Prediction of overall heat transfer coefficient for RMI insulation using the test and analysis

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1. Introduction

RMI is important insulation to minimize the heat loss from various component of Nuclear Power Plant. Above all, compared to other glass-fiber type, it is more satisfied with safety issue about long-term recirculation cooling of coolant loss accident. Major reason is relating with RMI's material property for the resistance against chemical reaction and corrosion.

RMI is compose of out-shell and multilayer with stainless steel of thin plate; both are assembled While covering the component surface with insulation parts, it has to consider the thermal insulation performance margin to satisfy the plant specification such as that of outside's temperature is less than 60℃. But because of complicate design about various insulation size and thin layers stacking, it is difficult to knowledge the total heat value the case by case. Both parts of shell and layers have different thermal transfer flow; shell-part is conductivity loss, layer is convective and radiative loss that would contribute to calculate the total heat value with difficulty.

We developed the new method about prediction of RMI's total value by separating the shell and layer as a function of heat resistivity. Whereas heat transfer value at the insulation shell is calculated by CFD analysis according to various insulation sizes, multi-layer would be done by thermal test. These predicted models are compared with final insulation sample of overall heat transfer value for the validation.

2. Methods and Results

In this section some of the techniques used to model the.

2.1 Review of RMI sample and analysis model

We focused on predicting the overall heat transfer coefficient of one-body insulation sample by separating inner layers and out-shell. That is mainly because of heat transfer behavior[1]. Inner-layer's value was confirmed at the thermal test by using the factor about the number of layer. Without insulation size, it seemed that inner-layer shows the similar insulation property. But heat transfer of especially conductivity loss is closely related with out-shell design such as shell thickness and insulation size and contract area.

We calculated overall heat transfer coefficient with sum of each thermal resistance for inner-layers and out-shell due to be arranged in parallel. Inverse of resistance(R) is expressed as heat transfer coefficient(h)

$$\frac{1}{R_{overall}} = \frac{1}{R_{inner-layer}} + \frac{1}{R_{out-shell}}$$

$$h_{overall} = h_{inner-layer} + h_{out-shell}$$

Eq. 1. Equation of overall heat transfer coefficient with sum of inner-layers and out-shell

Inner-layers are the one that thin plate is stacking each other with upward direction. Thermal resistance is derived from the thermal conductivity test which is considering the insulation thickness and surface thermal resistance. We carried the thermal test of insulation for inner-layer by using the GHP456 titan model, which is thermal conductivity. Thermal resistance at the inner-layer is a function of insulation thickness and surface thermal resistance and conductivity likewise Equation 2. Surface thermal resistance is generally known to have values likewise Table 1.

$$\frac{1}{R_{inner-layer}} = \frac{1}{R_{surface\_inside} + \Sigma \frac{d}{k} + R_{surface\_inside}}$$

R : thermal resistance (m^2-K/W)
d : insulation height (m)
k : thermal conductivity (W/m-K)

Eq 2. Calculation function for the part of inner-layers

Table I: Surface convection heat transfer coefficient as with heat flow conditions

	position	Heat flow	In case reflective	
			ε = 0.2	ε = 0.05
Static condition	Horizontal	Upward	0.19	0.23
		downward	0.48	0.80

Insulation sample for thermal test is 0.3m(width) × 0.3m(length) × 75mm(height). Mean temperature is 30℃, delta temperature is 20℃, so that hot plate is 40℃ and cold plate is 20℃. CFD analysis is also carried out heat transfer with same insulation size(0.3m(width) × 0.3m(length) × 75mm(height)) except for inner-layers, that is to assess the out-shell effect.

2.2 Assessment of inner-layer's heat transfer coefficient using the thermal test

At the previous work, we decided that optimum air-gap as a flat plat between the layers is bellows 9mm for minimizing the convection loss[2]. Also new type of bending structure was developed by applying the concept of less contacting and stacking structure of thinner air-gap with maximum fabrication limit[3]. Bending type RMI design is likewise Fig. 1 with air-gap is less than 6mm. it was fabricated with continuous bending procedures to minimize the cost. Multi-layer are comprise of many thin bending layers with being crossly stacking each other, seeing at the Fig. 2. Since air-gap is blocked by the wall of both plates, if it assumed that there are 8 layers, number of air-gap is 9.

