Numerical analysis of thermal lag with various convection heat transfers coefficient in severe accident environment

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1. Introduction

The severe accident has extremely low occurrence probability, but causing significant damage to the core and finally possible serious consequences in case of release of radioactive material outside of containment [1]. After the Level-7 accident in Fukushima Daiichi NPP in March 2011, requirements of severe accidents have been added significantly in the new safety regulatory requirements in NPPs. In the USA, NRC required that equipment survivability must be verified in severe accidents, according to regulatory requirements, 10CFR50.34(f), SECY90-016, and SECY-90-087. These regulatory requirements required that the both electrical and mechanical equipment, needed to prevent and mitigate the consequences of severe accidents. And the equipment must perform its function during severe accident environment (e.g., pressure, temperature, radiation) [2].

Safety-related equipment, such as emergency reactor depressurization valve (ERDV), must perform its safety function during severe accident environment for the needed period. Severe accident accompanying hydrogen burn generates harsher environment than normal operation condition and DBA. Because of unique characteristics of phenomenon in severe accident, assessment of equipment survivability is required to ensure operability of safety related equipment in severe accident. In case of metallic parts of essential equipment, those are nearly impervious to effect of temperature of hydrogen burn in severe accident.

However, non-metallic materials can be damaged by exposing to the temperature profile of severe accidents. Polymeric materials in equipment such as fluoroelastomer are known as more vulnerable than metal to harsh environment. Therefore, to predict the temperature of non-metallic materials in the equipment is important to ensure the survivability of equipment in severe accident environment [3].

In this paper, temperature of internal non-metallic materials was analyzed by thermal lag analysis method. Temperatures of metal surface and non-metallic materials in metal housing were analyzed using calculated convection heat transfer coefficient by Churchill & Bernstein equation.

2. Analysis

An analysis model consists of metal housing and polymeric materials inside of metal housing. The analysis model was designed as shown in fig 1. The temperature profile of severe accident used in the analysis is shown in fig 2. Fig 2 is a temperature profile of the emergency reactor depressurization valve (ERDV) which is exposed to severe accident [4].

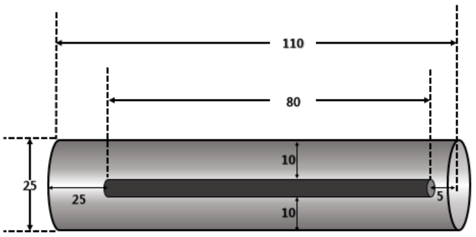


Fig. 1 Schematic diagram of analysis model

Table. 1 Thermal properties of each materials of analysis model

	Air	Carbon steel	FKM
Density (kg/m^3)	1.18	7860	1100
Specific heat (J/KgK)	1003.62	473.0	1660
Thermal conductivity (W/mK)	0.03	48.9	0.25

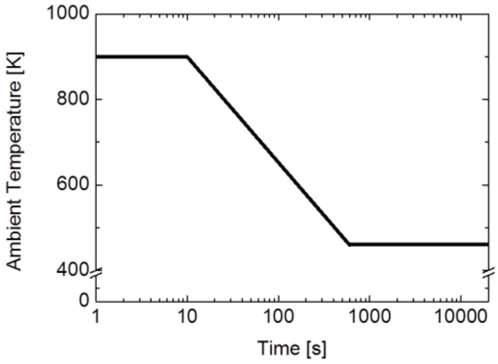


Fig. 2 Temperature profile of severe accident used for equipment survivability

The temperature of internal non-metallic materials was analyzed using the model shown in fig 3. In this analysis model, L was assumed to be infinite. Temperature distribution analysis of the metal and internal polymeric materials were performed according to the velocity of the fluid from the outside to the cylinder.

The convection heat transfer coefficients from the outside atmosphere to the specimen were calculated using the Churchill & Bernstein correlation equation as shown in equation (1) [5].

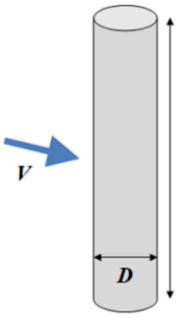


Fig. 3 analysis model for predict the temperature of internal non-metallic materials

