Design of Helium Brayton Cycle for Small Modular High Temperature Gas cooled Reactor

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1. Introduction

The small modular reactor (SMR) is gaining a lot of interest recently. Not only it can achieve better passive safety, but also it can be potentially utilized for the diverse applications to respond to the increasing global energy demands. As a part of the SMR development effort, SM-HTGR (Small Modular-High Temperature Gas-cooled Reactor), a 20MWth reactor is under development by the Korean Atomic Energy Research Institute (KAERI) for the complete passive safety, desalination and industrial process heat application.

The Helium Brayton cycle is considered as a promising candidate for the SM-HTGR power conversion. The advantages of Helium Brayton cycles are: 1) helium is an inert gas that does not interact with structure material. 2) helium is chemically stable that helium Brayton cycle can be utilized under the high temperature circumstance. 3) higher thermal efficiency is achievable under higher outlet temperature range. Moreover, high temperature advantage can be utilized (reinforced) by diverting part of the heat for industrial process heat. This paper will discuss the progress on the helium power conversion cycle operating condition optimization by studying the sensitivity of the maximum pressure, pressure ratio and the component cooling on the total cycle efficiency.

2. Helium Cycle Design

2.1. Cycle layout and analysis method

The Brayton cycle efficiency is highly influenced by the Turbine Inlet Temperature(TIT). For SM-HTGR, the maximum temperature is determined for 850°C and when the process heat is utilized the outlet temperature of a process heat exchanger is 750°C. The direct Helium Brayton cycle is considered for SM-HTGR. To assess the Helium Brayton cycle performance, an in-house Cycle code is developed by KAIST research team and the fluid properties are from NIST.

Fig. 1 shows the layout of SM-HTGR with direct Helium Brayton cycle and with a process Heat Exchanger. To assess the performance of the system, an in-house Cycle code is developed by KAIST research team.

In the cycle, helium flows to a process heat exchanger after absorbing heat from the reactor (point 1). Then, the fluid goes to a turbine and generates electricity (point2). The fluid goes through a recuperator and a precooler (point 3,4,5). The fluid goes to a compressor, (point 5 and the fluid is divided. The major flow goes to a recuperator to recover heat from the turbine outlet flow (point 6). 1% of compressor outlet is diverted to cool the turbine and 0.5% flows to cool the reactor vessel. After the recuperator, the fluid is transported to the reactor (point 7) and completes the cycle. Fig. 2 shows T-S, P-T and H-S diagram of the cycle.

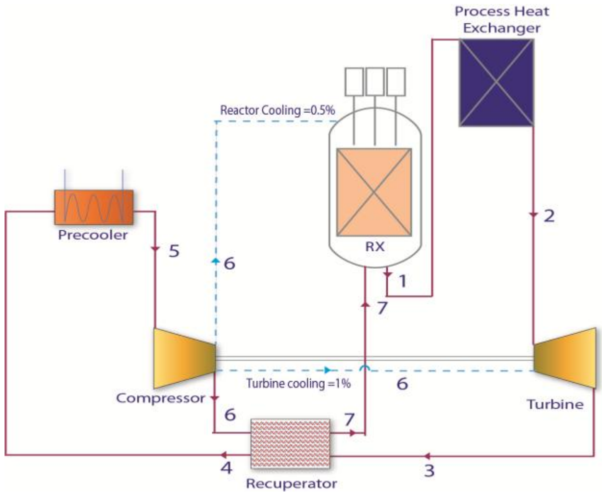

Fig. 1 The layout of SM-HTGR Helium Brayton cycle coupled with a process heat exchanger

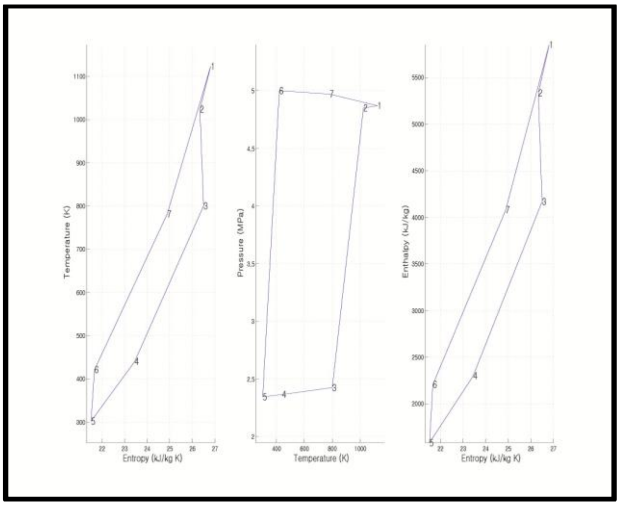

Fig. 2 T-S, P-T and H-S diagram of the cycle

2.2 Maximum pressure and pressure ratio study

The helium Brayton cycle efficiency varies with the cycle maximum pressure (compressor outlet pressure) and pressure ratio. The reference condition is compressor outlet pressure 5MPa, turbine inlet temperature 850°C and turbine pressure ratio of 2.

