Experimental Study on CO_2 critical flow comparison with MARS

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1. Introduction

Recently, the supercritical carbon dioxide Brayton (S-CO_2) cycle has been considered as the most promising power converter. The reason is high efficiency in the moderate turbine inlet temperature range (450 ~ 750 °C) and simple layout and compact power plant due to small turbomachinery. However, S-CO_2 cycle must be operated at high pressure because CO_2 can be supercritical state at the 7.38 MPa and 30.98 °C. At the high pressurized system, therefore, CO_2 can be leaked through the sealing part of the turbomachinery to the atmospheric pressure, which can lead to degrade the efficiency of the turbomachinery. Thus, predicting the amount of the leaked CO_2 is important in terms of quantification of supplementary CO_2 to maintain efficiency of turbomachinery. In this paper a thermal hydraulic system analysis code, MARS is selected whether this code is capable of predicting critical properties such as temperature, pressure and mass flux. Also, code validation is implemented by comparing experimental data and code data.

2. Experimental setup

In this section experimental facility to test the CO_2 critical flow are described. The conceptual diagram of experimental facility for CO_2 critical flow test is shown in Fig.1, photograph is shown in Fig.2 and the design specifications are shown in Table 1[1]. To measure the temperature and pressure, nine thermocouples and seven pressure gauges were installed throughout the facility. Three thermocouples and two pressure gauges were installed at the each of the tank. One thermocouple and one pressure gauge were installed at the inlet and outlet of nozzle. Furthermore, one thermocouple and one pressure gauge were installed between high pressure tank and a ball valve. To maintain the initial temperature of high pressure tank, two heater were installed at the top and bottom of the tank, respectively.

The experimental condition was based on 75MWe S-CO_2 power cycle for a SFR application which has the maximum pressure 20MPa. The low pressure tank was maintained ambient condition (0.1013MPa, 15°C) to maintain the critical flow state long time. The experimental cases are three varying the high pressure tank pressure and temperature. The specific experimental cases were shown in Table 2.

Before starting the experiment, the ball valve was totally closed to make the difference of pressure between the tanks. To pressurize the high pressure tank with CO_2, air compressor and booster pump were used. After filling the CO_2, two heaters were operated to meet the initial experimental condition. While the heaters were operated, the pressure of high pressure tank increased. Thus venting process is important to match the experimental condition. After setting the experimental condition, the heaters were turned off and the ball valve was opened. Then, the CO_2 flows from the high pressure tank to the low pressure tank until equilibrium.

Table 1 Design specifications for experimental facility

	Design parameters	
High/Low pressure tank	Pressure (MPa)	22
	Temperature (°C)	150
	Volume (L)	47
Pipe between two tanks	Internal diameter (mm)	57
	Length (mm)	1090
Heater	Electric capacity (kW)	5
Nozzle diameter (mm)	1.5	
Nozzle length (mm)	5.0	
Valve type	Ball valve	

Table 2 Experimental cases

		1	2	3
High pressure tank	Pressure (MPa)	10.04	13.43	20.16
	Temperature (°C)	103.3	161.5	151.2
Low pressure tank	Pressure (MPa)	0.101	0.101	0.101
	Temperature (°C)	14.5	15.6	14.1

3. Results

Temperature and pressure of the two tanks were measured in each seconds during the experiments and CO_2 density can be obtained from the NIST standard reference database from measured temperature and pressure. With these data, mass flow rate can be calculated by the mass difference of the low pressure tank per time step. Thus, Mass flux can be directly calculated by dividing mass flow rate with the nozzle area. The results were shown with temperature, pressure and mass flux from Fig. 3 to Fig. 5.

