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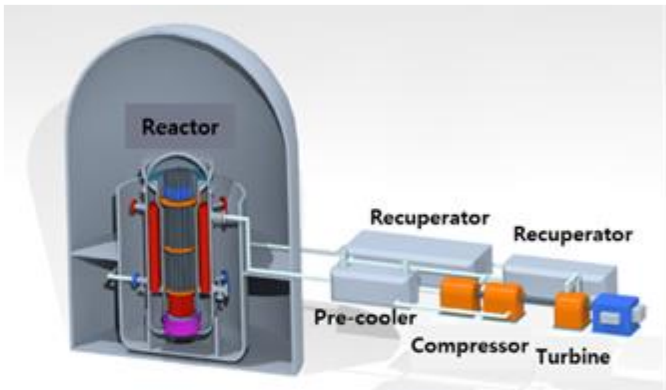
Study on Passive Turbocharger System for PRHRS in ATOM-sCO$_2$

Jeong Yeol Baek, Jeong Ik Lee*
Department of Nuclear and Quantum Engineering, KAIST
*Corresponding author: jeongiklee@kaist.ac.kr

NQe KAIST Nuclear & Quantum Engineering

Introduction

- ATOM (Autonomous Transportable On-demand reactor Module) reactor is a water-cooled small modular reactor (SMR) being developed by a university consortium led by KAIST, and it adopts the supercritical CO$_2$ (sCO$_2$) recompression cycle as a power conversion system.
- In this paper, the authors propose a passive turbocharger component coupled to PRHRS to improve the initial decay heat removal performance by increasing the mass flow in the natural circulation loop.
- The conceptual design of the turbomachinery under the ATOM-sCO$_2$ conditions has been carried out, and the case with and without the turbocharger system is compared with accident analyses using MARS code.

