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Comparative Study for Spacer Grid Models of TRACE and RELAP5 in FLECHT-SEASET Reflood Test

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1. Introduction

The spacer grids are installed in most pressurized light water reactor (PWR) fuel assemblies can affect significantly the fluid dynamics and the heat transfer in the core. TRACE [1] has implemented spacer grid models in 2010 that enhanced the heat transfer downstream of spacer grids, but a systematic assessment of those models has not been performed for various post-CHF heat transfer tests such as RBHT, FLECHT-SEASET, THTF, etc. The spacer grid models of TRACE consists of the single-phase convective enhancement model, the pressure loss model, the droplet breakup model, and the spacer grid rewet model, but the droplet breakup model and the grid re-wetting model are not fully implemented in current TRACE [2]. RELAP5[2] was updated as version 3.3jy by implementing the KNF (KEPCO Nuclear Fuel Co.) reflood model and the spacer grid model [4]. Especially, the spacer grid model of RELAP5 can be divided into three sub-models: single-phase heat transfer enhancement, grid rewet, and droplet breakup. In this study, the comparative study for spacer grid models of TRACE and RELAP5 was performed on FLECHT-SEASET tests. The RELAP5 developmental code version of KNF and TRACE patch 4 were used in this calculation.

2. Model Differences between Two Codes

The spacer grid model of RELAP5 is somewhat different from that of TRACE. For the convective heat transfer enhancement, the heat transfer enhancement due to the acceleration of the flow was only considered in RELAP5. The convective heat transfer enhancement could be under-estimated in tests with mixing vanes since the heat transfer enhancement due to the mixing vane could be large enough to influence to downstream near to spacer grid. For fuel bundles with typical mixing vanes, the heat transfer enhancement for mixing vanes could be below ~ 20% of the heat transfer enhancement due to the flow acceleration up to ~ 0.4 m downstream of the spacer grid. However, the effect for mixing vanes might be not shown in FLECHT-SEASET since the spacer grid without mixing vanes was installed in it. The laminar enhancement factor, F was used in TRACE but not in RELAP5.

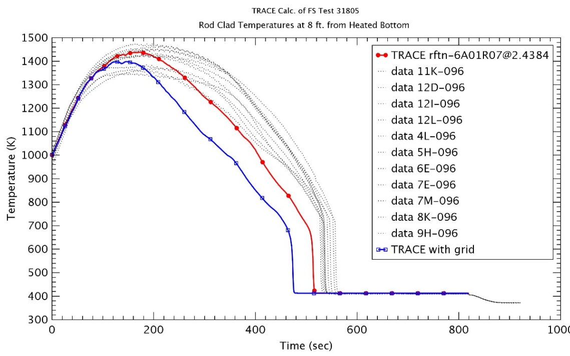
For the grid re-wetting model, the heat balance equation of TRACE was similar to that of RELAP5, but there were some differences in the detailed modelling. The radiation heat flux from the rods to the grid was obtained by using an electrical circuit analogy in TRACE [2], but it was calculated explicitly in RELAP5 [5]. The correlation for the rewetting temperature in RELAP5 was also different from that in TRACE. The rewetting temperature in RELAP5 was selected as the maximum value between the homogeneous nucleation temperature and two other minimum film boiling temperatures, while it in TRACE was determined by the minimum film boiling temperature.

For the droplet breakup model, the suggested model by Yao, Hochreiter, and Cai was used in TRACE [2], but the KAIST model was used in RELAP5 [5] since it could cover a wider range of the droplet Weber number. As the droplet Weber number was larger, the smaller shattered droplets occurred. In the upper region where the droplet dispersed flow regime was long maintained in which the droplet velocity and the number of entrained droplet were large, the droplet Weber number was large, and then the vapor temperature could be reduced because of the higher interfacial heat transfer between the droplets and the vapor phase. This could decrease the rod temperature and expedite the quenching time at that region.