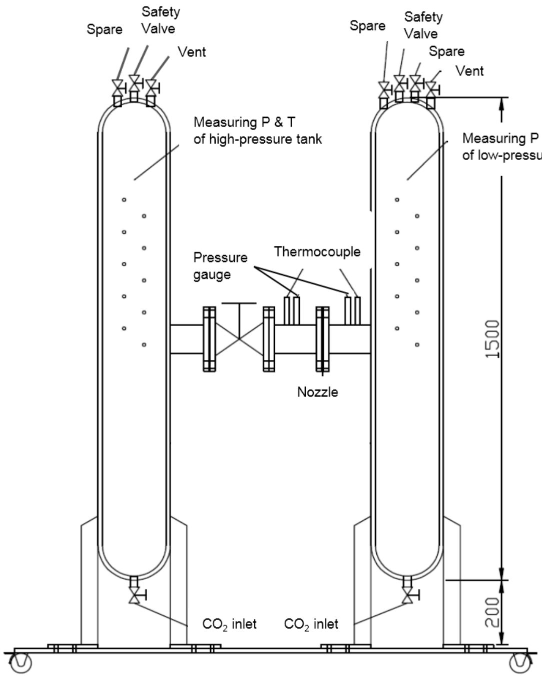

Figure 1 Conceptual diagram of the experimental facility for CO_2 critical flow test

Figure 2 photograph of the experimental facility for CO_2 critical flow test

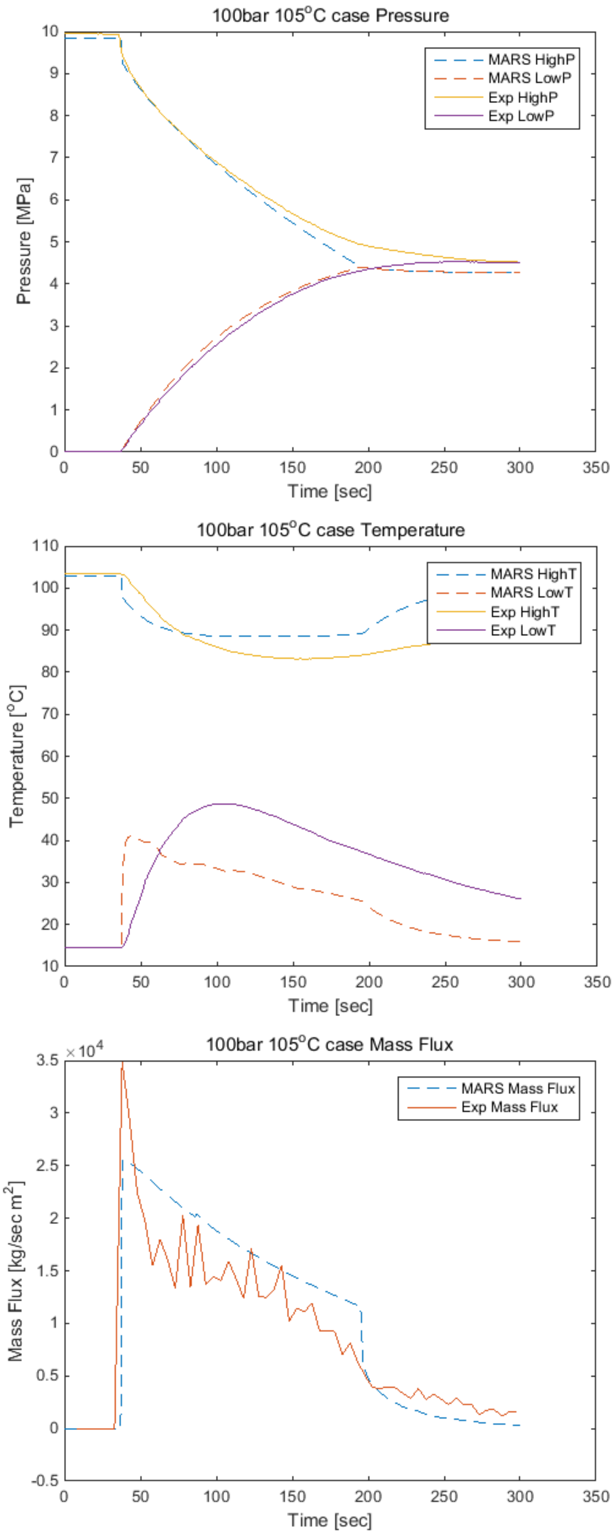

Figure 3 Pressure, temperature and mass flux plots between the experimental results and the MARS results (Case 1)

