MOX Fuel Simulation using ROPER Code

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***Keywords :** MOX fuel, fuel rod performance analysis code, ROPER

1. Introduction

The ROPER is a steady-state fuel rod performance analysis code which has been developed by KEPCO Nuclear Fuel [1]. The code has been licensed for commercial supply by the regulatory authority in Korea. In recent years, there has been a growing demand for a fuel rod performance analysis code capable of analyzing MOX fuel behavior for overseas business. MOX fuel has some differences in properties and performance models compared to conventional UO_2 fuel, so the ROPER has been modified to analyze in-pile behavior of MOX fuel. Modified ROPER code was validated using MOX fuel test data, and this paper includes comparison of ROPER simulation results with reference code [2].

2. Methods and Results

2.1 In-reactor behavior of MOX fuel

The overall in-pile behavior of MOX fuel is similar to that of conventional UO_2 fuel, but differs in smaller grain size, higher theoretical density, lower melting point and lower thermal conductivity depending on the Pu content. Additionally, the pellet radial power distribution of MOX fuel is different from that of conventional UO_2 fuel due to difference in reactor physics. At high burnup, the power density at pellet center increases and the fuel thermal conductivity decreases, so the fuel centerline temperature increases compared to conventional UO_2 fuel. In addition to the increase in centerline temperature, the amount of helium produced also increases, which increases the total fission gas production and release of MOX fuel. These properties affect the fuel behavior under normal operation and accident conditions.

2.2 ROPER modification for MOX fuel

ROPER has been modified to reflect the properties and performance models of MOX fuel. The theoretical density of MOX fuel can be calculated by inputting the mass fraction of Pu in the pellet. Fuel thermal conductivity model has also been modified to require input for the oxygen-to-metal ratio for MOX fuel calculations. In addition, the helium gas production rate, fission gas diffusion coefficient, and Xe/Kr production ratio were modified to be able to simulate the fission gas production/release behavior of MOX fuel. But there are no modifications for grain size and melting temperature, because grain size is already treated as an input value and ROPER does not covers accident condition so melting point is not considered.

2.3 MOX fuel simulation cases

A validation of the modified ROPER was performed by comparison of simulation data with measured fuel centerline temperature (FCT) and fission gas release (FGR). Comparison with reference code was also performed. Total 21 MOX fuel rods were used as simulation cases. The pellet radial power distribution for each case was produced separately using TUBRNP model used in FRAPCON/TRNASURANUS.

2.4 Fuel centerline temperature predictions

For fuel centerline temperature, 14 MOX fuel rods from Halden research reactor was taken and compared to ROPER predictions.

Figure 1 shows the measured and predicted centerline temperature of IFA-597.4/.5/.6/.7 as a representative case [3]. In IFA-597.4, the measured temperature in rod 10 is lower than in rod 11, but in IFA-597.5/.6/.7 the measured temperature in rod 10 is slightly higher than in rod 11. The predicted temperature of rod 10 shows slightly higher than measured temperature in IFA-597.4 and .7, but shows good agreement in IFA-597.5 and .6. Predicted temperature of rod 11 shows slightly lower than measured temperature in IFA-597.4, but shows good agreement in IFA-597.5/.6/.7.

Figure 2 shows the measured and predicted centerline temperature of IFA-629.3 as another representative case [4]. In IFA-629.3, the measured temperature in rod 5 is higher than in rod 6 due to the higher burnup of rod 5. Predicted temperature of rod 5 shows good agreement with measured temperature. While the predicted temperature of rod 6 shows good agreement in first irradiation period, but shows slightly higher than measured temperature in second irradiation period.

Figure 3 shows comparison between ROPER's predictions and the reference code's predictions. The ratio of the ROPER prediction to the reference code prediction was 0.977, which indicates that the ROPER calculated fuel temperature slightly lower than the reference code, but there is no significant deviation.

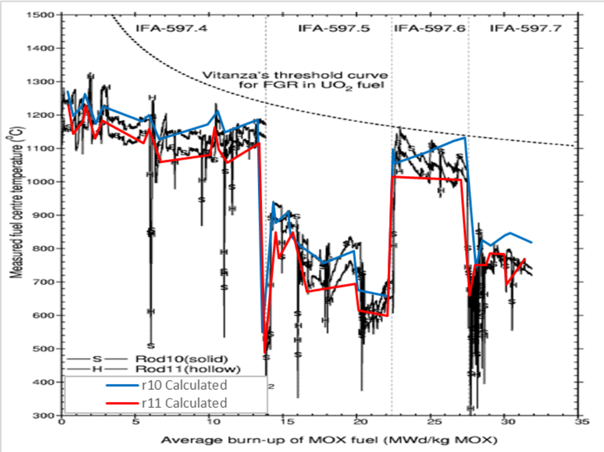

Fig. 1. Comparison of Predicted and Measured Fuel Temperature for Halden IFA-597.4/.5/.6/.7

