Numerical Analysis of S-CO_2 Test Loop Transient Conditions near the Critical Point of CO_2

Seong Jun Bae [a], Bongseong Oh[a], Yoonhan Ahn[a], Seongjoon Baik[a], Jekyoung Lee[a], Jeong Ik Lee[a*]
[a]*Dept. Nuclear & Quantum Eng., KAIST, 373-1, Guseong-dong, Yuseong-gu, Daejeon, 305-701, Republic of Korea*
[*]*Corresponding author: jeongiklee@kaist.ac.kr*

1. Introduction

A supercritical carbon dioxide (S-CO_2) Brayton cycle is being considered as a promising power conversion system that shows promise for a wide range of applications, such as next generation nuclear system, high temperature fuel cells, combined cycle power plant, concentrated solar power, etc [1-5]. It was identified that controlling CO_2 compressor operation near the critical point is one of the most important issues to operate a S-CO_2 Brayton cycle with a high efficiency. Despite the growing interest in the S-CO_2 Brayton cycle, a few previous research on the transient analysis of the S-CO_2 system has been conducted previously [6-8]. Moreover, previous studies have some limitation in the modelled test facility, and the experiment was not performed to observe specific scenario. The KAIST research team has conducted S-CO_2 system transient experiments with the CO_2 compressing test facility called SCO2PE (Supercritical CO2 Pressurizing Experiment) at KAIST In this study, authors use the transient analysis code GAMMA (Gas Multidimensional Multicomponent mixture Analysis) code for analyzing the experiment.

Two transient scenarios were selected in this study; over cooling and under cooling situations. The tests were conducted in the SCO2PE by decreasing or increasing the mass flow rate of cooling water line of SCO2PE. Before the whole SCO2PE loop is simulated, major components, the compressor and the heat exchanger, were separately modeled.

2. The modeling of SCO2PE with GAMMA code

Main components of SCO2PE, the canned motor type compressor and the printed circuit type heat exchanger, need to be separately modelled with the information from the SCO2PE before the loop was simulated. The modelled components were verified with the experimental data, and then the whole SCO2PE loop was finally modelled as shown in Fig. 1. The figure shows the nodalization of the facility with the steady-state operating condition comparison between the experimental data and GAMMA analysis at each point, the compressor inlet and outlet, and the heat exchanger inlet. The modelling result shows that the GAMMA code can simulate the SCO2PE condition under steady-state quite well compared with the experimental data.

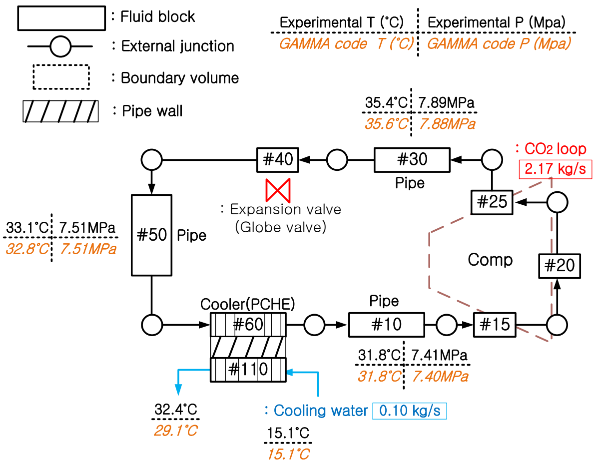

Fig 1. Nodalization of SCO2PE loop for GAMMA code and the steady-state operating condition comparison

3. Validation of the GAMMA code with SCO2PE data

The experimental tests were performed under the selected scenarios by adjusting the cooling water flow rate over time while monitoring the changes in operating condition.

3.1 Under cooling situation

The cooling water decrease case (cooling water 0.1→0 kg/s) was conducted without any specific problems not only for the experiment, but also for the GAMMA code analysis. Fig. 2 shows that the cooling water and CO_2 mass flow rates variation versus time. Fig. 3 and 4 separately represent the pressure and temperature comparisons between the GAMMA analysis and experimental data in accordance with the cooling water variation in Fig. 2.

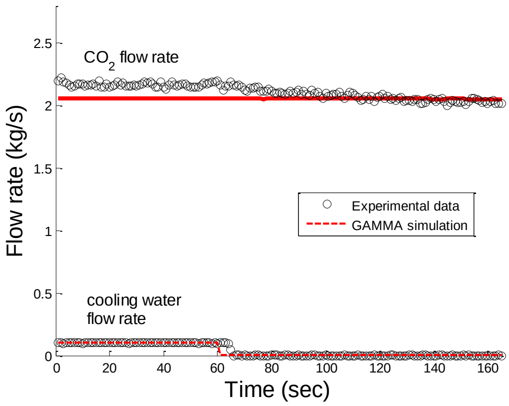

Fig 2. Transient mass flow rate data comparison between experiments and GAMMA code for transient state (Under cooling scenario)

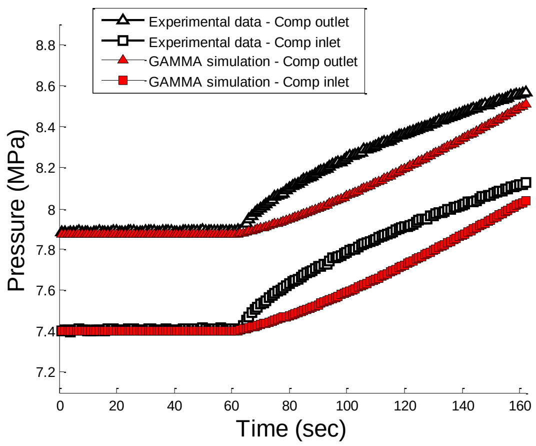

Fig 3. Transient pressure data comparison between experiments and GAMMA code for transient state at the CO_2 side of SCO2PE (Under cooling scenario)