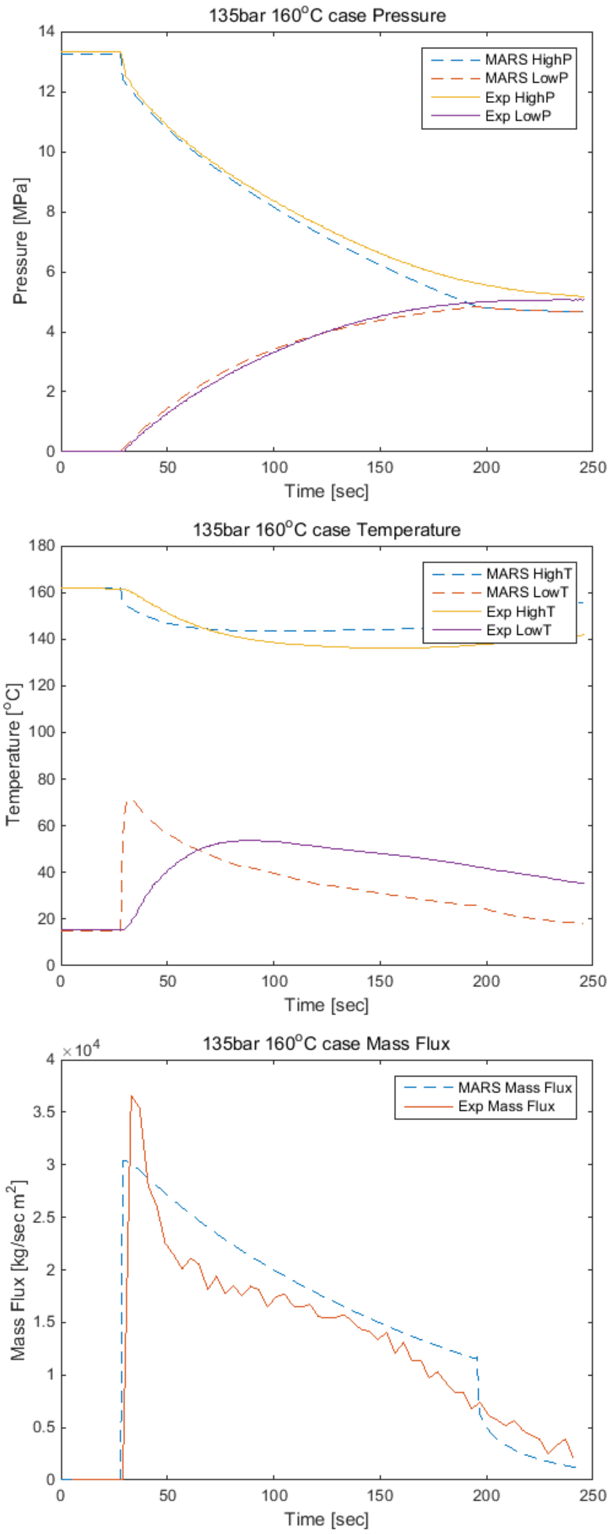

Figure 4 Pressure, temperature and mass flux plots between the experimental results and the MARS results (Case 2)

