Design of Supercritical CO_2 Heat Transfer Test Loop

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1. Introduction

The 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. The SCWR is considered to be a feasible concept of new nuclear power plant if the existing technologies developed in fossil fuel fired plant and LWR together with additional researches on several disciplines such as materials, water chemistry and safety. Among the research areas, heat transfer experiments under supercritical conditions are required for the proper prediction of thermal hydraulic phenomena, which are essential for the thermal hydraulic designs of reactor core. Heat transfer test loop using carbon dioxide (CO_2) as a surrogate fluid is being constructed at KAERI for the study of heat transfer from the single tube, single rod and rod bundle. The heat transfer correlations obtained at the KAERI test loop will be compared with the other correlations generated at Kyushu university and INEEL. This paper describes the design characteristics of heat transfer test loop of supercritical CO_2 at KAERI. The test is expected to start at the 1st quarter of 2005.

2. Design of Heat Transfer Test Loop

2.1 Description of Test Loop

The critical pressure and temperature of water are 22.12 MPa and 374.14 °C. It is not easy to perform a heat transfer test with supercritical water. As a substitute for water CO_2 is selected for the test, since the critical pressure and temperature of CO_2 are 7.38 MPa and 31.05 °C which are much lower than water. The test will be performed to investigate the heat transfer characteristics of supercritical CO_2 with changing heat and mass fluxes at a given pressure. The range of pressure will be 7.3 ~ 10.0 MPa and the pressure effect on the heat transfer characteristics will also be investigated.

The test facility of supercritical CO_2 is schematically shown in Fig. 1. The test facility consists of a CO_2 circulation pump, a CO_2 supplying tank with booster, an accumulator, a pre-heater, a test section, a vacuum pump, a power supply, a heat exchanger, a chiller unit, a bypass line, associated valves and instruments. The design pressure and temperature of the main loop are 12.0 MPa and 80 °C. The CO_2 remains a liquid-like supercritical fluid from the outlet of heat exchanger to the inlet of test section. As power is supplied to the test section, the liquid-like supercritical CO_2 is changed to the gas-like supercritical CO_2. After initial venting of the main loop is accomplished using a vacuum pump, CO_2 is charged into the main loop using a CO_2 supplying tank with booster. A gear type CO_2 circulation pump is used to minimize the flow fluctuation.

The pressure in the main loop is controlled by an accumulator where a flexible membrane between sub-cooled CO_2 and gaseous He exists. The inlet and outlet temperatures are controlled by the pre-heater and power supply. The direct electric heating method is applied to the test section as possible as can in order to make an uniform heat flux on surface. The ranges of inlet and outlet temperatures of the test section are 15 °C ~ 27 °C and 40 °C ~ 55 °C, respectively. The mass flow is controlled by adjusting a valve in the by-pass line. The main loop is insulated to minimize the heat loss. The size of the main loop is about 20 mm. A steam flow meter, manual flow control and isolation valves, pressure transmitters and thermocouples are installed in the test facility. Two units of CO_2 circulation pump, flow meter and power supply are installed in parallel. The lower capacity unit is for the single tube and single rod tests and the higher capacity unit is for the rod bundle test.

2.2 Sizing of Test Loop

The sizing criteria of the test loop is that the single tube, single rod and rod bundle tests shall be performed at the test loop and data at the pseudo-critical conditions shall be measurable to investigate the heat transfer deterioration for each test. Fig. 2 shows the pseudo-critical line of CO_2.

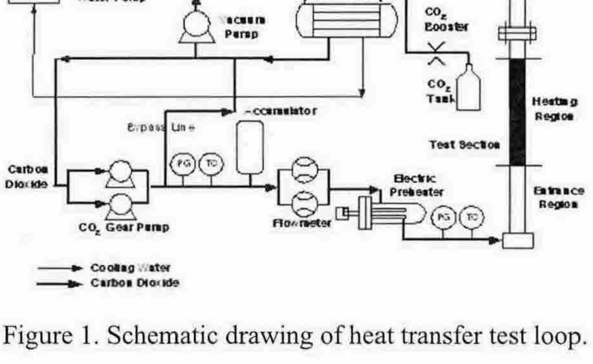

Figure 1. Schematic drawing of heat transfer test loop.

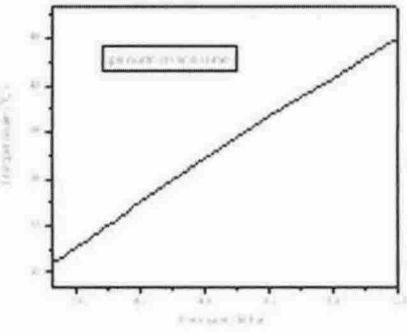

Figure 2. Pseudo-critical line of CO_2.

