Design and Progress of the SPHINX in KAERI

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1. Introduction

The SCWR (**S**uper**C**ritical **W**ater-cooled **R**eactor) 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 plants and LWRs are incorporated 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 in the reactor core designs. A heat transfer test loop using carbon dioxide (CO_2) as a surrogate fluid has been constructed in KAERI. The test facility, named as SPHINX (**S**upercritical **P**ressure **H**eat transfer **I**nvestigation for **N**e**X**t generation), will be used for the study of heat transfer in a single tube, single rod, and rod bundle. The heat transfer correlations obtained from the SPHINX will be compared with the other correlations generated at Kyushu University and INL. This paper describes the design characteristics and progress of the SPHINX in KAERI. The construction of the facility is completed and a trial run is being conducted. The test and the data production are expected to start by April 2005.

2. Design and Progress of the SPHINX

2.1 Description of the Test Loop

The critical point of water is 22.12 MPa and 374.14 ^{o}C. Since a heat transfer test on such a condition is not easy, CO_2 is selected as a surrogate fluid, which has a much lower critical condition (7.38 MPa, 31.05 ^{o}C) than water. The test aims to investigate the heat transfer characteristics of supercritical CO_2 with varying heat and mass fluxes at a given pressure. The range of pressure will be 7.3 ~ 10.0 MPa. The pressure effect on the heat transfer characteristics will also be investigated.

Fig.1 shows a schematic diagram of the test facility using supercritical CO_2. The design pressure and temperature of the main loop are 12.0 MPa and 80 ^{o}C.

The CO_2 remains in a liquid-like state from the outlet of the heat exchanger to the inlet of the test section. The liquid-like supercritical CO_2 changes to the gas-like supercritical CO_2 as it flows through the heated test section.

Two units of CO_2 circulation pump are installed. The lower capacity unit is for the single tube and single rod tests, and the higher capacity unit is for the rod bundle test. A gear type pump is adopted to minimize flow

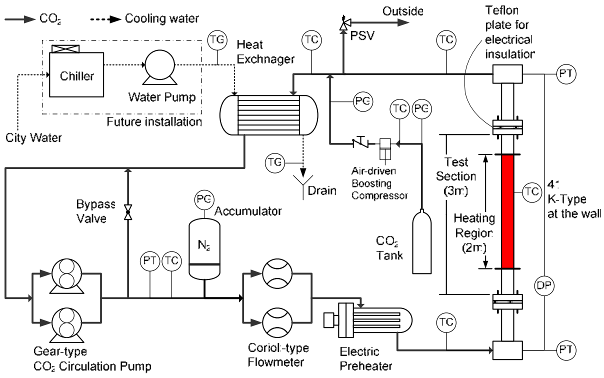

Figure 1. Schematic diagram of the heat transfer test loop.

fluctuation. The accumulator filled with gaseous nitrogen, which is located at the discharge of pumps, also reduces any fluctuation in flow. The pre-heater and the power supply control the inlet and outlet temperatures of the test section. The single tube test section is heated by direct electric heating to make a uniform heat flux on the surface. The mass flow rate is regulated by adjusting the bypass valve and/or the speed of the pumps. A Corioli type flow meter, manual flow control and isolation valves, pressure transmitters, and thermocouples are installed in the test facility. The size of the main loop is about 20 mm. The main loop is insulated to minimize heat loss to the atmosphere.

2.2 Design of the Test Loop

The test loop is so designed 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.

For the single tube test, the geometry is same as the one used in R22 tests at Kyushu University. The heated length and diameter of the tube are 2 m and 4.4 mm, respectively. The mass flow rate is determined from the fact that the inlet Re number is 50000, which is same as the core inlet Re number of SCLWR-H, the prototype of SCWR. The heater power to test section is determined so that the fluid temperature at test section outlet becomes at least 40 ^{o}C with the inlet temperature of 27 ^{o}C. The test range of pressure will be 7.3 ~ 10.0 MPa. The estimated mass flow rate and heater power vary as pressure changes. Conservatively, the mass flow rate and heater power to test section are determined to be 50 kg/hr and 2.2 kW. Table 1 shows the fluid temperatures at the outlet of the test section, which are estimated from the selected mass flow rate and heater power. The pre-heater power is conservatively determined at 0.625 kW so that CO_2 is

Table 1 Test section outlet temperature with pressure.