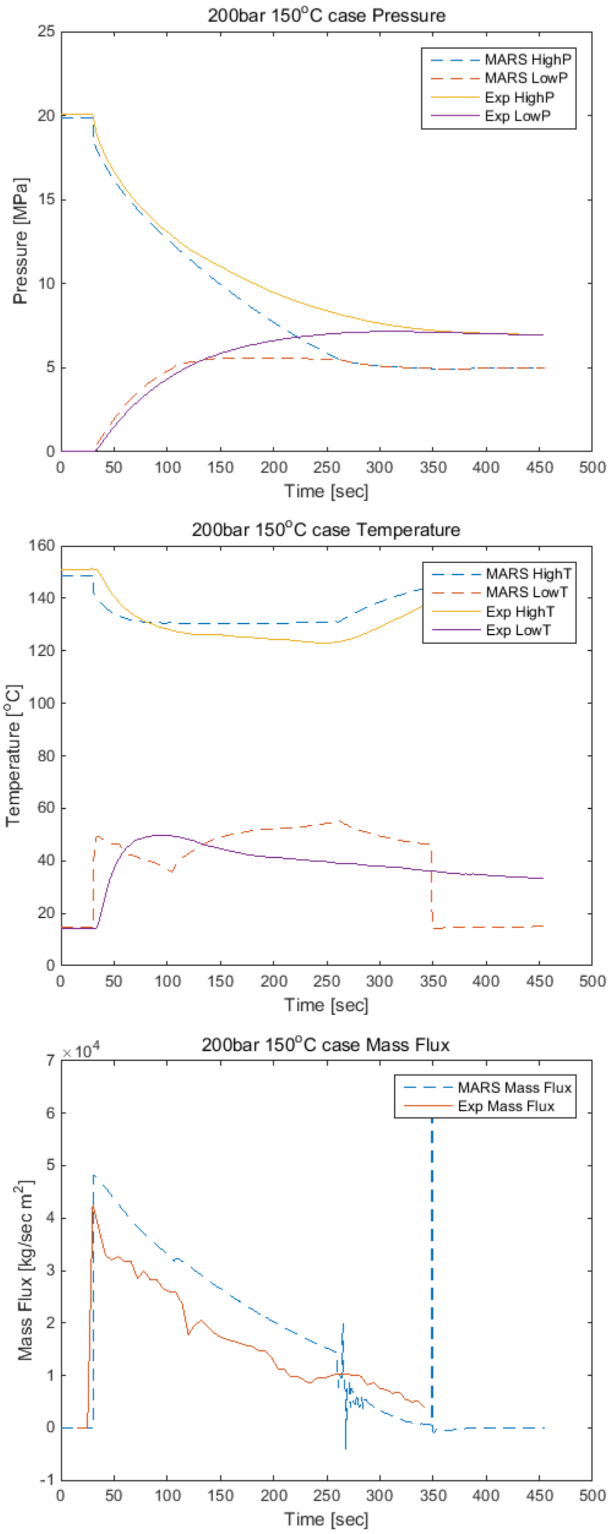

Figure 5 Pressure, temperature and mass flux plots between the experimental results and the MARS results (Case 3)

The MARS has the Henry-Fauske critical flow model. It needs 2 input variables. One is discharge coefficient that is the ratio of actual mass flow rate to the theoretical mass flow rate. The other is throat equilibrium quality. In the MARS analysis, we assumed that actual mass flow rate is the same as the theoretical mass flow rate. Also the homogeneous equilibrium model was assumed. For this reason, discharge coefficient was set to 1 and throat equilibrium quality was set to 0.14.[2][3]

At the every case, the pressure and the mass flux look like similar tendency. However, the differences between the experimental results and the MARS results of the temperature and mass flux existed after opening the ball valve. Heat insulation problem maybe influences to the difference of the temperature. High pressure tank only was insulated well but low pressure tank and connecting pipe did not have the insulation system. That makes the heat loss to the ambient air.

4. Conclusions

Obtaining the leak flow rate is imperative to sustain the high performance of S-CO_2 power cycle. In this paper, estimating the mass flux of CO_2 critical flow by measuring the temperature and pressure was conducted. Experimental results and the MARS results have a similar tendency about pressure and mass flux. Therefore, the MARS is appropriate to simulate the CO_2 critical flow.

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