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Status of the GAMMA-FR code validation – two phase flow

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1. Introduction

The GAMMA-FR (Gas Multicomponent Mixture Transient Analysis for Fusion Reactors) code is an in-house system analysis code to predict the thermal hydraulic and chemical reaction phenomena expected to occur during the thermo-fluid transients in a nuclear fusion system. [1] A safety analysis of the Korea TBS (Test Blanket System) for ITER (International Thermonuclear Experimental Reactor) is underway using this code. This paper describes validation strategy of GAMMA-FR and current status of the validation study with respect to two phase flow analysis capability.

2. Status of the GAMMA-FR code Validation

GAMMA-FR is a breach of the GAMMA+ code, therefore the general thermal hydraulic validation of the mother code is directly inherited to GAMMA-FR. Under a subcontract with General Atomics, KAERI has carried out transient analyses for the conceptual design of the NGNP plant. The GAMMA+ code with a version of Rev00-Mod11, which is the base code of the GAMMA-FR code, was used for the analyses. The SVVR (Software Verification and Validation Report: SVVR-NHDD-CD-10-01) was written to support the GAMMA+ code to enhance the reliability of the numerical results for the NGNP project. [2]

GAMMA-FR validation has two methods, i.e., fusion system related experimental validation and code to code validation using MELCOR. Validation regarding two-phase flow is one of the sub items and this work is part of UCLA-NFRI collaboration on R&D. The collaboration will utilize U.S. modelling and analysis capabilities and U.S. laboratory facilities. NFRI will utilize the results of this R&D work to support the Korean ITER TBS program effort as well as other longer range research activities.

2.1 Validation with respect two phase flow

A schematic of two-phase test is presented in Figure 1. In constructing a MELCOR model for this test problem, the application of this surface area multiplier turns out to be a key modeling parameter because how this multiplier is used in the heat transfer equations for this rod is not documented. For example, MELCOR has a heat structure multiplier that effectively simulates the contribution from say 57 similar rods. This would have the effect of producing 57 times the surface area for the heated rod. However, to maintain the correct overall rod mass, the alumina density would have to be divided by 57. In addition, to maintain the correct thermal response, the rod power to mass ratio must also be preserved by dividing the total power (100 kW) by 57.

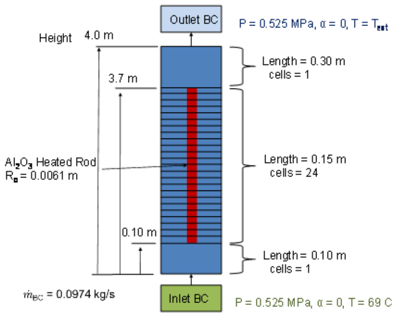

Figure. 1 Shematics of two-phase flow test problem

A second modeling approach, which leads to identical results, is to increase the rod diameter by 57 to give desired surface area, but since the volume also increases by 57^2 or 3249, the alumina density must be divided by the same number to maintain the correct rod mass. To maintain the same rod temperature rise at full rod power (100 kW), the alumina thermal conductivity would have to be increased by 57.

Regarding the equilibrium vapor void fraction, the two-phase flow void fraction is related to the vapor mass fraction or quality (x), phase densities, and the ratio of vapor to liquid velocity, or phase slip. [3]

In this case, the vapor quality can be determined from the total heat the rod transfers to the water (100 kW) divided by the product of the water mass flow rate times the heat of vaporization. Checking the MELCOR predictions demonstrated that this power is being correctly conserved by the code with the developed model. Assuming that both codes use nearly identical water equations-of-state for liquid and vapor densities, this leaves only the phase slip in question. MELCOR uses a very simplistic drift flux model approximation to derive an inter-phase drag coefficient. This formulation depends only on phase densities and flow void fraction. According to Reference [4], this formulation gives the correct bubble terminal rise velocity in normal stagnant water. In contrast, the GAMMA-FR code uses a detailed two-phase flow map to determine the interfacial drag coefficient. Obviously the model in the GAMMA-

FR code is more sophisticated and possibly more correct for this test problem. But this area of modeling has not been an emphasis for the MELCOR code development, which has concentrated on including adequate physics packages for all of the phenomena that occur during severe accidents in nuclear reactors facilities. MELCOR does allow the user to modify the distance over which the inter-phase force is considered through user flow path input.