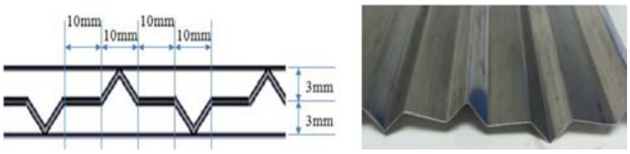

Fig 1. Bending type RMI sheet

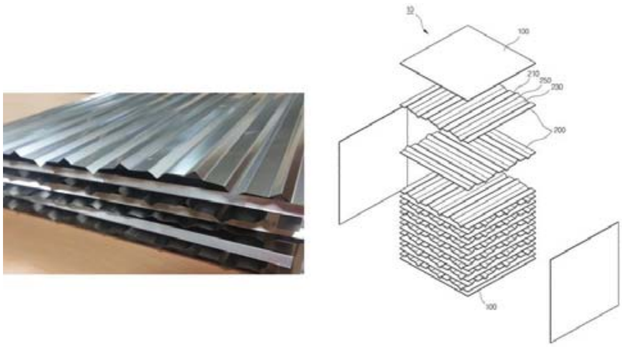

Fig 2. Multi-layer stacking design figure

Figure 3 is heat transfer coefficient of inner-layers for both type of flat plate and bending design in condition of air-gap 25 mm thickness. It is that same condition is considered such as air-gap thickness, insulation size, and emissivity. Bending type is better improved insulation performance with 4% compared to flat type due to be seemed that there is convection effect. In this point of view, we would know and manage the bending type performance with fixed ratio as flat type

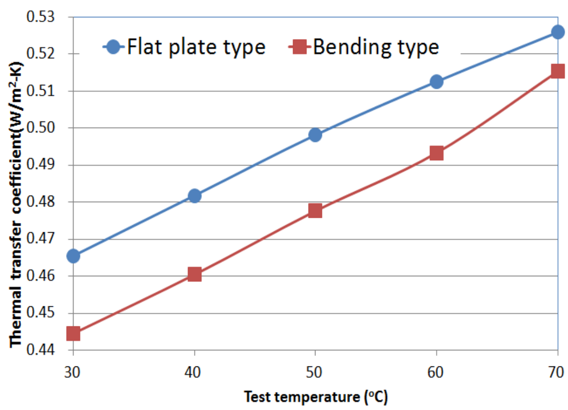

Fig. 3. Heat transfer coefficient of inner-layers for flat and bending type design

2.3 Calculation of heat transfer for insulation out-shell along

The analysis of the RMI consider the solution of the heat transfer(conduction, convection) which was obtained by CFX tool with CFD-code. The initial condition used in hot surface is 30°C, 5W/m^{2}K and the initial condition used in cold surface is 10°C, 5W/m^{2}K. Then, the boundary conditions are: left and right adiabatic boundary and no-slip condition in the walls. In the solid-gas interface, the temperature and the heat flux must be continuous. Laminar model was used for the turbulence analysis. Different combinations of out-shell thickness with heat flux of vertical were analyzed by using the CFX. Figure 4 shows heat transfer coefficient of RMI(plat & bending type, 2 layers). Out-shell thickness is also expressed by insulation size as shell ratio. According to increasing the shell thickness, it means that insulation size becomes small and heat conductivity loss gets large.

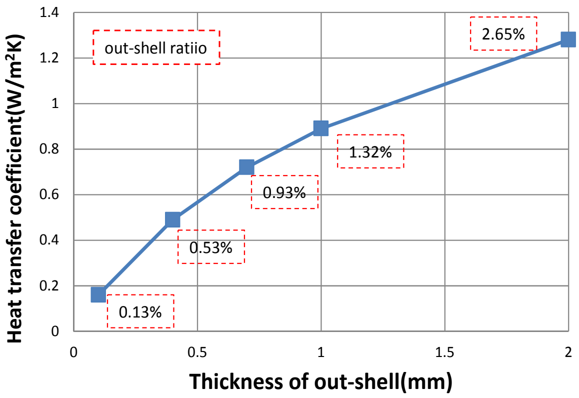

Fig. 4. Heat transfer coefficient of RMI with various out-shell thickness

Table Ⅱ: relationship of out-shell ratio and insulation size

out-shell ratio(%)	insulation rectangular size(mm)
0.47	600
0.40	700
0.35	800
0.31	900
0.28	1,000
0.25	1,100

