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Development and Testing of Gallium Properties for Natural Convection Analysis employing MARS-LMR Code

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1. Introduction

The passive decay heat removal system is one of the new concepts having advance design features. Because the principle of this system is basic laws of physics such as gravity or natural convection, it is able to function without electric power or actuation by control equipments. In the decay heat removal system of the SFRs, gallium can work properly to avoid the interaction between sodium and air. As discussed above, it is suggested that liquid gallium can be substituted to sodium of PDHRS as shown in Fig. 1. The properties of liquid gallium are indicated in Table. 1 [1][2][3]. There are several advantages such s low melting point and high boiling point and higher thermal conductivity compared to lead or lead-bismuth eutectic (LBE). Before the safety evaluation of a gallium-cooled passive decay heat removal system (PDHRS) are analyzed, the set of physical properties and thermodynamic tables of MARS code for gallium was generated and compared with existing equations.

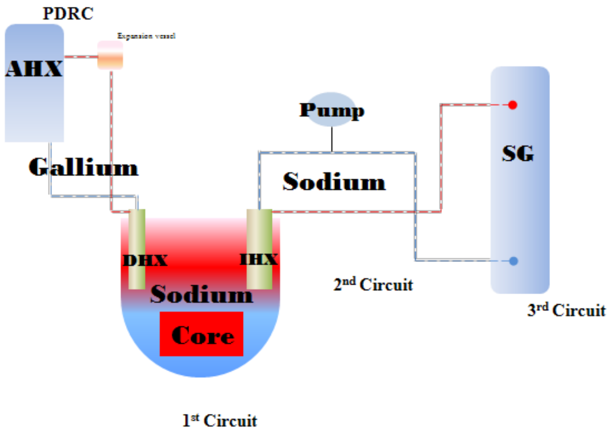

Fig. 1. Liquid Gallium as PDHRS coolant

2. Method and Results

To generate the set of physical properties and thermodynamic tables of MARS code, it needs the three equations as Helmholtz energy equation, pressure and energy equation (eq.1-3)[4]. These equations have the 6 constants: epsilon, sigma, cohesive energy, Madelung constant, n, m, and Q. These constants can be determined by each fluid. Table 2 and eq.4-7 show the 6 constants and physical properties [1][2][3]. These data were obtained from David A. Young et al., Cochran et al., and Yamanaka et al. respectively.

Table I: Thermo physical properties of gallium [1,2,3]

Atomic Number	31
Atomic Weight (kg/mol)	0.06972
Melting Point (℃)	29.8
Boiling Point (℃)	2203
Density (kg/m^3)	5822
Heat Capacity (J/kg·K)	380
Thermal Conductivity (W/m·K)	50.9
Cohesive Energy (J/kg)	3.901×10^6
Enthalpy at melt (J/kg)	8.204×10^4

Table II: Constants for gallium in Helmholtz energy, pressure and energy equation [4]

n	8.8	m	0.75
Q	0.95	ε	1.42×10^{-18}
σ	3.1×10^{-30}	C_n	11.9

Eq. (1-3)

$$A = NkT\left[-\ln\frac{Ve}{N\lambda^3}+C_n\rho^{\frac{n}{3}}\left(\frac{\varepsilon}{kT}\right)+\frac{1}{2}(n+4)Q\rho^{\frac{n}{9}}\left(\frac{\varepsilon}{kT}\right)^{\frac{1}{3}}-\rho^m\left(\frac{\varepsilon}{kT}\right)\right]$$

$$P = \frac{NkT}{V}\left[-\frac{1}{v}+\frac{n}{6}C_n\rho^{\frac{n}{3}}\left(\frac{\varepsilon}{kT}\right)-\frac{n}{36}(n+4)Q\rho^{\frac{n}{9}}\left(\frac{\varepsilon}{kT}\right)^{\frac{1}{3}}-\frac{m}{2}\rho^m\left(\frac{\varepsilon}{kT}\right)\right]$$

$$E = NkT\left[\frac{3}{2}+C_n\rho^{\frac{n}{3}}\left(\frac{\varepsilon}{kT}\right)+\frac{1}{6}(n+4)Q\rho^{\frac{n}{9}}\left(\frac{\varepsilon}{kT}\right)^{\frac{1}{3}}-\rho^m\left(\frac{\varepsilon}{kT}\right)\right]+E_{coh}$$

where, λ is the deBroglie wavelength, C_n is the fcc Madelung constant, ρ is the normalized density, and Q is a multiplier to account for electronic effects on the heat capacity [4].

