An Evaluation of a Film Boiling Heat Transfer Correlation For Fuel Coolant Interactions

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1. Introduction

Many of the fuel coolant interaction (FCI) processes are not fully understood which is especially true for the exotic parameter range encountered in nuclear safety problems. Therefore there are a variety of models for the important phenomena of FCIs. The purpose of the present work is to use the experiments that have been performed at Forschungszentrum Karlsruhe during the last ten years for determining the most appropriate models and parameters for premixing calculations[2]. This is done by recalculating experiments in two steps: 1.The results of a QUEOS 58 are used to fix the parameters concerning a heat transfer. The QUEOS the experiments are especially suited for this purpose as they have been performed with small hot solid spheres. Therefore the area of a heat exchange is known. 2. With the heat transfer parameters fixed in this way, a PREMIX experiment is recalculated. In this paper, the first step for a heat transfer correlation is presented. All the calculations of this work have been performed with MC3D version 3.5 patch1,by CEA, France, which is owned by IRSN, France[2].

2. Input Model for QUEOS 58

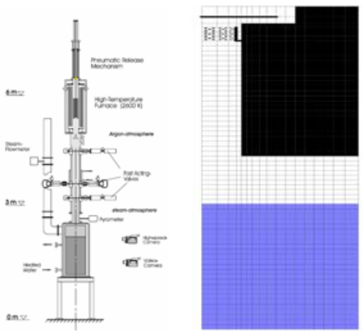

Fig. 1 QUEOS facilities and simulation model

This experiment was performed with 10.84 kg (about 28,000) spheres made of ZrO2 with a radius of about 5 mm and a temperature of about 2100 K. The initial diameter of the sphere jet was 0.18 m. The water was slightly subcooled by 2.3 to 3.2 K. The experiment is simulated in the present work in a cylindrical symmetry using 17 radial and 64 axial meshes. The spheres are held initially in a volume given by 3 radial times 3 axial cells. Figure 1 shows the configuration of the QUEOS facilities and a plot of the mesh including the no-flow zones (in black), the initial pile of spheres (indicated by dots), and the water pool (in blue/light grey). The scales in the radial and axial directions are different in this figure. The radius of the pool is 0.4088 m, its height 1.0 m. The experiment is simulated from a zero level (bottom plate) up to a level of 3.174 m, i.e. the uppermost gas-tight valve.

3. Models and Parameters

The intense thermal interaction of QUEOS 58 could not be reproduced with the standard film boiling model based on the Epstein-Hauser correlation and adapted to data from Liu and Theofanous, the classical Epstein-Hauser correlation and the correlations by Liu and Theofanous, as well as by Bromley. Only the correlation by Dhir and Purohit gave reasonable results. To obtain the same sort of results with the Epstein-Hauser correlation at least initially, its heat transfer coefficients had to be multiplied by a factor of about five. This large factor highlights how strongly the heat exchange in a highly agitated multiphase mixture deviates from what is observed on single large spheres at rest or with small forced convection velocities.

The so obtained high heat transfer causing a high evaporation rate as well, had to be counterbalanced by a similarly strong increased condensation. This is more difficult to obtain. The most effective way proved to be prescribing small diameters of the water droplets and, above all, the bubbles. Their sizes can be influenced by setting minimum and maximum values for the diameters and, to some extent, by the fragmentation models applied. The Meignen's bubble fragmentation model which gave the best results for the rising flank of the pressure peak, gave unsatisfactory results later on so that it couldn't be used. However, varying the critical Weber number in the standard fragmentation model has a somewhat uncertain effect on the bubble size as it mostly jumps to and fro between the maximum and minimum values that are prescribed.

The properties of the film boiling models available have been studied in a certain situation resembling the base case described below. The following table shows the results concerning the maximum heat transfer rates. In that, 'Conduction' means conduction through the film (MC3D output variable FLFBS) and 'Radiation' stands for radiation to the liquid (MC3D output variable RDRLS). These two are by far the most important heat transfer modes.

