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Validation of the Modified MARS Code for Modeling of $S\text{-}CO_2$ Cycle Using Compressor Test Results from KAIST

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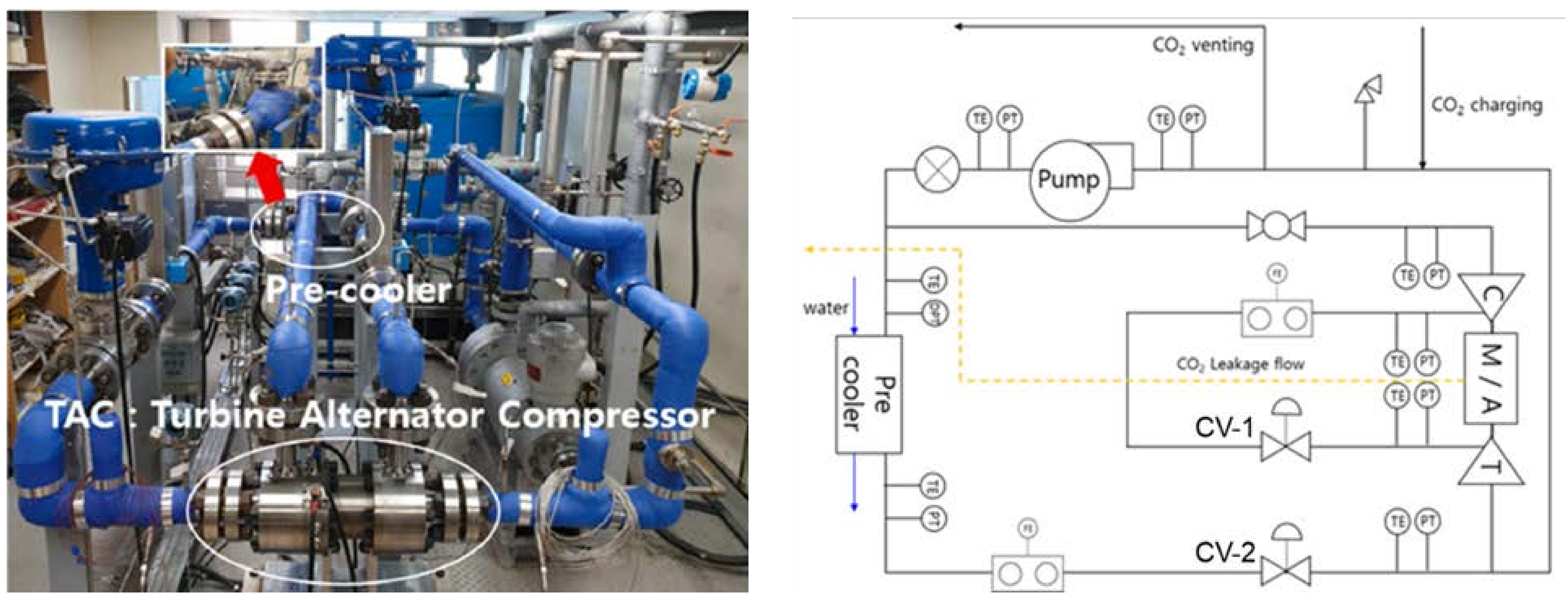
Introduction

- ✓ Recently, the supercritical carbon dioxide cycle ($S\text{-}CO_2$) has attracted attention as the next generation power conversion system of nuclear power plants.
- ✓ There have been many studies to apply the $S\text{-}CO_2$ cycle to pressurized light water reactors (PWR) as well as high-temperature gas reactors (HTGR).
- ✓ To analyze thermal hydraulic phenomena in normal operation and abnormal conditions of nuclear systems, a system analysis code is required.
- ✓ Most nuclear thermal hydraulic codes are focused on safety analysis and the modeling of the power system is not their strength.
- ✓ However, due to the growing demand for load-following operations on nuclear systems, not only the accident analysis but also the performance analysis of the power conversion system has become important.
- ✓ In this paper, validation of the modified MARS code has been performed through comparison with the results of the compressor performance test conducted at KAIST.

S-CO2 Compressor Test

➢ Test facility and compressor performance test

- ✓ The below figure shows the $S\text{-}CO_2$ compressor test loop installed in KAIST. As shown in the figure, this facility is constructed with the $S\text{-}CO_2$ turbo alternator compressor (TAC) and a cooling loop.
- ✓ Design conditions of the compressor are summarized in the below table. The target pressure ratio is 1.3 and mass flow rate is 3 kg/sec.



▲ Compressor performance test loop in KAIST and schematic diagram

- ✓ Although equipped with TAC, the compressor performance test was performed without the turbine to carry out experiments step by step.