$$\sigma = 708 - 3.9 \times 10^5 (T - 303) \quad (4)$$

$$\eta = 0.012 - 5.754 \times 10^5 T + 7.891 \times 10^{-8} T^2 \quad (5)$$

$$k = 7.08 + 8.014 \times 10^{-2} T - 2.7 \times 10^5 T^2 \quad (6)$$

$$\log P = 101325 \times 10^{\left(\frac{14900}{T+200} - 0.515 \log(T+200) + 7.34\right)} \quad (7)$$

where, σ is a surface tension, η is a viscosity, and k is a thermal conductivity [1].

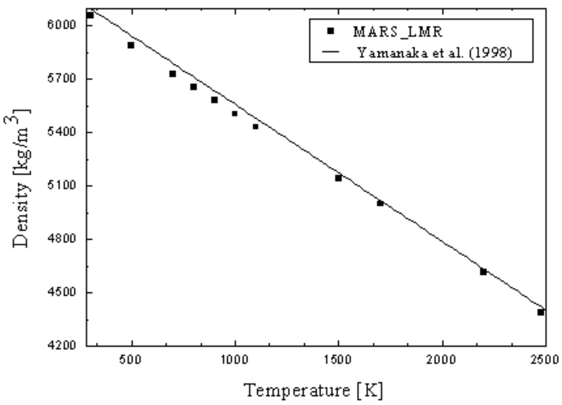

Fig. 2. Density Comparison with MARS-LMR tables and Yamanaka et al.

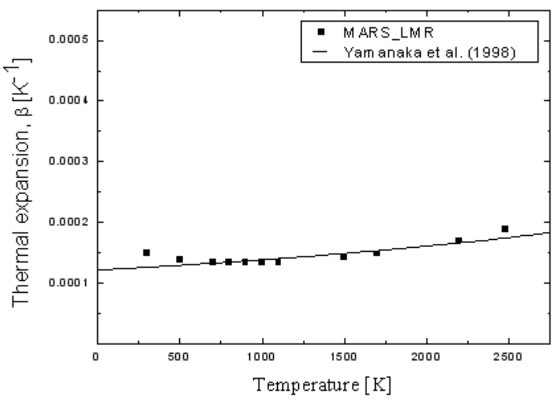

Fig. 3. Thermal Expansion Comparison with MARS-LMR tables and Yamanaka et al.

From fig. 2 to fig. 4 show the comparison with the generated code value and existing equations in Yamanaka et al. and IAEA report. Each black point indicates the generated value by using MARS-LMR code and each line indicates the existing correlation. The comparison of the physical value in gallium data code shows excellent agreement. Using this table code for gallium, modified steady state input file about gallium-cooled PDHRS of KALIMER-600 was analyzed.

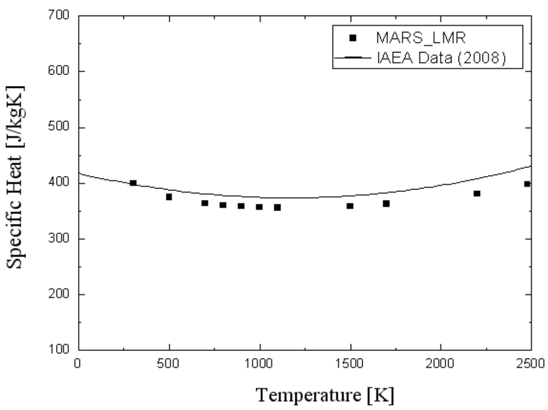

Fig. 4. Specific heat Comparison with MARS-LMR tables and IAEA report

3. Conclusion and Recommendation

In this study, MARS-LMR was selected to analyze the evaluation of a gallium-cooled PDHRS. MARS-LMR properties and thermodynamic tables of MARS code for gallium which is applicable for gallium-cooled systems was made by modifying physical properties in MARS while maintaining its original numerical methods [5]. To evaluate a gallium-cooled PDHRS, the design bases events like transient of over power, Loss of flow, Loss of heat sink, and Pipe break will be analyzed using MARS-LMR [6].

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