

CTF Residual Formulation Solid Liquid Coupling

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Abstract

Nuclear engineering codes are being used to simulate more challenging problems and at higher fidelities than they were initially developed for. In order to expand the capabilities of these codes, state of the art numerical methods and computer science need to be implemented. One of the key players in this effort is the Consortium for Advanced Simulation of Light Water Reactors (CASL) through development of the Virtual Environment for Reactor Applications (VERA). The sub-channel thermal hydraulic code used in VERA, COBRA-TF (Coolant-Boiling in Rod Arrays - Three Fluids), is partially developed at the Pennsylvania State University by the Reactor Dynamics and Fuel Management Research Group (RDFMG). The RDFMG version COBRA-TF is referred to as CTF.

The current version of CTF solves eight conservation equations for liquid, entrained droplet, and vapor phases of water boiling within the rod structure of a LWR reactor core. After linearizing some terms in the Jacobian matrix, the conservation equations analytically reduce into a pressure matrix and are solved using a semi-implicit method. The solid conduction equations are then implicitly solved to determine the temperature within the fuel. Since the liquid solution is solved independent of the solid solution, the solid and liquid equations are explicitly coupled.

In an effort to help meet the objectives of CASL, a version of CTF has been developed that solves the residual formulation of the one dimensional single-phase conservation equations. The formulation of the base equations as residuals allows the code to be run semi-implicitly or fully implicitly while clearly defining the original conservation equations. This paper outlines work to integrate one dimensional solid conduction equations into the residual formulation. This allows the coupling between the solid and liquid equations to be either explicit or implicit. Different physical models, such as the homogeneous liquid solid energy model, can be readily implemented by adding the residual functions and variables. A simple test problem consisting of a single liquid channel and fuel pin is used to compare the original version of CTF to the different numerical and physical models available through the new residual formulation. The methods are compared both for steady state and transient conditions to quantify the accuracy and stability of each method. The input parameters are varied over a variety of conditions to demonstrate when different methods are most appropriate. The ability to choose appropriate numerical methods and physical models allows for greater fidelity and decreases computational expenses.

Keywords: thermal hydraulic, residual, Jacobian, solid liquid coupling, CTF, PETSC