Preliminary Concept of Advanced Passive Decay heat Removal System using Liquid gallium for Sodium-cooled Fast Reactor

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1. Introduction

The safety issues of the SFR are important due to the fact that it uses sodium as a nuclear coolant, reacting vigorously with water and air. For that reason, there are efforts to seek for alternative candidates of liquid metal coolants having excellent heat transfer property and to adopt improved safety features to the SFR concepts. As a liquid metal coolant, liquid gallium has technical advantages as shown in Table 1. The attractive properties ensure that gallium can play an important role in nuclear safety as an alternative coolant of the decay heat removal system of the SFR. Therefore, this study aims to calculate the natural convection capability of gallium as a feasibility study for the development of gallium-based passive safety features and compare to sodium Passive Decay heat Removal Circuit (PDRC).

2. Methods and Results

2.1 Preliminary Concept

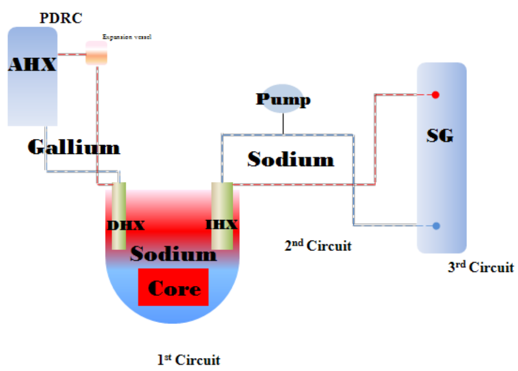

Fig.1. Liquid Gallium as PDRC coolant

The passive heat removal system is one of the new concepts of SFRs having advance design features. In the decay heat removal system of the SFR, gallium having several advantages can work properly to avoid the interaction between sodium and air. Fig. 1 shows the conceptual design for PDRC of the SFR.

2.2 Calculation

Fig. 2 shows the thermal hydraulics data of PDRC in KALIMER-600. Heat removal rate eliminated by PDRC loop of KALIMER-600 should be 16.5MW_{th} [3].

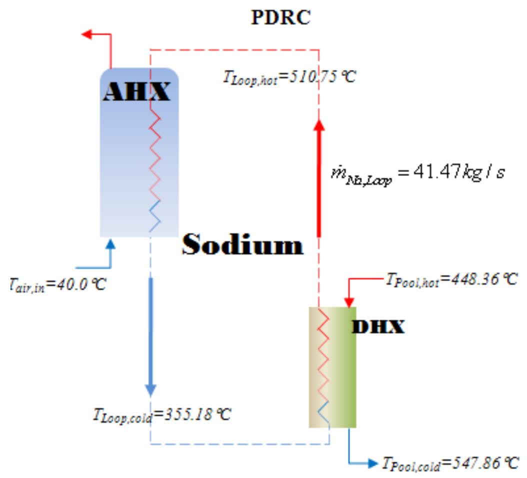

Fig.2. Design factor of PDRC at KALIMER-600

Because KALIMER-600 has two PDRC loops, each loop has to eliminate the decay heat of 8.25MW_{th}. If liquid gallium is used as a coolant in PDRC loop, it should also eliminate the same amounts of decay heat, 8.25MW_{th}.

$$Q = \dot{m} C_p \Delta T \qquad (1)$$

Firstly, if we assume that the flowrate ($m_{Na,Loop}$) and $T_{Loop,cold}$ of liquid gallium are same compared to condition of KALIMER-600 as shown in Fig. 2, the $T_{Loop,hot}$ of liquid gallium will be about 885℃. Secondly, if we assume again that the temperature difference ($T_{Loop,hot}$-$T_{Loop,cold}$) is the same compared to condition of KALIMER 600 as shown in Fig. 2, the flowrate of liquid gallium needs to be about 141kg/s or more than that. The natural convection flowrate of liquid gallium can be considered by using eq. (2).

$$\dot{m} = \left[\frac{2\rho_o^2 \beta g \Delta H P}{C_p R} \right]^{1/3} \qquad (2)$$

where, β is the coefficient of thermal expansion, ρ is the density, g is the gravity, P is the power, ΔH is the elevation difference between the center of heater and heat exchanger, R is the flow resistance parameter, C_p is the specific heat capacity.

$$Nu_L = \left\{ 0.825 + \frac{0.387 Ra_L^{1/4}}{\left[1 + (0.492/\mathrm{Pr})^{9/16}\right]^{8/27}} \right\}^2 \qquad (3)$$

Eq.(2) is the function of the flow resistance parameter, R and the elevation difference, ΔH. Fig. 3 shows the expected flowrate change of liquid gallium according to $(\Delta H/R)^{1/3}$ using eq.(2). Because the dimensions of the PDRC loop can't confirm exactly, fig. 4 shows the calculated heat transfer coefficient of various liquid metals using liquid gallium natural convection loop [2] and eq. (3) to compare to the heat transfer coefficient of sodium and gallium.