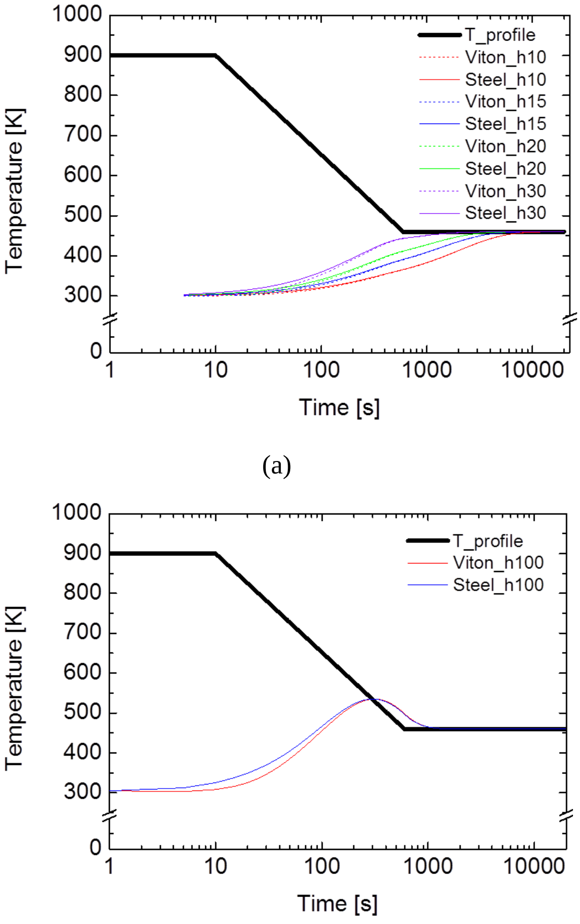
$$Nu = \frac{hD}{k} = 0.3 + \frac{0.62Re^{\frac{1}{2}}Pr^{\frac{1}{3}}}{[1+\frac{0.4}{Pr^{\frac{2}{3}}}]^{\frac{1}{4}}}[1+\frac{Re}{28200}^{\frac{5}{8}}]^{\frac{4}{5}} \qquad (1)$$

Where h is convection heat transfer coefficient, D is diameter of specimen, Re is Reynold's number and k is thermal conductivity. Initial temperature of specimen is 300 K. Numerical analysis for predicting the temperature distribution of inside and outside of the cylinder model was carried out in severe accident environment using the above conditions.

3. Results

To predict the temperature of polymeric material in the metal housing of equipment, thermal lag analysis was performed using analysis model as shown in fig 3. To evaluate the influence of velocity of external fluids, the heat transfer coefficients were set as 10, 15, 20, 30, and 100 W/m^{2}K, respectively.

Temperature distribution of metal and non-metallic materials was analyzed when the convection heat transfer coefficients are 10, 15, 20 and 30 W/m^{2}K, as shown in fig. 4 (a). The time reaching the steady state decreases as convection heat transfer coefficients increase. In other words, thermal lag effect from outside atmosphere to equipment decrease as convection heat transfer coefficient increases. The temperature of the outside atmosphere and internal non-metallic materials became equal after 1000s. The temperature was maintained at 460K regardless of heat transfer coefficient. Meanwhile, when convection heat transfer coefficient was 100 W/m^{2}K, as shown in fig. 4 (b), temperature profile include peak temperature of 540K was derived by analysis.



(a)

(b)

Fig. 4. Analysis result when heat transfer coefficients were (a) 10, 15, 20, 30 and (b) 100 W/m^{2}K

4. Conclusion

Numerical analysis of the temperature distribution for the analysis model in the environment with various convective heat transfer coefficients was performed. The convection heat transfer coefficients were calculated using Churchill & Bernstein correlation equation. The temperatures of metal housing and polymeric materials increase as convective heat transfer coefficient increase. The convection heat transfer coefficient was 100 W/m^{2}K when velocity of the external atmosphere is sound speed due to hydrogen burn. The convection heat transfer coefficient was 100 W/m^{2}K, which is different from when the heat transfer coefficient was 10, 15, 20, and 30 W/m^{2}K, and the surface temperature of the analysis model was 540K peak.

Temperatures inside and outside of the analysis model were almost same, due to the high heat transfer coefficient of the metal.

In the actual hydrogen burn environment, external fluid speed should be considered when calculating the heat transfer coefficient. Numerical analysis of the temperature of inside and outside of the specimen will be carried out by applying the calculated heat transfer coefficient. And the temperature of internal non-metallic material will be predicted through modelling the actual ERDV shape by using computational analysis.

Acknowledgment

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REFERENCES

[1] Jean-Pierre Van Dorsselaere, Thierry Albiol and Jean-Claude Micaelli, Nuclear Power - Operation, Safety and Environment, InTech, 2011
[2] USNRC, 10CFR50.34(f), Additional TMI-Related Requirements, 2009
[3] EPRI, “Plant Support Engineering: Elastomer Handbook for Nuclear Power Plants”, 1014800, 2007
[4] Bo Hwan Choi, Gi Chan Jang, Sung Min Shin, Soo Ill Lee, Hyun Gook Kang and Chun Taek Rim, Development of Highly Reliable Power and Communication System for Essential Instruments Under Severe Accidents in NPP, Nuclear Engineering and Technology, 2016
[5] Churchill. S.W, Bernstein. W, A Correlating Equation for Forced Convection From Gases and Liquid to a Circular Cylinder in Crossflow, J. Heat Transfer. ASME, 1977