Application of Trans-Critical CO_2 power conversion system in MicroURANUS

, Sungwook Choi[a] , Bong Song Oh[a], Jeong Ik Lee[a,*]

[a]*Department of Nuclear and Quantum Engineering, Korea Advanced Institute of Science and Technology, 373-1 Guseong-dong Yuseong-gu,Daejeon 305-701, Republic of Korea*

**Corresponding author: jeongiklee@kaist.ac.kr*

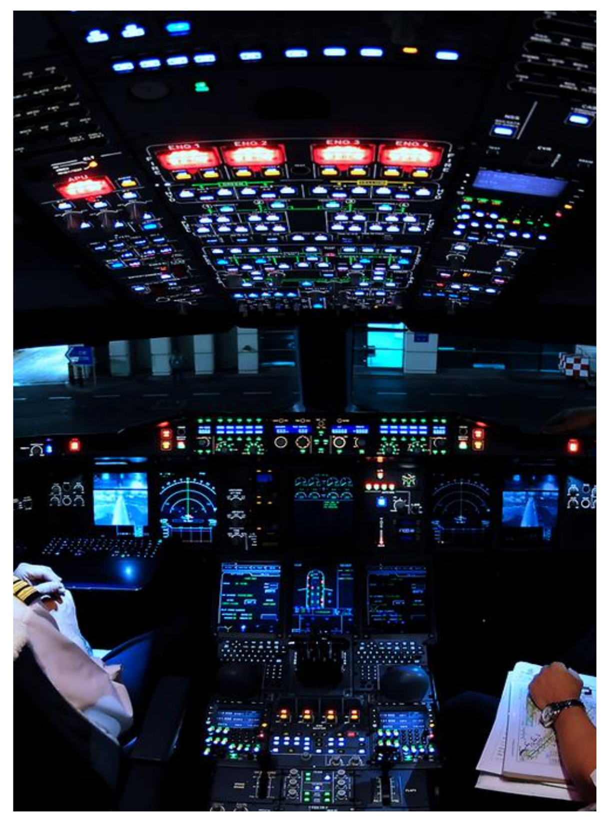
Introduction

▣ MicroURANUS is a 60 MW_{th} lead-cooled micro modular reactor, used for propulsion of ships sailing in Northern Sea Route.

▣ Due to limited area on-board, the power conversion system should only include small sized components with adequate thermal efficiencies.

▣ The average water temperature of Northern Sea ranges from -2°C to 5 °C. Since the sea water temperature is far less than the critical temperature of supercritical carbon dioxide (31 °C), trans-critical carbon dioxide Rankine cycle should be used as the power conversion system in MicroURANUS.

▣ Application of trans-critical carbon dioxide cooled power conversion system in MicroURANUS was analyzed using GAMMA+