Table 1: Comparison of film boiling correlations

Film boiling model	Conduction	Radiation
EPSTEIN-HAUSER modified	1.7 E 06	1.1 E 06
EPSTEIN-HAUSER modified *1.7	3.0 E 06	1.1 E 06
EPSTEIN-HAUSER modified*2.0	3.45 E 06	1.1 E 06

EPSTEIN-HAUSER modified*4.0	6.8 E 06	1.1 E 06
Classical EPSTEIN-HAUSER	3.5 E 06	1.1 E 06
Liu-Theofanous	1.93 E 06	1.2 E 06
Dhir-Purohit	8.4 E 06	0.8 E 06
Dhir-Purohit with high condensation	7.3 E 06	0.65 E 06
Bromley	1.93 E 06	1.2 E 06

3. Best Fit Case

Figure 1 show the results of the calculation that is judged to give overall the best results. The main criteria are the timing and the peak value of the main peak. The agreement in the initial phase was obtained by setting the initial value and fitting the pressure at 0.3 sec. The rest of the pressure development is a result of the heat transfer that cannot be influenced in detail. The peak pressure was fitted by adjusting the minimum bubble radius. It is obvious that the steep pressure rise of the experiment could not be reproduced fully. Less drag of the spheres in the water and less condensation gave a better approximation but had disadvantages in other aspects.

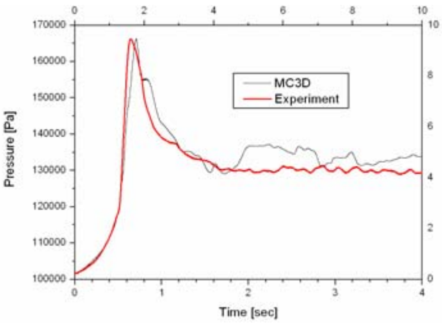

Fig. 2 Comparison of pressure developments

The pressure level after 1.5 sec was roughly adjusted with the help of the amount of non-condensable gas in the atmosphere. However, the vivid pressure variations in the calculated results show that thermal equilibrium is not as well established in the calculation as in the experiment. This may, however, be a consequence of too strong boiling from the spheres lying on the bottom of the facility. The Bromley correlation is the only one that can be chosen to be applied to special bottom regions instead of the main correlation and its heat transfer rates are only about 23 % of that of the Dhir-Purohit correlation.

The second criterion for choosing the base case calculation was the result concerning the void. The measured void is characterized by a high void at the center and a much lower value at radius 15 cm, with most of it appearing somewhat later. Although the calculated voids don't really match the measured ones and were quite sensitive to parameter changes, these two main properties could be found in several simulations. Figure 3 compares the void measured and calculated at the central position (up to radius 3 cm). Here the gas volume fraction is somewhat sketchy and denoted as a void because the sphere volume fraction in the corresponding volume is always small.

It is obvious that the calculated void comes too late, is not large enough but lasts much too long. The delay is partly due to the belated arrival of the spheres at the level of the void sensors (0.400 m) which occurs at 0.71 sec instead of 0.65 sec. An additional delay occurs because the void initially grows only slowly (as the sphere void fraction grows, see below). In a calculation with the drag between the liquid water and spheres reduced to 15 %, the spheres (correctly) reached the measurement level at 0.65 sec and the void started to grow (even earlier!) at 0.64 sec reaching a maximum of 90 %, but the spheres and void were practically absent at 15 cm radius. Therefore a default drag was used.

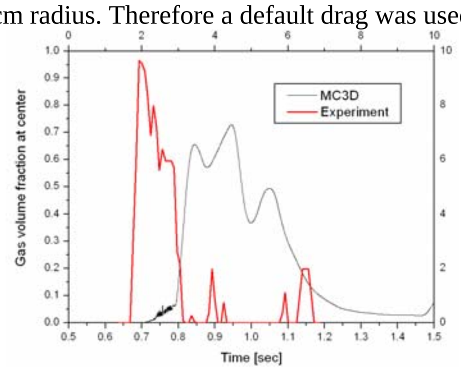

Fig. 3 Comparison of void histories

4. Conclusions

The important finding of this study is that the intense heat transfer from hot particles (liquid or solid) to their highly agitated two-phase surrounding that forms when these particles are mixed with liquid water, cannot be described properly with the standard film boiling correlations like those of Epstein-Hauser, Liu-Theofanous or Bromley that are available in MC3D. Only the correlation by Dhir-Purohit gives reasonable results. But even with Dhir-Purohit the steep pressure rise in the beginning of the experiment QUEOS 58 cannot fully be reproduced. This could mean that even Dhir-Purohit underestimates the heat transfer or that the condensation is overestimated during this phase with the parameters chosen in these calculations.

ACKNOWLEDGMENTS

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