Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 18-19, 2017

Simulation of RMI(Reflective Metal Insulation) design for air gap effect between multi-layer plate and side-wall

Sung-Myung Lee [a*], Hong-Yeong Oh [b], Kye-Hwan Jang [a], Won-Seok Kim [a]
[a]122, Jangbaek-ro, Jangji-ri, Gunbuk-myeon, Haman-gun, Gyeongsangnam-do, Republic of Korea
[b] *40, Techno 3-ro, Yuseong-gu, Daejeon, Republic of Korea*
[*]*Corresponding author: smlee@bhi.co.kr*

1. Introduction

Nuclear power plants are sensitive to cope with various accident condition such as LOCA(loss of coolant accident) scenario. Debris with NUKON and calcium-silicate, used as insulation and flowed out at accident, is obstacle to ensure the RCS(Reactor cooling system) long-term-cooling during several months. Many considerations are carried out to solve the serious safety issues[1]. For example, upgraded ECCS strainers have been installed at the bottom of containment building to filter debris mixture with pure cooling water. But it is not fully resolve the debris problem, because debris particles with very small size bring out downstream effect such as local overheating of fuel assembly. US NRC have recognized above phenomenon and suggested other alternative about replacing existing insulation(NUKON) with RMI(reflective metal insulation). RMI insulation composed of only stainless steel already is reported to solve the safety issues such as hydraulic loss and chemical reaction effect and debris clogging.

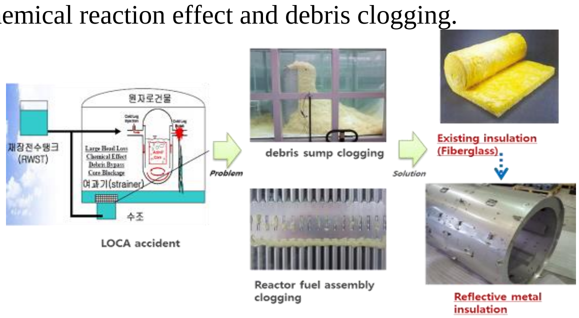

Fig. 1. Plant safety accident and RMI application

In order to apply RMI insulation instead of existing NUKON insulation, it has to satisfy safety-enhanced design requirements related with performance, fabrication, verification and other standards. Our new developing RMI product shows four different innovative insulation properties. First, insulation performance like heat transfer coefficient(W/m^2-K, called as Tr) and mean insulation surface temperature have proper values with satisfying the requirements. Insulation test was carried out by guarded hot-box test and guarded hot-plate test[2]. Measured values with heat transfer coefficient and surface temperature are less than 0.8 W/m^2-K and 60^{o}C. Second, thin embossing plate as role of multi-layer to decrease radiation heat transfer has been fabricated with clean surface figure by minimizing local stress concentration. It would maintain the radiation heat transfer rate and stable stress distribution related with durability. Third, RMI insulation assembly have been verified to withstand severe seismic situations likewise OBE(Operating Basis Earthquake) and SSE (Safe Shutdown Earthquake) condition by test and CFD analysis. RMI sample copy from natural frequency of reactor vessel shows stable structural integrity and no change of natural frequency during the test condition which max input load is 5g. Fourth, RMI design about considering plant site's space and operation make easy to move and install insulation products. RMI unit weight is around 20kg that two people could pull up together, and buckle fastener are useful to assembly RMI each segments and inspect specific inner part of component after removing RMI segment.

This paper covers the especially RMI insulation performance related with thin plate design and build-up that is most important design factor to minimize the heat loss along the insulation. It is issue about how to stack embossing thin plates(minimum 12EA) in the segment box. Heat transfer properties of RMI are reviewed design factors whether plate and segment side are contacted or not by using the CFD calculation and test. It would provide the optimized design with low heat loss along the insulation thickness.

2. Methods and Results

In this section, RMI design especially related with thin plate and side contact are reviewed according to CFD calculation. Main key-point to judge heat transfer property is heat transfer coefficient value and vector flow figure. CFD result's reliability was identified with checking with insulation test.