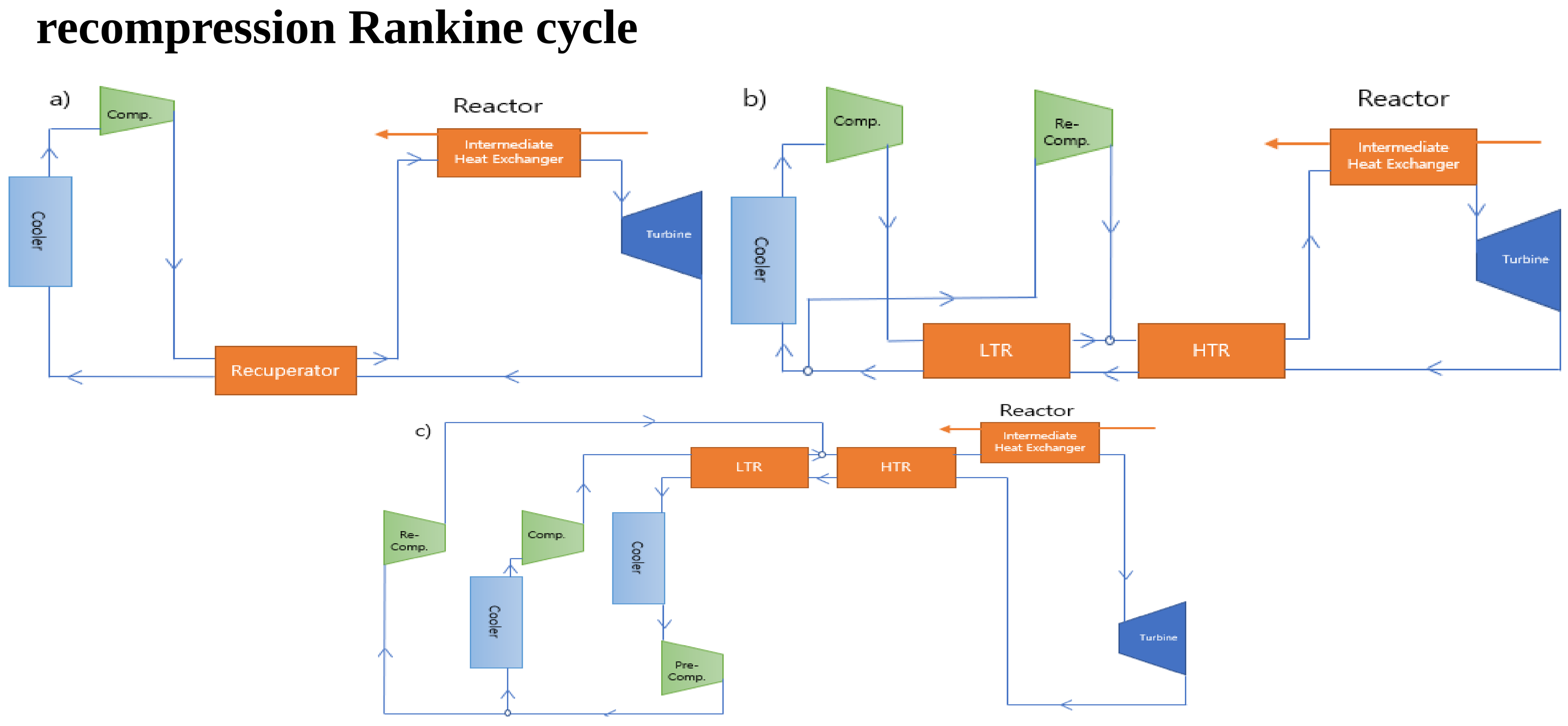
△ **Digital Twin of MicroURANUS**

Methods

1. Cycle Layout Selection

▣ Among the various trans-critical carbon dioxide Rankine cycle layout, the simple recuperated, recompression, and precompression-recompression Rankine cycles were compared.

▽**Layout of a) simple recuperated b) recompression c) precompression-recompression Rankine cycle**



▣ Three cycle layouts were evaluated by their simplicity, thermal efficiency, and control variables.

▣ In perspective of simplicity, he simple recuperated cycle is the simplest cycle among the candidates. Then, the recompression cycle and precompression-recompression cycle follow, respectively. Because the precompression-recompression cycle has too many components in the layout, it is not suitable to be used in this case.

▣ For thermal efficiency and control variables, the recompression cycle is superior to the simple recuperated cycle.

▣ The recompression cycle is selected for the layout of the trans-critical carbon dioxide Rankine cycle.

2. Cycle optimization

▣ To calculate the design parameter of the recompression cycle, KAIST CCD, a MATLAB-based in-house code was used.

▣ For the cycle optimization, the effectiveness of the recuperators, compressors, and turbine were assumed to be 95%, 82% and 93%, respectively.

▣ The inlet and outlet temperature of intermediate heat exchanger was set to 250 °C and 350 °C