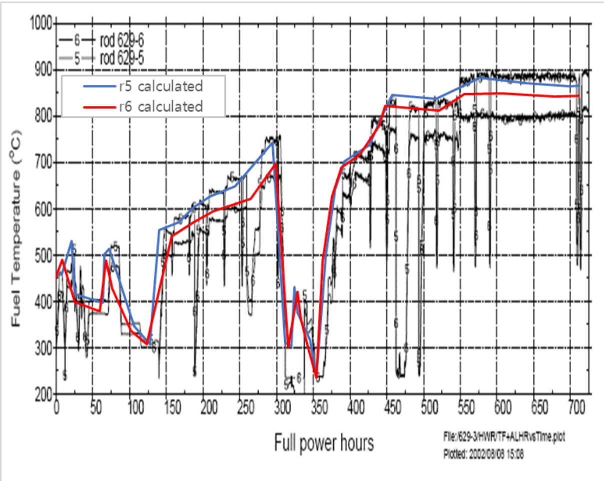

Fig. 2. Comparison of Predicted and Measured Fuel Temperature for Halden IFA-629.3

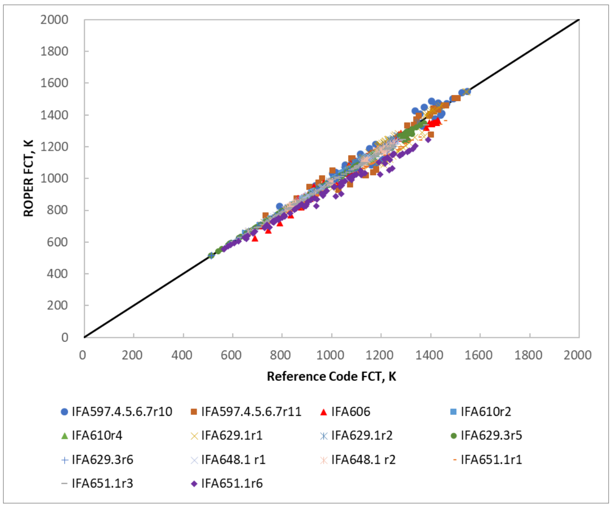

Fig. 3. Comparison of ROPER and Reference Code for Fuel Centerline Temperature Predictions

2.5 Fission gas release predictions

Prediction of FGR is important because it is necessary for the calculation of rod internal pressure (RIP) and gap conductance. Figure 4 shows the measured and predicted FGR for 16 cases. The average measured to predicted ratio (M/P) of 16 cases is 1.11. And the standard deviation for M/P is 0.597, which is similar to the M/P for FGR of standard UO_2 fuel. This result indicates that the ROPER predicts fission gas release of MOX fuel well. It is expected that the M/P would be closer to 1.0 if additional information was provided such as grain size, densification behavior, etc.

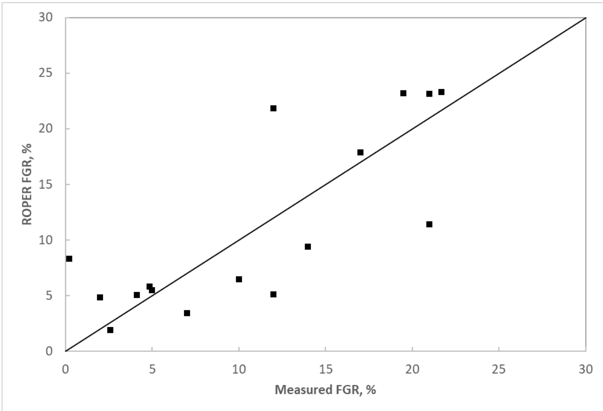

Fig. 4. Comparison of Predicted and Measured Fission Gas Release for MOX Fuels

3. Conclusions

The ROPER steady-state fuel rod performance analysis code has been modified for MOX fuel application and was validated using MOX fuel in-pile test data. For fuel centerline temperature, it shows good agreement between the ROPER prediction and the measured data. And it shows slightly underprediction of ROPER relative to the reference code but there is no significant deviation. For fission gas release, it shows reasonable agreement between the ROPER prediction and measured data. Therefore, the modified ROPER code has been validated for temperature and fission gas release behavior of MOX fuel and can be utilized for MOX feasibility studies.

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