Modification of GAMMA+ code for MicroURANUS transient Analysis

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Introduction

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

▣ Transcritical-CO_2 Rankine cycle has been selected as the power conversion system of the MicroURANUS due to its small sized components and suitable thermal efficiency.

▣ To simulate the steady state and transient conditions, GAMMA+ code was used.

▣ Previously, MARS-LBE code was used to analyze the lead-bismuth cooled reactors, because the thermophysical property of lead-bismuth was updated by Seoul National University.

▣ The thermophysical property of lead-bismuth implemented in GAMMA+ code differs from that of MARS-LBE.

▣ Therefore, the thermophysical property of lead-bismuth implemented in GAMMA+ code was modified so that GAMMA+ code can accurately analyze the MicroURANUS and its power conversion system.

Methods

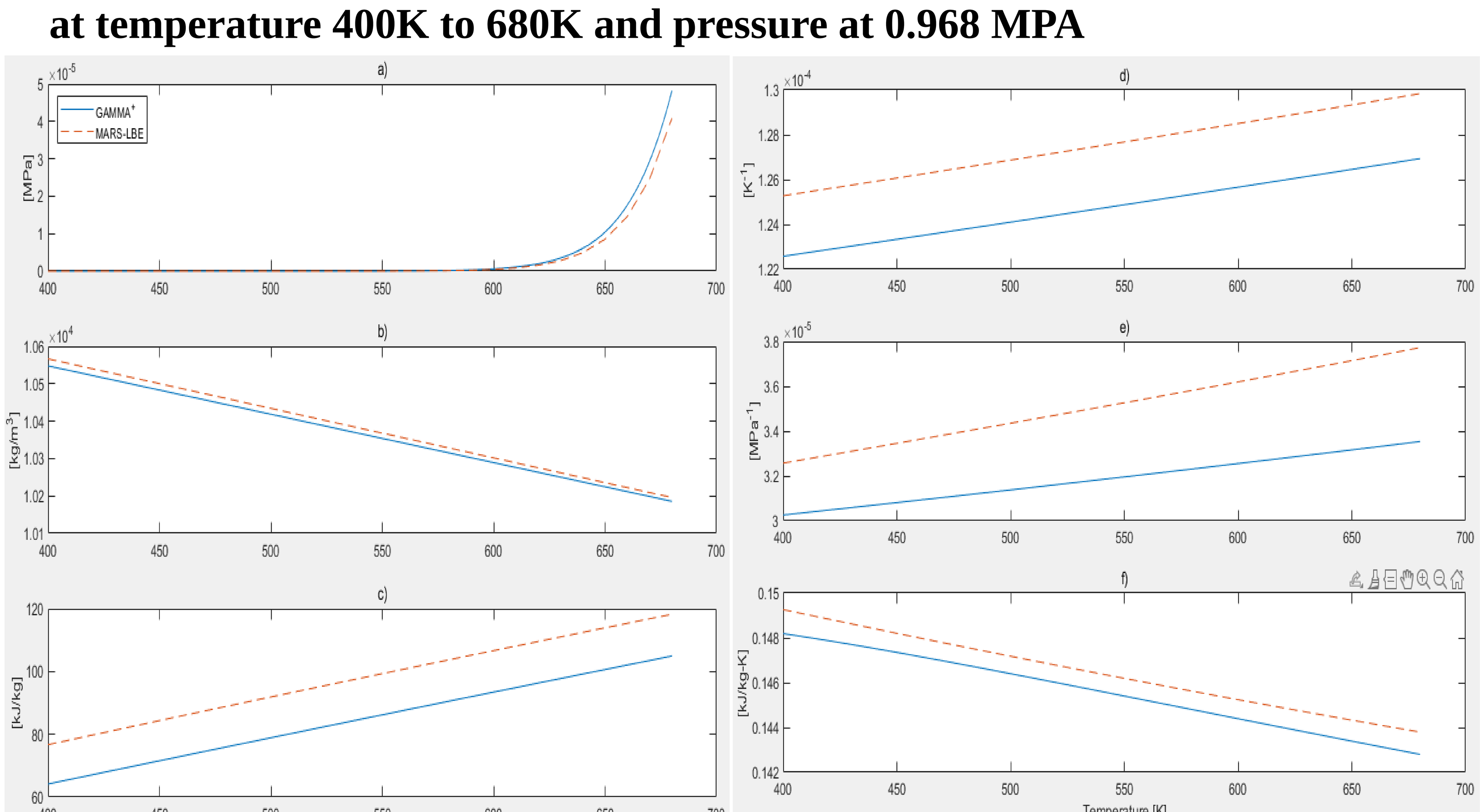
1. Comparison of Lead-Bismuth Properties

▣ Thermophysical properties, such as saturation pressure, density, enthalpy, thermal expansion, compressibility, and specific heat, implemented in MARS-LBE and GAMMA+ code are compared.

