Performance Estimation of Supercritical CO_2 Micro Modular Reactor (MMR) for Varying Cooling Air Temperature

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1. Introduction

As the concerns about the global climate change gradually increases, the nuclear energy is considered as one of the promising candidates to attain the economics and regulate the CO_2 emission at the same time. In addition, a Small Modular Reactor (SMR) receives interests for the various application such as electricity co-generation, small-scale power generation, seawater desalination, district heating and propulsion. As a part of SMR development, supercritical CO_2 Micro Modular Reactor (MMR) of 36.2MWth in power is under development by the KAIST research team. To enhance the mobility, the entire system including the power conversion system is designed for the full modularization. The system concept and design parameters are shown in Figure 1 and Table 1, respectively.

Based on the preliminary design, the thermal efficiency is 31.5% when CO_2 is sufficiently cooled to the design temperature [1]. However, the S-CO_2 compressor performance is highly influenced by the inlet temperature and the compressor inlet temperature can be changed when the atmospheric temperature varies. To estimate the S-CO_2 cycle performance of MMR in the various regions, a quasi-static system code for S-CO_2 cycle is developed by the KAIST research team.

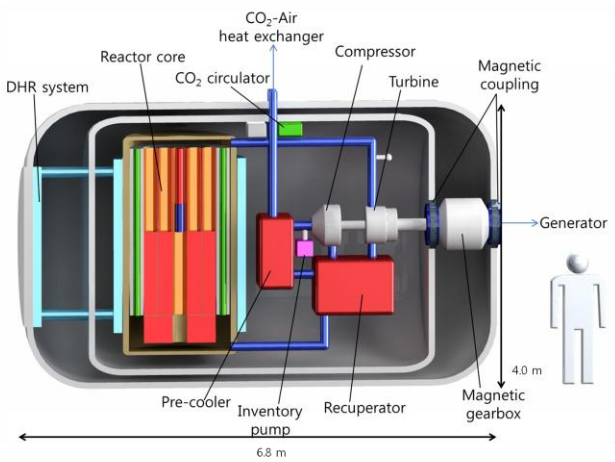

Fig. 1. The module of Supercritical CO_2 MMR system

Table I. The design parameters of Supercritical CO_2 MMR

Thermal power, MW_{th}	36.2	Turbine inlet temperature, °C	550
CO_2 mass flow rate, kg/s	175.8	Compressor inlet temperature, °C	60
S-CO_2 cycle layout	Simple recuperated	Turbine / compressor isentropic efficiency, %	90.7 / 84.1
Thermal efficiency, %	30.9	Recuperator effectiveness, %	93.1
Heat exchanger pressure drops, %	3.3	Turbine / Compressor rotating speed, RPM	20,200
Compressor inlet / outlet pressure, MPa	7.5 / 20	Heat exchanger volume, m^3	0.91

2. Off-design performance of S-CO_2 turbomachineries

To estimate the off-design performance of S-CO_2 turbomachineries, the Sandia National Lab (SNL) experimental results are utilized [2]. Based on the design parameters of S-CO_2 turbomachineries manufactured by Barber & Nichols Inc., the off-design performance of S-CO_2 compressor and turbine is estimated as shown in Fig. 2.

The flow coefficient (Φ) and normalized flow coefficient (Φ_{norm}) are defined as below.

$$\Phi = \frac{Q}{ND^3} \tag{1}$$

$$\Phi_{norn} = \frac{\Phi_{inlet}}{\Phi_{design}} \tag{2}$$

where Q, N, D are volumetric flow rate, rotating speed and impeller diameter, respectively.

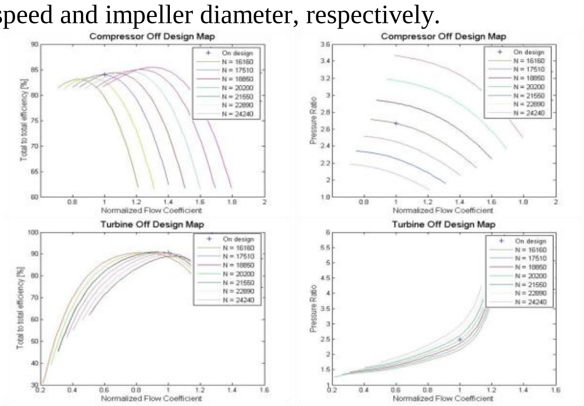

Fig. 2. Off-design performance of $S\text{-}CO_2$ compressor and turbine

3. A quasi-static analysis

With the preliminary component design and performance parameters, a quasi-static system code is developed and its algorithm is shown in Fig. 3. The thermal efficiencies are predicted for the compressor inlet temperature variation as shown in Fig. 4. As the compressor inlet temperature decreases, the thermal efficiency increases. An abrupt decrease in thermal efficiency is shown when the compressor inlet temperature reaches 70^{o}C.

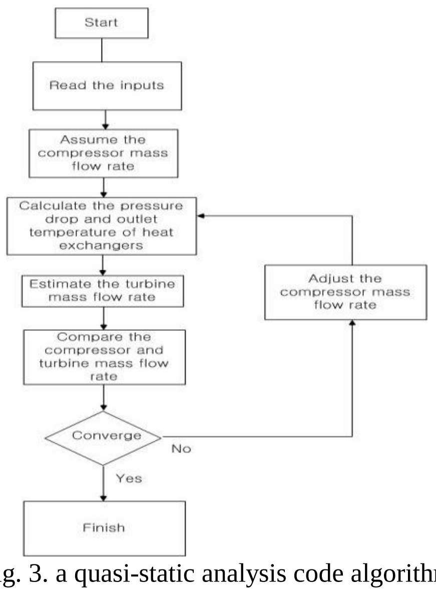

Fig. 3. a quasi-static analysis code algorithm

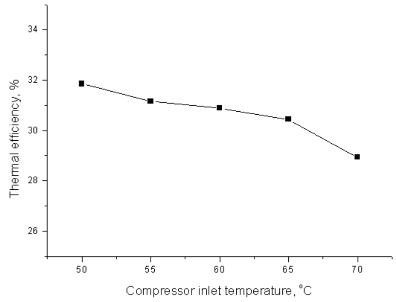

Fig. 4. Thermal efficiency of $S\text{-}CO_2$ cycle with the compressor inlet temperature variation

4. Summary and further works

A supercritical CO_2 MMR is designed to supply electricity to the remote regions. The ambient temperature of the area can influence the compressor inlet temperature as the reactor is cooled with the atmospheric air. To estimate the $S\text{-}CO_2$ cycle performance for various environmental conditions, A quasi-static analysis code is developed. For the off-design performance of $S\text{-}CO_2$ turbomachineries, the experimental result of Sandia National Lab (SNL) is utilized.

However, the turbomachinery performance is based on the SNL experiment facility, only limited information is released. To validate the off-design performance of $S\text{-}CO_2$ turbomachineries, the detailed experiment results are required.

REFERENCES

[1] S. G. Kim, M. G. Kim, S. J. Bae, J. I. Lee, Preliminary Design of S-CO2 Brayton Cycle for KAIST Micro Modular Reactor, Transactions of the Korean Nuclear Society Autumn Meeting, 2013

[2] S. A. Wright, P. S. Pickard, Operation and analysis of a S-CO2 Brayton cycle, SANDIA Report, SAND2010-0171, 2010