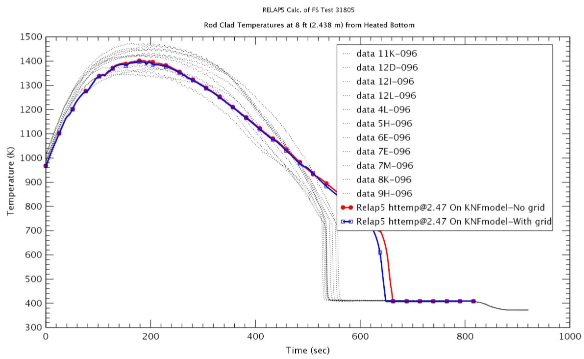
3. Calculation Results

3.1 Effect of the spacer grid model

The rod temperatures for FLECHT-SEASET Run No. 31805 at z ~ 2.4 m were shown in Fig 1. Run No. 31805 was a test with a flooding rate of 2.1 cm/sec at 0.28 MPa and 79 ^{o}C inlet subcooling temperature. When the spacer grid model of TRACE was applied, the effect of mixing vane was not considered since the egg-crate spacer grid was installed in the FLECHT-SEASET. Therefore, the convective Nusselt number was enhanced due to the flow acceleration and the turbulence increase for a spacer grid without the mixing vane. As would be expected, the lower rod temperatures and earlier rod quenches were predicted in the case with a spacer grid model. When the results of RELAP5 were compared with those of TRACE, the effect of the spacer grid model was more significantly shown in TRACE although the convective heat transfer enhancement was only considered in TRACE. The rod temperatures of TRACE started to reduce due to the spacer grid even at a low elevation. However, the rod temperatures of RELAP5 did not changed at elevation z ≤ 2.4 m except for the earlier quenching at elevation z=2.4 m as shown in Fig. 1. Compared to RELAP5, the larger convective heat transfer of TRACE may result from the modeling characteristics of TRACE and the laminar enhancement factor (F). The convective heat transfer effects of TRACE were integrated over the downstream axial cells for 50 hydraulic diameters. In this test, 50 hydraulic diameters is about 0.5 m, and this effect could be considered for longer downstream cells in comparison with that of RELAP5. In addition, the laminar enhancement factor that was not considered in RELAP5 varies from 1.0 to 1.75 with Reynolds number, and the convective heat transfer enhancement of TRACE could be significantly varied as shown Fig. 2.



(a) TRACE results



(b) RELAP5 results

Fig. 1. Heater rod temperature at 2.4 m – Run No. 31805.

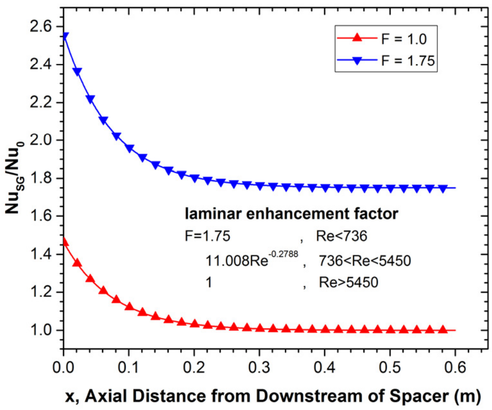


Fig. 2. Change of heat transfer enhancement due to a laminar enhancement factor.

3.2 Modeling error of the spacer grid model in RELAP5

According to RELAP5 input manual, the KNF reflood model could be used by option 40 of card 1 and invoked regardless of the spacer grid input (43000000 cards). However, the spacer grid model could be applied only when the option 40 was used in card 1. Fig. 3 showed the results for the use of KNF reflood model (option 40) and spacer grid input (43000000 cards). The results using a spacer grid model and no option 40 (green line) were completely in accord with those with a spacer grid and option 40 (cyan line). It was also an unusual thing that the effect of spacer grid model was significantly shown in Fig. 3 even though option 40 was not used in card 1. For example, in the case with a spacer grid model (green line), the growth of rod temperature and the delay of quenching time were predicted as compared with the case without it (Red line). It was also contrary to what we expected. Consequently, the current RELAP5 version (3.3jz ~ 3.3kl) including the KNF reflood and spacer grid models may have some troubles to implement these models.

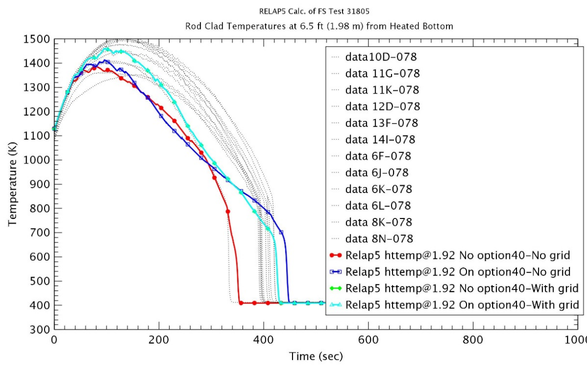


Fig. 3. Heater rod temperature at 1.98 m – Run No. 31805.

4. Conclusions

The effect of the spacer grid model in TRACE was shown well to simulate the FLECHT-SEASET tests. From the comparison with the RELAP5, it may be found that the effect of the spacer grid of TRACE could be over-estimated for the rod temperature behaviors, and the current RELAP5 version (3.3jz ~ 3.3kl) had some errors to implement the spacer grid model.

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