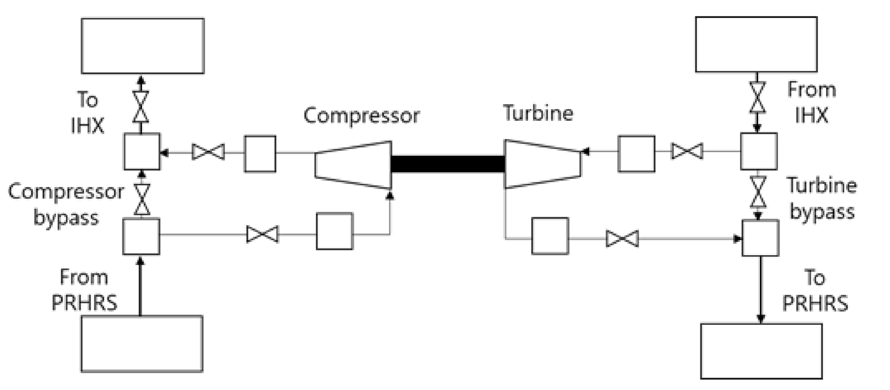


▲ Fig. 1. Concept diagram of ATOM-sCO$_2$

Method and Results

Concept of Passive Turbocharger System

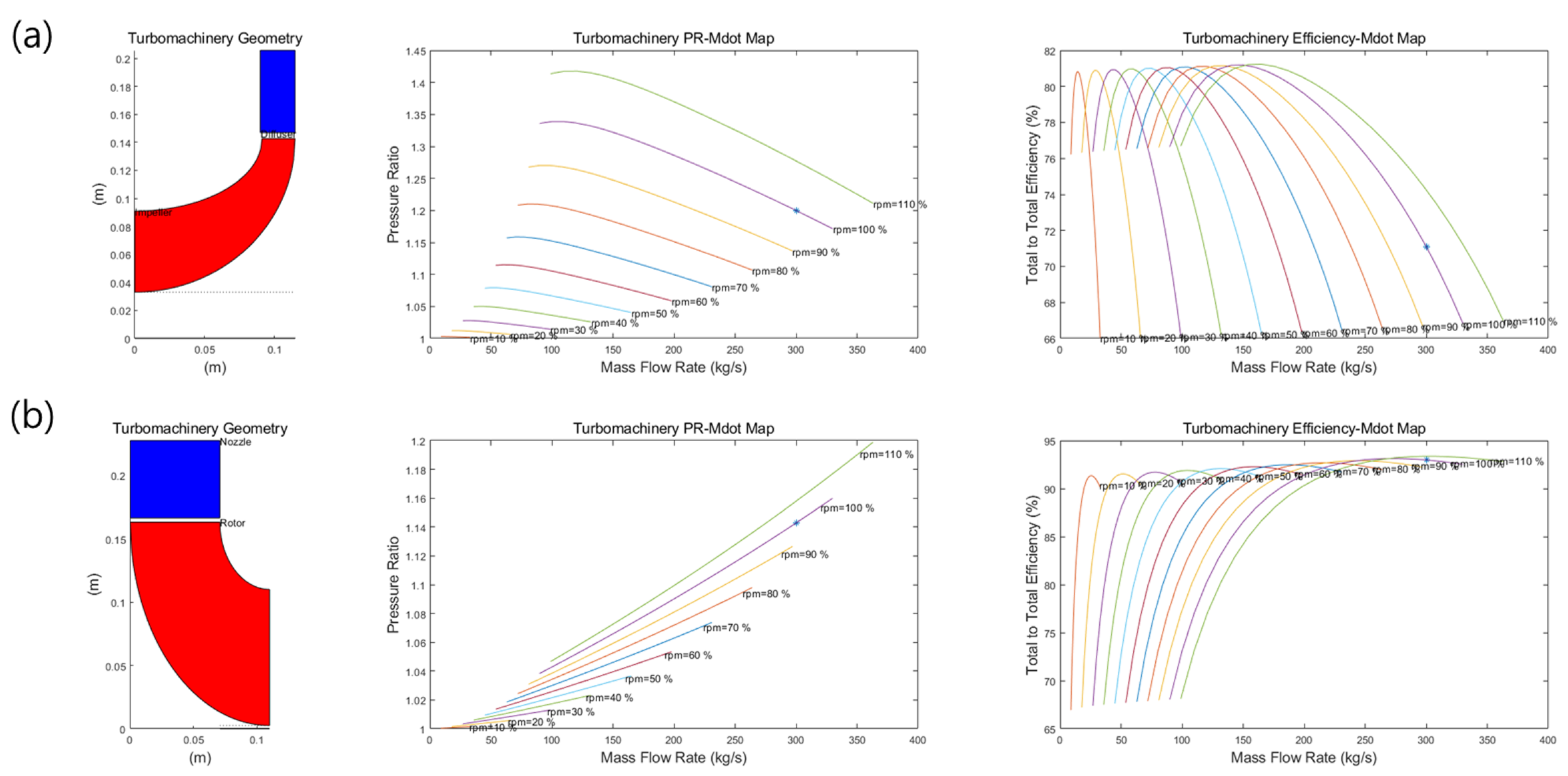
- Fig. 2 shows the concept of passive turbocharger system applied to PRHRS in ATOM-sCO$_2$. When reactor trip occurs, the sCO$_2$ power system is isolated and heat from the primary water side in the intermediate heat exchanger (IHX) is transferred via the PRHRS. Existing PRHRS passively removes residual heat by relying on natural circulation flow.
- In the passive turbocharger component, a turbine and a compressor are attached to the IHX and PRHRS connections, so that the working fluid having high enthalpy drives the turbine, which in turn drives the compressor resulting improvement of circulation force in PRHRS loop at the initial stage of an accident.
- As decay heat removal proceeds, the turbine inlet enthalpy will decrease and the compression work becomes larger than the turbine expansion work. This will result in shaft rotation speed to reduce due to the work balance between the compressor and the turbine. If it falls below a certain level, it can act as a flow resistance, thus the two bypass valves are opened to return to the existing natural circulation loop.
- Table I shows the design points after several design iterations based on the accident analysis data in the original system, and Fig. 3 shows the design results including the geometry and off-design performance maps of each turbomachinery.