For the single tube test, the geometry is the same as the one used in R22 tests at Kyushu university for the direct comparison of the test results. The heated length and diameter of the tube are 2m and 4.4mm, respectively. The mass flow rate is determined based on the fact that the inlet Re number is 50000 which is the same as the core inlet Re number of SCLWR-H, the prototype of SCWR. The heater power to test section is determined based on the fact that the test section outlet temperature becomes at least 40 °C with the inlet temperature of 27 °C. The test range of pressure will be 7.3 ~ 10.0 MPa. The estimated mass flow rate and heater power are different with the change of pressure. Conservatively, the mass flow rate and heater power to test section are determined at 50 kg/hr and 2.2 kW. It is necessary to check if the pseudo-critical conditions could occur at the test section with the mass flow rate of 50 kg/hr and heater power of 2.2 kW.

Table 1 shows that the outlet temperatures of test section are higher than the pseudo-critical temperatures. The pre-heater power is conservatively determined at 0.625 kW which could raise the CO_2 temperature from 15 °C at the heat exchanger outlet to 27 °C at the test section inlet.

The geometry of single rod and rod bundle is shown in Fig. 3. For the single tube and rod bundle tests, it is required to get the similar test ranges as shown in Table 1. In order to maintain the same Re number, i. e. 50000, at the inlet of test section, the following relation should be satisfied.

Table 1 Test section outlet temperature with pressure.

Pressure	h(kJ/kg) at 27°C	h(kJ/kg) at outlet	Outlet temp.(°C)
7.3 MPa	275.12	433.52	43.40
7.38 MPa	274.39	432.79	43.70
7.4 MPa	274.22	432.62	43.80
7.5 MPa	273.38	431.78	44.30
7.6 MPa	272.61	431.01	44.90
7.7 MPa	271.88	430.28	45.40
7.8 MPa	271.21	429.61	46.00
7.9 MPa	270.56	428.96	46.50
8.0 MPa	269.96	428.36	47.10
8.5 MPa	267.33	425.73	50.10
9.0 MPa	265.18	423.58	53.00
9.5 MPa	263.36	421.76	55.90
10.0 MPa	261.80	420.20	58.60

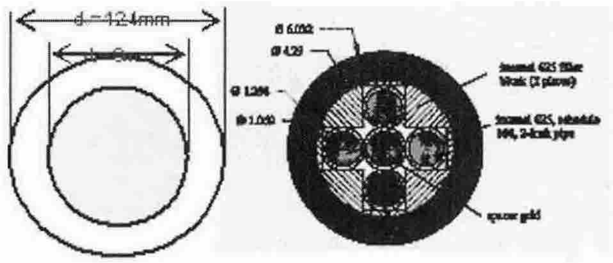

Figure 3. Geometry of single tube (left) and rod bundle (right)

$$\left(\frac{\dot{m}}{Perimeter}\right)_{single\ tube} = \left(\frac{\dot{m}}{Perimeter}\right)_{single\ rod} = \left(\frac{\dot{m}}{Perimeter}\right)_{rod\ bundle}$$

For the single rod test, the mass flow rate is about 2.6 times larger than single tube test. Consequently, the heater power to test section and pre-heater power should be also 2.6 times larger than single tube test for the similar test ranges to the single tube test. The mass flow rate, test section heater power and pre-heater power are 130 kg/hr, 6.0 kW and 1.6 kW.

For the rod bundle test, the mass flow rate is about 24 times larger than single tube test. So, The mass flow rate, test section heater power and pre-heater power are 1200 kg/hr, 52 kW and 15 kW.

Actually, the components are being purchased to have some margins on the test loop design values. The pre-heater power and heat removal capacity of heat exchanger are 20 kW and 60 kW, respectively. Two power supplies with the capacity of 10 kW and 80 kW and two pumps with the capacity of 250 kg/hr and 1500 kg/hr will be installed.

3. Conclusion

General description and design characteristics of supercritical heat transfer test loop using CO_2 as a surrogate fluid are provided. Sizing criteria of some key components such as pump, power supply, heat exchanger and pre-heater are also presented. The tests aims at the investigation of heat transfer from the single tube, single rod and rod bundle under the supercritical conditions. The single tube test will start at the 1st quarter of 2005.

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