Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 22, 2009

Evaluation about Validity of the Passive Containment Cooling System using Multi-pod Heat Pipe

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1. Introduction

ECSBS(Emergency Containment Spray Backup System) will be introduced to Shinkori Reactor No. 3 and 4 (APR-1400). The system is an accident management facility which is operated when an overpressure preventing facility of the reactor building does not function well in a severe accident. This system has its function and strong point expected at the severe accident, but could not secure isolation. Also, it requires additional expense for pipe arrangement, security of water source, continuous holding of operators, etc. As its weakness. Therefore, the MHP(Multi-pod Heat Pipe) for minimizing a leakage of radioactivity passively with the low maintenance/repair cost is suggested instead.

2. Requirement of Multi-pod Heat Pipe

2.1 Heat Removal Requirement

The energy equation is set up on the assumption that fluids (cooling water and air) in the containment and the whole structure (primary system and related structures all) are one system.

$$\frac{dE)_{Containment}}{dt} = \dot{Q} - \dot{W}$$

Then, $\dot{W}$ =0 could be safely applied because a general containment is a concrete structure with no shaftwork.

According to the previous study result (code calculation), FLC of APR-1400 was 124.7psia and the shortest time for reaching to the FLC in the LOCA accident was 24.7hr. If MHP designed to eliminate heat at a certain rate is operated continuously after the accident, it would be safe that pressure of the containment is not over the FLC for 72 hours.

$$\dot{Q}_R \times 72hr = Q_D(72) - Q_D(24.7)$$

Here, Q_R=heat of MHP, Q_D(t)=elimination rate are a total dacay heat by the time t after shutdown, obtained by integrating the collapse heat equation of ANS. As a result of calculation,

$$Q_D(72) - Q_D(24.7) = \Delta Q_D = 933.8P_0 \sec(MJ) \qquad \Delta\dot{Q}_D = 933.8P_0$$

$$P_0 = 1400 \times \frac{1}{0.33} \Rightarrow (efficiency = 33\%) \qquad \Delta Q_D = 3.96 \times 10^6 MJ$$

the amount of heat to be cooled by MHP per time unit is

$$\dot{Q}_R = \frac{3.96 \times 10^6 MJ}{72 \times 3600 \sec} = 15.3MW$$

2.2 Arrangement and shape of MHP

On the assumption that the thermal conduction rate of the whole condensing unit is 6W/m^2℃ and that the average pressure at the containment is 830kPa (~120psia), Sat. Temp. is approximately 172℃ and that the atmospheric temperature is 40℃, $\Delta T \approx 130^{\circ}$C.

$$15MW = 6W/m^{2\cdot}C \times 130^{\cdot}CA \qquad A = 1.92 \times 10^4 m^2$$

On the other side, on the assumption that a diameter and the length of the heat pipe are 2cm and 3cm respectively, the heat transfer area of one heat pipe is a=9.4×10^{-2}m^2. Then, approximately 200 thousand pipes are needed, but this is unrealistic. Therefore, the heat transfer are could be increased about three times by elongating the condensing unit to 5m, mounting fins in installation of the chimney, and using optimal D/P (approximately 2.0). Therefore, the total thermal conduction rate based on the outer area of the pipe is u=20w/m$^{2\cdot}$C .

$$15MW = 20W/m^{2\cdot}C \times 130^{\cdot}CA$$

$$A = 5.77 \times 10^3 m^2, a = \pi 0.01 \times 5 = 1.57 \times 10^{-1} m^2$$

$$N = \frac{5.77 \times 10^3 m^2}{1.57 \times 10^{-3} m^2} \cong 3.7 \times 10^4$$

Conservatively, 4×10^4 heat pipe (pod)s are needed. On the assumption that D/P is 2.0, D is 2cm, so P is 4cm. Therefore, a hexagonal array of size 4m×4m possibly receives more than 10^4 pods and requires 4 MHP manifolds of which each one is 4m×4m.

3. Conclusions

3.1 Shape of MHP

Heat pipe is composed of an evaporating region (heating region), an adiabatic region, and a condensing region. If these are simply applied to cooling of the containment, tens of thousands of heat pipes and numerous containment penetrations are needed to satisfy its huge cooling condition. Eventually, it is not easy to satisfy functional requirements of the containment which should be air-tight, and its construction and maintenance would come harder.

Therefore, adiabatic regions (their part passing through the containment) were integrated into one cylinder to minimize the number of penetration regions. Thereby, the outer wall of the adiabatic region with no relation to heat transfer could have the stronger structure, so it is installed, maintained, and repaired at the containment more easily. On the other side, the evaporating region and the condensing region should actively transfer heat, so they were designed to have numerous pipes.

