Presentation Poster: CFD-Informed Spacer Grid Model Implementation in COBRA-TF

Taylor S. Blyth
The Pennsylvania State University

August 4, 2014
Introduction/Background

Importance of capturing the effects of spacer grids on subchannel flow and heat transfer

Spacer grids are used within fuel assemblies to hold the fuel rods in place as well as to increase fluid turbulence and therefore heat transfer from the rods to the bulk fluid. These grids are essentially small blockages in the axial flow and subchannel codes need to model their placement and geometry in order to capture their influence on the surrounding flow. By utilizing actual spacer grid data and results from CFD, the uncertainty of prediction of these related parameters can be decreased which lowers the operational margin. The ability to accurately model and simulate results in a subchannel code using CFD-supplied data would provide a quick method to perform subchannel analysis which could be expanded to the required geometry.

Subchannel code, COBRA-TF (CTF)

Pacific Northwest Laboratories originally developed the Coolant Boiling in Rod Arrays – Two Fluid (COBRA-TF) code in 1980. Since then it has been improved and upgraded at several locations including Washington State University, Pacific Northwest National Laboratory, and recently at Oak Ridge National Laboratory (ORNL). Currently, PSUs Reactor Dynamics and Fuel Management Group (BDFMG) manages a version which has been adopted into CASLs VERAs code suite, called CTF. CTF is a Light Water Reactor (LWR) Thermal/Hydraulic (TH) code used to simulate the core vessel using a two-fluid, three-field approach.

Computational Fluid Dynamics (CFD) Code, Hydra-TH

Hydra-TH, developed at Los Alamos National Laboratory, is CASLs CFD code in the VERA suite. This CFD code is able to model on a much smaller scale than CTF users by meshing within each subchannel much more finely. There needs to be a method for effectively using all these data taken from CFD simulations and applying them to the coarser mesh of CTF.

Current Status

Models within CTF

CTF contains models and correlations to account for select general spacer grid effects. There are also some effects which are geometric in nature. These effects include the calculation of the grid temperature and the grid pressure loss coefficient. The axial pressure drop is calculated using a general correlation based on the projected area of the grid.

Spacer grids have a large impact on downstream flow and its properties. The Yao/Hochreiter/Leech correlation was commonly used in order to predict the downstream spacer grid enhanced heat transfer. This correlation is able to produce an additive factor to the heat transfer coefficient based on the blockage ratio of the grid [1]. This correlation could be used by users in order to fit certain grids and boundary conditions better. Another offering another model to calculate the heat transfer enhancement without having to tune parameters is preferable for most users. This factor would be based on the CFD data, so Validation and Uncertainty Quantification (VUQ) work would have parameters which are already exposed. Equation 1 shows the Yao/Hochreiter/Leech correlation and the parameters a, b, c, d are able to be chosen by the users. If d is set to 0.0, then the mixing vane portion of the equation is turned off. This is sometimes preferred because the authors did not have access to actual mixing vane grid data for this portion of their equation 1, 2, 3 is the blockage ratio and A is the projected area of the grid and angle. The distance downstream from the spacer grid is also taken into account. The comparisons of the Nusselt numbers is used as the Nusselt number is an important factor in determining heat transfer in a subchannel.

\[ N_u = 1 + a e^{ux} \left( \frac{2}{11} \left[ 1 + 4 \tan^2 (90°) \right] \right) e^{11x} \]

Equation 1: The Yao/Hochreiter/Leech Correlation as it appears in CTF [1]

Reasoning for CFD data within CTF

Using data from actual spacer grid designs and then allowing users to select from these grid designs offers an advantage over using typical correlations. It means that specific grid data can be applied to various boundary conditions and the same tabular data can be used. Grids could also become more complicated and contain various values of vane angles. This would be applicable for corner and side subchannels. Typical models within CTF would not be able to capture this effect and the updated CFD data would be required if it were available.

Spacer Grid Models Missing from CTF

The horizontal swirl flow due to lateral exchanges between subchannels is not currently modelled. By collecting data on the velocities from the CFD simulations, a model could be implemented in order to capture this effect.

State of the Art in CFD/Subchannel coupling

Capturing the effects of spacer grids with single-phase CFD simulations has been implemented to account for various impacts on the subchannel calculations. Two-phase approaches are starting to appear and can capture the void fraction and void drift very well [2]. The swift effects are also important and appear to be the main factor that influence the inter-subchannel swirl as a method of improving heat transfer. Modelling parameters upstream of the spacer grids that influence the bulk flow should also be considered in order to get a best estimate.

Potential Issues

Single-Phase vs. Two-Phase Flow

The current strategy is to enhance CTF with single-phase CFD simulations in order to capture the effects of the grids on the flow patterns, heat transfer, and pressure drop along the subchannel. Also, it is difficult to develop a CFD model that includes water/steam parameters which change with axial location.

Capturing Specific Geometry Effects

In order to run enough CFD cases to create meaningful data, the geometry of the fuel assemblies must be modeled and time to a reasonable amount. For example, a 2x2 subchannel case with only internal-type subchannels may be used as the base geometry for the development of the correlations affected by the spacer grids. Given these values may not translate well to different types of subchannels. Corner and side subchannel connections have different gap sizes and often contain unheated conductors (walls) which would not be accounted for in the 2x2 internal-type subchannel CFD simulations. If the data from internal-internal connections were applied to the entire fuel assembly, there would be some over- and under-prediction of parameters along the corner and side type subchannels. The difference in geometry is illustrated in Figure 2, where there are two examples of 2x2 subchannels. The left side of the figure shows a model which contains a corner, two side, and an internal subchannel while the right side of the figure contains four internal subchannels. The multiple-subchannel CFD runs are required for capturing crossflow effects, but single-subchannel simulations may provide enough data for parameters such as the pressure drop. Cases should be run with and without the grids in place in order to determine how much of the friction/pressure drop is caused by the wall and how much is from the grid.

Availability of Grid Data and Experimental Results

Proprietary spacer grid designs could also inhibit some of this work. The idea of allowing a user to choose a grid from a list of CFD-analyzed spacers might have to become more generic. Experimental cases which have released their spacer grid designs are limited, and there are few which include single-phase results for validation.

Future Work

Complete Implementation and Comparison with Experimental Data

The proposed experimental data with which to compare the working models are the NUPEC PSBT Benchmark cases. These contain steady-state DNB prediction cases which can be used for temperature comparisons, at least. The other parameters such as pressure drop may be more difficult to validate.

Inclusion of Two-Phase Models

Void drift, a phenomenon impacted by the location and design of spacer grids, occurs in subchannels with two-phase flow. Simulating these with a CFD code would provide the ability to better predict the void drift for specific grids and subchannel layouts.

Application to CRUD Modelling

Since CTF is being coupled with the chemistry-code MAMBA, it may be feasible to utilize those spacer grid effects to better predict CRUD depositions due to its close ties with thermal conditions within the subchannel.

References

