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Preliminary Analysis on Heat Removal Capacity of Passive Air-Water Combined Cooling Heat Exchanger Using MARS

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1. Introduction

After the Fukushima Daiichi nuclear power plant accident, improvement of passive long-term cooling is major issue in the nuclear safety. S. Korea is in the development process of PAFS(Passive Auxiliary Feedwater System) that is passive safety system of new type nuclear power plant APR+. PAFS condenses vapor which come from steam generator and this condensate is resupplied to steam generator, then it cools steam generator.

Current design requirement for working time of PAFS heat exchanger is about 8 hours. Thus, it is not satisfied with the required cooling capability for the long term SBO(Station Black-Out) situation that is required to over 72 hours cooling. Therefore PAFS is needed to change of design for 72 hours cooling[1].

In order to acquirement of long terms cooling using PAFS, heat exchanger tube has to be submerged in water tank for long time. However, water in the tank is evaporated by transferred heat from heat exchanger tubes, so water level is gradually lowered as time goes on. Accordingly, KAERI is studying on a passive air-water combined cooling system(Fig. 1) for maintain water level in the long term[1]. The capacity of an air cooling heat exchanger depends on natural convectional heat transfer of external air around tube. So fin attachment on the tube surface is considered for an improvement of the cooling capacity.

In case of newly developed apparatus, it has to be evaluated its capacity before it is installed on the nuclear power plant. So, preliminary analysis is essential to a decision of validity of apply. Thus in this paper, air cooling heat exchanger is modeled by MARS, and the preliminary analysis of the cooling capacity on this heat exchanger is done. It is used for decision of validity of apply.

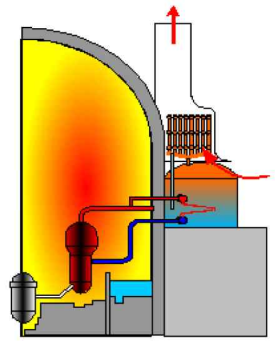


Fig. 1. Passive air-water combined cooling system[1]

2. Development of input model

In this study, a shape of heat exchanger is assumed like figure 2 and MARS input model is developed. Figure 3 shows assuming finned tube in the heat exchanger. Figure 4 shows a nodalization of MARS modeling about pre-described air cooling heat exchanger.

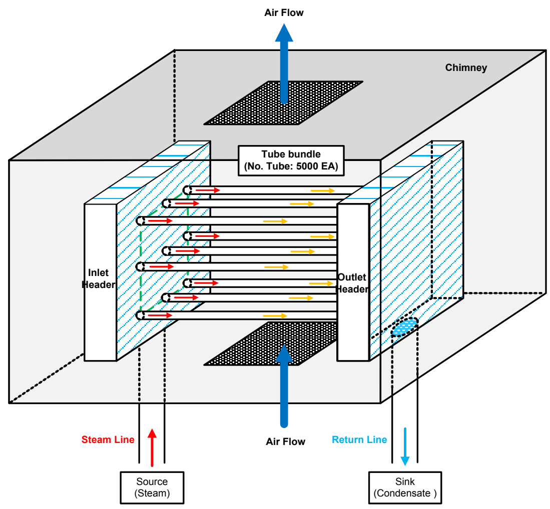


Fig. 2. Conceptual design of air cooling heat exchanger

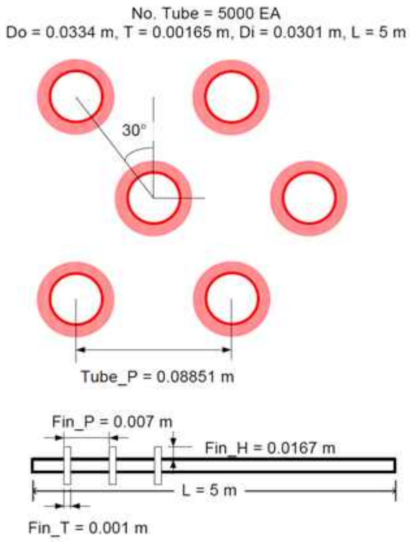


Fig. 3. Conceptual design of finned tube

The results of analysis of preliminary input model and component sensitivity are reflected in the node system of air cooling heat exchanger. So, the header of heat exchanger is composed of 'PIPE' component, the bundle of heat exchanger has 5 'PIPE' component, the number of sub-volume of 'PIPE' component is 10. And chimney that has down-comer is physically validate and numerically stable on pressure, temperature, flow, heat removal rate.

Fouling factor should be reflected in increased external area by fin and the fin efficiency. The rate of increased external area is 8.297, in here additionally applied to mean fin efficiency 81.4%, the final fouling factor of the heat exchanger become 6.754.