2.1 RMI design consideration

Basic RMI sample is comprised segment box and thin multi-layer. Segment box is designed to protect insulation from external impact or force, and also transfer heat into the thin plates. Thin multi-layer plates act as actual insulation medium to reduce heat coming from the component heat source(around 330 ^{o}C). Previous work covered optimized design related with thin plates specific factor likewise plate number, plate shape and stacking method using small dimple concept [3-4]. It is second important design factor to consider contact effect between thin plate and box side-wall if RMI design of thin multi-plates is fixed. There are practically air gaps between plate and side-wall after RMI sample fabrication. That air gap would be way of heat loss or leak from inside to outside. But it was not noticed detail how much heat loss is generated about air gap effect.

There are three cases to check the air gap effect between thin plate and side-wall : All contact type, all 5mm off type and single(8th) only contact type. the value with 5mm off is fabrication allowance could possible get generally.

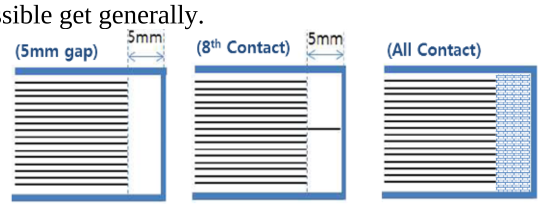

Fig. 2. Three kinds of air-gap type between plates and side

2.2 CFD boundary conditions related with heat transfer

CFD model size and number of plate is 914mm and 12EA. Outer cover thickness is 0.7mm and inner thin-plate is 0.06mm stainless steel. Emissivity and temperature condition are same with test condition. To low calculation load, it was adopted half symmetry model. Inside hot temperature is 330°C for component surface's max temperature and outside cold temperature 25°C is mean ambient temperature. Detail condition is likewise below;

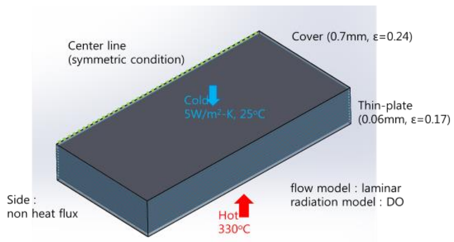

Fig. 3. CFD model and boundary conditions

2.3 CFD calculation results and review

First, it could identify the insulation performance according to air gap and its design factors. Calculation data has similar trend compared to test data even though number of plates are different. From more than number of plate with 10 EA, convection flow between two plates is negligible and radiation heat transfer is dominant factor at there. All contact type is better than 5mm off type with 17 % effect.

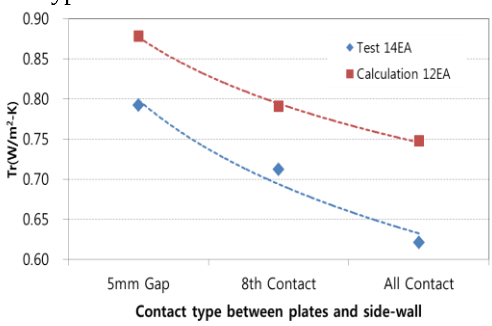

Fig. 4. Heat transfer coefficient variation according to design factors

It could find the reason why all contact type and single(8th) contact type has better than 5mm gap by reviewing the vector velocity flow. For 5mm gap type, air flows along the air-gap way from hot side to cold side with high velocity(max 16.9 cm/s) due to buoyancy effect. By the way, all contact type has each circulation air flow with small velocity compared to 5mm gap type. Complete contact between plates and side-wall could make air-flow block perfectly, and air flow is act as convection heat transfer, as Fig 4 and Fig 5.

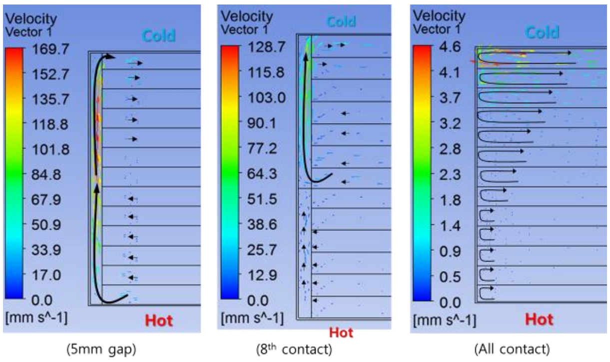

Fig.5. Air velocity vector flow as with three design factors

Along the three kinds of heat transfer such as convection and conduction and radiation, dominant factor to increase heat loss is convection and conduction term. Air-gap effect at between 5mm gap and 8th contact is larger, and thing about both 8th contact and all contact type is nearly small that is related with key space is near the cold side.

