 1.1 and 1.2 times the critical pressure. The inlet temperature of the test section is kept at 27 ^oC and the outlet temperature of the test section is restricted below 100 ^oC for safety. For each test, heat flux at given mass flux and pressure is selected so that the fluid crosses the pseudo-critical point inside the test section for the investigation of hest transfer deteriorations. Table 1 shows the range of test conditions.

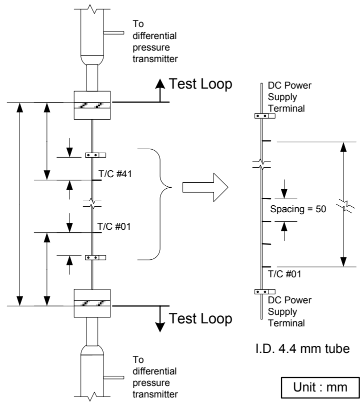


Figure 1. The test section and measuring locations

Table 1. Range of the test conditions

Condition	Unit	Value
Inlet pressure	MPa	7.75, 8.12, 8.85 (1.05, 1.1, 1.2 P_{cr} respectively)
Inlet temperature	^oC	27
Mass flux	kg/m^2 sec	400, 500, 750, 1000, 1200
Heat flux	kW/m^2	Up to 150

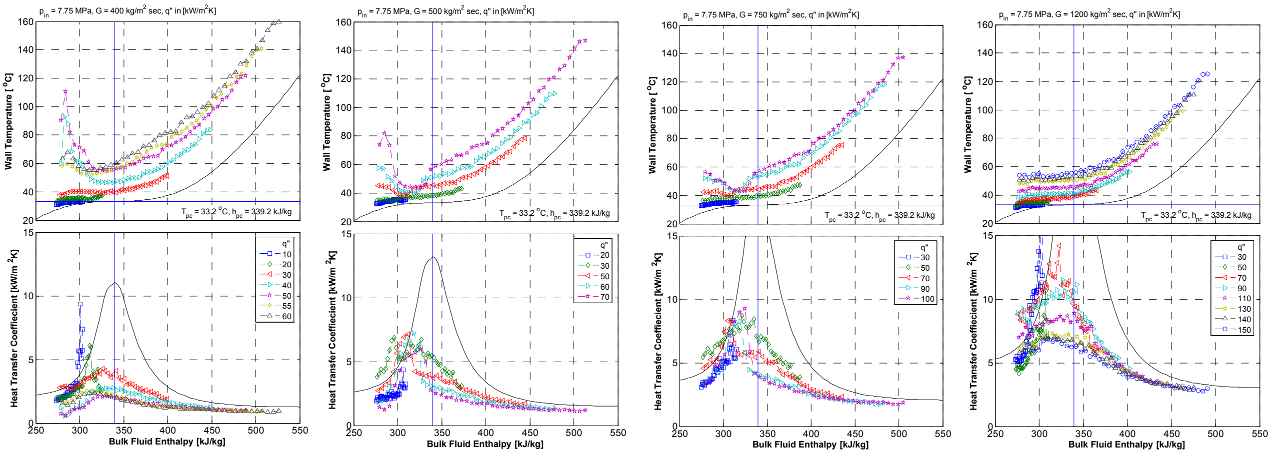
3. Results

3.1 Heat Transfer Coefficient

Fig. 2 shows the surface temperature and the heat transfer coefficient with the change of mass flux and heat flux in case the inlet pressure of the test section is 7.75 MPa which is 1.05 times the critical pressure of CO_2.

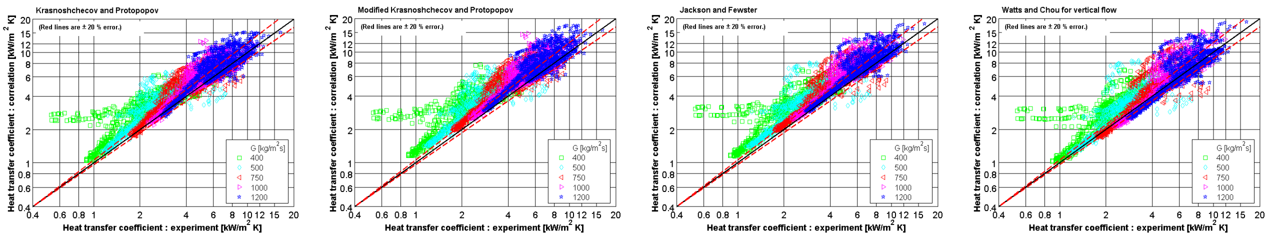
The Dittus-Boelter correlation[3] predicts the heat transfer coefficient well in the temperature range far from the pseudo-critical temperature since the fluid has the characteristics of single phase. But, it is shown that the Dittus-Boelter correlation overestimates the heat transfer coefficient near the pseudo-critical temperatures.

Heat transfer deterioration is mainly observed at the mass flux of 400 and 500 kg/m2 sec. and faintly observed at the mass flux of 750 kg/m2 sec. The peak surface temperature of tube becomes larger when the mass flux is lower.



(a) Mass flux = 400 kg/m^2s (b) Mass flux = 500 kg/m^2s (c) Mass flux = 750 kg/m^2s (d) Mass flux = 1200 kg/m^2s

Figure 2. Wall temperature and heat transfer coefficient measured at 7.75 MPa. (solid black line : the bulk temperature of CO2 and the heat transfer coefficient obtained by the Dittus-Boelter [2] correlation, solid blue line : the pseudo-critical temperature and the specific enthalpy)



(a) Krasnoschchekov and Protopopov (b) Modified Krasnoschchekov and Protopopov (c) Jackson and Fewster (d) Watts and Chou

Figure 3. Comparison of heat transfer coefficient from the experiment with that from the published correlations. (red line is ±20 % error bound)

3.2 Comparison with existing correlations

The measured value is compared with 4 correlations for supercritical water - Kransnoshchekov and Protopopov [4], Modified Kransnoshchekov and Protopopov [4], Jackson and Fewster [4], and Watts and Chou [5].

Fig. 3 shows that the data obtained in the tests deviate a lot from the correlated ones and heavily scattered. The large prediction error may come from the uncertainty in estimating bulk fluid enthalpy near the pseudo-critical temperature or from the difference of the working fluid. Near the pseudo-critical temperature, the error in heating power estimation and consequently in heat flux may be as large as 50 %. The plots also give indirect comparison with another supercritical heat transfer test at Kyushu University using Freon(R-22) [6]. They compared their test data with the above 4 correlations and showed a more conforming result.

3. Conclusion

The heat transfer test is performed for a vertical upward flow of supercritical CO_2 in a circular tube. The heat transfer deterioration is observed at low mass flux and high heat flux. The data are compared with the correlated ones. The measured value deviates from the correlations about 20 % in average. Drastic change of specific heat capacity near the pseudo-critical temperature may result in the large discrepancy. Supplementary test is being executed to reduce the uncertainty in the data.

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