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PCU arrangement of a supercritical CO_2 cooled micro modular reactor

Seong Gu Kim[a], Seungjoon Baik[a], Seong Kuk Cho[a], Bong Seong Oh[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

Small modular reactor (SMR) concepts are being developed in many research institutions since SMRs can offer electricity to the remote region. However, previous SMR concepts based on the water-cooled technologies with a steam Rankine cycle have shown that the complete modularization is still technically challenging. As part of the SMRs development effort, the authors propose a concept of supercritical CO_2 (S-CO_2) cooled fast reactor combined with the S-CO_2 Brayton cycle. The reactor concept is named as KAIST Micro Modular Reactor (MMR) [1]. The S-CO_2 Brayton cycle has many strong points when it is used for SMR's power conversion unit. It occupies small footprints due to the compact cycle components and simple layout. Thus, a concept of one module containing the S-CO_2 cooled fast reactor and power conversion system is possible. This module can be shipped via ground transportation (by trailer) or marine transportation. In this study, the authors propose a new conceptual layout for the S-CO_2 cooled direct cycle while considering various issues for arranging cycle components.

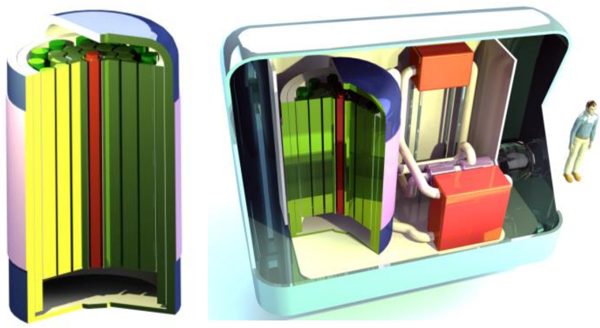

Fig. 1. Conceptual figure of KAIST Micro Modular Reactor.

2. Engineering Issues for PCU arrangement

An arrangement process for S-CO_2 cycle components has to consider several pertinent issues. These principles were established in the previous studies; small and medium sized application of S-CO_2 cycle, and conceptual study of S-CO_2 GFR [2-3].

1) Dimensions of pipe : To avoid excessive pressure drop, pipes and ducts should not be larger than one meter. Especially, sudden expansion at the low pressure turbine outlet leads to a large pressure drop. The length of pipes should be minimized to reduce piping loss

2) Limit in heat exchanger size : The maximum available size of a single printed circuit type heat exchanger (PCHE) is 0.6m(W) x 0.6m(H) x 1.5m(L). Above this size, parallel connections of PCHEs with manifold type ducts, and headers may be required.

3) Grid synchronization : Rotational speed of generator have to be 3,600rpm (2pole) or 1,800rpm (4pole). The reduction gear or transformer with high-speed synchronous generator can be used for turbine-generator coupling.

4) Number of shafts : Separated shafts of multiple turbomachines, motors lead to high cycle efficiency, and low cost. It comes from the flexibility in cycle control, and optimized rotating speed of turbomachines. Otherwise, it results in challenging control issues (control valve, bypass), and bulky footprint.

5) Dispersed or module layout : Most of gas-cooled reactor Brayton cycles are designed to have dispersed layout. Controlling the bypass, check, valves in single vessel will be a challenging task.

6) Number of loops : Most of PWRs have 2 to 4 PCU loops per system (BWRs have single loop). Two or more loops ensure improved safety in transient operation.

However, the MMR has small power rating (11.7MWe). Therefore, two-loop configuration results in high-speed turbomachine with a huge reduction gear and complex cycle layout. The priority goals of MMR are mobility and lightweight. Thus, a simple recuperated cycle (one compressor with one recuperator) was chosen. The recompression cycle is also capable with additional 22 tons of weight in the same module. The comparison was made for simple recuperated, and recompression recuperated cycle as shown in Table 1.

Table 1. Performance comparison of simple recuperated, recompression recuperated layout.

	Thermal efficiency	**Net electricity**	**Mass flow rate**	**Mass of heat exchanger**
Simple recuperated	33.9%	11.8MW	175.7 kg/s	3,977 kg
Recompression recuperated	39.0%	13.6MW	349.6 kg/s	22,606 kg

Table 2. Comparison of pressure drop.

