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Feasibility Study on Two-phase Thermosiphon for External Vessel Cooling Application of SFR

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1. Introduction

As the necessity of sodium fast reactor in order to reduce spent fuel, the development of designing sodium fast reactor becomes an issue. Even though there is PDRC and RVACS for the decay heat removal (DHR) system, each system has disadvantage of sodium fire and low performance, respectively. Therefore, to increase the safety of SFR, the new passive safety system design is needed without sodium fire and high performance, which can applied for large SFR.

The DHR system using two-phase thermosiphon for external vessel cooling application is suggested in this paper. The proposed design have advantage that there is no structure in reactor vessel, which means no system modification and no sodium fire with perfect isolation. Also, it provide the method to mitigate sodium fire in case of sodium leakage from reactor vessel.

2. Design of Thermosiphon

To design thermosiphon, it is necessary to select working fluid, structure material and geometry.

2.1 Selection of Working Fluid

The temperature range of sodium coolant in SFR is approximately 350~650℃ including normal condition and accidental transient condition. By considering the temperature range, there are three options for working fluid: Mercury (Hg), Caesium(Cs) and Pottassium(K). Since Cs and K have higher reactivity with water and air than sodium, they are not proper for the coolant of decay heat removal system. Moreover, mercury shows no reaction with water, air and sodium. Also, there is another option using organic fluid; however it is expensive and have not been proven yet.

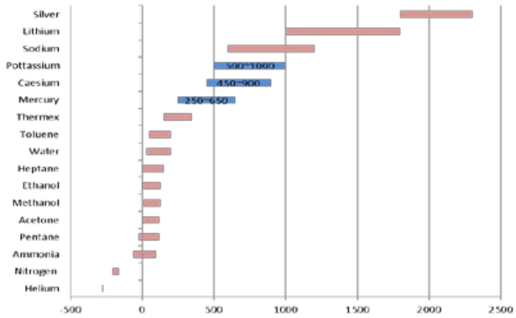

Fig. 1. Working fluid options for temperature range

2.2 Structure Material

The selection of structure material of two-phase thermosiphon is depending on working fluid. The chemical reactivity with working fluid, thermal resistance under high temperature, corrosion resistance under working fluid and high temperature/oxygen condition should be considered. Therefore, the stainless steel (SUS 316) is selected, against high corrosive character of mercury.

2.3 Geometry

For installation of two-phase thermosiphon, evaporator should be installed on external vessel. Since evaporator of thermosiphon can be compactly manufactured, no significant change inside containment is required. Condenser is installed outside of containment and cool saturated vapor from evaporator by air (Ultimate heat sink). Therefore, decay heat from reactor core transfer to reactor vessel, gap, containment vessel, evaporator, adiabatic section (insulated riser pipe), condenser and atmosphere in order (Fig. 2.).

Total four trains of thermosiphon loop are considered for the redundancy. Four evaporators would be attached on containment vessel around its circumference, so that one train of thermosiphon evaporator covers one fourth of the circumference each. The geometry of each component of thermosiphon is shown on table I.

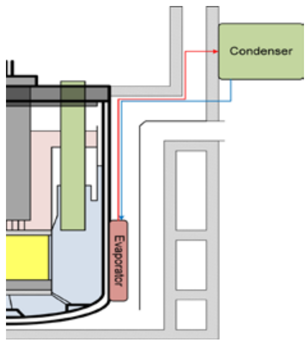

Fig. 2. Schematic of proposed ex-vessel cooling thermosiphon

Table I: Geometry of thermosiphon components

	Geometry
Evaporator	Hollow quarter-circular arcs
Adiabatic	Single tubes
Condenser	Finned multiple tubes

3. Method

Several conditions were assumed in order to evaluate the feasibility of thermosiphon on reactor containment vessel (CV). Reference reactor is KALIMER600 and the required decay heat removal was assumed to 15MWth, which is 1% of thermal power, 3 hours after reactor shutdown. All parameters of reactor vessel structure were from KALIMER600. The analysis was progressed along four main parts of heat transfer: Reactor vessel, evaporator, adiabatic section and condenser. All heat transfer was assumed to one dimension only.