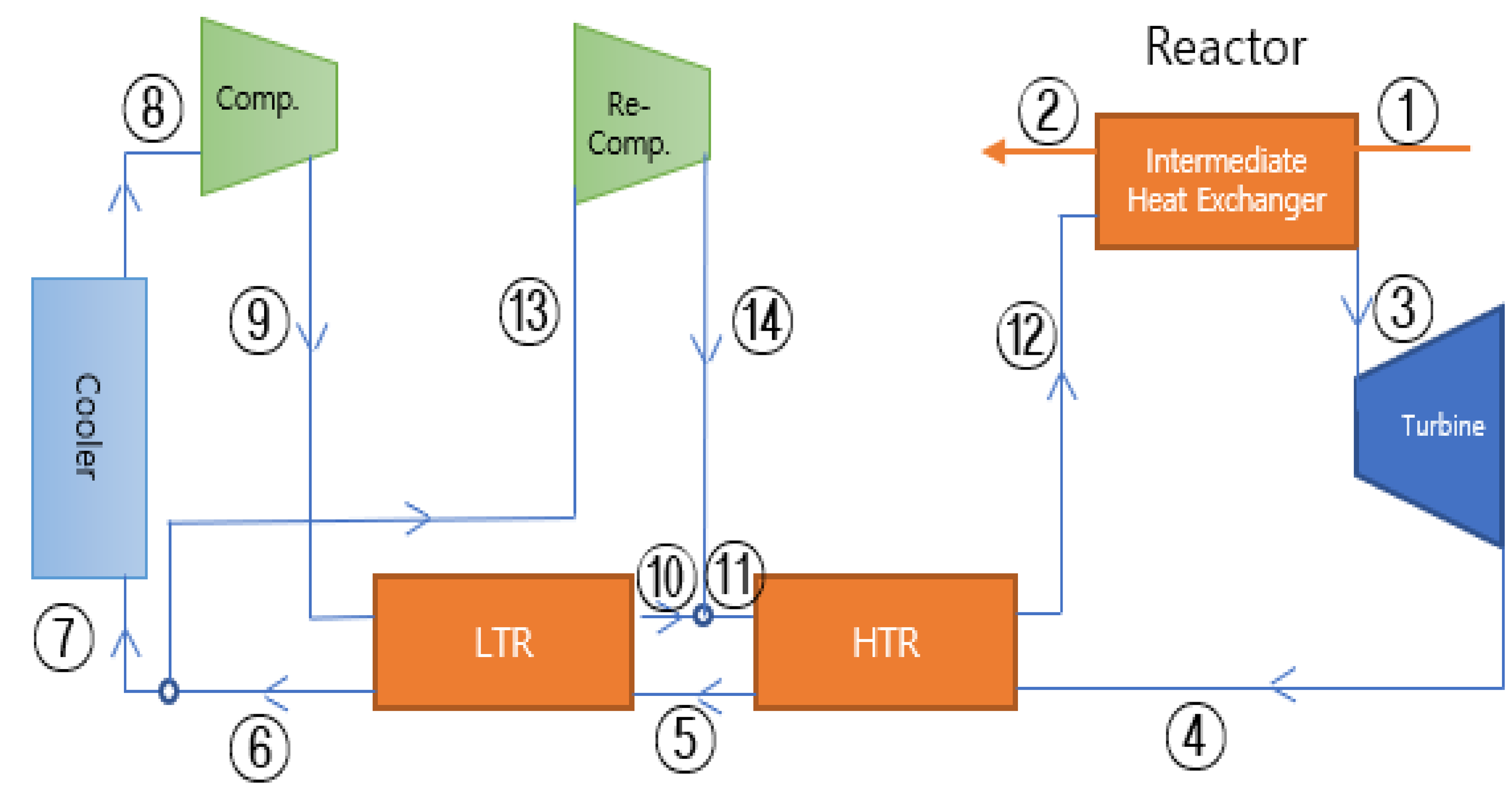
3. GAMMA+ Modeling

▣ GAMMA+, General Analyzer for Multi-component and Multi-dimensional Transient Application, is a code developed by Korea Atomic Energy Research Institute to analyze the VHTR.

▣ GAMMA+ is modified to be capable of analyzing trans-critical carbon dioxide power conversion system.

▣ The inlet and outlet temperature of intermediate heat exchanger was set to 250 °C and 350 °C

Result



△ **Design parameter check points for the recompression cycle**

Code Point	KAIST CCD		GAMMA+	
	Temp (°C)	Pres (MPa)	Temp (°C)	Pres (MPa)
1	350.0	-	350.0	-
2	250.0	-	251.8	-
3	327.0	14.7	327.1	14.7
4	243.6	6.5	243.6	6.5
5	114.5	6.33	116.4	6.23
6	35.4	6.2	35.8	6.18
7	35.4	6.2	35.8	6.18
8	15.0	6.15	15.1	6.16
9	25.4	14.85	25.6	14.96
10	107.4	14.85	109.2	14.94
11	109.0	14.85	110.8	14.93
12	207.3	14.72	208.2	14.88
13	35.4	6.2	35.8	6.18
14	110.3	14.9	112.3	14.93

△ **Results from KAIST CCD and GAMMA+**

▣ From KAIST CCD, the estimated net efficiency of the cycle is 32.9%, and the total mass flow rate of carbon dioxide is 412.0 kg.

▣ The cycle efficiency seems quite low for the trans-critical carbon dioxide cycle, but considering that the intermediate heat exchanger outlet temperature is about 350 °C, which is similar to the reactor outlet temperature of LWR, the cycle efficiency is reasonable.

▣ The split ratio between points 6 and 7 is 0.48345.

▣ The result from GAMMA+ corresponds to the result of KAIST CCD, which indicates that the net efficiency of 32.9% for the power conversion system with trans-critical carbon dioxide recompression Rankine Cycle.

Summary and Future works

▣ The result from GAMMA+ corresponds to the result from KAIST CCD. The net thermal efficiency of the cycle is 32.9%.

▣ For future work, the primary side of MicroURANUS should be modeled using GAMMA+.

▣ After modeling the primary side of MicroURANUS, the full transient condition of MicroURANUS can be simulated.