Preliminary Analysis of Supercritical CO_2 loop Using MARS

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1. Introduction

The supercritical carbon dioxide Brayton cycle has become a strong candidate for use in the next generation nuclear reactors. The simplicity, compactness, cost, and thermal efficiency are known as the main advantages of the cycle. The relatively high efficiency can be reached in lower temperature range than that of helium Brayton cycles. The size of the turbomachinery is also very small compared to the helium Brayton cycle or the steam Rankine cycle, which also contributes in reducing the cost. [1]

To test the cycle under many different conditions a facility named SCO2PE has been built in KAIST. The experimental data is to be compared with simulation results from a code named MARS.

2. Tools

2.1 SCO_2PE [2]

SCO_2PE is a facility built to test CO_2 under supercritical conditions. This device is designed specifically to observe how a compressor performs near the critical point of CO_2. Although there is a lot of data regarding pumps for water or compressors for ideal gas, there is still insufficient data for use with supercritical CO_2. The device consists of a heat exchanger, a canned motor pump type compressor, and a globe valve.

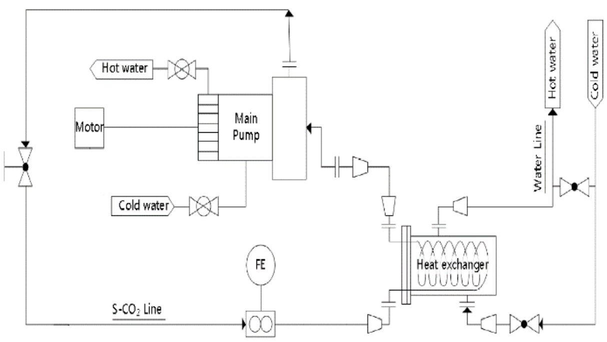

Fig. 1. A schematic diagram of the main CO_2 loop

2.2 MARS Code [3]

MARS Code is a thermal hydraulic system analysis code developed by KAERI. It was designed as an integration of RELAP5/MOD3 and COBRA-TF codes. It is mainly designed for the analysis of water but CO_2, D_2O, He, Be, and Na can also be tested.

3. Methods and Results

The compressor was modeled with MARS first individually. The experimental results were compared to those from MARS. After the validation of the compressor, the whole loop was analyzed.

3.1 Compressor

The pump component in MARS is used for modeling the S-CO_2 compressor. It requires the homologous curve for accurate analysis. Four important variables are required for the homologous curve: volumetric flow, head rise, rotational speed, and shaft torque. These values are then compared to the rated values and the ratio is added to the input. The following formulas were used to calculate the missing values.

$H = w/g$ (1)
$w = \Delta enthalpy$ (2)
$\tau = Power/\omega$ (3)

Table I: Rated Values

H_R	$44.85\ m$
τ_R	$28.11\ N \cdot m$
ω_R	$483.8\ m^3/s$
ρ_R	$321.9\ kg/m^3$
Q_R	$4.893\ E{-3}\ m^3/s$

$\nu = Q/Q_R$ (4)
$\alpha = \omega/\omega_R$ (5)
$h = H/H_R$ (6)
$\beta = \tau/\tau_R$ (7)

Table 2: Homologous Curve Values

ν/α	h/α^2	β/α^2
0.0	0.0	0.0
0.657	3.179	0.906
1.0	1.0	1.0

Table 3: Homologous Curve Values

α/ν	h/ν^2	β/ν^2
0.0	0.0	0.0
0.657	0.0508	0.604
1.0	1.0	1.0

Two tests with different boundary conditions were executed, one with a pressure boundary on the inlet and outlet, the other with a mass flow rate boundary on the inlet and a pressure boundary on the outlet.

Table 4: Pressure Boundary Result

	Mass Flow Rate
Experiment	1.3417 kg/s
MARS	1.1020 kg/s

Inlet Pressure: 8.020 MPa
Outlet Pressure: 8.271 MPa
Inlet Temperature: 39.43°C
Outlet Temperature: 42.68°C
Mass Flow Rate Difference: 17.87%

Table 5: Mass Flow Rate Boundary Result

	Experiment	MARS
Inlet P	8.020 MPa	8.160 MPa
Pressure Ratio	1.031	1.014
Inlet T	39.43°C	41.04°C
Outlet T	42.68°C	43.69°C

Outlet Pressure: 8.271 MPa
Mass Flow Rate: 1.3420 kg/s
Pressure Ratio Difference: 1.65%
Δ P Difference: 55.78%

3.2 Loop

The SCO_2PE is nodalized as follows.

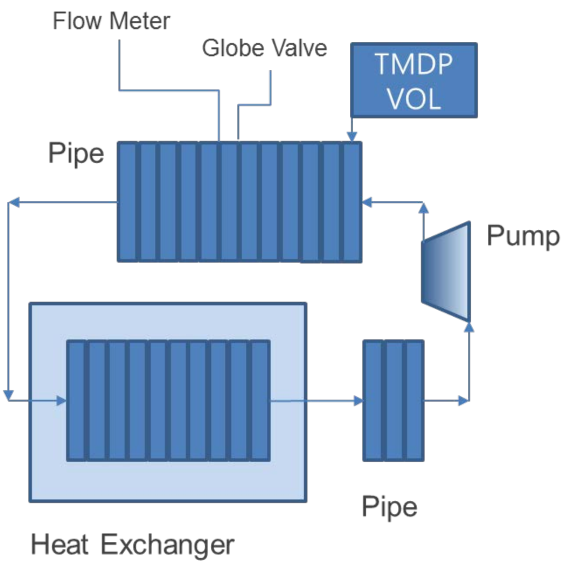

Fig. 2. Nodalization Model of SCO_2PE

Total length of the pipe without the compressor and heat exchanger is 9.983 m and pipe area is 1.140e-3 m^2. A time dependent volume was added to stabilize the pressure of the system. Form loss coefficients were given as the following table.

Table 6: Form Loss Coefficient

Threaded 90° elbow	1.5
Globe Valve	101.0
Flow Meter	7.0

The heat exchanger was nodalized with a pipe for the tube containing CO_2 and a time dependent volume for the shell containing water. The pipe was divided into 10 volumes and properties of stainless steel 316 was used. The specification of the heat exchanger is as follows.

Table 7: Heat Exchanger Specification

Area	9.428e-4 m^2
Total Length	21.221 m
Form Loss	34.2

Results of the loop computation is as following.

		Exp.	MARS	Diff.
Pump Inlet	P	8.315 MPa	8.309 MPa	0.07%
	T	312.99 K	313.80 K	0.26%
Pump Outlet	P	8.608 MPa	8.611 MPa	0.03%
	T	315.12 K	317.40 K	0.72%
HX Inlet	P	8.406 MPa	8.408 MPa	0.02%
	T	314.01 K	315.46 K	0.46%
HX Outlet	P	8.323 MPa	8.315 MPa	0.10%
	T	312.99 K	313.90 K	0.29%
Mass Flow Rate		1.5725 kg/s	1.1617 kg/s	26.15%
Power		10.70 kW	9.63 kW	10.0%

4. Summary and Further Works

A MARS base input deck was created for SCO_2PE. The compressor performance was checked by comparing experimental results with computational results from MARS. Then the loop performance was validated preliminarily.

Since MARS is mainly constructed for two phase flow modeling and the correlation package is based on water, we should check how well current MARS can simulate supercritical CO_2 system. Any alternatives that can draw more accurate results should be checked for. Also, additional experiments should be executed in different temperature and pressure ranges.

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