3.2 Design of Adiabatic Region

The adiabatic region serves as a channel to actively send vapor generated at the evaporating region where water boils by absorbing decay heat in the containment to the condensing region where condensation occurs due to emission of heat to the atmosphere, and to send a liquid-phase fluid condensed at the condensing region down to the evaporating region again. Also, it should be air-tightly mounted on the structure of the containment, and designed strongly to bear up under physical load in a certain range and to easily reform/repair/replace the structure.

In the adiabatic region, gas (upflow) and liquid (downflow) would generate counter-current flow. Two-phase flow phenomena, such as undesirable CCFL (Counter-Current Flow Limit), entrainment, etc. should be prevented. Therefore, the adiabatic region was designed to have a double, concentric cylindrical structure inside so as to flow a liquid-phase fluid (small volume) through the inner cylinder and a gas-phase fluid through the outer cylinder

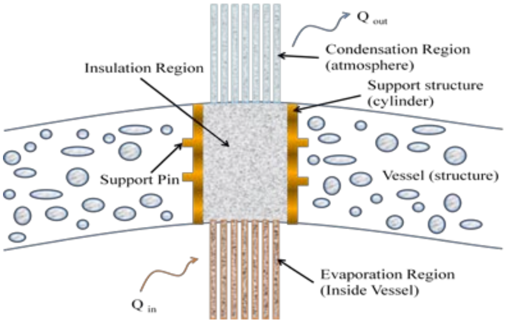

Fig. 1 Conceptual diagram of the Containment Cooling MHP

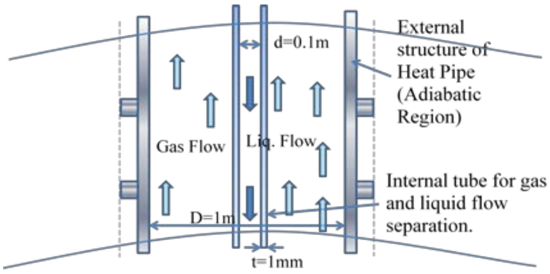

Fig. 2 Adiabatic Region Design

By calculating each flow amount of (downward) liquid and (upward) gas , it was shown that both the diameter of the inner cylinder and the inner diameter of the heat pipe were long enough.

3.3 Design of Evaporating Region

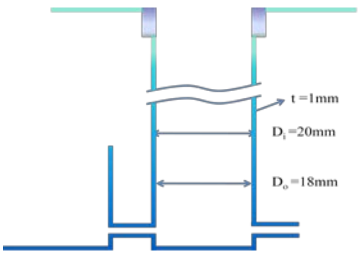

Fig. 3 Evaporating Region Design

The evaporation regions were grouped to exchange liquids with each other so as to prevent non-uniform distribution of the liquid inside. The number of pipes in a group should be limited to a certain level to prevent numerous pipes from being failed at once when one pipe fails. Also, a connection passage maintains regular intervals between pipes and supports the structure.

Table I: Total Flow Rate of Liquid and Vapor of Water in Heat pipe

Parameter		*Operating Range*	
		145 ℃(415kPa)	*175 ℃(890kPa)*
$h_{fg}(KJ/kg)$		*2129.6*	*2032.4*
$\dot{m}(kg/sec)$		*9.86*	*10.33*
Volume Flow Rate	$\dot{Q}_l(m^3/sec)$	*0.01*	*0.012*
	$\dot{Q}(m^3/sec)$	*4.4*	*2.24*
Gas Flow velocity (m/sec)	*D=1m (A=0.785m²)*	*5.6*	*2.85*
	D=2m (A=3.14m²)	*1.4*	*0.71*

*- Operating Range(Press) = 860 kPa (124.7 psia)
For the conservatism Starting press
= 415 kPa ≑ 4 atm (Design pressure of containment)
≑ 145℃ ~ 175℃ (890 kPa)

3.4 Final shape of MHP

Finally, relative size and shape of MHP are shown at the following figure.

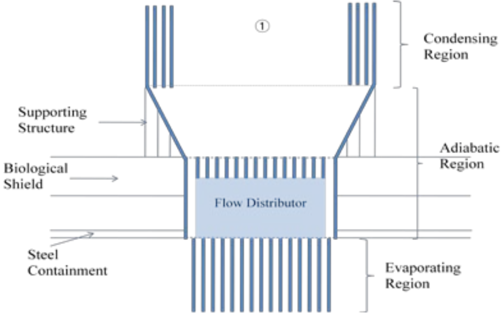

Fig. 4 Schematic Diagram of MHP

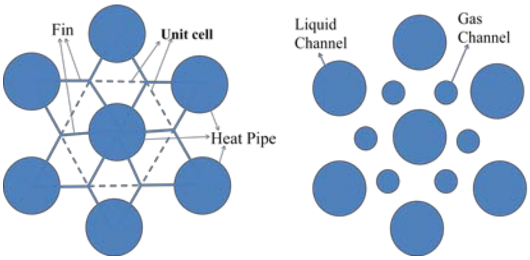

Fig. 5 Hexagonal array of Heat Pipe and Fins (① of Fig. 4)

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