**COBRA-TF Residual Formulation Solid Liquid Coupling**

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**Abstract**

Nuclear engineering codes are being used to address more challenging problems through the use of modern tools, enhanced fidelity, and uncertainty quantification. A key player in this effort is the Consortium for Advanced Simulation of Light Water Reactors (CASL) and its development of the Virtual Environment for Reactor Applications (VERA). The sub-channel analysis code COBRA-TF (Coolant-Boiling in Rod Arrays - Three Fluids) that is used in VERA is partially developed at the Pennsylvania State University by the Reactor Dynamics and Fuel Management Research Group (RDFMG).

In an effort to meet the objectives of CASL, a version of COBRTA-TF has been developed that solves the residual formulation of the 1D 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 1D solid conduction equations into the residual formulation. Some test problems were run that compare the original and residual versions of COBRA-TF, as well as demonstrate implicit coupling of the solid liquid equations.

Currently, COBRA-TF solves 8 conservation equations for liquid, entrained droplet, and vapor phases of water boiling within the rod structure of a LWR reactor core. The conservation equations analytically reduce into a pressure matrix and are solved using a semi-implicit method. The enthalpy and velocity are then back solved from the solution of the pressure matrix. The solid equations are then implicitly solved using these values. Since the liquid solution is solved independent of the solid solution, the solid and liquid equations are explicitly coupled.

The residual formulation of COBRA-TF re-writes the 1D single phase equations in residual form as independent functions. The residual variables that are to be solved for are pressure, enthalpy, and velocity. The jacobian matrix is computed numerically using these functions, and is then handed over to PETSC to be solved. The solid conduction equations are represented as another residual function, paired with the extra residual variable solid temperature. The liquid residuals are applied at the location of each liquid cell, and the solid residuals at the location of each solid node. This builds one jacobian matrix, and the solid and liquid equations can be explicitly or implicitly coupled depending on which terms in the residual equations are lagged.

**Keywords:** thermal hydraulic, residual, Jacobian, solid liquid coupling, COBRA-TF, PETSC