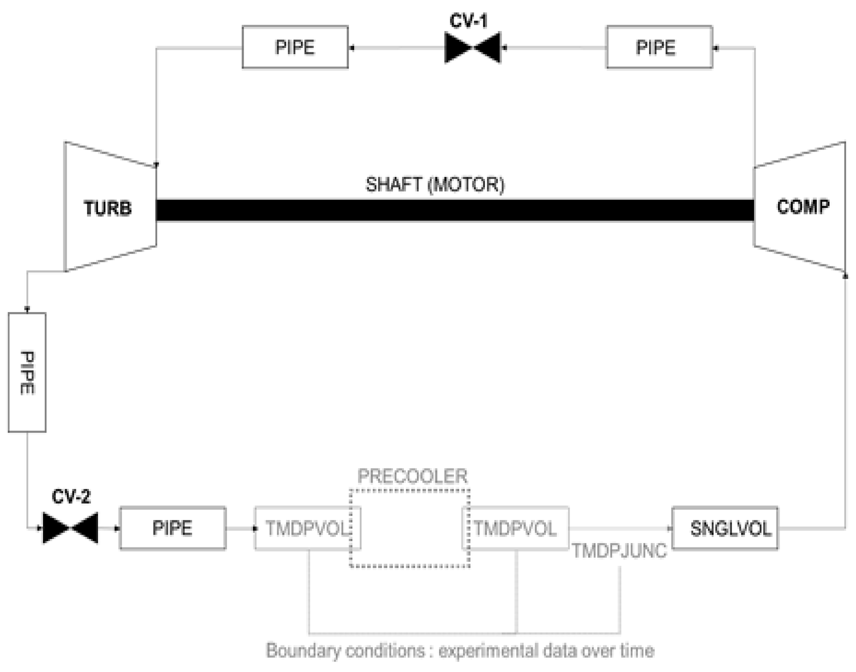
Pressure ratio	1.3
Inlet total temperature	31.36 ℃
Inlet total pressure	7599 kPa
Efficiency	56 %
Rotating speed	40,000 rpm

▲ Design condition of KAIST compressor

- ✓ Therefore, the $S\text{-}CO_2$ flow within the experimental loop is compressed through the compressor and expanded through two control valves (CV).
- ✓ The water flow rate in cooling part was controlled to maintain the inlet conditions of the $S\text{-}CO_2$ compressor.
- ✓ Experiments were conducted for three rpm cases: 32,000 rpm, 36,000 rpm, and 40,000 rpm. The compressor performance was measured by adjusting the opening fraction of control valves at each rpm.
- ✓ For each rpm case, the CV-1 opening fraction was set to 10% and the CV-2 opening fraction was reduced from 100%.
- ✓ In this study, the data obtained when the valve opening area of CV-2 was changed from 100% to 50% for 36,000 rpm is compared to the MARS-KS simulation results.