In Fig.3, the intercooling cycle layouts are compared to the simple recuperated cycle to check the potential of different cycle layout. It is noticed that the thermal efficiencies of the intercooling cycle layouts vary with the recompressing compression pressure ratio. It shows that thermal efficiency is at best increased by 2.3% by adding one more compressor and heat exchanger to the system. However, the simple cycle is preferred in this paper since the total cycle volume will be much smaller which is better for SM_HTGR power conversion system.

Calculating the thermal efficiency for increasing compressor outlet pressure, the cycle efficiency steadily increases as shown in Fig. 3. However, when the outlet pressure is over 5MPa, the efficiency increases less than 0.5 %.

Fig. 4 shows the simple Brayton cycle thermal efficiency for different turbine pressure ratio. Regardless of the maximum pressure, the optimized pressure ratio for the best thermal efficiency is at 1.8.When the turbine pressure ratio is 1.8, the thermal efficiency for the 5MPa cycle is 47.6%.

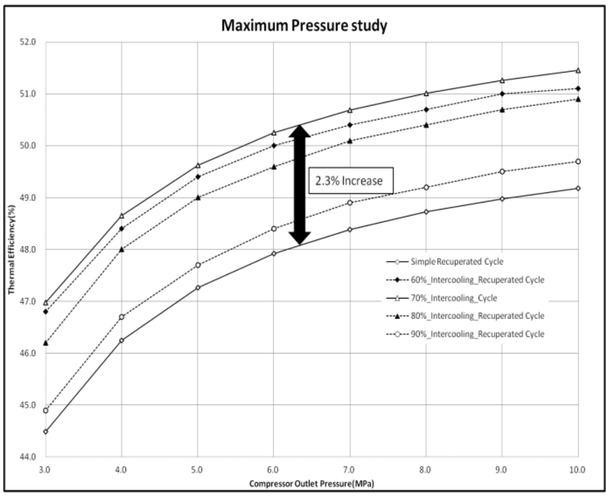

Fig. 3 Thermal efficiency of Simple-recuperated cycleand various intercooling cycle for different pressure ratio split

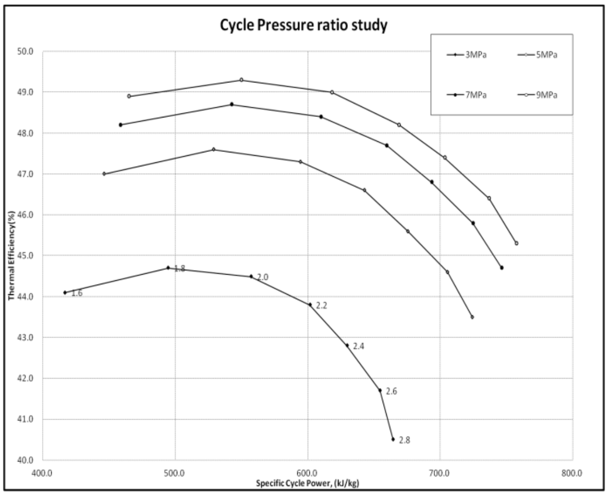

Fig. 4 Thermal efficiency of simple-recuperated cycle varied with specific cycle power

2.3 Turbine and RPV cooling

During the reactor normal operation, SM-HTGR components such as reactor pressure vessel (RPV) and turbine needs to be cooled to extend the lifetime of the structure material. Helium coolant from the compressor outlet is circulated to RPV and turbine for this purpose. The reactor pressure vessel maximum operating temperature is slightly over 300°C and the pressure drop is 60kPa when the power is 100% and the vessel cooling flow is 0.5% for GTHTR-300[1][2]. The turbine cooling flow is 1% and the temperature is assumed to be the turbine outlet temperature. The pressure loss is not determined yet. To cool the turbine and RPV, 0.5% of thermal efficiency is reduced. Further research is required in the future.

3. Summary

Recently Small Modular-High Temperature Gas –cooled Reactor is under development. As a part of the design process, the KAIST team is designing the power conversion unit for the reactor. The reference cycle layout is simple recuperated Brayton cycle and the operating temperature and pressure are 850°C, 5MPa, respectively. The turbine pressure ratio is 2. Sensitivity studies to the cycle maximum pressure and turbine pressure ratio are being carried out as well as more complicated cycle layout is under investigation.

REFERENCES

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