▽**Lead-bismuth thermophysical property correlations, temperature ranges and estimated error in GAMMA+ Code.**

Parameter	Correlation	Temperature Range [K]	Estimated Error
Saturation Pressure [Pa]	$(1.22\times10^{10})\cdot e^{\left(\frac{-22552}{T}\right)}$	670 – 1927	60%
Density [kg m^{-3}]	$11065-(1.293\ \cdot T)$	400 – 1300	0.8%
Enthalpy [J kg^{-1}]	$164.8\ \cdot T-(1.97\times10^{-2})\cdot T^2 + (4.167\times10^{-6})\cdot T^3+(4.56\times10^5)T^{-1}$	400 – 1100	7%
Thermal Expansion [K^{-1}]	$\frac{1}{8558-T}$	400 – 1300	0.8%
Compressibility [Pa^{-1}]	$\frac{1}{(38.02-1.296\times10^{-2}\cdot T+1.320\times10^{-6}\cdot T^2)}$	400 – 1000	3%
Specific heat [J kg^{-1} K^{-1}]	$164.8\ -(3.94\times10^{-2})\cdot T + (1.25\times10^{-5})\cdot T^2-(4.56\times10^5)T^{-2}$	400 - 1100	7%

▽**Comparison of a) saturation pressure b) density c) enthalpy d) thermal expansion e) compressibility and f) specific heat of GAMMA+ and MARS-LBE at temperature 400K to 680K and pressure at 0.968 MPA**

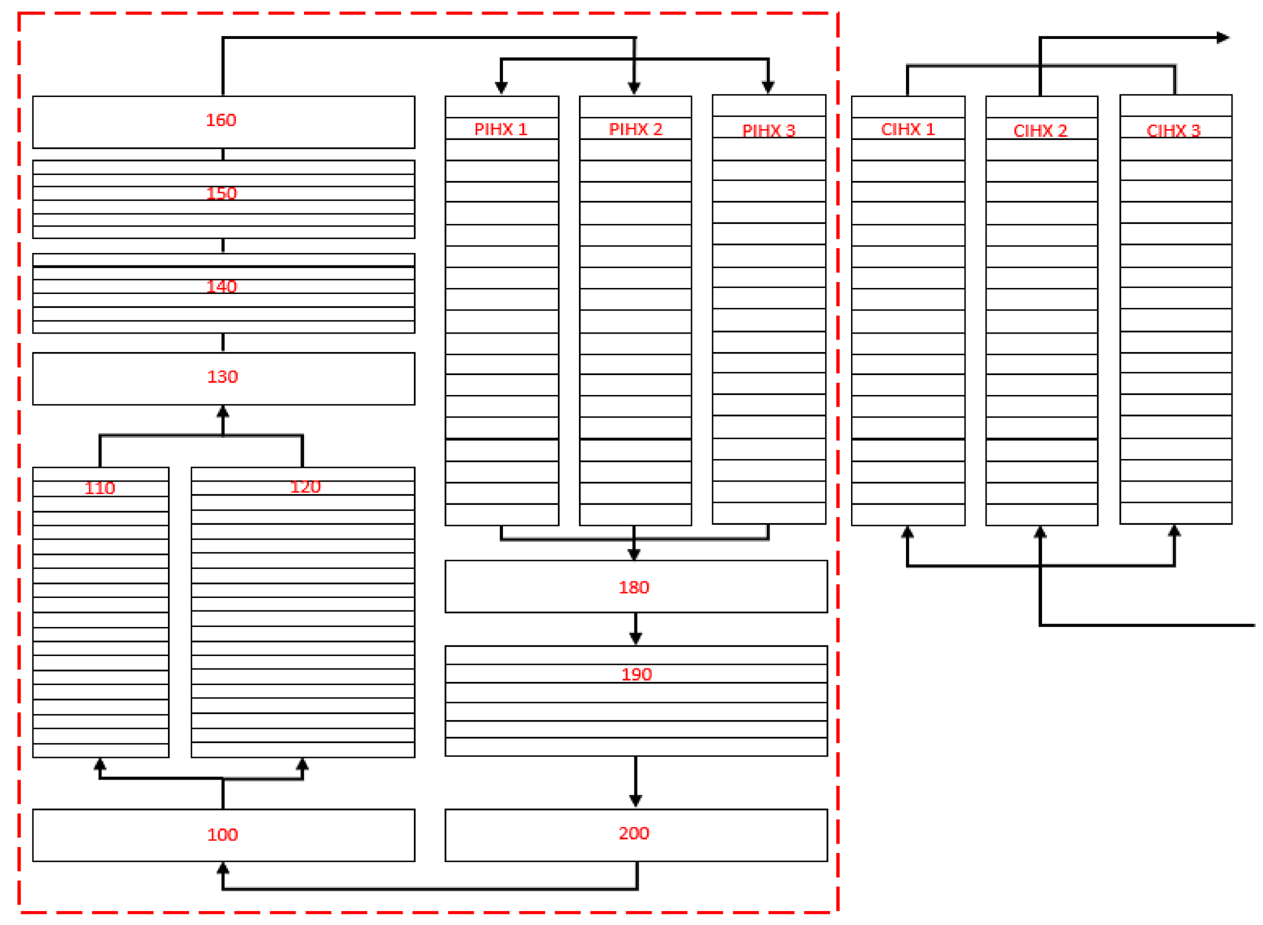


▣ As shown in the plots above, the thermophysical properties, especially the enthalpy, calculated in the GAMMA+ code differs from those calculated in the MARS-LBE code.