The thermal analysis was conducted by using MATLAB R2011b. For evaporator outside, thermal resistance along to radial direction of reactor vessel and containment vessel was estimated. Gap effect was considered and contact resistance between CV and evaporator was neglected. For evaporator, 1D heat transfer with two heat flow path, liquid film and liquid pool, was considered by film condensation model. Adiabatic section was assumed to insulate and film condensation model is also used in condenser analysis.

Detailed design process is shown on figure 3.

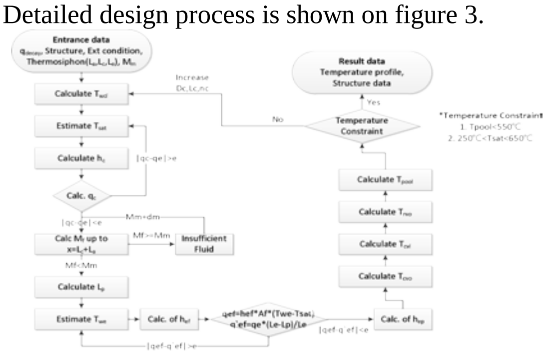

Fig. 3. Flowchart of thermosiphon design process

4. Results

The design of thermosiphon is followed by the design process stated on the method part. The design parameters for each component of thermosiphon are shown on table II.

Table II: Problem Description

Thermosiphon Module	
Number of module	4
Mass of mercury	200kg / module
DHR performance	3.75MW_{th} / module
Material	SUS 316
Evaporator (Hollow quarter-circular arc)	
Length	4.5m
Wall thick	2mm
Envelopethickness	15mm
Adiabatic Section (Single tube)	
Length	10m
Diameter	0.2m
Condenser (Finned multiple tubes)	
Length	1.9m
Number of tubes	50
Inner diameter	38mm
Outer diameter	40mm

The operation conditions in equilibrium state is shown on Table III and partial thermal resistance load is presented on Table IV. Table III shows more that approximately more than 50kg of mercury is required and temperature constraints for hot pool(<550℃) and mercury (250℃~650℃) are satisfied. Table IV presents that there is relatively high thermal resistance on condenser outside and gap. Therefore, large number of condenser tube and idea to enhance heat transfer in gap should be discussed. As a result of the thermosiphon design, 340% of DHR performance increase than RVACS for same operation condition.

Table III. Operation condition in equilibrium state

Operation Condition	
Pressure	0.35 bar
Mass of mercury (film/pool)	47.85 / 152.15kg
Equilibrium Temperature	
Hot pool	536.83℃
Evaporator wall	302.78℃
Saturated mercury	302.30℃
Condenser wall	302.28℃
Condenser fin	276.28℃

Table IV. Thermal resistance load

Operation Condition	
Condenser outside	0.0034 K/W
Condenser pipe	6.94x10^{-6} K/W
Condenser inside	2.33x10^{-7} K/W
Evaporator inside	1.30x10^{-7} K/W
Evaporator pipe	3.88x10^{-6} K/W
Containment vessel	4.57x10^{-6} K/W
Gap	3.26x10^{-5} K/W
Reactor vessel	2.13x10^{-5} K/W

5. Conclusions

This study shows that ex-vessel cooling by two-phase thermosiphon is feasible for large size of SFR. The result presents that further studies to increase heat transfer on condenser-air and gap is necessary and the experiment should be conducted for the validation. Also, the heat loss through evaporator during normal operation, corrosion, consideration of organic fluid to exclude the poison of mercury should be studied.

REFERENCES

[1] F. V. Andre and B. H. Marcia, Analysis of a High Temperature Thermosyphon, Federal University of Santa Catarina
[2] Yamamoto T., Nagata K., Katsuta M., and Ikeda Y., Experimental Study of Mercury Heat Pipe, Experimental Thermal and Fluid Science, vol 9, pp. 39-46, 1994