▲ Fig. 2. Concept of passive turbocharger system

Design point	Compressor	Turbine
T_{in} [°C]	50	200
P_{in} [MPa]	10	12
Pressure ratio	1.2	1.143
$\dot{m}$ [kg/sec]	300	
RPM	8000	

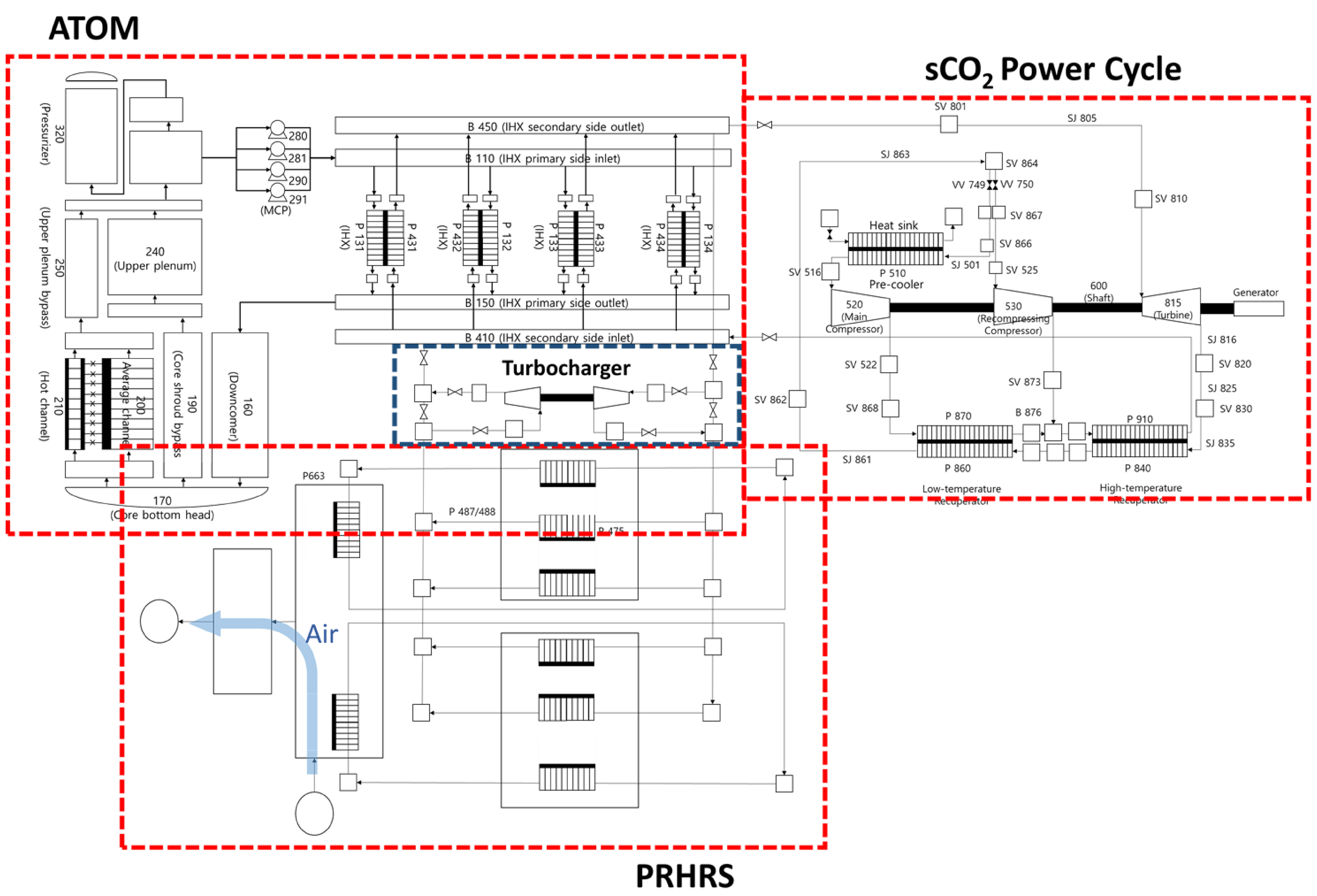
▲ Table I: Design point of each turbomachinery