	Pre-cooler	**HTR**	**LTR**	**Total △P in HX**
Simple recuperated	90kPa	Hot 97kPa Cold 33kPa	-	220kPa
Recompression recuperated	70kPa	Hot 70kPa Cold 38kPa	Hot 50kPa Cold 16kPa	244kPa

3. Conceptual layout

The conceptual layout was made based on the simple recuperated cycle. To minimize the duct length, compressor and turbine were installed on the shelf with upward and downward inlet/outlet locations. The volume of heat exchangers was included in the header regions. Turbine shaft is now connected to the magnetic coupling and magnetic reduction gear without hole and seal [5]. The height of the pre-cooler was determined in preparation of natural circulation after the reactor shutdown.

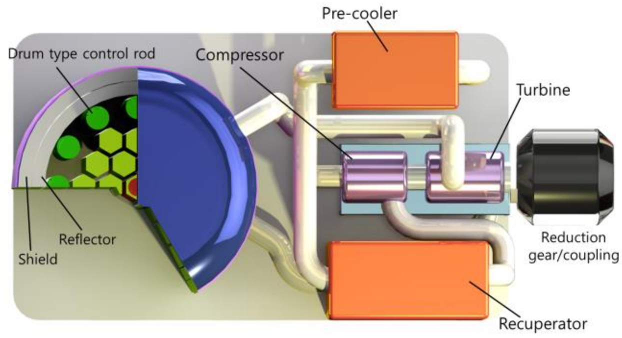

Fig. 2. Top view of PCU with reactor.

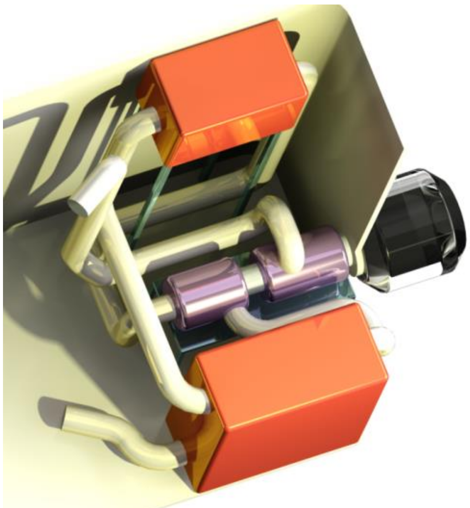
Fig. 3. Isometric view of PCU.

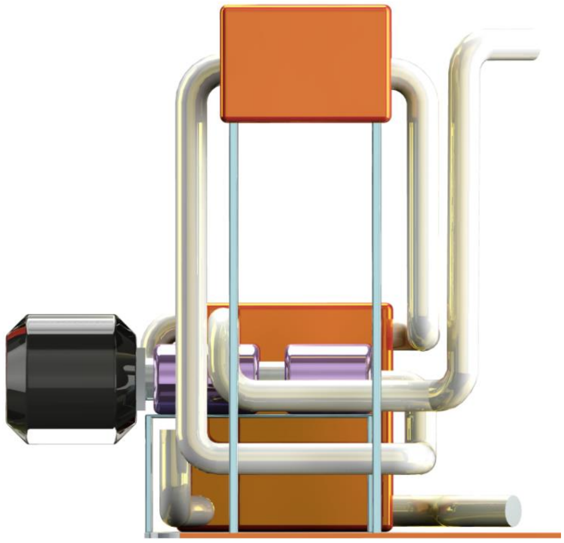
Fig.4. Rear view of PCU.

4. Summary & Conclusion

A new conceptual layout for KAIST MMR was proposed by establishing the component arrangement principles. The new design has an improved cycle efficiency (from 31% to 34%) than the earlier version of MMR [6] by reducing pressure drops in the heat exchangers. As a more efficient option, a recompression recuperated cycle was also designed. It improves 5% of thermal efficiency while 18tons of mass can be added in comparison to the simple recuperated cycle. Even if we adopt recompression cycle as a PCU, the weight of module (152tons) is less than the ground transportable limit (260tons).

As a further works, thermal leakage and radiation leakage will be examined. After that, additional insulation or shielding materials will be designed for the KAIST MMR.

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