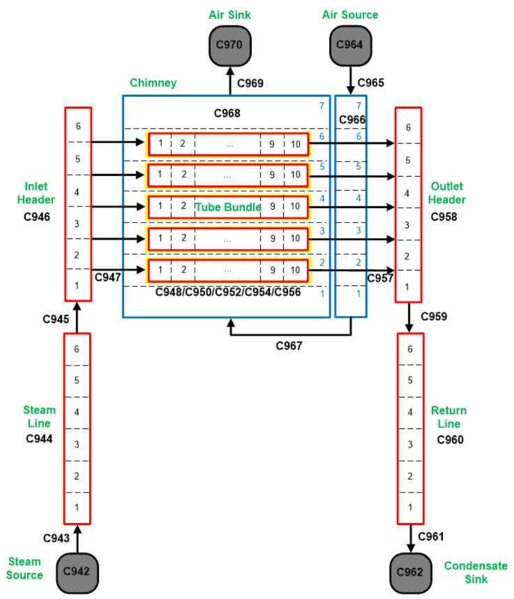


Fig. 4. MARS nodalization of air cooling heat exchanger

Figure 5 shows the result of predicted heat removal capacity of heat exchanger that is changed by variation of an inflow air velocity in the chimney. The capacity of heat exchanger remarkably depends on air velocity. The inflow air velocity that is over 6 m/s can supply required heat removal capacity on current input model. However, predicted inflow air velocity in the chimney is 1.5 m/s ~ 2 m/s.

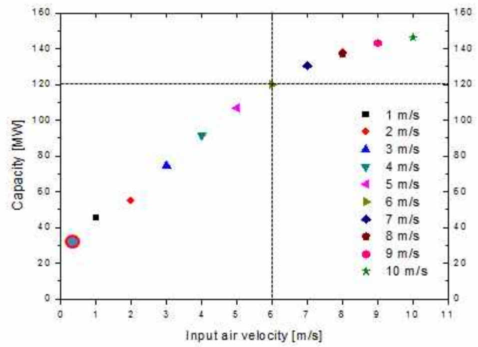


Fig. 5. Variation of heat removal capacity

3. **Preliminary analysis of applicability on nuclear power plant system**

This section shows analysis result for cooling capacity of the passive air-water combined heat removal system. Target plant type is APR+, and target analysis accident scenario is FLB(Feed Line Break). A Preliminary analysis of applicability on air cooling heat exchanger is performed. And an analysis of an air cooler on PAFS water tank is performed, too.

In the Passive air-water combined cooling heat exchanger, vapor come from steam generator is condensed by PAFS heat exchanger and vapor come from water tank is condensed by air cooling heat exchanger. So, water level in the water tank can be maintained for long term.

Analyses using the passive air-water combined heat exchanger are performed on the below cases:

Case 1) Vapor that is not condensed by air cooling heat exchanger is discharged into the air (Fig. 6(b))

Case 2) Air cooling heat exchanger that is isolated from the air (Fig. 6(c)).

Case 3) A valve is installed on the upper part of the exit header of air cooling heat exchanger, and the valve will be open over 2.1 bar and close under 1.9 bar(Fig. 6(d)).

Case 4) Increment of tube number compare to Case 3. Tube number is increased from 5000 to 8000.

Case 5) Increment of inflow air velocity compare to Case 3.

Case 6) Increment of inflow air velocity compare to Case 3.

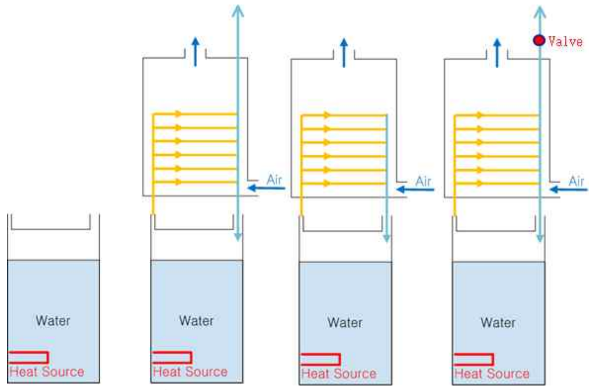
In this study, PAFS water tank and air cooling heat exchanger are only used in the modeling of Passive air-water combined cooling heat exchanger, like that figure 6, for simplification of long term cooling analysis. In APR+ FLB accident analysis, the heat which is removed by PAFS is treated as internal heat source.

