The Temperature Distribution of a Fuel Rod With the Presence of a Thermocouple Using COMSOL MULTIPHYSICS

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1. Introduction

Temperature profile is an important base in predicting and evaluating the performance of a fuel in a normal or an accident condition. A direct measurement of the temperature in a fuel rod normally is obtained by a fuel rod in which a thermocouple is inserted. However, the measured data have to be carefully interpreted, since the measured temperature may not be the value of the centerline temperature. The precise analysis for the temperature distribution in a fuel rod that has a thermocouple in it is needed for the right estimation of the centerline temperature. We have analyzed the temperature distribution of the fuel rod in the Halden Reactor experiment, i.e., IFA-432. In the NUREG/CR-6534 report, a thermocouple was installed at the bottom of the IFA-432 nuclear fuel rod of the Halden HBWR reactor to confirm the temperature distribution. Based on the results of the above report, the temperature distribution model was created using the COMSOL MULTIPHYSICS program and the results were compared to the measured temperature distribution of the fuel rod. The results of the program are intended to confirm the suitability of the 'thermocouple' when measuring the temperature of the fuel rod.

2. Methods and Results

2.1 COMSOL MULTIPHYSICS Program

COMSOL MULTIPHYSICS is a multiphysical phenomena analysis program that analyzes various complex phenomena using finite element method. In this study, thermal analysis and flow analysis module of COMSOL MULTIPHYSICS program were used to analyze the temperature profile of the fuel rod. The heat transfer equations for solid materials used in the thermal analysis process are shown in (1) and (2), and the heat transfer equations in the fluid are (1) and (3). Q_{ted} and Q_{vd} are thermal elastic damping and viscous dissipation factors which were ignored in the thermal analysis of this study. The fluid flow equation is shown in (4). In this study, only the natural convection due to the density difference was considered. The water flowing on the surface of the fuel rod was calculated through the heat flux function, and the equations used are expressed as (5) and (6).

$$\boldsymbol{q} = -k\nabla T \tag{1}$$

$$\rho Cp\frac{\partial T}{\partial t} + \rho Cp\boldsymbol{u}\cdot\nabla T + \nabla\cdot\boldsymbol{q} = Q + Q_{ted} \tag{2}$$

$$\rho Cp\frac{\partial T}{\partial t} + \rho Cp\boldsymbol{u}\cdot\nabla T + \nabla\cdot\boldsymbol{q} = Q + Q_p + Q_{vd} \tag{3}$$

$$\rho\frac{\partial \boldsymbol{u}}{\partial t} + \rho(\boldsymbol{u}\cdot\nabla)\boldsymbol{u} = \nabla\cdot\left[-p\boldsymbol{I} + \mu\left(\nabla\boldsymbol{u} + (\nabla\boldsymbol{u})^T - \frac{2}{3}\mu(\nabla\cdot\boldsymbol{u})\boldsymbol{I}\right] + \boldsymbol{F} \tag{4}$$

$$q_0 = h\cdot(T_{ext} - T) \tag{5}$$

$$h = h_{water}(L, U, T_{ext}) \tag{6}$$

2.2 Modeling and material setup

IFA-432r2 fuel rod of Halden HBWR reactor is used for modeling in this study. Total length of fuel rod is 579 mm and radius of it is 6.3944 mm. The thickness of the cladding is 0.9398mm and it composed with Zircaloy-2. The thickness of the initial gap is 0.1905 mm. At the bottom part, a thermocouple with radius of 0.9mm and total length of 100mm is inserted. 2D Axisymmetric dimension was used and the actual model of the fuel rod was simplified. Only the lower part where the thermocouple was inserted was described in this study. The physical properties of nuclear fuel and cladding were expressed in terms of the function of temperature.

2.3 Calculation results and analysis

In this study, the transient analysis results up to 22.64 days were examined, and the LHGR from UO_2 was averaged up to 22.64 days. Fig. 1 shows the results of the 2D Axisymmetric form analyzing the temperature profile of the fuel rod depending on the presence of the thermocouple. The black arrows indicate the convection direction of the filling gas at the GAP.

