Comparison Between helium cycle and Supercritical CO_2 Cycle for MMR & AMR

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1. INTRODUCTION

Due to possibility of having a large scale black out and spreading of small scale power generation with clean energy sources, the demand to reliable distributed power generation is slowly increasing. With this perspective, the Korea Atomic Energy Research Institute (KAERI) started the development of Mobile Multi-Purpose Reactor (MMR), which is a 10MWth gas-cooled reactor. MMR is aiming for maximizing mobility, high performance, durability and safety. This is in order to use the MMR for many purposes such as ship propulsion, train engine and so on. MMR generally uses helium Brayton cycle as a power conversion system since it can obtain very simple system arrangement with direct cycle.

However, some researchers have proposed that the supercritical carbon dioxide (S-CO_2) Brayton cycle can be more efficient energy converting cycle for the high temperature gas cooled reactor (HTGR) and the very high temperature reactor (VHTR) system as well. Thus, this paper is to compare helium Brayton cycle to the S-CO_2 Brayton cycle in terms of the efficiency while varying turbine inlet temperature. A cascaded S-CO_2 cycle which had been proposed by Argonne National laboratory (ANL) [1] was used as the S-CO_2 Brayton cycle configuration. This cycle is to overcome the mismatch of temperature drop between reactor coolant and CO_2 through the reactor heat exchanger (RHX) [1].

Our research team reviewed the ANL research by using the in-house codes developed by the Korea Advanced institute of Science and Technology (KAIST) research team. The calculation error between the in-house code and previous result was -0.36%.

Table I: Comparison of MMR to AMR

	MMR	AMR
Electric capacity (MWe)	~10	~1
Lifetime (years)	5~	10~
Coolant	He, CO_2, Air	Solid (passive) He (dynamic)
Objective	Multi-purpose reactor (electricity, desalination, propulsion, etc.)	Space propulsion application

Furthermore, since KAERI is developing an Autonomous Mini Reactor (AMR) in parallel with MMR for space application, the comparison of helium cycle to S-CO_2 cycle was performed in AMR target condition as well.

2. CYCLE ANALYSIS

2.1 Cascaded S-CO_2 Cycle

To reduce the gap of temperature drop on each sides of the RHX, ANL proposed a cascaded S-CO_2 cycle. This concept is connecting three standard S-CO2 recompression cycles in series. Fig.1 shows the configurations for bottom, middle, and top cascading cycle, respectively [1].

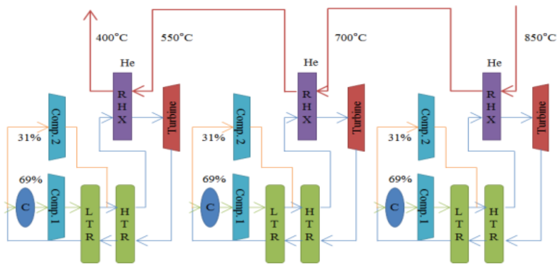

Fig.1 Configuration for bottom, middle, and top cascading cycle [1].

2.2 Comparison of helium cycle to S-CO_2 cycle under MMR condition

The helium Brayton cycle is generally known as the most desirable power conversion cycle for the HTGR. This is because helium is an inert gas which results in less degradation of the structural material and can compose a compact system. The helium cycle also shows good thermal efficiency in HTGR or VHTR condition.

However, the S-CO_2 cycle has advantages over the helium cycle in achieving higher efficiency at the same turbine inlet temperature and the component size can be more compact [2]. Fig.2 shows the thermal efficiency of a cascaded S-CO_2, a helium simple recuperated, a helium single intercooling and a double intercooling Brayton cycles with varying turbine inlet temperature

(T.I.T) [3]. The thermal efficiencies from all layouts are increasing with T.I.T rise. It is worthy of mentioning that the thermal efficiency of the cascaded S-CO_2 cycle was remarkably higher than any other helium cycles without referencing to any T.I.T.