Figure 7 and Figure 8 show the result of MARS analysis on the passive air-water combined heat exchanger cooling. In case of PAFS heat exchanger only exists, its water dry-out takes about 24 hours. While in case 1, air cooling heat exchanger and PAFS heat exchanger coexist, its water dry-out takes more time than that of previous case (Fig. 7). However, in case 1, heat removal capacity of air cooling heat exchanger is low because of it works in the atmosphere pressure and non-condensable gas is co-exist(Fig. 8). In case 2(air cooling heat exchanger is isolated from the atmosphere), initial heat removal rate of air cooling heat exchanger is lower than heat production rate from PAFS heat exchanger (Fig. 7). So the pressure of water tank is increased during 15 hours, then air cooling heat exchanger works at high pressure, heat removal capacity considerably increase as the pressure increases (Fig. 8). Therefore the pressure of water tank became decreased. But, in case 2, the pressure of water tank can be increased by 45 bar, so this case is excluded in view of reality.

In this study, like that case 3 ~ case 6, a valve installed on the upper part of exit header of air cooling heat exchanger, and the capacity test of air cooling heat exchanger was performed on 2 bar to consider mass effects on the water tank wall. In case 3, water dry-out is delayed about 9 hours compare to case 1. In case 4, the number of tube increases from 5,000 to 8,000, so water dry-out is delayed about 23 hours compare to case 1. But it is insufficient to meet target time 72 hours.

In case 1 ~ case 4, inflow air velocity into the chimney is about 1.5 m/s. Inflow air velocity is the decisive factor of cooling capacity on air cooling heat exchanger. Air velocity in case 5 and case 6 is used arbitrarily about 3 m/s for sensitivity analysis. From the result of analysis, it is found that water in PAFS water tank doesn't dry-out and the cooling of over 72 hours is possible (Fig. 7). In case 6, that used 8,000 tubes, water level in the water tank is not reduced below about 7m. That means heat removal capacity of air cooling heat exchanger is better than heat generation from heat source, since then about 17 hours from accident occurrence(Fig. 8). In case 5, that used 5,000 tubes, heat removal capacity of air cooling heat exchanger is better than heat generation from heat source, since then about 70 hours from accident occurrence(Fig. 8). So water level in the water tank is not reduced below about 3.2m (Fig. 7).

The heat removal rate of air cooling heat exchanger shows about 23 MW, this means that if each tube can be remove about 4.8 kW heat, this passive combined cooling system will be applicable to the long term cooling of nuclear power plant. Later on, if it is capable to the improvement of heat removal capacity, PAFS attaching air cooling heat removal system is applicable to long term cooling.



(a) PCCT (b) Open (c) Close (d) Valve

Fig. 6 Passive air-water combined cooling heat exchanger

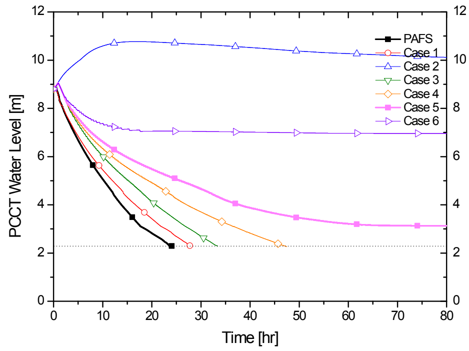


Fig. 7 Water level in PAFS water tank

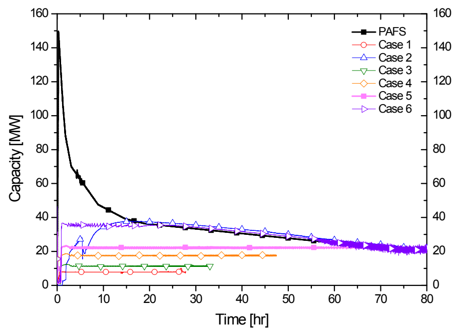


Fig. 8 Heat removal rate of heat exchanger

4. Conclusions

The heat removal capacity of air cooling heat exchanger is core parameter that is used for decision of applicability on passive air-water combined cooling system using PAFS in long term cooling. In this study, the development of MARS input model and plant accident analysis are performed for the prediction of the heat removal capacity of air cooling heat exchanger. From analysis result, it is known that inflow air velocity is the decisive factor of the heat removal capacity and predicted air velocity is lower than required air velocity. But present heat transfer model and predicted air velocity have uncertainty. So, if changed design of PAFS that has over 4.6 kW heat removal capacity in each tube, this type heat exchanger can be applied to long term cooling of the nuclear power plant.

REFERENCES

[1] Bae, S. W. and Kwon, T. S., 2014, Evaluation of a Design Concept for the Combined Air-water Passive Cooling PAFS+, Trans. Korean Nuclear Society Spring Meeting, Korea, May 29-30

[2] Incropera, F. P., DeWitt, D. P., 2007, Fundamentals of Heat and Mass Transfer (6th edition), Willey.

[3] KINS, 2012, Design Basis Accident Assessment for the Safety Evaluation of APR+ Passive Auxiliary Feedwater System(Chapter. 6), KINS/HR-1188

[4] KAERI, 2009, MARS CODE MANUAL, KAERI/TR-2811/2004