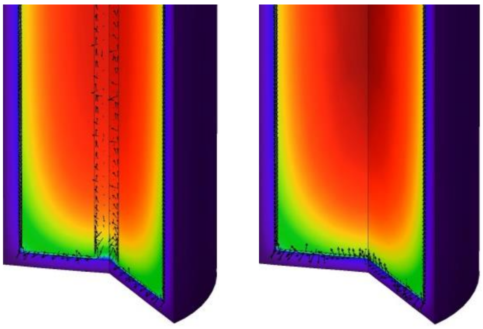

Fig. 1. The temperature distribution of the fuel rod (IFA-432rod2) depending on the presence of the thermocouple. The left fuel rod is a model with a thermocouple and the right is a model without.

For a fuel rod in which a thermocouple is inserted, the temperature difference in the centerline between the height of 105 mm and 96 mm from the bottom is about 43K. This can be seen from the results in Fig. 2. For a fuel rod which a thermocouple is not inserted, there is little temperature difference between the height of 105 mm and 97 mm from the bottom.

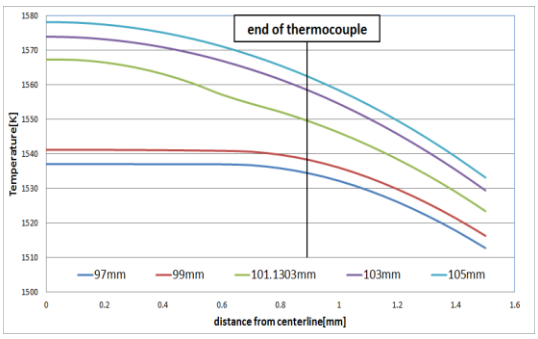

Fig. 2. Temperature profile from centerline to 0.68mm with thermocouple.

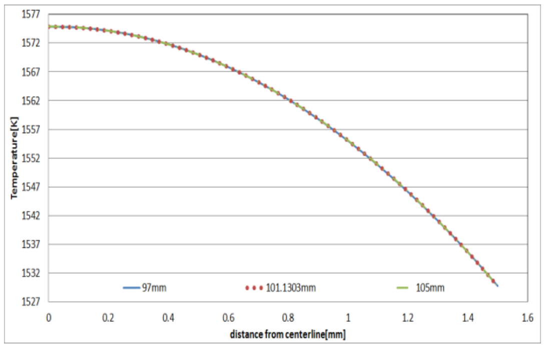

Fig. 3. Temperature profile from centerline to 0.68 mm in the absence of thermocouple.

The temperature profile at the height of 1.2 mm from the bottom of the fuel rod is shown in Fig. 4.

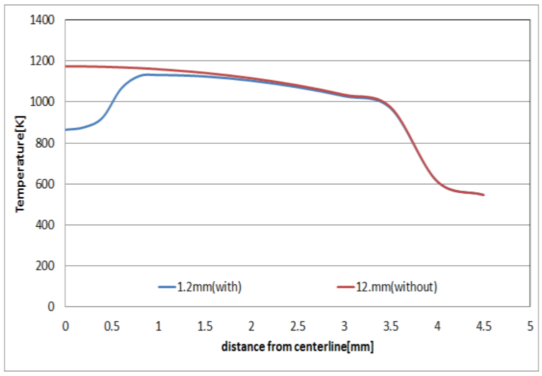

Fig. 4. Temperature distribution at 1.2 mm height of model with and without thermocouple.

The above results are caused by the fact that the heat generation and conduction are removed from the GAP and the influence of the convection of the filling gas becomes dominant.

3. Conclusion

The temperature at the height where the thermocouple is inserted is about 30-40K lower than the temperature at the height where the thermocouple is not inserted. Therefore, when measuring the temperature of a fuel rod through a thermocouple, it should be considered that the actual temperature is higher than the temperature detected through the thermocouple.

REFERENCES

[1] D.D. Lanning[(a)], C.E. Beyer[(a)], G.A. Berna[(b)], “FRAPCON-3: Integral Assessment”, NUREG/CR-6534 Volume3, PNNL-11513(1997).