Pressure (MPa)	h(kJ/kg) at 27^{o}C	h(kJ/kg) at outlet	Outlet temp. (^{o}C)
7.3	275.12	433.52	43.40
7.38	274.39	432.79	43.70
	…		
9.0	265.18	423.58	53.00
9.5	263.36	421.76	55.90
10.0	261.80	420.20	58.60

warmed up from 15 ^{o}C at the heat exchanger outlet to 27 ^{o}C at the test section inlet. The ranges of inlet and outlet temperatures of the test section are 15 ^{o}C ~ 27 ^{o}C and 40 ^{o}C ~ 55 ^{o}C, respectively. The mass and heat fluxes will be 300 ~ 1200 kg/m^{2}sec and 10 ~ 120 kW/m^{2}, respectively.

Fig. 2 is the geometry of the single rod and the rod bundle. In order to maintain the similar test ranges (Table 1) and the same Re number, i.e. 50000, at the inlet of the test section, the following relation should be satisfied.

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

For the single rod test, the mass flow rate is about 4.6 times larger than the single tube test. Consequently, the mass flow rate, the heater power to the test section, and the pre-heater power should be 230 kg/hr, 10.3 kW, and 3.0 kW. For the rod bundle test, the mass flow rate is about 15.3 times larger than the single tube test. The mass flow rate, the main heater power, and the pre-heater power are 800 kg/hr, 35 kW, and 10 kW. The data from the single tube and the single rod tests will be compared with R22 test results from Kyushu University, and the data from the rod bundle test will be compared with water test results from INL

In fact, the components are sized to have enough margins on the design values of the test loop. The pre-heater power and heat removal capacity of the heat exchanger are 20 kW and 60 kW, respectively. The loop is equipped with a 6 kW DC power supply and two pumps with a capacity of 250 kg/hr and 1500 kg/hr. An AC power supply (60 kW) will be installed for the single rod and the rod bundle tests.

2.3 Current Progress

As of March 2005, the main loop of the test facility is completed. The test section for the single tube test is installed to the main loop. The instrumentation and DAS (data acquisition system) are ready to run.

The single tube test section is made of Inconel 625. 41 K-type thermocouples are soldered with silver to measure the surface temperatures along the heated length. To accommodate longitudinal thermal expansion, only the upper end of the test section is anchored while the lower end is routed with a flexible hose. The test section is directly heated by a DC power supply. Thus, 10 mm thick Teflon plates electrically insulate the both ends of the test section.

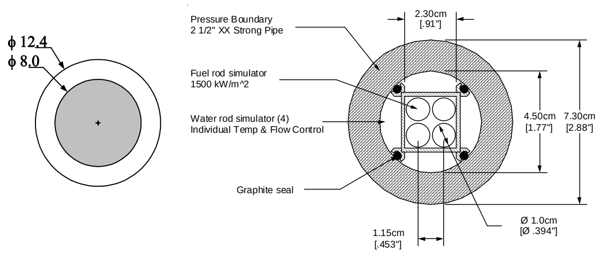

Figure 2. Geometry of single tube (left) and rod bundle (right)

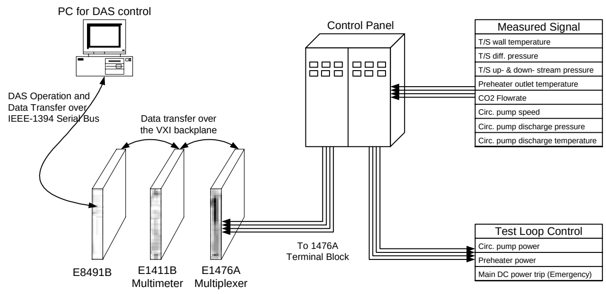

Figure 3. PC-based data acquisition system

For data collection, a PC-based DAS is implemented (Fig. 3). The assembly of a VXI-based multiplexer and multimeter scans and digitizes process variables from the loop, and then transfers the data to the PC over IEEE1394 bus. The equipment can scan 64 channels at the rate of 300 Hz. The number of process variables in the loop is 52 and the experiments will be done under steady state. Thus, the installed DAS has sufficient capacity for the tests.

Currently, a trial run is being conducted to confirm the operability of the test loop and instrumentation. Actual data production for the single tube test will begin in April 2005.

3. Conclusion

The article describes the design and status of the SPHINX, which aims to investigate the heat transfer characteristics in a single tube, single rod, and rod bundle under supercritical conditions. The design principles of some key components and instrumentations are presented. The construction of the main loop is completed and shakedown tests are being performed. The single tube test will begin in April 2005.

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