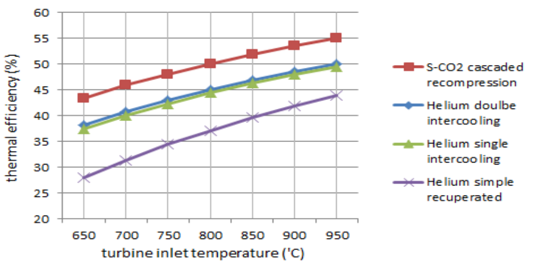

Fig.2 The thermal efficiency vs. T.I.T of different layouts (MMR)

The cascaded S-CO_2 cycle has many components than the others. However, the S-CO_2 cycle has an advantage of achieving remarkably smaller size of the turbomachinery as mentioned earlier [2]. Fig.3 shows the steam, helium and S-CO_2 turbine sizes comparison.

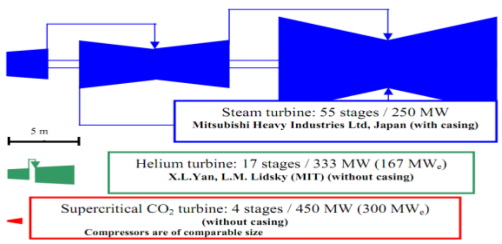

Fig. 3 Comparison of steam, helium and S-CO_2 turbine respectively [2].

2.3 Comparison of helium cycle to S-CO_2 cycle under AMR condition

Because AMR is required to be much smaller than MMR due to its special application, the configuration of AMR should be very compact than MMR. The layout has to be very simple, but still it should achieve the target efficiency. However, smaller the configuration is, more losses result in the power conversion system. To compare the net efficiency, a simple Brayton and a recuperated cycle was tested for S-CO_2 and helium cycles. Fig.4 shows the net efficiency of each layout while varying T.I.T and the target efficiency of AMR is shown in the figure as well. The net efficiency was calculated under the condition of generator efficiency of 98%, mechanical losses of 1%, parasitic losses of 2% and switch yard losses of 0.5% [2]. The S-CO_2 cycle net efficiency achieved the target efficiency when the T.I.T is at 650℃ while helium cycle achieved the target efficiency when the T.I.T is at 850℃.

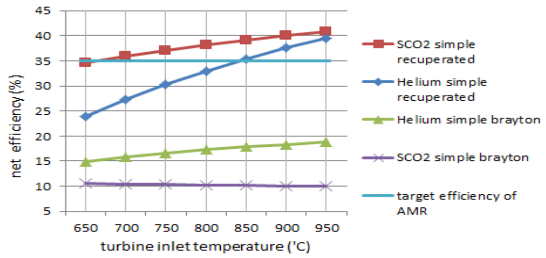

Fig.4 The net efficiency according to the variation of the T.I.T (AMR) and the target efficiency of AMR.

The net efficiency of the S-CO_2 simple recuperated cycle is higher than the others. However, the net efficiency of the S-CO_2 simple Brayton cycle is very low compared to the requperated cycle which clearly shows that the S-CO_2 cycle has to be highly recuperating cycle in nature which is consistent with other researchers findings.

3. SUMMARIES AND FURTHER WORKS

This study shows that the S-CO_2 cycle can achieve higher efficiency at similar T.I.T. Although the S-CO_2 cascaded recompression cycle and simple recuperated cycle may require more components than the corresponding helium cycle, this disadvantage can be overcome by a smaller turbomachinery and heat exchangers [2]. However, more structural material study for the S-CO_2 cycle and optimized layout design should be carried out in the future progressively.

A helium turbomachinery test and a S-CO_2 turbomachinery test are scheduled to be conducted in KAERI in the near future. These experimental results will definitely provide more detail for both cycles and more realistic cycle analysis and component designs can be carried out.

ACKNOWLEDGEMENT

This research was supported by the National Research Foundation of Korea (NRF) and Innovation project of Korea Atomic Energy Research Institute (KAERI).

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