Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 29-30, 2015

Development of heat insulation device to protect pressure measuring instruments from high temperature under the severe accident

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1. Introduction

Under severe accidents, in-containment data such as pressure, temperature, and radiation dose should be obtained for proper mitigation processes. To obtain these data, measuring instruments such as Thermocouple (TC), Resistance Temperature Detector (RTD), pressure transmitter, and radiation sensors should endure the harsh condition created by the severe accident. TC, RTD, and radiation sensor do not need to be protected below the melting temperature. Besides, they are expected to lose their accuracy when they are blocked. But, pressure transmitter which converts analog pressure signals from a sensor to electronic signals should be protected. Micro Control Unit (MCU), communication module, and power supply system are also needed to be protected for the pressure transmitter.

The harsh condition in containment which is created by the severe accident are composed of five elements: high temperature, high pressure, high humidity, high radiation, and physical threats by shrapnel generated during the process of the severe accident. Among these five elements, high temperature should be focused because other elements can be solved even with the thin shield. There was a study which builds a conceptual design of heat insulation device to protect pressure measuring instruments from the high temperature under the severe accident done by Min Yoo in 2013 and 2014 [1, 2]. In this study, a detailed design of the heat insulation device which will be installed in the containment based on the Min Yoo's study and a verification test are done.

2. Pressure measuring instruments

Pressure measuring instruments are consist of transmitter which needs to be protected, communication module, MCU which controls the others, power suppliers and converters. Power suppliers and converters are consist of two methods. One is the wireless system which is supported by outside of insulation device, and the other is battery system. Components can be fully supplied by one of these methods.

Li-ion secondary battery with 16.2Wh is selected for the battery system considering the conditions below:

- Easier maintenance
- Polymer type for safety
- Commercially used for reliability
- Workable temperature should be higher than that of transmitter
- Lower heating power, higher energy density
- Stable, and long life cycle

Total heating power from pressure measuring instruments are conservatively calculated with below conditions:

- Power consumption is wholly converted to heating power
- Considering the maximum power consumption for each components
- Efficiency of each converters are assumed to 70 % (Normally, it shows 80 ~ 95 % efficiency)

The wireless system supplies power to MCU and communication module through one converter, transmitter is supplied power through two converters. But if battery system is used as power supplier, converter is only used for transmitter. So total power consumption is lower when the battery system is used as a power supplier. To minimize the heating power from pressure measuring instruments, battery system should be used first in real operation, but heating power should be considered with the wireless system, 4.62W, for the conservative design. In this case, 18 batteries are required. Conceptual map of pressure measuring instruments is shown in figure 1, and the heating power from each power supply systems are showed in table I and II.

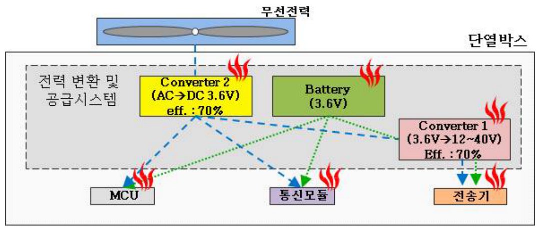

Fig. 1. Conceptual map of pressure measuring instruments

Table I: Total power consumption with wireless power supply

	Component	Maximum Power consumption (W)	Converter 1 eff. (%)	Converter 2 eff. (%)	Total Power Consumption (W)
Wireless Power Supply	MCU	1.20	-	-	1.71
	Communication module	0.75	-	-	1.07
	Transmitter	0.90	70	-	1.84
	Sum	2.85	-	70	4.62

Table II: Total power consumption with battery

Power Supply by Battery	Component	Maximum Power Consumption (W)	Converter 1 eff. (%)	Total Power Consumption (W)
	MCU	1.20	-	1.20

	Communication module	0.75	-	0.75
	Transmitter	0.90	70	1.29
	Sum	2.85		3.24

Shape of the container which contains the pressure measuring system is determined as circular cylinder for the structural stability, and the size of the container is determined as 350mmD x 300mmH. 3D arrangement of pressure measuring instruments is shown in figure 2.

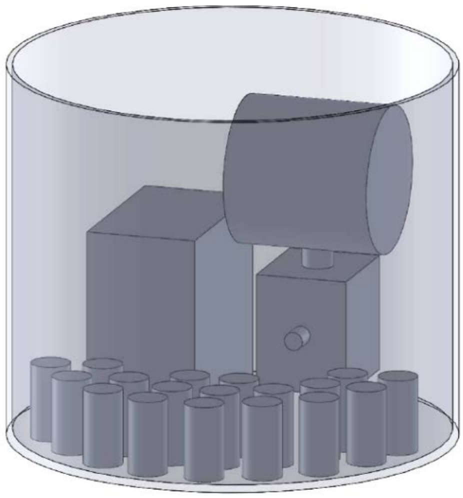

Fig. 2. 3D Arrangement of pressure measuring instruments

3. Conceptual design

The objective of heat insulation system is maintaining the temperature of pressure measuring instruments below the 80℃ during 72 hours under the high temperature and the 4.62W from the system. The initial temperature is assumed as 20℃.

