Conceptual Design of S-CO_2 Cooled Micro Modular Reactor

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1. Introduction

Nowadays, development of small modular reactor (SMR) which can be factory manufactured and constructed by adding modules came to the fore. Currently, existing SMRs in the world definitely have smaller in size, but still the reactors are not fully modularized. Since most of power conversion system in SMR is a steam Rankine cycle, complete modularization of power generation system is quite difficult. To resolve this problem, an innovative design idea to cool the reactor directly using the fluid in a supercritical state is proposed. Authors suggest application of supercritical CO_2 cycle for power generation system and to obtain total modularization and significant reduction in size. And, most of safety systems of existing SMRs are not designed to be fully-passive for infinite amount of time which the operator cannot walk away during an accident. Therefore, a complete passive safety system is suggested in the conceptual design of KAIST Micro Modular Reactor to overcome this problem. In this paper, supercritical CO_2 cooled micro modular reactor, developed by KAIST, will be described.

2. Supercritical CO_2-cooled Micro Modular Reactor

2.1. Supercritical CO_2 Cycle

Supercritical CO_2 cycle is an innovative power generation cycle, which has small size and high efficiency. As shown in Fig.1[1], turbomachines of supercritical CO_2 cycle are remarkably smaller than those of steam cycle or helium cycle.

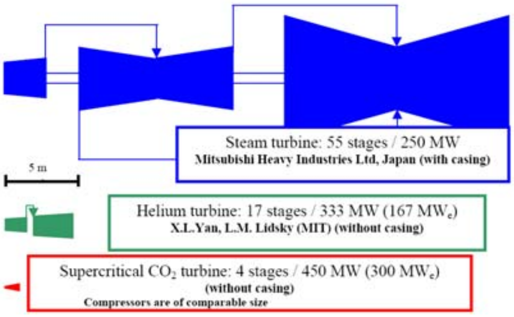

Fig.1 Comparison of turbine sizes for steam, helium and CO_2[1]

Another advantage of the S-CO_2 cycle is that the cycle achieves comparable efficiency with the helium Brayton cycle with much lower turbine inlet temperature (550℃ vs. 850℃) [1]. Thus, this cycle is appropriate for a nuclear reactor, which has core outlet temperature above ~500℃ [1]. The main reason why the S-CO2 cycle can achieve high efficiency is because the compression work is greatly reduced due to sudden property changes near the critical point of CO_2 [1].

2.2. KAIST Micro Modular Reactor

KAIST Micro Modular Reactor (KAIST MMR) is a gas-cooled fast reactor, using supercritical CO_2 as coolant. The overall shape of KAIST MMR is cylindrical. Fig.2-a and 2-b show the cross section of schematic design of KAIST MMR. Fig 2-a shows flow path at the condition of normal operation. Flow path of safety system which operates at abnormal condition is shown in fig.2-b.

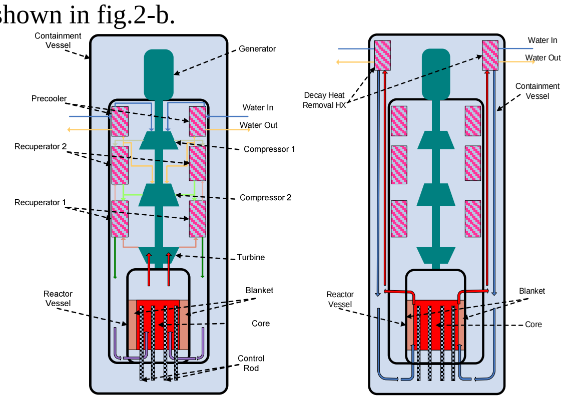

Fig.2 – a, 2 – b Schematic design of KAIST MMR

Recompressing Brayton cycle is chosen for the power generation system of KAIST MMR. Components of cycles are 2 recuperators, 2 compressors, a precooler, and a turbine. Coolant flows through the core, and pass through the turbine. And, coolant follows a series of recompressing and recuperating process, returning back to inlet of the core. Fig.4 shows power generation cycle layout of KAIST MMR.

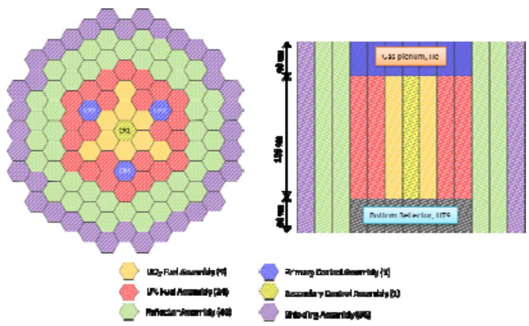

Fig.3 Core layout

Core layout of KAIST MMR is shown in fig.3. The core consists of 33 hexagonal fuel assemblies and 4 control assemblies, and it is surrounded by 48 reflector assemblies and 36 shield assemblies. The reactor power is set to be 50 MWth. The equivalent active core radius is around 88.5 cm and the core active height is 150 cm.

