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Preliminary Design of KAIST Micro Modular Reactor with Dry Air Cooling

Seung Joon Baik [a], Seong Jun Bae [b], Seong Gu Kim [b], Jeong Ik Lee [b*]
[a]*Dept. of Mechanical Engineering, KAIST, 373-1, Guseong-dong, Yuseong-gu, Daejeon, 305-701, Republic of Korea*
[b]*Dept. of Nuclear & Quantum Engineering, KAIST, 373-1, Guseong-dong, Yuseong-gu, Daejeon, 305-701, Republic of Korea*
[*]*Corresponding author: jeongiklee@kaist.ac.kr*

1. Introduction

Recently, small modular reactor (SMR) systems are gaining a lot of interest from global community as more attention is given to the world energy issue. Since SMR should be constructed and operated with more flexibility than the existing conventional large nuclear power plant, it is imperative to demonstrate that the proposed SMR can be easily transported and constructed under various conditions.

KAIST research team recently proposed a Micro Modular Reactor (MMR) concept which integrates power conversion unit (PCU) with the reactor core in a single module. Using supercritical CO_2 as a working fluid of cycle can achieve physically compact size due to small turbomachinery and heat exchangers. The objective of this project is to develop a concept that can operate at isolated area. The design focuses especially on the operation in the inland area where cooling water is insufficient. Thus, in this paper the potential for dry air cooling of the proposed reactor will be examined by sizing the cooling system with preliminary approach.

2. Design of air cooling type heat exchanger

2.1 Design Condition

For 10MWe MMR design, it was identified from the previous study that 24.21 MWt of waste heat should be removed [1]. The fluid of heat transfer cycle is also CO_2 because of less risk of leakage and corrosion. The pressure of CO_2 in heat exchanger is determined to be 11MPa to minimize power consumption of circulation.

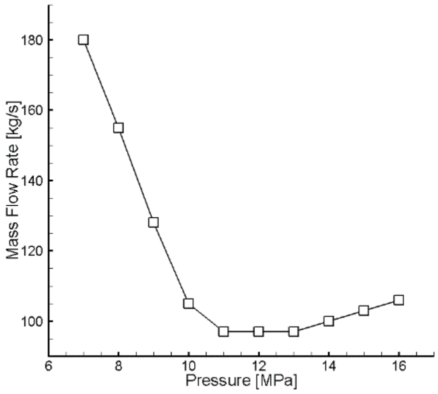


Fig. 1. CO_2 mass flow rate with pressure in heat transfer cycle.

Heat is being delivered by 97kg/s of CO_2 at 11MPa from the precooler. 148.6℃ of CO_2 should be cooled down to 45℃. Ambient air condition is assumed to be at 25℃, 0.101MPa. The power cycle of MMR is described in Fig. 2.

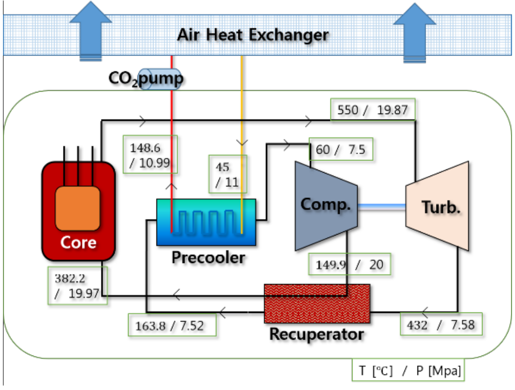


Fig. 2. Schematic of MMR cycle.

Multi pass outer finned tubular heat exchanger is assumed for the CO_2 to air heat exchanger since the selected type can minimize the volume. The reference dry air cooler is from the High-temperature engineering test reactor (HTTR) in Japan [2]. The geometry of 30MWt dry cooling heat exchanger is shown in Fig. 3. Due to the total amount of necessary heat removal capacity, four heat exchangers are required. Each heat exchanger is made of 168 tubes, and weighs about 2.7 ton.

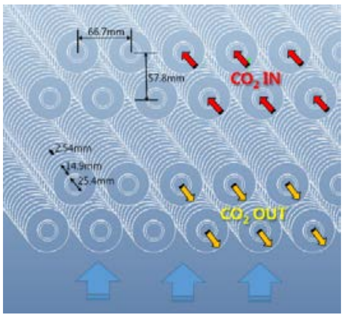


Fig. 3. Schematic of heat exchanger.

