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Study for Automatic Control Logic for Supercritical CO_2 Cycle

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1. Introduction

A supercritical CO_2 (S-CO_2) power cycle is a compact and efficient power conversion system, and researchers from a wide range of application, including gas turbine, fossil fuel and nuclear, are paying attention. Supercritical state is a state, where distinction between liquid and gas states disappear above critical pressure and temperature. In critical state, a fluid has gas-like small surface tension and viscosity, but has liquid-like relatively large density. Especially, the reduced compression work near the critical point facilitates compression process with minimized power consumption [1]. The S-CO_2 power cycle uses supercritical state CO_2 as a working fluid, resulting high power conversion efficiency and compact layout with economic advantages.

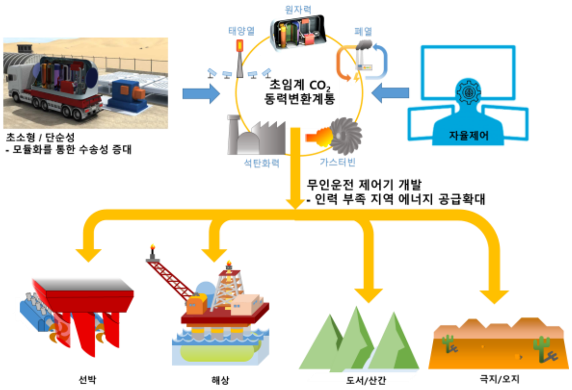

Fig. 1. Possible application of S-CO_2 power cycle with autonomous control

Fig. 2. S-CO_2 coupled distributed power system concept diagram (KAIST-MMR) [2]

Nowadays, as environmental concerns rise, there is a demand for innovation in the field of power generation and propulsion. Furthermore, the expansion of renewable energy expedites the decentralization of power system. A distributed power system can serve as an independent power source in electrically isolated region. The key feature of distributed power system is a load-following capability due to fluctuation of electricity demand.

The S-CO_2 power cycle is expected to be able to operate as a distributed power source because the system has simple layout and high power density. Moreover, autonomous control logic can make it possible to cover the electricity variation without intervention by operators.

The S-CO_2 cycle shows different performance according to controller position, gain, and input speed. Thus, it is necessary to consider system response characteristic while designing controller. Currently, the study for dynamic characteristics of the S-CO_2 system is at an early stage all over the world. Most of the studies have been conducted through analysis, but it is crucial to demonstrate control logics with experiment loop. In this research, the control logic for S-CO_2 power cycle is studied with an existing S-CO_2 compression loop.

2. Methods and Results

2.1 Experimental setup

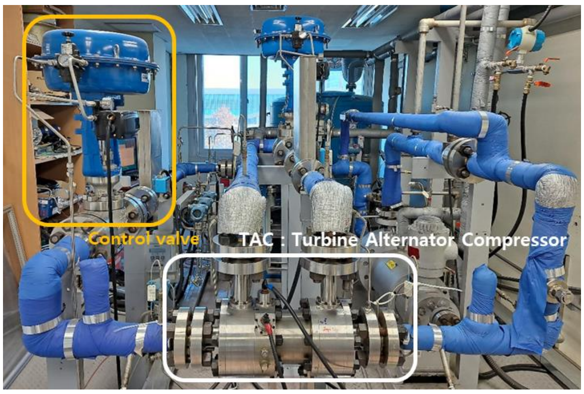

Fig. 3. S-CO_2 compression test loop (SCO_2PE) [3]

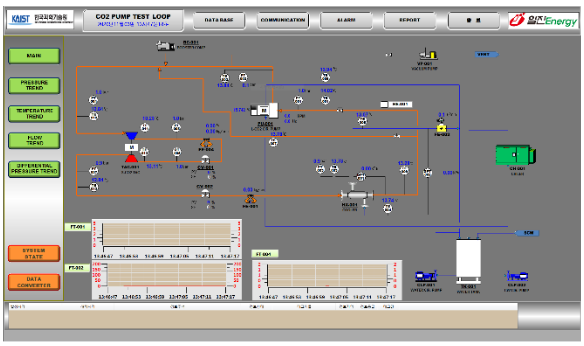

Fig. 4. System control panel display

The test loop consists of TAC (Turbine-Alternator-Compressor), heat exchanger, chiller, and two automatic flow control valve [3]. In this experiment, it is intended to maintain mass flow rate by changing valve opening fraction. Control panel displays mass flow rate, temperature and pressure in the test loop as shown in Fig 4. Valve opening fraction can be manipulated between 0-100% by 1%. PID (Proportional, Integral, and Derivative) control logic was implemented by Python library.

2.2 Analysis code – GAMMA+

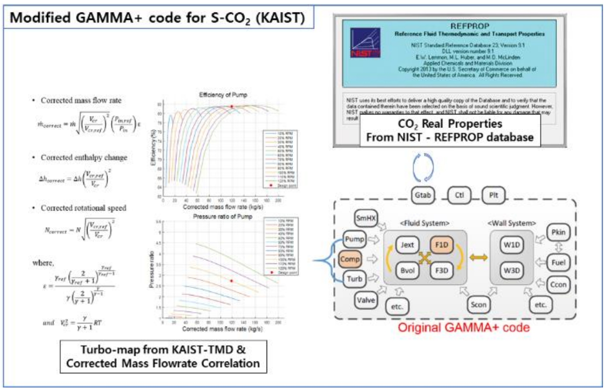

Fig. 5. Components of modified GAMMA+ code

Experiment results was compared with GAMMA+ code. GAMMA+ code was developed for accident analysis of high temperature gas-cooled reactor originally in KAERI [4]. Later, the code was modified to analyze the performance and dynamic characteristic of S-CO$_2$ system in KAIST research team [5].