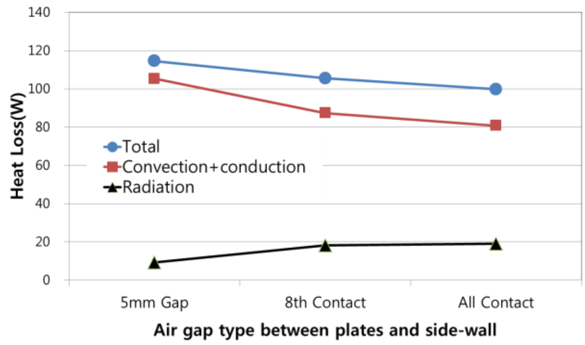

Fig. 6. Spitted heat transfer terms as three design factors

It seems difficult to separate 'convection+conduction' term into each part directly. But outlet temperature distributions as with three air-gap types show meaningful value for conduction heat transfer along the side wall which is of stainless steel. For 5mm gap between plates and side-wall, high heat with 330°C form hot side flow to cold side without reduction compared to other types. That concept is related with heat absorption between plates and side-wall. Likewise, heat loss at air-gap between plates and side-wall mainly attribute to convection and conduction effect.

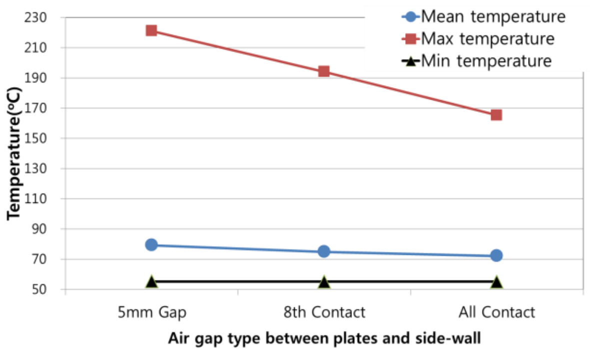

Fig. 7. Temperature variation at the outlet side as three design factors

3. Conclusions

It is well known for need to apply RMI insulation instead of existing NUKON insulation for solving the Nuclear Power plant's safety issue such as debris clogging and reactor stability.

This paper especially covers RMI insulation performance reviews among the several design requirements and targets. The most important design factor except for design of multi-layer is air-gap effect between plates and side-wall. It is simply classified with three kinds : all contact type, single(center) contact type, 5mm gap type. Details and as below;

- Heat transfer coefficient variation according to design factors by CFD calculation is meaningful as with test data. All contact type has 17% effect compared to 5mm gap type.
- First reason that why all contact type is better is heat flow form hot side to cold side along the air-gap way. It is something related with convection therm.
- Second reason is conduction heat loss along the side-wall as stainless steel. 5mm gap type's max temperature at the outlet surface is higher than all contact type. As heat flows from hot side to cold side, if plates were contacted with side wall, each plate takes away heat from side-wall.
-

ACKNOWLEDGMENTS

This study was performed as a part of "Development of the Safety-enhanced Reflective Metal Insulation" project sponsored by "MINISTRY of TRADE, INDUSTRY & ENERGY"

REFERENCES

[1] Seoug B. Kim. "A Study on the Insulation Design Parameters of the Reactor in the Korean Standard Nuclear Power Plant", Energy Engg. J, Vol. 8. No. 2, pp. 285~292, 1999

[2] Y. A. Cengel, Heat and Mass Transfer: Fundamentals and applications 4th edition, McGraw-Hill, 2012

[3] Eo Min-hun, Lee Sung-Myung, Jang kye-hwan and Kim Won-Seok, "Development of High-Performance Reflective Metal Insulation Through Optimized Sheet Plate Design", Transactions of the Korean Nuclear Society Autumn Meeting Gyeongju, Korea, October 29-30, 2015

[4] K.J. Jang, W.S. Kim, "evaluation of thermal insulation performance for multiple layered reflective metal insulation system" Proceedings of the 23rd National Heat and Mass Transfer Conference and 1st International ISHMT-ASTFE Heat and Mass Transfer Conference IHMTC