Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 24-25, 2013

Design of Passive Decay Heat Removal System using Mercury Thermosyphon for SFR

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1. Introduction

There are various type of decay heat removal systems for LMR (Liquid Metal Reactor) such as PDRC (Passive Decay heat removal circuit) of KALIMER-600 [1], RVACS (Reactor Vessel Auxiliary Cooling System) of PRISM [2], DRC (Direct Reactor Cooling) of EFR [3], SGDHRS (Safety Grade decay heat removal system) of PFBR [4] and DRACS (Direct reactor auxiliary cooling system) of ABTR [5]. Although, the passive type of decay heat removal systems have been designed for years but still exists the active parts that operators have to control when the accidents occurred. In this study, thermosyphon application is suggested to accomplish the fully passive safety grade system and compactness of components via enhance the heat removal performance.

A two-phase evaporating thermosyphon operates when the evaporator is heated, the working fluid start boiling, the vapor that is formed moves to the condenser, where it is condensed on the walls, giving up the heat of phase change to the cooling fluid. Gravity forces cause the condensate to condensed liquid flow to the evaporator again. These processes occur continuously, which causes transfer of heat from evaporator to condenser vice versa.

2. Thermal System Design

2.1 System Configurations

The conceptual layouts of the loop type mercury thermosyphon components are shown in Fig. 1 and Fig. 2. Each loops of thermosyphon system consists of evaporator section and condenser section wherein reactor core and outside of containment respectively. Total four loops are designed to removing the decay heat and evaporators are inserted hot pool of reactor core between IHX and pump in the axial position.

Evaporator section is sodium-liquid mercury heat exchanger, and one evaporator bundle is designed for rated thermal power of 7.5 MW_{th}. One bundle could be consisted of 5 evaporator pipes for increasing heat transfer area to remove sufficient amount of decay heat. The main material for evaporator pipes, internal and other structures of the bundle is SS304L stainless steel that compatible with mercury. Pipes are connected each other at the bottom of an evaporator bundle which is liquid mercury collector to evaporate continuously. As shown in Fig. 1, evaporated mercury vapor flow pass through the one main pipeline in the upper end of the evaporator bundle. The pipe bundle of each evaporator contains 5~6 straight pipes of 10 cm inner diameter with 2 cm thickness and all pipes are arranged in radial direction.

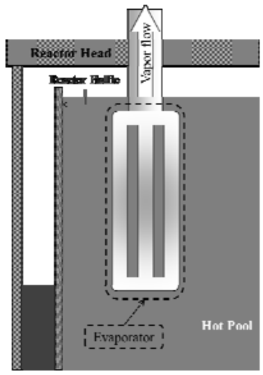

Fig. 1. Evaporator bundle layout.

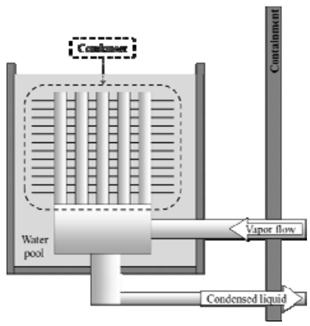

Fig. 2. Condenser bundle and water pool layout.

Condenser section, placed on the ground and outside of the reactor building, has the function of carrying decay heat into the heat sink, the cooling water pool and atmosphere. The heat is moved from the hot sodium pool into working fluid, evaporated mercury vapor, via evaporator bundle and condensed by lower temperature in inner wall of condenser. Those processes are removing the heat of primary sodium pool continuously. All condenser pipes are connected its bottom side to collecting condensed liquid mercury to down below. The fin structure could be increase the heat removal performance of the thermosyphon system and it affect the total plant economic efficiency by reducing component size and accomplish the compactness.

2.2 Thermal Design Process

Thermosyphon heat transfer mechanisms for the high temperature can be described by heat balance model. From the Fourier's Law, heat removal performance of mercury thermosyphon system can be calculated [6, 7]. Faghri et al., divided thermosyphon for four sections and calculated the heat transfer coefficient or thermal resistance of each sections. In this study, iteration process was performed to design the single thermosyphon geometry using Faghri's thermal design method by following Fig. 3. The basic input data are total heat removal rate, diameter of thermosyphon pipe, length of three parts, temperature of condenser and evaporator and total mass of working fluid.

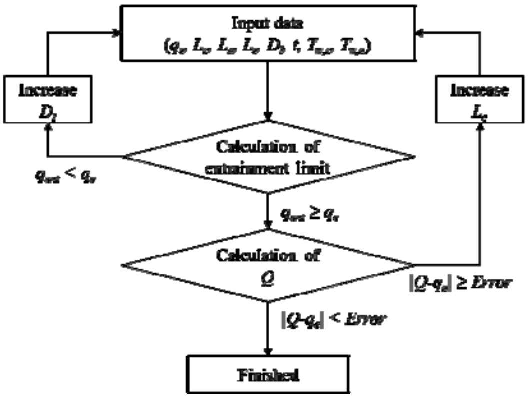

Fig. 3. Flowchart of thermal design process of mercury thermosyhpon.

Calculated design data will be described of one loop of mercury thermosyphon. As shown in Fig. 4, each loop is designed to remove 7.5 MW_{th} and total four loops of thermosyphon are inserted for decay heat removal of 1500 MW_{th} SFR. Evaporator and condenser bundle design data at the design point of the decay heat removal system are summarized in Table I.

Table I: Design data for one loop of mercury thermosyhpon decay heat removal system.

Items	Data
Overalls	
Material	Chrome Lined SS304L
Number of Loops (#)	4
Evaporator Pipes	
Number of tubes	6
Inner diameter (cm)	10
Outer diameter (cm)	14
Thickness (cm)	2
Length (m)	4.5
Condenser Pipes	
Number of tubes	20
Inner diameter (cm)	10
Outer diameter (cm)	14
Thickness (cm)	2
Length (m)	1
Water Pool	
Area (m^2)	400
Height (m)	2
Amount of water (ton)	500

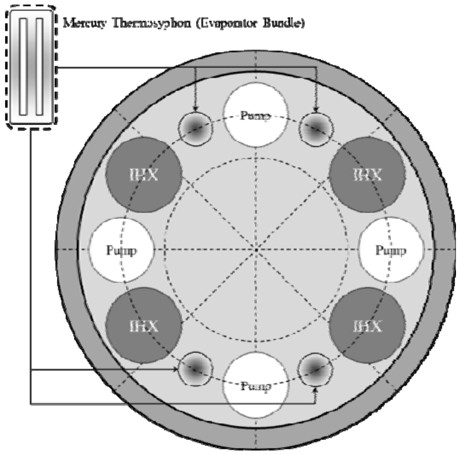

Fig. 4. Axial position of evaporator bundle

3. Conclusions

After the thermal design and performance evaluation, the results were compared with the performance of conventional DRACS system. For the same amount of decay heat removal performance of PDRC system of KALIMER-600 mercury thermosyphon system can archive around 30~50% of compactness. For the detailed design, improved analytical model and experimental data for the validation will be required to specify the new DHR system.

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