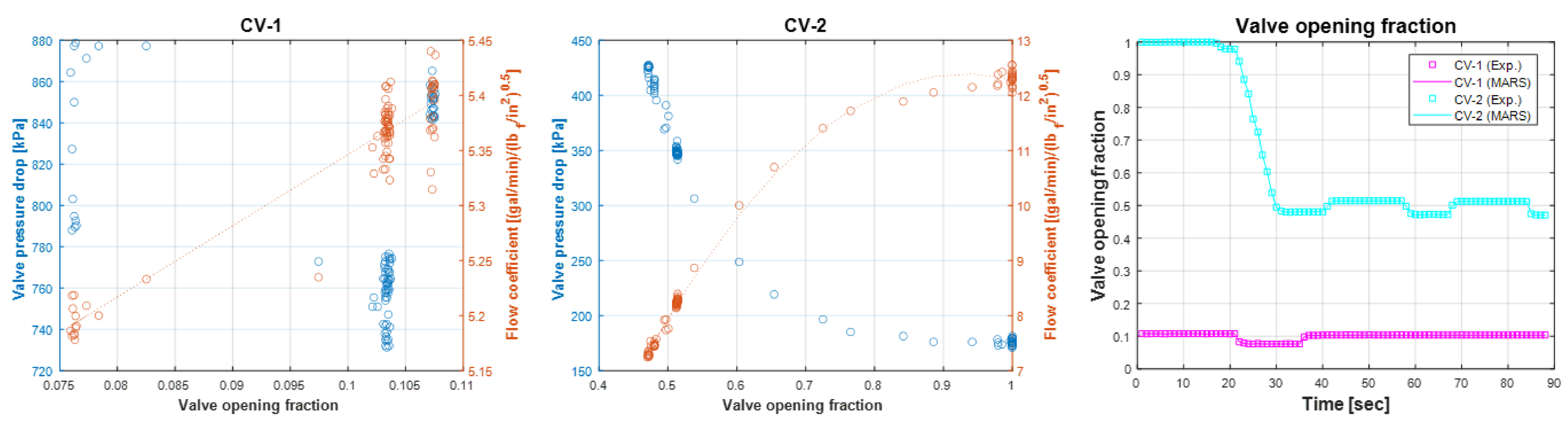
MARS Code Modeling

- ✓ The authors previously modified the MARS code to model the $S\text{-}CO_2$ cycle as follows.
- ✓ First, the NIST property data program was linked to accurately calculate rapidly changing CO_2 properties near the critical point.
- ✓ Second, the printed circuit heat exchanger (PCHE) correlation was added to the heat structure.
- ✓ Third, the turbomachinery model was modified to correctly model the pressure ratio and the isentropic efficiency of a turbomachinery via off-design performance map.
- ✓ Figure shows the nodalization diagram of MARS code input for the compressor test facility.
- ✓ The cooling part was treated as boundary conditions and only the $S\text{-}CO_2$ flow part was modeled.
- ✓ The compressor is modeled with the off-design performance map derived from the performance test results.

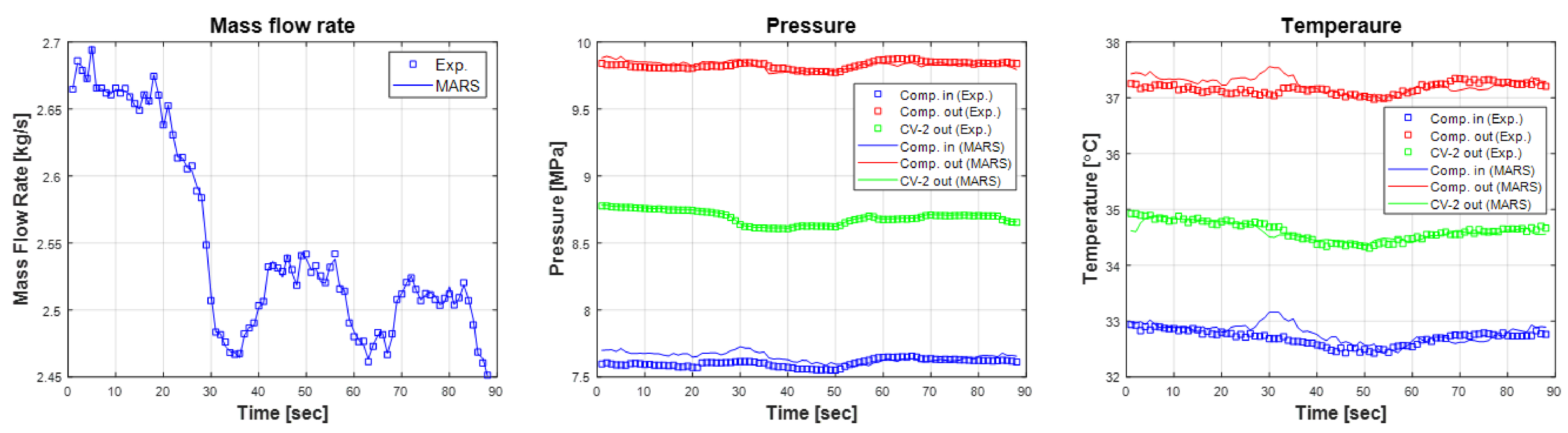


▲ MARS modeling for compressor test facility

- ✓ Two control valves were modeled as a servo valve, and the flow coefficient for the normalized valve area of each valve was calculated from the measured pressure loss as shown in the below figure.



▲ Flow coefficient for normalized area of each control valve and opening fraction over time



▲ Comparison of experimental data and simulation results

- ✓ The above figure show the comparison of the MARS code simulation results to the experimental results. In some areas, there is a slight difference in temperature and pressure values at the inlet and the outlet of the compressor.
- ✓ This seems to be caused by the uncertainty propagation of temperature and pressure to enthalpy since the experiment was performed in a region very close to the critical point.
- ✓ This is expected to be confirmed again by simulating the experimental results in the region relatively far from the critical point in the future. The simulated mass flow rate, pressure, and temperature show generally good agreement with the experimental results.

Summary and Further Works

- ✓ In this study, the $S\text{-}CO_2$ compressor test loop was modeled and a transient simulation was conducted to validate the modified MARS-KS code.
- ✓ In the future, safety and performance analysis of the nuclear system with the $S\text{-}CO_2$ cycle will be carried out using the modified MARS-KS code.

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