▣ MARS-LBE calculates its thermophysical properties by interpolating the values that are in the thermophysical property tables, which are implemented in the code.

▣ Thus, the thermophysical property tables were implemented in GAMMA+ code to match the values calculated from MARS-LBE.

Result

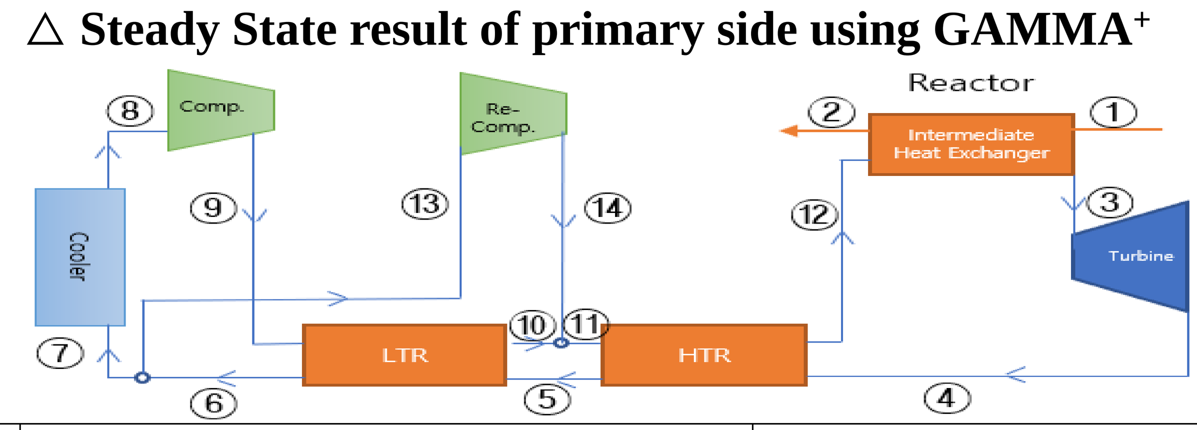


Lower Plenum	100
Core Average. Channel	110
Core Hot Channel	120
Upper Nozzle	130
Middle Plenum	140
Upper Plenum	150
Weir	160
Intermediate Heat Exchanger	PIHX1-3
Concourse	180
Downcomer	190
Coldwell	200

△ **Nodalization of MicroURANUS Primary side**

Component	Temp [°C]		Pres [MPa]	
	Inlet	Outlet	Inlet	Outlet
100	254.28		1.133	
110	254.34	351.93	1.045	0.778
120	254.34	352.24	1.045	0.778
130	351.94		0.768	
140	351.96	352.09	0.745	0.539
150	352.12	352.27	0.489	0.242
160	352.34		0.126	
PIHX1-3	348.79	254.72	0.106	0.382
180	254.69		0.414	
190	254.66	254.53	0.470	0.684
200	254.44		0.832	

△ **Steady State result of primary side using GAMMA+**



	KAIST CCD		GAMMA+	
	Temp (°C)	Pres (MPa)	Temp (°C)	Pres (MPa)
1	350.0	-	348.79	0.106
2	250.0	-	254.72	0.382
3	327.0	14.7	329.60	14.45
4	243.6	6.5	246.14	6.33
5	114.5	6.33	117.27	6.25
6	35.4	6.2	35.93	6.19
7	35.4	6.2	35.92	6.19
8	15.0	6.15	14.97	6.18
9	25.4	14.85	25.38	15.02
10	107.4	14.85	110.45	14.99
11	109.0	14.85	111.51	14.99
12	207.3	14.72	210.53	14.94
13	35.4	6.2	35.93	6.19
14	110.3	14.9	112.53	14.99

△ **Steady State result of secondary side using GAMMA+**

▣ The design conditions of the MicroURANUS are following: core inlet and outlet temperatures are about 250 ℃ and 350 ℃, respectively. The steady state result of primary side using GAMMA+ code well matches with the design condition.

▣ The design condition of the secondary side is the result from the KAIST-CCD code. As shown in the table above, the steady state result of secondary side using GAMMA+ code is similar to that of KAIST-CCD code.

Summary and Future works

▣ Since the thermophysical properties of lead-bismuth calculated by GAMMA+ code and MARS-LBE code were different, GAMMA+ code was modified to match the values from MARS-LBE code.

▣ After the modification, the steady state calculation using GAMMA+ code converged to the design condition of the MicroURANUS.

▣ For future work, GAMMA+ code will be used to analyze various transient conditions of MicroURANUS.