2.3 Comparison results

The experiment was conducted at 20℃, 50bar condition. Considering valve operating speed, new valve opening fraction was given every five second. Two experiment cases were carried out. In Test 1, the mass flow rate was 0.27kg/s at first, but when automatic control was activated, the system was control to achieve and maintain the mass flow rate of 0.2kg/s as shown in Figs 6 and 7.

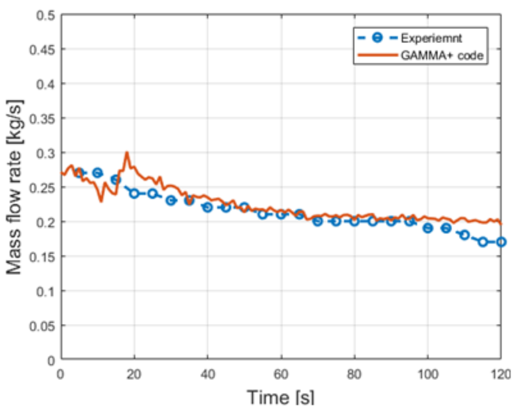

Fig. 6. Mass flow rate (Test1 1)

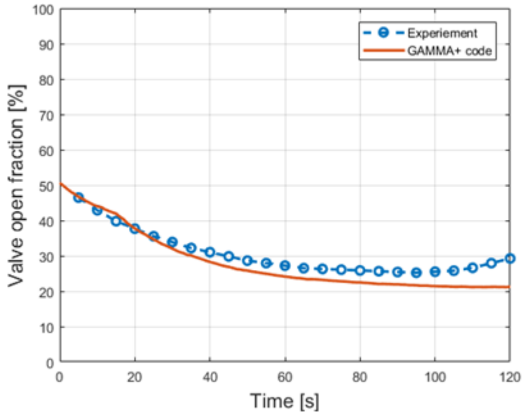

Fig. 7. Valve opening fraction (Test 1)

In Test 2, compressor rotational speed was changed from 10,000 to 13,000 rpm at 220s. As a result, the mass flow rate was raised abruptly, but soon it was stabilized to 0.17kg/s because of valve opening fraction change as shown in Figs 8 and 9. Additionally, the test results were compared with the analysis results by GAMMA+. Provided that the code and experiment results present good agreements, it might be possible to simulate the control logic and dynamic response of CO$_2$ system.

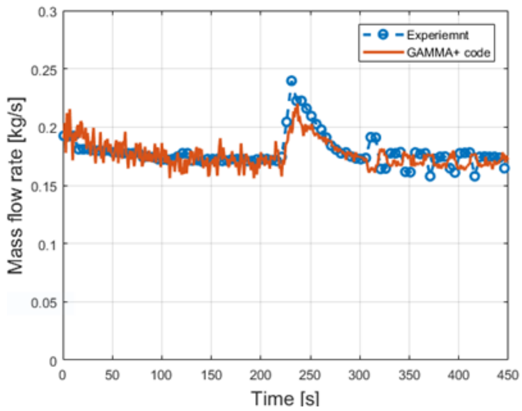

Fig. 8. Mass flow rate (Test 2)

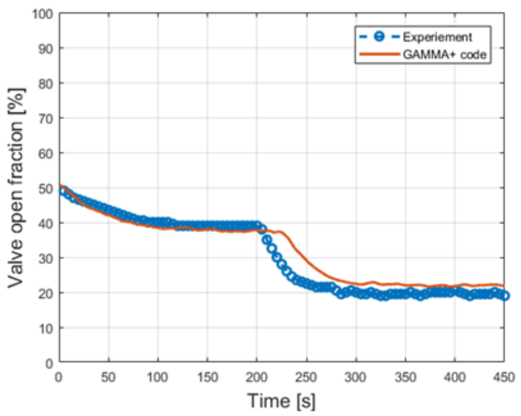

Fig. 9. Mass flow rate (Test 2)

3. Summary and conclusions

To achieve load-following capability and to realize the distributed power source, it is necessary to investigate the dynamic characteristics and control logic for the S-CO_2 cycle. Majority of the existing studied are based on code analysis. Since control logic demonstration on actual system has an important role, the experimental study should be carried out.

In this paper, valve control logic was implemented for S-CO_2 test loop to control and maintain mass flow rate. The test results were compared with the results by GAMMA+ code, which shows good agreements. Therefore, it is expected to study control logic and dynamic characteristic of S-CO_2 with GAMMA+.

REFERENCES

[1] Ahn, Yoonhan, et al. "Review of supercritical CO2 power cycle technology and current status of research and development." Nuclear Engineering and Technology 47.6 (2015): 647-661.
[2] Kim, Seong Gu, et al. "A concept design of supercritical CO2 cooled SMR operating at isolated microgrid region." International Journal of Energy Research 41.4 (2017): 512-525.
[3] Cho, Seong Kuk, et al. "Optimum loss models for performance prediction of supercritical CO2 centrifugal compressor." Applied Thermal Engineering 184 (2021): 116255.
[4] Lim, H. S. General Analyzer for Multi-component and Multi-dimensional Transient Application, GAMMA+ 1.0 Volume II: Theory Manual. KAERI/TR-5728/2014, 2014.
[5] Oh, Bong Seong, et al. "Safety evaluation of supercritical CO2 cooled micro modular reactor." Annals of Nuclear Energy 110 (2017): 1202-1216.