2.3 Comparison

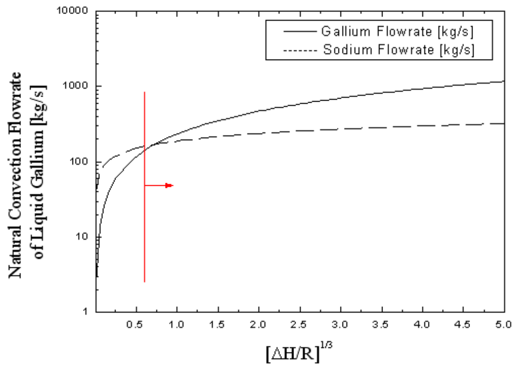

Fig.3. The natural convection flowrate for liquid gallium

If we assume the condition of the liquid gallium system is same compared to sodium PDRC system and the value of $[\Delta H/R]^{1/3}$ is more about 0.6, the liquid gallium PDRC can eliminate the amount of decay heat, $8.25MW_{th}$.

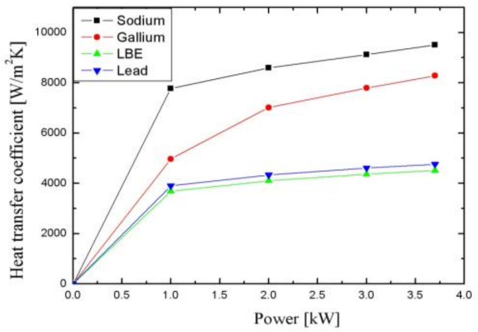

Fig.4. The calculated value of heat transfer coefficient of liquid metals using eq.(3).

Fig. 4 shows that the average heat transfer coefficient of sodium is higher (about 20%) than that of gallium. As shown in table 1, the price of sodium is much lower than that of gallium. Other properties are also written in table 1.

3. Conclusions & Recommendation

Using the existing conditions of KALIMER-600 such as temperature and flowrate of sodium, the temperature difference and flowrate of liquid gallium in PDRC can be calculated to eliminate decay heat. Because the liquid gallium can remain liquefied from 30℃ to about 2200℃, the hot temperature of liquid gallium, 885℃ in PDRC loop can be considered as design factor. Although the heat removal capability by comparing flowrate and heat transfer coefficient of liquid gallium is lower than that of sodium, gallium also should be eliminate the amount of decay heat, $8.25MW_{th}$ when the ratio of the ΔH to R have 0.6 or more than that. Compared to other widely used liquid metals, properties of liquid gallium make it safer and easier to handle to be used by coolant of PDRC and can work properly to avoid the interaction between sodium and air.

REFERENCES

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[3] Jae-Hyuk Eoh et al., Component Sizing and Design Characteristics of the PDRC system in KALIMER-600, Korea Atomic Energy Research Institute, KAERI/TR-2827/2004

Table 1. Thermo Properties of various liquid metals

	Na	Pb	LBE	He(gas)	Ga	GaIn	NaK
Atomic Weight	22.997	207.21	208	4	69.723	-	-
Melting Point (°C)	97.8	327.4	123.5	-	29.76	15.7	-11.1
Boiling Point (°C)	892	1737	1670	-267	2204	2000	783.8
Density (kg/m³)	880	10500	10300	0.178	6095	6280	872
Specific Heat(J/kg-K)	1300	160	146	5200	381.5	326	1154
Thermal Conductivity (W/m-K)	76	16	11	0.152	29	41.8	25.3
Viscosity (cP)	0.34	2.0-2.5	1.7	0.018	1.810	1.69	0.468
Absorption cross section (Σa)	0.01347	0.005603	0.003034	-	0.148		
Coefficient of volumetric thermal expansion ($10^{-6}K^{-1}$)	200	87	130	-	59.5		39.35
Price (Won/ kg)	33,000	2,730			870,000		

(2011.08.24 기준)