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Supercritical Carbon Dioxide Flowing Up Vertical Small Tube

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1. Introduction

The supercritical carbon dioxide (SCO_2) is currently being considered as working fluid for power conversion in some Generation IV Nuclear Energy Systems. SCO_2 has such advantages as high density, easy accessibility, low price and no toxicity compared against other fluids. But one of the most salient characteristics is its low critical point. This characteristic renders change from CO_2 to SCO_2 easier than other gases. These benefits lead SCO_2 to be used in power stations in lieu of water or helium.

2. Methods and Results

The Pressure Applied CO_2 Operation (PACO) aims to determine thermophysical characteristics of SCO_2. To this end, use is made of a vertical small circular tube to guide the upward flow. The tube wall temperatures are obtained at a fixed pressure by varying other parameters such as the inlet temperature, heat flux and mass flow rate. PACO is schematically demonstrated in Fig. 1.

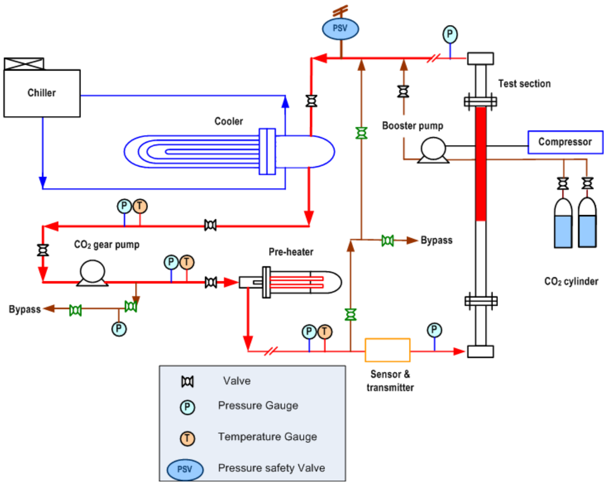

Fig. 1. PACO test apparatus.

The CO_2 critical temperature and pressure are 31.06℃ and 7.38 MPa, respectively as compared with other fluids in Table I.

Table I: Thermophysical Properties at Critical Point

Fluid	Pressure (MPa)	Temperature (℃)	Density (kg/m^3)
He	0.23	-267.9	69.3
H_2O	22.10	374.1	315
CO_2	**7.38**	**31.06**	**468**

2.1 Experimental Setup

During the t PACO est the pressure is fixed at 8 MPa, while the temperature and mass flow are varied. The flow loop includes the booster pump to aid pressure increase with. The temperature and mass flow rate are controlled by the pre-heater and cooler, and gear pump, respectively. Six rods provide the heat flux in the test section. The circular tube inside diameter is 8.1 mm and heated length is 1.2 m. The entrance length is 0.8 m for the flow to be fully developed.

2.2 Pretest with Nitrogen

Preliminary tests are carried out with nitrogen (N_2). The pressure safety test is made as well. The operating pressure is 8 MPa. The pressure is increased to 9 MPa to check against leakage.

In the pretest the inlet temperature, pressure and mass flow rate are fixed at 32.6 °C, 8.13 MPa and 0.04783 kg/s, respectively. The heat flux is varied as 12.833 kW/m^2 and 18.667 kW/m^2. Test results are presented in Fig. 2 for temperature at the tube outer wall.

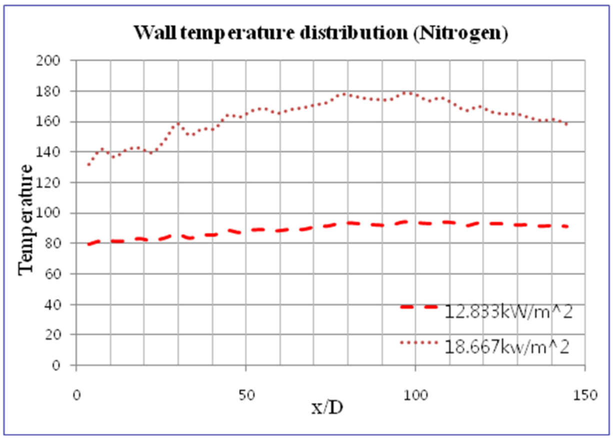

Fig. 2. Measured tube outer wall temperature for N_2.

Notwithstanding the continued heat input during the test the temperature tends to level off downstream. A plausible explanation may be the buoyancy effect at the inner wall of the heated tube. That is, the upward flow is accelerated at the wall on account the heating, while the bulk flow is not. This dissimilarity appears to render turbulence to appear and to disturb the otherwise forced convective flow. Another likelihood may be mechanical defect. The heated rods are 1.2 m long so that the heat flux may not axially be uniform despite the constant voltage and current.

The computed results in Fig. 3 do not illustrate the point on the other hand. Further investigation is being made to check on the deviation between the measured and calculated values and trends.

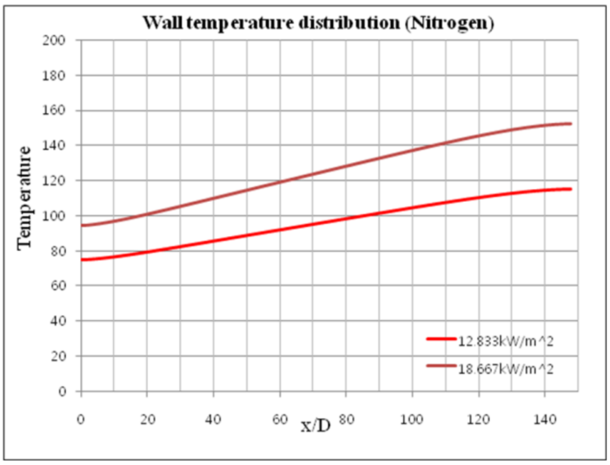

Fig. 3. Computed tube outer wall temperature for N_2.

2.3 Pretest with CO_2

The test is then made for CO_2 to measure temperature distribution at the wall as presented in Fig. 4. Note the similar tendency of temperature decrease near the exit. It is thus suspected that the rods are not necessarily heated uniformly.

While the inlet temperature is fixed at 22.4 °C, rapid temperature shift appears in the middle of the test section. It is hence deemed that the characteristic of CO_2 is rapidly changed near the critical point, thus strongly affecting the heat transfer mechanism involved.

3. Conclusions

The pretest results have apparently shown the effect of buoyancy and the critical point on the heat transfer. In particular, the buoyancy effect is seen to exceed the prediction. Potential design difficulties may arise due to this anomalous behavior of SCO_2 in power conversion system.

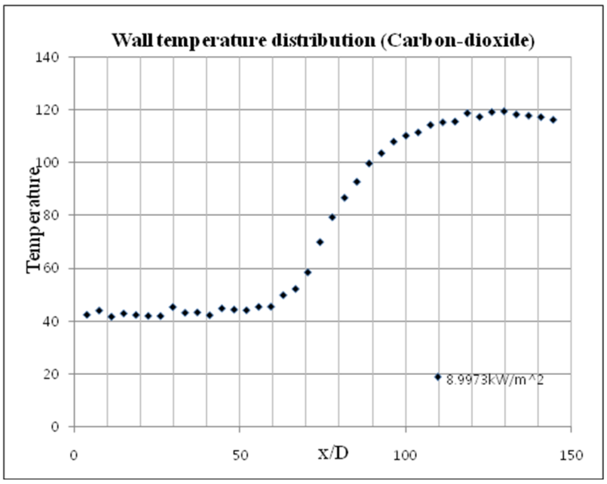

Fig. 4. Measured tube outer wall temperature for CO_2.

ACKNOWLEDGMENTS

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