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Numerical investigation of the CS28-1 experiment by using CAISER code

K.H. Kim [a*], J.H. Bae [a], D.G. Son [a], J.Y. Kang [a]
[a]*KAERI, 1045 Daedeok-daero, Yuseong-gu, Daejeon, Korea*
*Corresponding author: khyun@kaeri.re.kr

1. Introduction

CAISER(CANDU Advanced Integrated SEveRe accident code) has been developed from the need of CANDU severe accident code with high accuracy. The core degradation and heat transfer models adopted by CAISER are well introduced in previous works[1,2]. For the purpose of CAISER code verification, numerical works were conducted for the CS28-1 experiment[2,3]. The papers[2,3] showed that temperature distributions of the main components in a fuel channel, which are a fuel, cladding, a pressure tube and a calandria tube, are in line with the experimental data.

In the present work, we have modified the CAISER to better reflect the CS28-1 experiment conditions. The properties of the fuel and cladding in CAISER code are modified to reflect the FES's alumina insulator and graphite rod heater. Also, we adopted more realistic temperature dependent thermophysical properties, such as heat conductivity and heat capacity, for the main components.

2. Introduction of CS28-1

The CS28 series(CS28 -1, 2, 3) experiments were carried out to understand high temperature behavior of fuel channel and influence of the moderator as a heat sinker. The experiments provide various data on the temperature in fuel rods, a pressure tube, a calandria tube and a moderator tank when CANDU-PHW reactor is under sever accident conditions.

The CS28-1 experiment is one of the three experiments of the CS28 series using a full scale horizontal fuel channel with a 28-element fuel bundle. Figure 1 shows the cross-section of the 28-element bundle in the CS28-1 experiment. The 28-element section consists of three rings of FES(Fuel Element Simulator), i.e. 4 elements in the inner ring, 8 elements in the middle ring and 16 elements in the outer ring. The FES bundle is equipped inside the pressure and calandria tube concentrically. Several thermal couples are installed in the calandria tube, the pressure tube and the FES bundles. As shown in Figure 2, each FES is comprised of Zr-4 cladding, annular alumina pellets and a graphite rod heater.

Figure 3 shows the axial cutaway view of the experiment section. The FES bundles, the pressure tube and the calandria tube of 1.8m length is surrounded by an tank water of 40℃. All the FES in the pressure tube are supported by five Zirconium spacer grid plates.

The superheated steam(~ 700℃) with 10g/s mass flow rate is provided into the inlet of test section. The power provided to the graphite rod heater increases with time step by step as shown in figure 4. The normalized FES powers for the inner, middle and outer rings are 0.775, 0.894 and 1.111.

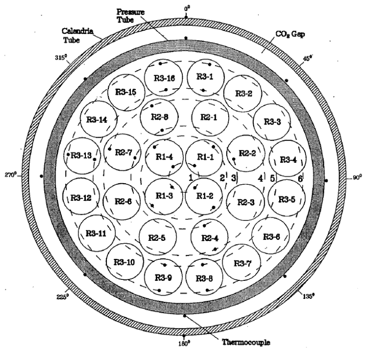

Fig. 1. Cross-sectional view of CS28-1 experimental test section

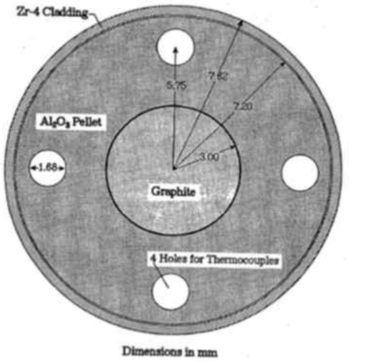

Fig. 2. Cross section of a Fuel Element Simulator(FES) of CS28-1

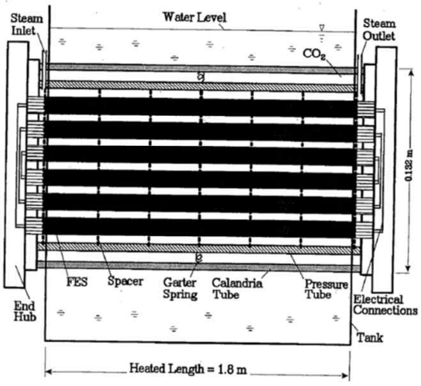

Fig. 3. Axial(Z direction) cutaway view of CS28-1

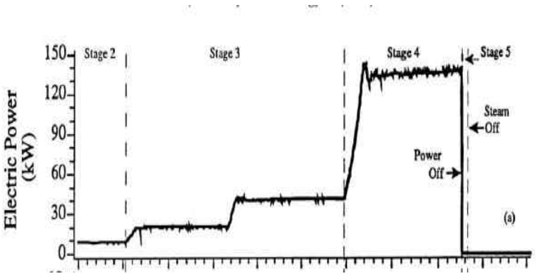

Fig. 4. Electric power to the heater in CS28-1 experiment

3. Simulation results of the CS28-1 experiment

3.1 System modeling

As shown in figure 5, 3 by 6 node system is adopted to simulate the cross-section of the FESs. 12 nodes are deployed in a flow direction(Z direction). In the present work, we have modified CAISER code as followed,

1) The material properties of the fuel and cladding, such as density, heat conductivity and heat capacity, are modified to reflect the FES's alumina insulator and graphite rod heater of the CS28-1 experiment.
2) CAISER code adopts temperature dependent heat conductivity and heat capacity values for the main components.