▲ Fig. 3. Design results of each turbomachinery (a) compressor (b) turbine

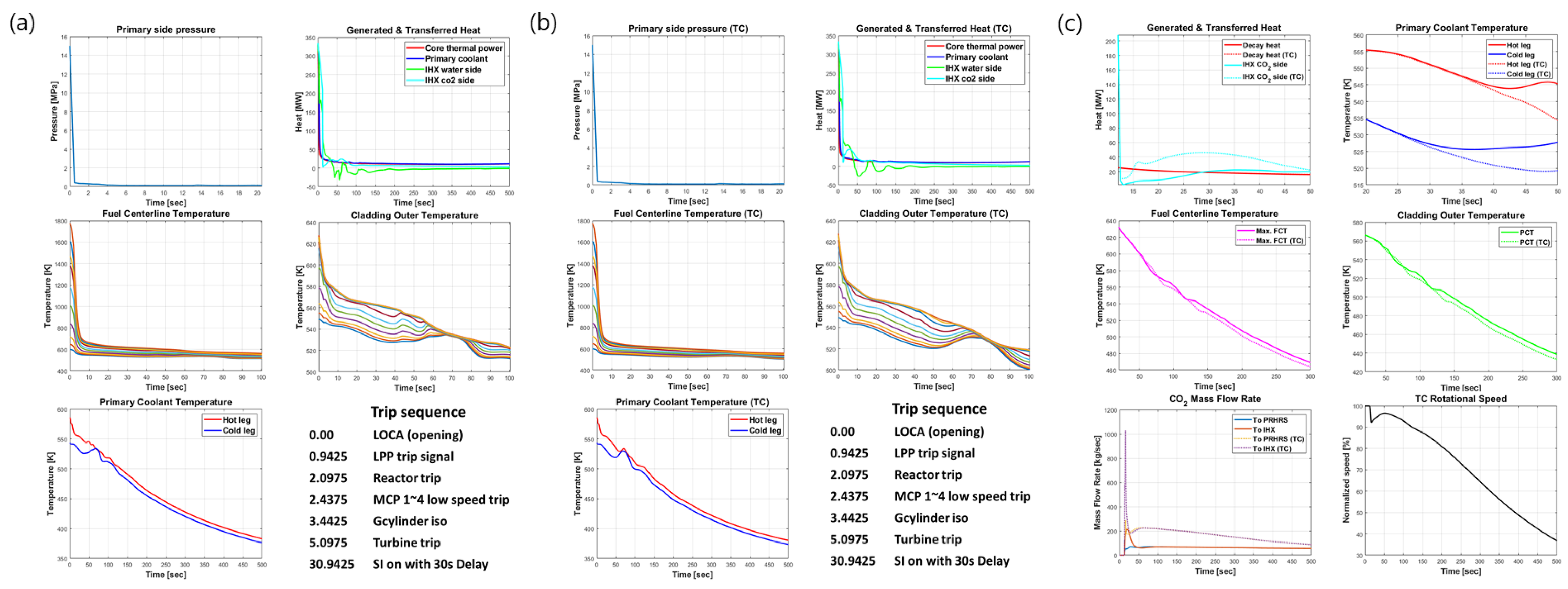
Accident Analysis

- Fig. 4 shows the input nodalization of ATOM-sCO$_2$ system for MARS code simulation. The red dashed box represents each system in the existing input, and the blue dashed box represents the newly added passive turbocharger component.
- Due to the nature of the analysis code, there is a limit to simulating the startup procedure of the shaft. Therefore, when the power conversion system is isolated, the initial rotational speed of the turbocharger is assumed to be the design value.
- The energy to be provided to initially operate at 100% RPM is calculated from the rotational moment of inertia of the turbocharger, and it is about 4.88 kWh.
- It can be assumed that this amount of energy is initially provided by an energy supply device such as a battery, flywheel, or super capacitor at the beginning but after the operation continuous power supply is not needed.