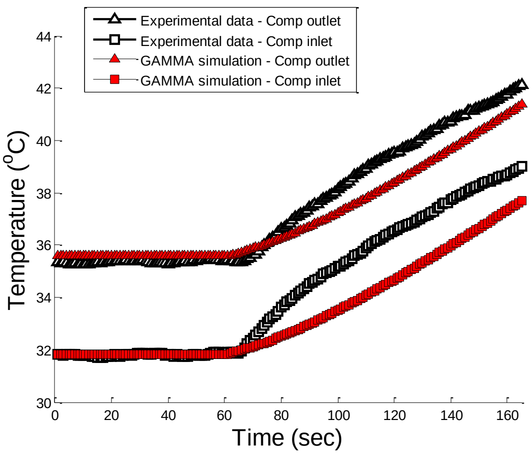

Fig 4. Transient temperature data comparison between experiments and GAMMA code for transient state at the CO_2 side of SCO2PE (Under cooling scenario)

3.2 Over cooling situation

In case of the cooling water rise scenario, since the operating condition of the compressor inlet is quite close with the critical point of CO_2, the compressor operation goes through the 2-phase condition of CO_2.

It is noteworthy that although the loop condition moved through the phase change during the experiment, there were no particular noticeable indications such as excessive noise or unusual vibration, etc. However, the transient analysis could not be carried out when the cooling water mass flow rate increases about the twice (0.10→0.21 kg/s) of the steady state value due to errors.

Fig. 5 shows the T-s diagram of the experimental data and GAMMA analyses results for two transient scenarios at the compressor inlet.

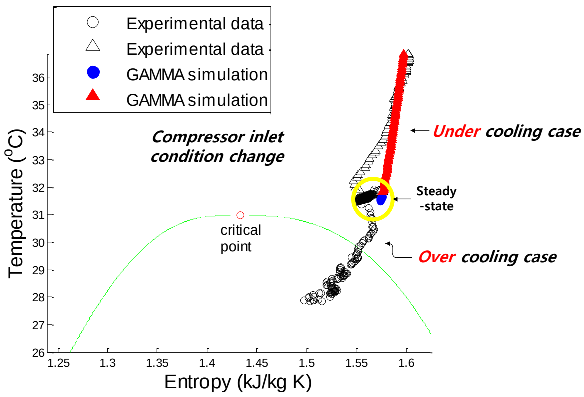

Fig 5. The T-s diagram of the experiment and GAMMA analyses according to the transient scenarios at the compressor inlet point

4. Conclusions

The S-CO_2 system transient experiment and analysis were conducted with the S-CO_2 compressing test facility in KAIST, SCO2PE, and the gas system transient analysis code, GAMMA. The selected transient scenarios are related with the cooling system performance change; the reduction of cooling water flow rate event and the increased cooling water flow rate case. The selected transient situation is of particular interest since the compressor inlet conditions start to drift away from the critical point of CO_2.

The results represent that the GAMMA code can simulate the S-CO_2 test facility, SCO2PE. However, as shown in the cooling water flow rate increasing scenario, the GAMMA code shows calculation error when the phase change occurs. Furthermore, although the results of the cooling water flow rate decrease case shows reasonable agreement with the experimental data, there are still some unexplained differences between the experimental data and the GAMMA code prediction.

To reduce the differences and remove the 2-phase error issue, the update of GAMMA code is necessary in the future.

ACKNOWLEDGEMENT

This work was supported by the On Demand Development Program of Core Technology for Industrial Fields (10054621, Development of a FEED Framework for Next Generation Power System using Pilot Plant) funded By the Ministry of Trade, industry & Energy(MI, Korea)

REFERENCES

[1] V. Dostal, M. J. Driscoll, P. Hejzlar, A Supercritical Carbon Dioxide Cycle for Next Generation Nuclear Reactors, MIT-ANP-TR-100, 2004

[2] H. J. Yoon, Y. Ahn, J. I. Lee, Y. Addad, Potential advantages of coupling supercritical CO2 Brayton cycle to water cooled small and medium size reactor, Nucl. Eng. Des. 245, 223-232, 2012

[3] Y. Ahn, J. I. Lee, Study of various Brayton cycle design for small modular sodium-cooled fast reactor. Nucl. Eng. Des. 276, 128–141, 2014

[4] Y. Ahn, J. I. Lee, Study of Various Brayton Designs for Small Modualr Sodium-cooled Fast Reactor, Nuclear Engineering and Design, Vol. 276, 128-141, 2014

[5] W. S. Jeong, J. I. Lee, Y. H. Jeong, Potential improvements of supercritical recompression CO2 Brayton cycle by mixing other gases for power conversion system of a SFR, Nucl. Eng. Des., 241, 2128-2137, 2011

[6] M. J. Hexemer, Supercritical CO2 Brayton Recompression Cycle Design and Control Features to Support Startup and Operation, SCO2 Power Cycle Symposium, 2014

[7] K. D. Rahner, S-CO2 Brayton Loop Transient Modeling, SCO2 Power Cycle Symposium, 2014

[8] A. Moisseytsev and J. J. Sienicki, Recent Developments In S-CO2 Cycle Dynamic Modeling And Analysis at ANL, SCO2 Power Cycle Symposium, 2014