# Analysis of the Temperature Fluctuation in the Plenum due to a Flow Blockage Of the Fuel Assembly in KALIMER

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## 1. Introduction

A local cooling deficiency inside the pin bundle of the KALIMR (Korea Advanced Liquid Metal Reactor) fuel element caused by a partial blockage of the flow section or by a compaction of the bowing rods is considered as one of the possible initiating events of a whole core accident. The accident sequence would be a rapid pin-to-pin and fuel-element-to-fuel element failure propagation after the cooling deficiency zone has reached a critical size. Therefore much attention has been paid in the last years to the exploration of the possibilities to detect a cooling deficiency at an early stage. One of the detection methods considered is based on the measurement of the coolant temperature fluctuations behind the fuel bundle outlet. [1]

In a cooling deficiency zone, the coolant temperature is increased by a reduction of the local mass flow. The resulting temperature perturbation is convected by the flow towards the bundle outlet. At an early stage of the event, no significant global flow reduction in the fuel element is expected. In this case, a distortion of the temperature profile at the outlet with respect to the known nominal profile is the only signal which could be used to detect the cooling deficiency developing inside the bundle.

In the coolant plenum behind the bundle outlet the time average coolant temperature profile decays by a random motion of the fluid particles (turbulence diffusion), which gives rise, at the same time, to coolant temperature fluctuations. We analyzed the main characteristics of the fluctuating temperature field in the plenum to those of a distorted time average temperature profile at the bundle outlet. We used the LES (Large Eddy Simulation) turbulence model in the CFX 5.7 code when the temperature fluctuation was analyzed. The LES model is proven to be suitable for the analysis of a temperature fluctuation. [2]

## 2. LES Turbulence Model

The LES is performed using the CFX-5.7 code and the LES model for the CFX-5.7 code is given as follows;

$$\frac{\partial}{\partial t}(\overline{U_i})+\frac{\partial(\overline{U_i U_j})}{\partial x_j}=-\frac{1}{\rho}\frac{\partial \overline{p}}{\partial x_i}+\frac{\mu}{\rho}\frac{\partial^2 \overline{U_i}}{\partial x_j \partial x_j}-\frac{\partial \tau_{ij}}{\partial x_j} \quad (1)$$

where $\overline{U_i}$ are the filtered velocity components such as

$$\overline{f}(x_i,t)=\iiint_{vol} G(x_i-x_i')f(x_i',t)dx_i' \quad (2)$$

In the Smagorinsky model the $\tau_{ij}$ in Eq.(1) is expressed as follows;

$$\tau_{ij}-\frac{1}{3}\tau_{kk}=-2\nu_{SGS}\overline{S_{ij}}=\nu_{SGS}\left(\frac{\partial \overline{U_i}}{\partial x_j}+\frac{\partial \overline{U_j}}{\partial x_i}\right) \quad (3)$$

where

$$\nu_{SGS}=(C_S\Delta)^2\left|\overline{S}\right| \quad (4)$$

$$\left|\overline{S}\right|=\left(2\overline{S_{ij}}\,\overline{S_{ij}}\right)^{1/2} \quad (5)$$

$$\Delta=(Vol)^{1/3} \quad (6)$$

$$C_S=0.065\sim 0.25 \quad (7)$$

Close to the walls, the turbulent viscosity can be dampened using a combination of a mixing length minimum function, and a viscosity damping function, $f_\mu$.

$$\mu_T=\rho.\min(l_{mix},f_\mu C_S\Delta)^2\sqrt{2S_{ij}S_{ij}} \quad (8)$$

where

$$l_{mix}=\kappa y \quad (9)$$

$$f_\mu=1-\exp(-\tilde{y}/A),A=25,\ \ \tilde{y}=(y\bullet\tilde{U})/\nu \quad (10)$$

and $\kappa$ is the von Karman constant (=0.4), $y$ is the wall distance and $\tilde{U}$ is the local velocity scale.

In the LES the central difference scheme is used for treating the convection terms. Also, for treating the unsteady term in LES, the second-order backward differencing scheme is used.