2.4 Approximate prediction of overall heat transfer coefficient according to various insulation size

Sum for inner-layers and out-shell is plotted linearly by figure 5. Over half of overall values about RMI is from the heat loss at the out-shell part. For increasing temperature, whereas out-shell part is tiny change, inner-layers part is softly increased. In practice, being out-shell is 0.7mm around the insulation body, we easily estimate the overall heat transfer coefficient of RMI sample. Whereas out-shell part is independent of temperature changing, inner-layer is proportion to the temperature factor, so we could expect overall heat transfer coefficient value around 340°C as design condition is about 1.9 W/m^2K

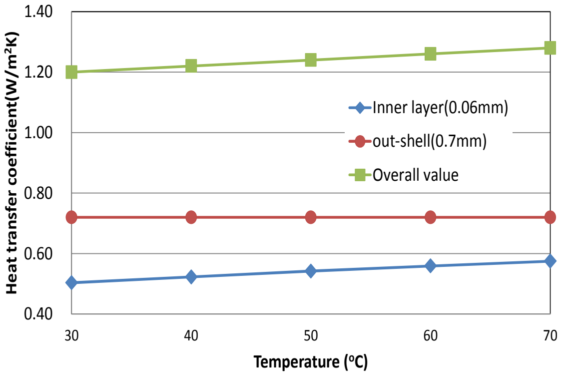

Fig. 5. Sum of heat transfer coefficient of inner-layer and out-shell

Since RMI design is changed according to component design requirement such as size and radius and curvature, we have to design and fabricate many insulation types with various sizes. Out-shell ratio as insulation size is dominant factor for determine the final insulation performance. It means that we have to validate various insulation designs and find the final design. Figure 6 is Prediction of overall heat transfer coefficient for air-gap 6.8mm(in practice) in comparison with air-gap 25mm. We already knew the flow of overall heat transfer coefficient of air-gap 25mm(2 layers and 3 air-gap) by combine the values of layers and shell. Considering the existing values, for example air-gap 25mm, we would predicted overall heat transfer coefficient for air-gap 6.8mm model likewise Figure 6 of dotted line. It is assumed that air-gap variation as with out-shell ratio is similar. As see at the Figure 6, temperature range is up to 70°C. Next work is focused on the high temperature based test around max 340°C.

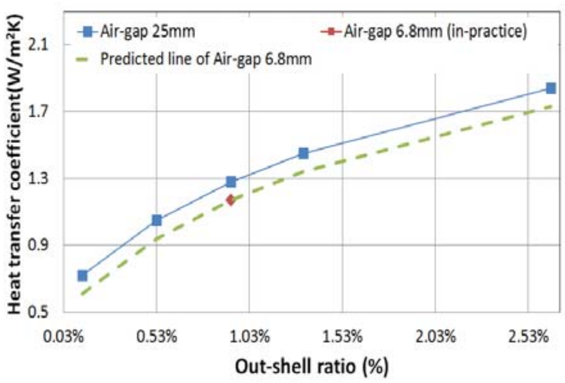

Fig. 6. Prediction of overall heat transfer coefficient for air-gap 6.8mm(in practice) in comparison with air-gap 25mm

3. Conclusions

RMI insulation was investigated by GHP (guarded hot plate) measuring instrument (inner-layer) and thermal analysis simulation(CFD method) to predict the approximate value of overall heat transfer. The results are as follows.

- Thickness of out-shell as same meaning of out-shell ratio is determined very carefully at RMI design. Because it can lead to very large changes in heat transfer. For example, whereas thickness of out-shell with 0.1mm(0.13%) shows 0.16 W/m^2K through surface of out-shell, that of 0.4mm(0.53%) thickness is 0.49 W/m^2K which is increased nonlinearly.
- Inner-layer and out-shell of RMI is arranged in parallel, so that overall heat transfer coefficient would be written with sum of each part. For example, at the condition of 70°C, inner-layer part(0.06mm) is 0.56 W/m^2K and out-shell part(0.7mm) is 0.72 W/m^2K, and overall value is 1.28 W/m^2K.
- We could expect that heat transfer value is changed according to out-shell ratio, because out-shell ratio as conductivity loss is connected with insulation size and inner-layer as radiation blocking is independent. If we know the specific value of air-gap and insulation size(out-shell ratio), it is possible to predict the approximate value of overall heat transfer coefficient.
- Future work is to investigate the predicted values of various insulation designs by using the test on site condition.

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