2.2 CO_2 to Air Heat exchanger Design

Overall heat transfer coefficient was obtained from Equation (1). Since aluminum has high thermal conductivity, the thermal resistance of wall is neglected. The efficiency of the fin is assumed to be 0.9.

$$\frac{1}{Uc} = \frac{1}{h_h(\frac{A_h}{A_c})} + A_c R_w + \frac{1}{\eta_{oc} h_c} \quad (1)$$

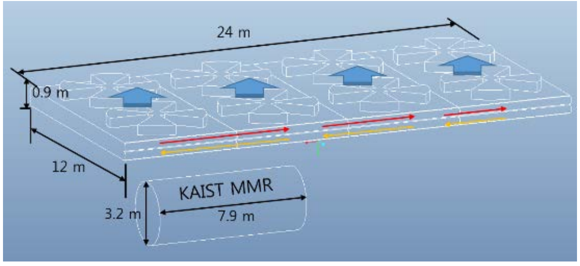
Table I: Parameters of dry cooling heat exchanger

Heat duty (MWt)	24.21
LMTD (℃)	47.75
Overall heat transfer coeff. ($W/m^2{\cdot}K$)	24.05
Heat transfer area (m^2)	26713
Tube side	
Fluid	CO_2
Flow rate (kg/s)	97
Pressure (MPa)	11
Inlet Temp. (℃)	148.6
Outlet Temp. (℃)	45
Flow velocity (m/s)	1.8
Reynolds number	367000
Heat transfer coeff. ($W/m^2{\cdot}K$)	1490
Pressure loss (kPa)	6.53
Air side	
Flow rate (kg/s)	806
Pressure (MPa)	0.101
Inlet Temp. (℃)	25
Outlet Temp. (℃)	54.8
Air mass velocity ($kg/m^2{\cdot}s$)	5.6
Reynolds number	11500
Heat transfer coeff. ($W/m^2{\cdot}K$)	43.5
Pressure loss (Pa)	57

Equation (2) gives the total amount of electricity consumption of the heat transfer cycle's CO_2 circulator which is 3.5kW, assuming average efficiency of the circulator as 0.7. The size of MMR with dry air cooler is shown in Fig. 4.

$$P = \frac{\Delta P\, Q}{\eta} \qquad (2)$$

Fig. 4. Configuration of MMR with CO_2 to air heat exchanger.



2.3 Power requirement for fan cooling

To make enough air flow for the cooling, a cooling fan is necessary. From Equation (2) and assuming average efficiency of electric fan as 0.6, the total amount of electricity consumption of the fan is estimated to be 68.2kW. This value is 0.569% of the total generated electricity from MMR.

2.4 Dry cooling tower

Dry cooling tower can also create natural air draft but without any power consumption. The buoyancy force is generated from the density difference due to temperature difference. From the estimated pressure drop, the necessary height of cooling tower is 59.6 m for fully passive cooling.

$$\Delta p = \Delta\rho\, g\, H \qquad (3)$$

The cooling tower geometry is described in Fig.5. The heat exchangers are arranged around the cooling tower in order to avoid the interference of the air flow. The tower occupies land circular area of 17m in diameter, and the tower is tall enough to cause 806kg/s of air flow naturally. The air enters with 2.5m/s of velocity through the entrance at 6m high from the bottom. The exit on the top of chimney, the air velocity is 3.55m/s.

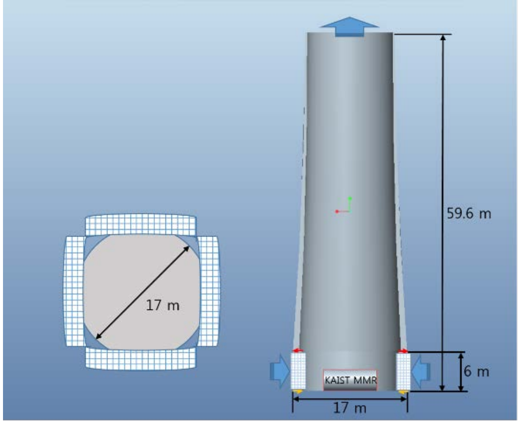


Fig. 5. Schematic of dry cooling tower design.

Table II: Comparison

	Fan type	Cooling tower
Volume (m^3)	322.7	13528
Electricity consumption (kW)	68.2	-
CO_2 Circulation power consumption(kW)	3.5	3.5
Percentage of consumption (%)	0.60	0.03

3. Conclusions

The KAIST MMR is a recently proposed concept of futuristic SMR. The MMR size is being determined to be transportable with land transportation. Also the size of 10MWe plant is estimated to have a size equivalent to 20ft container box, which can be installed anywhere. Furthermore, the core is designed to have a long life, which enables to produce electricity reliably for a long time without refueling.

Special attention is given to the MMR design on the dry cooling, which the cooling system does not depend on water. With appropriately designed air cooling heat exchanger, the MMR can operate autonomously.

Two types of air cooling methods are suggested. One is using fan and the other is utilizing cooling tower for the air flow. With fan type air cooling method it consumes about 0.6% of generated electricity from the nuclear reactor. Cooling tower occupies an area of 227 m^2 and 59.6 m in height. This design is just a preliminary estimation of the dry cooling method, and therefore more detailed and optimal design will be followed in the next phase.

ACKNOWLEDGEMENT

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