## 3. Application

By using the LES model in CFX 5.7, we analyzed the partially-blocked single fuel assembly in KALIMER. At first, we assumed a 10% blocked fuel assembly as shown by the red-colored region in Fig. 1. According to a previous steady state analysis of a sub-channel in a fuel assembly, we assumed that the blocked region is uniformly overheated by 60℃. [3] Then, we analyzed the transient temperature fluctuation with the LES model in CFX 5.7. Additionally, we analyzed the temperature fluctuation in the case of a 5% blockage and no blockage in a fuel assembly in order to evaluate the characteristics of the temperature fluctuation according the size of blocked area, respectively. We assumed that the blocked region is uniformly overheated by 30℃ in the case of a 5% blocked fuel assembly.

Table 1 shows the analysis results with mean, standard deviation and skewness of the temperature fluctuation at 30 cm and 60 cm away from the bundle outlet, respectively. Figure 2 shows the temperature fluctuation with time at 30 cm away from the bundle outlet and Figure 3 shows the results at 60 cm.

## 4. Conclusions

The characteristics of the temperature fluctuation such as the standard deviation and skewness factor are considered to be the physical parameters for detecting a small fuel assembly blockage at an early stage. However, the analysis of a single fuel assembly does not show the real temperature fluctuation in the core of KALIMER. Therefore, we will analyze the temperature fluctuation in the upper plenum of a whole core. After a whole core analysis, we will develop and determine the parameters as well as the requirement of the early core blockage detection system from the results.

***Acknowledgements***

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## REFERENCES

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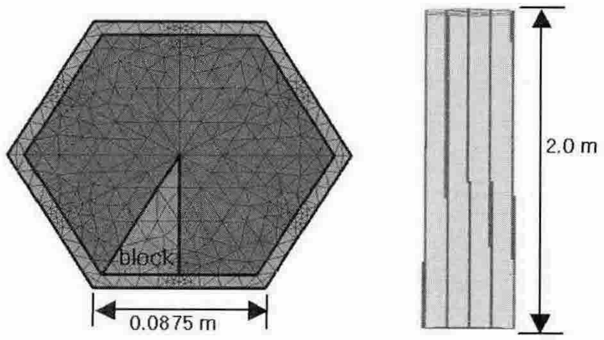


Fig. 1 Geometry of Blocked Fuel Assembly

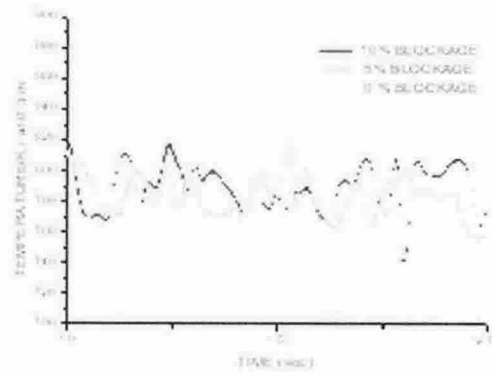

Fig. 2 Temperature Fluctuation with Time and Amount of Blocked Area (at z = 0.3 m apart from the outlet)

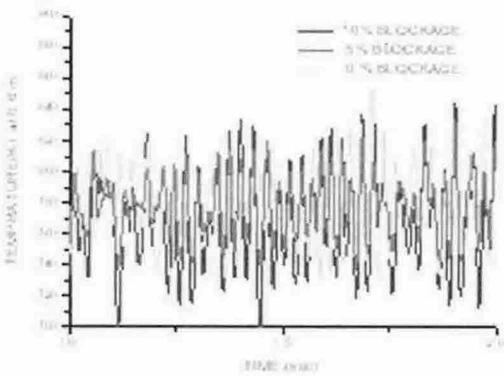

Fig. 3 Temperature Fluctuation with Time and Amount of Blocked Area (at z = 0.6 m apart from the outlet)

Table 1 Characteristics of Temperature Fluctuation (K)

| Pos. | Para. | 10% block | 5% block | 0% block |
|---|---|---|---|---|
| 0.3 m | Mean | 803 | 799 | 801 |
| | S.D. | 27.4 | 22.0 | 25.9 |
| | Skew | 19.5 | 21.8 | 19.7 |
| 0.6 m | Mean | 762 | 774 | 776 |
| | S.D. | 30.5 | 22.0 | 18.4 |
| | Skew | 23.2 | 18.0 | 13.4 |