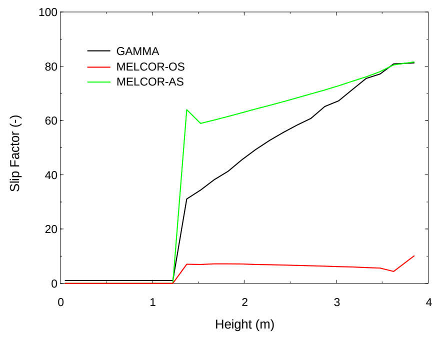

Figure 2. GAMMA vapor-slip factor along the vertical axis of the two-phase test problem at 400 s compared to MELCOR with the OS and adjusted slip-length (AS) predictions.

Figure 2 presents the slip factor (V_g/V_f) for the GAMMA-FR code compare to MELCOR with the default inter-phase force or original slip length (MELCOR-OS). The MELCOR-OS prediction results in a slip factor of ~10 as the flow exits the heated section compared to GAMMA-FR's prediction of ~80. To verify the relationship given by Equ.1, the slip length was uniformly adjusted (AS) along the channel to allow the MELCOR-AS prediction to match the exit void fraction prediction of GAMMA-FR, as can be seen in this same figure.

A comparison of the predicted void fraction up the flow channel at 400 s for each case appears in Figure 3. These results indicate an even closer match between GAMMA-FR and MELCOR after this slip factor was adjusted for MELCOR.

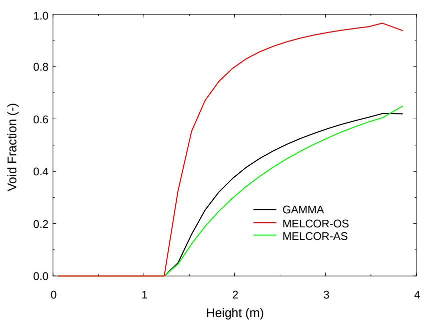

Figure 3. GAMMA predicted void fraction along the vertical axis of the two-phase test problem at 400 s compared to MELCOR with OS and AS predictions.

The second issue defined above is the point in time that boiling occurs. Given that the water volume and flow rate is correct and similar in both the GAMMA-FR and MELCOR models, the only time dependent factor that is left to consider is the thermal response of the heater rod, which depends on the mass of the rod and the specific heat capacity for alumina. As mentioned above, we could not find an explanation of how the surface multiplication factor is used in the rod conduction equation formulation. However, to demonstrate how the MELCOR onset of boiling is affected by rod mass, two additional MELCOR runs where made with 57 times what we think is the correct rod mass (CRM) and half of that number (28.5) times the CRM. The results appear in Figure 4. As can be seen, the MELCOR calculation with 28.5 times the CRM appears to fit best with the GAMMA-FR prediction. This is a discrepancy that still needs to be resolved.

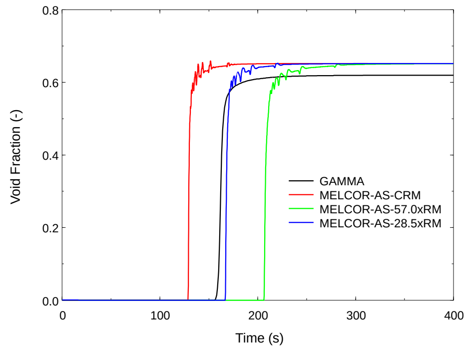

Figure 4. MELCOR AS model predicted onset of boiling for the correct rod mass (CRM), 57 times the CRM, and 28.5 times the CRM compared to GAMMA prediction

3. Conclusion

The GAMMA-FR code was scheduled for validation during the next three years under UCLA-NFRI collaboration. Through this research, GAMMA-FR will be validated with representative fusion experiments and reference accident cases. Currently two-phase flow validation is on-going and this study is able to show that the predictions between the codes are close; and that most of the differences noted can be explained by the adopted modeling approaches that the developers took for these codes. The predicted differences in the onset of boiling and single phase heat transfer needs to be studied further.

References

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