Minimum size of the insulation device for the 350mmD x 300mmH container is shown in below which includes 10% of margin when the design methodology from the Min Yoo’s previous study is applied:

- Thickness of upper insulation layer : 77mm
- Thickness of side insulation layer : 72mm
- Thickness of water layer : 80mm
- Outer diameter of device : 327mm
- Height of device : 529mm

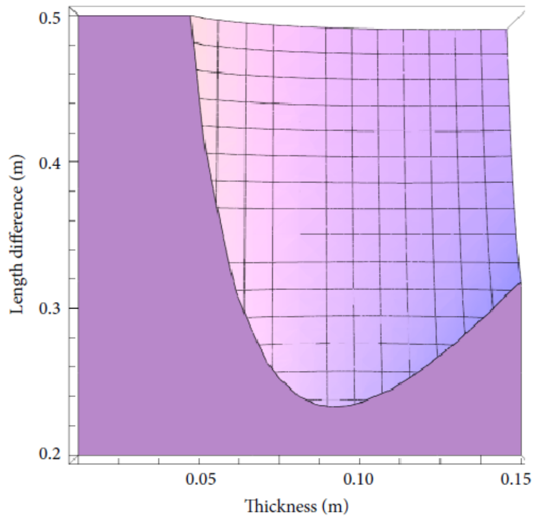

Fig. 3. Minimum wall thickness and length difference between inner and outer protector which are satisfied the goal temperature until 72 hours

4. Detailed design

Three requirements should be installed for the maintenance of insulation device:

- Pillars to prevent the deformation of the insulation layer
- Connection layer to open the device for maintenance
- Penetration pipes for the TC and transmitter

These three requirements are additional heat paths to the pressure measuring instruments.

$$Q_x = \frac{1}{R_{tot}} \cdot \Delta T \quad (1)$$

Additional temperature rise which soaring 90% from the device without requirements is expected to the lumped model of the device with requirements by the calculation with equation (1). To design the minimum size of the insulation device with water which can satisfy the objective, r and h in figure 6 should have values which can make the differentiation of V_{total} as 0 in equation (5).

$$Q_{total} = Q_0 + Q_{add} = \mathrm{C} \cdot \mathrm{m}_0 \cdot \Delta\mathrm{T}_0 = \mathrm{C} \cdot m' \cdot \Delta\mathrm{T}' \quad (2)$$

$$V_{water} = r^2 \cdot \pi \cdot h - C_1 \quad (3)$$

$$V_{insulation} = (r + C_2)^2 \cdot \pi \cdot (h + C_3 + C_4) - r^2 \cdot \pi \cdot h \quad (4)$$

$$V_{total} = C_1 + V_{water} + V_{insulation} \quad (5)$$

Minimum size of the insulation device with the detailed design which considering the calculations above is like below:

- Thickness of upper insulation layer : 77mm
- Thickness of side insulation layer : 72mm
- Thickness of upper water layer : 60mm
- Thickness of side water layer : 115mm

- Thickness of lower water layer : 331mm
- Outer diameter of device : 382mm
- Height of device : 900mm

Only the thickness of water layer is changed comparing to the conceptual design. In the detailed design, 80mm of water layer which is the thickness of conceptual design locates the upper side of instruments to protect the heating directly from the upper side of the device. With the upper water layer, 10% of temperature rise decreased. Also, pillar in the side insulation layer, supportive structures in the edges are installed for the structural stability.

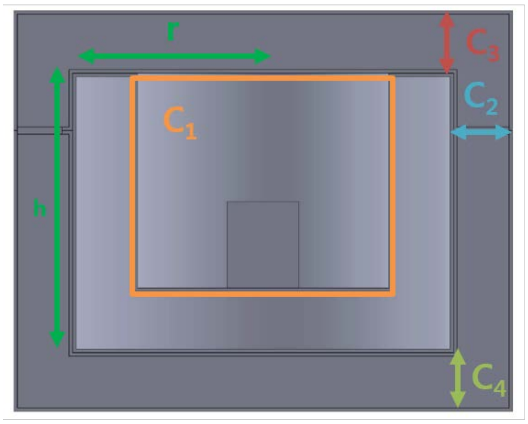

Fig. 4. Calculation method for the minimum volume of detailed design based on conceptual design

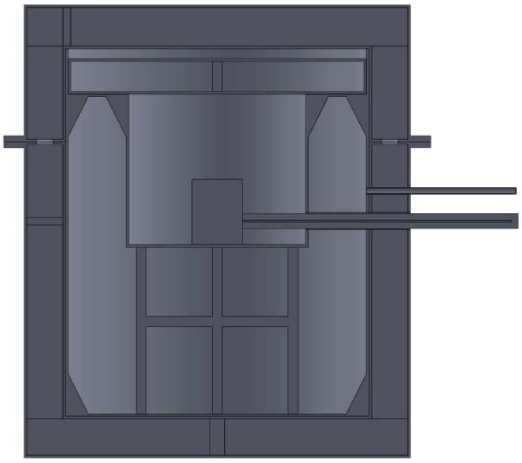

Fig. 5. Sectional view of detailed design

6. Verification test results

Results of the verification test will be added later.

Fig. 6. Site image of the verification test

7. Conclusion

Development of heat insulation device which enables operator to get in-containment data for the proper mitigation process under the severe accident was done in this study. With researches for severe accident management systems which proceeding actively since the Fukushima accident, researches for reliable instrumentations of in-containment data which is necessary to operate severe accident management systems properly in harsh condition during accident also should be progressed.

REFERENCES

[1] Min Yoo and Hyun Gook Kang, Harness Design for the Improvement of Transmitter Survivability in a Severe Accident, American Nuclear Society, Boston, Massachusetts, USA, April 4-6, 2013.

[2] Min Yoo, Sung Min Shin, and Hyun Gook Kang, Development of Instrument Transmitter Protecting Device against High-Temperature Condition during Severe Accidents, Science and Technology of Nuclear Installations, Article ID 345729, p.7, 2014.