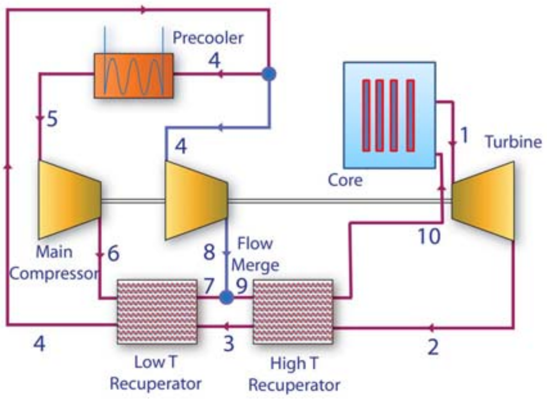

Fig.4 Power generation cycle layout of KAIST MMR

Target specification of KAIST MMR is listed on Table I. Table II shows static points of power generation cycle.

Table I. Specification of KAIST MMR

Cycle Type	Recompressing Brayton Cycle
Power	50MWth
Efficiency	35%
Pressure	15MPa
Core mass flow rate	297.17kg/s
Turbine inlet Temperature	923.15K
Turbine outlet Temperature	786.75K
PCU volume	<$2m^3$
Total Height	<6m

Table II. Static point of power generation cycle

Point	T(℃)	P(bar)	Point	T(℃)	P(bar)
1	650	148.3	6	113.5	150
2	533.4	59.2	7	245.7	149.9
3	246.2	58.3	8	229.7	149.9
4	129.0	57.3	9	240.9	149.9
5	32	57.1	10	513.6	149.6

2.3. Safety systems of KAIST MMR

When a nuclear reactor is turned off during an abnormal operating condition, decay heat has to be removed by safety systems to protect the core. Lessons from the Fukushima accident clearly demonstrate the importance of a passive decay heat removal system. Thus, fully passive decay heat removal system is important in KAIST MMR and authors are currently developing a conceptual design.

So far, the safety system of KAIST MMR is suggested to be divided into two parts to respond to non-LOCA and LOCA type accidents, respectively. The first safety system is a non-LOCA safety system which directly utilizes components from the normal operation. Power Conversion Unit (PCU) of KAIST MMR is used for removing decay heat via turbocharger operation of turbine-compressor connection.

The second safety system is isolated decay heat removal heat exchanger (DHX) for containment and reactor vessel cooling during a LOCA type accident. This system is described in fig.2-b. DHX is connected to the reactor core if there is any leak from the reactor vessel to the containment. The coolant flows from core to DHX directly and decay heat is removed by an established natural circulation flow path. The pressure drop occurred by internal components and complicated flow path is by-passed, which results in reduction of necessary height for natural circulation. Thus, the size of reactor can be further reduced.

3. Summary and Further Works

KAIST MMR is a gas-cooled fast reactor, which is fully modularized and has a very small size. Authors suggested that by using supercritical CO_2 as a coolant of reactor as well as working fluid for power conversion unit. Because the size of turbomachines of the supercritical CO_2 cycle is much smaller than those of existing helium Brayton cycle and steam Rankine cycle, the whole power conversion unit can be integrated with the core inside a reactor vessel. Safety systems of KAIST MMR will be designed to remove decay heat passively for indefinite amount of time. So far two safety systems are being considered to respond to non-LOCA and LOCA accident separately. The non-LOCA safety system will be utilizing the power conversion unit directly by operating the turbine and compressor in a turbocharger mode and adjusting the flow path appropriately. The LOCA safety system will be utilizing a separate heat exchanger located in the containment vessel to cool the whole reactor system by natural circulation.

More detailed design will be followed in the near future to estimate the size of reactor more realistically and evaluate the steady state and transient performances more accurately. For the reactor safety and higher efficiency, operating pressure of reactor will be increased from 15MPa to 20MPa. Cycle and neutronics calculation will be done again. Approximate volume calculation will be done after drawing simple 3-D model of KAIST MMR. The passive safety system design and analysis will be performed after the steady state design is finished.

ACKNOWLEDGEMENT

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REFERENCES

[1] V. Dostal, A Supercritical Carbon Dioxide Cycle for Next Generation Nuclear Reactors, M.I.T. Ph.D Thesis, 2006.