A Conceptual Study of Using an Isothermal Compressor on an S-CO_2 Cooled KAIST Micro Modular Reactor (KAIST-MMR)

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1. Introduction

Recently, the energy industry has been focusing on the distributed power generation that allows the supply of electricity to remote regions. The development of small modular reactors (SMR) has been gathering attention due to factory manufacturing, but the power system required for a steam cycle in a water-cooled SMR is significantly large. A new concept called the KAIST Micro Modular Reactor (MMR) has been designed previously to make use of the supercritical CO_2 (S-CO_2) cycle to significantly decrease the size and to improve its cycle efficiency.

To further enhance the advantages of the KAIST-MMR concept, the conventional compressor is replaced with an isothermal compressor in the S-CO_2 cycle. This idea minimizes compression work and further reduces the system size by removing the precooler component. Under the operating conditions of the KAIST-MMR, a new cycle layout is analyzed to justify its potential use.

2. Methods and Results

A new concept for the S-CO_2 Cooled KAIST Micro Modular Reactor (KAIST-MMR) is applying an isothermal compressor to the conventional Brayton cycle layout. The concept of replacing a conventional compressor and a precooler with an isothermal compressor in a Brayton cycle layout is newly named the "iso-Brayton cycle". This is more specifically described in Ref. [1].

Using an isothermal compressor poses significant potential in improving the overall cycle efficiency and decreasing the size of the cycle layout. This is because it minimizes compression work under the isothermal compressor process, and merges two components into one turbomachine.

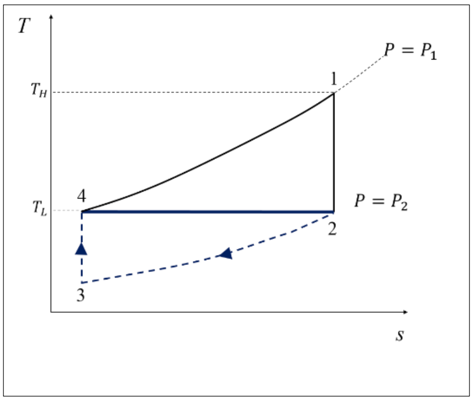
2.1 Definition of efficiency of an isothermal compressor

To analyze the efficiency of the isothermal compressor, a new definition is required because no previous references specify the real work involved in the isothermal compression process. By adopting a new definition for the isothermal compressor efficiency, the following equation can be obtained:

$$\eta_{iso-c} = \frac{w_{iso-c}}{w_{real,a,c}} = \frac{RT_L \ln\frac{P_1}{P_2}}{h_4 - h_3} = \frac{RT_L \ln\frac{P_1}{P_2}}{h_4 - h_{3s}}\,\eta_{a,c} \quad (1)$$

Equation (1) is derived using a two-staged approach to model an isothermal compression process, under ideal gas assumptions. The two-staged approach that divides the process into separate cooling and adiabatic compression processes allows the efficiency of the isothermal compressor to be compared to that of a conventional compressor. This way, a conceptual study of using an isothermal compressor can be facilitated by adopting to cycle analysis frameworks already existing.

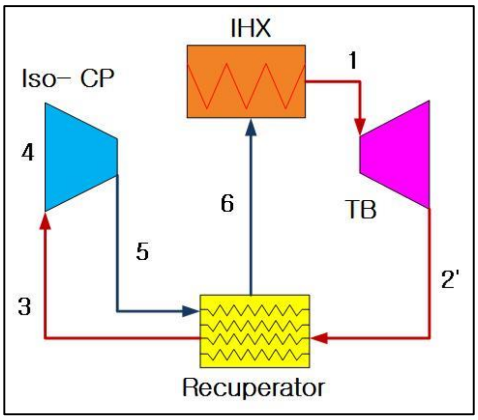
Figure 1 - Two-staged approach to model the isothermal compression process (2-4)



2.2 Formulation of the iso-Brayton cycle for KAIST-MMR

By replacing the compressor and the precooler with an isothermal compressor in the Brayton cycle, a new cycle layout named the "iso-Brayton cycle" is constructed. The reference cycle suggested in the original KAIST-MMR power cycle is a simple recuperated Brayton cycle. Therefore, a newly formed iso-Brayton cycle layout for KAIST-MMR includes a recuperator in the cycle.

Figure 2 - Iso-Brayton cycle layout for KAIST-MMR

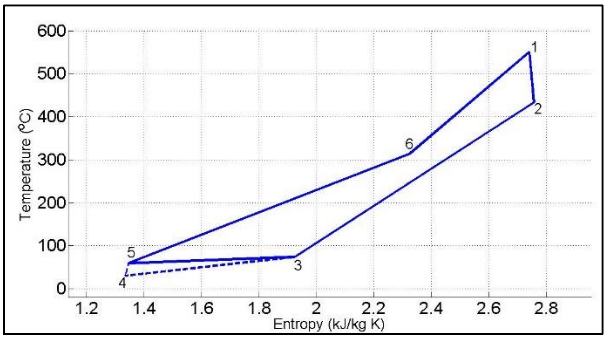


The KAIST-MMR concept has been described in the previous references [2], and according to recent modifications, the operating conditions under the iso-Brayton cycle layout are given in Table 1. Using KAIST-Closed Cycle Design (KAIST-CCD), an in-house code, the cycle pathway is formulated.

Table 1 – Design parameters for KAIST-MMR cycle analysis

Design Parameters	Values
Q (MWth)	36.2
Turbine inlet temperature (°C)	550
Compressor outlet pressure (MPa)	20
Compressor inlet temperature (°C)	60
Pressure ratio	2.59
Turbine efficiency (%)	92.3
Compressor efficiency (%)	85.0
Recuperator effectiveness (%)	94.6
Recuperator pressure drop (hotside) (kPa)	96.7
Recuperator pressure drop (coldside) (kPa)	33.5
Cooler pressure drop (kPa)	89.7
IHX pressure drop (kPa)	50
Generator efficiency (%)	98
Gear reductions loss (%)	2

Figure 3 - T-s diagram of iso-Brayton cycle for KAIST-MMR



2.3 Analysis of the iso-Brayton cycle under KAIST-MMR conditions

Comparing the cycle performance of the simple recuperated Brayton cycle (reference cycle) and the suggested iso-Brayton cycle layout, it can be seen that the cycle net efficiency increases by around 2%. This can be greatly held accountable by the reduced compressor work due to the isothermal compressor and the increased recuperated heat.

Table 2 – Overall cycle performance results for two cycle layouts

	Simple recuperated	Iso-Brayton
Cycle thermal efficiency (%)	33.9	36.4
Cycle net efficiency (%)	32.5	34.9
Compressor Work (MW)	10.18	2.72

3. Conclusions

Although the isothermal compressor technology is not fully matured for commercialization, its potential to reduce the compressor work and the cycle physical size due to the merging of the compressor and the precooler into one turbomachine can be utilized well especially in a concept such as the KAIST-MMR.

Future works include optimization of the cycle layout and parameters to enhance performance, calculation of the heat exchanger sizes, and turbomachinery design of components.

REFERENCES

[1] J. Heo, Y.Ahn, J.Lee, A Study of S-CO_2 Power Cycle for Waste Heat Recovery Using Isothermal Compressor, Proceedings of ASME Turbo Expo 2016, June 13-17, Seoul, South Korea. (Accepted)

[2] S. Kim, S. Baik, J. Moon, H. Yu, Y. Jeong, Y. Kim, J. Lee, Conceptual System Design of a Supercritical CO_2 cooled Micro Modular Reactor, Proceedings of ICAPP 2015, May 3-6, Nice, France.