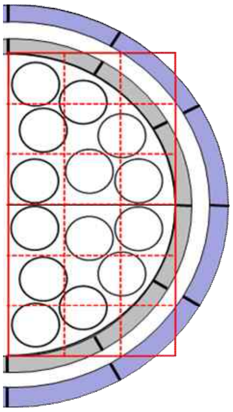

Fig. 5. CS28-1 nodal system in CAISER code

3.2 Results and discussions

Figure 6 shows the comparisons of FES's inner, middle and outer ring temperature between the CS28-1 and CAISER code. At early times, the experiment shows that the temperatures of FES's inner, middle and outer ring are similar each other and gradually increase with the input power increasing. When FES's temperatures reach around 1200K, the temperatures rise more quickly because of the steam-zirconium exothermal oxidation reaction. In the experiment, the electric power was shut off around 852 second, but the steam was shut off 865 second. Due to the exothermal oxidation reaction, the maximum FES's temperatures in the CS28-1 experiment were observed around 865 second, which was the steam shut off time. Even though the electric input power of the outer ring was the highest, the peak value of the outer ring temperature was the lowest among three rings in the experiment. On the other hand, the highest temperature was measured in the inner rings where the lowest power was supplied to. These results reflect the cooling effect of the water moderator tank as the heat sinker. In the figure 6, the simulation results of CAISER follow well the experiment. At early stage, the experimental and numerical results are almost overlapping. In the previous works[2,3], the FES temperatures of CAISER tended to be somewhat lower than those of CS28-1 at the early stage. But, good agreements are shown in the present work with the modified code, especially at early stage. A change in the rate of temperature increase is detected around 1200K in CAISER code and the peak temperature of the outer ring is the lowest among three rings. Although there are slight differences in the peak temperatures between the experiment and the code, the phenomenon observed in the FES of the CS28-1 are well simulated by CAISER code.

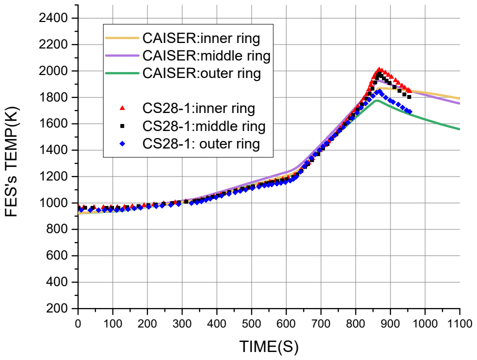

Fig. 6. FESs temperature evolution at Z= 1725mm

The temperature distributions of the FES's inner ring in the flow directions are displayed in figure 7. At low temperature regions, CAISER predicts well the FES's temperatures of the CS28-1. But, as the temperature increases, some deviations are observed. These would be partly related to the deflection of the FES at high temperature regions. In the experiment, the sagged FES could drive the non-uniformity of flow areas in the flow direction, thus, it might lead to the steam cooling imbalance in the flow direction. However, CAISER does not clearly simulate these trends related to the deflection of FES.

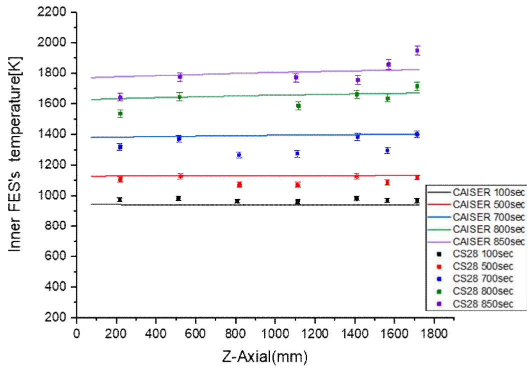

Fig. 7. FES temperature distribution in axial(Z) direction

4. Conclusions

Numerical simulations of the CS28-1 experiment were conducted by using CAISER code. The code predicts well the temperature increase behavior and distributions of the fuel rod. And, we were able to get more accurate results than the previous works[2,3]. However, some temperature deviations are observed at high temperature regions. It reveals that the code is still limited in predicting the structural deformation of the fuel rod. The influence of the FES deflection on the heat transfer at high temperature regions should be considered in the future.

ACKNOWLEDGEMENTS

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