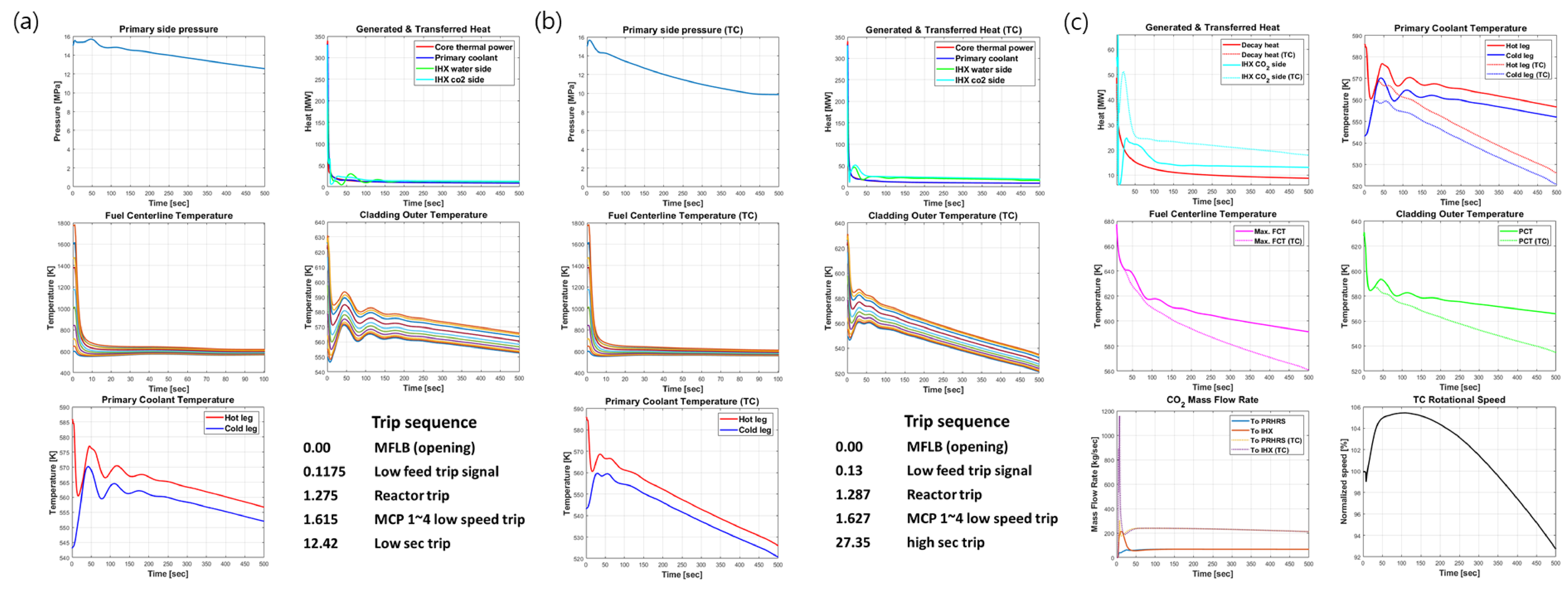
▲ Fig. 4. Input nodalization of ATOM-sCO$_2$ with turbocharger

- Fig. 5 (a) and (b) show the results of LOCA analysis with and without the turbocharger, respectively. As the overall trend is similar, but as the authors have expected the initial response during the accident is better when the turbocharger component is added.
- Fig. 5 (c) compares the LOCA analysis results in two cases. Due to the operation of a passive turbocharger, the mass flow rate of PRHRS increased, and the amount of heat removed from the sCO$_2$ side of the IHX increased. As a result, it can be confirmed that the initial residual decay heat cooling performance is improved.
- As decay heat is removed and decreases, the rotational speed of the turbocharger is reduced by the work balance between the turbine and the compressor, and it can be expected that in the long term, it will be the same as the cooling method of the existing natural circulation loop.



▲ Fig. 5. Results of LOCA analysis (a) with TC (b) without TC (c) comparison

- Fig. 6 shows the results of the MFLB analysis, and it can be seen that the initial decay heat cooling performance is improved due to the increased PRHRS mass flow similar to the LOCA analysis.



▲ Fig. 6. Results of MFLB analysis (a) with TC (b) without TC (c) comparison

Conclusions

- In this paper, a passive turbocharger component was proposed to improve the initial cooling performance of PRHRS in ATOM-sCO$_2$, and each turbomachinery was designed using KAIST-TMD code.
- Using MARS code, SBLOCA and MFLB accident analysis were performed by adding a turbocharger component to the existing ATOM-sCO$_2$ design.
- As a result of comparing the accident analysis results for two systems, it was confirmed that the initial cooling performance was improved by applying the passive turbocharger component to the existing natural circulation loop based PRHRS.

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