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

**C. Dances1, M. Avramova1 and V. Mousseau2**

1: Department of Mechanical and Nuclear Engineering, The Pennsylvania State University, 137 Reber BuildingUniversity Park, PA 16802, USA

2:Computer Science Research Institute, Sandia National Labs, 1450 Innovation Parkway, Albuquerque, NM 87123, USA

[cad39@psu.edu](mailto:cad39@psu.edu)  
[mna109@psu.edu](mailto:mna109@psu.edu)

[vamouss@sandia.gov](mailto:vamouss@sandia.gov)

**Abstract**

Objective: *What are you trying to do? Demonstrate the advantages of residual CTF* WC (19)

Use the new 1D residual formulation of COBRA-TF to implicitly couple the solution of the solid and liquid equations.

Motivation: *Why should I care?* More accurate computation, but faster. WC (126)

A fully implicit coupling computes more accurate results that the explicit coupling. For large power excursions, there should be greater stability in a fully implicit coupling between the solid and liquid mediums. Further more, the inner iterations should be allow for larger numerical time steps while keeping a high level of accuracy. The inclusion of the solid energy equations into the Jacobian matrix increases the percentage of the code that was parallelizable. The residual formulation will make the code easier to read, and more accurately quantify the convergence of the solution method. This will help in exposing parameters for validation and uncertainty quantification (VUQ). The inclusion of the solid equations into the Jacobian matrix might make COBRA-TF to better couple to other nuclear engineering computer codes.

Background: *What is COBRA-TF and how does it work currently?* WC (84)

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. Currently, the conservation equations analytically reduce into a pressure matrix and are solved using a semi-implicit method. The solid equations are then implicitly solved for using the results back solved from the solution of the pressure matrix. The pressure matrix has the option to be solved using PETSC for parallel computation, but the solid equations must be solved in serial.

Technical Approach: *How did you accomplish your objective?* WC(178)

The current version of the residual formulation of COBRA-TF is currently 1D single phase. The liquid mass, momentum, and energy conservation equations are written in a residual form as independent functions. The residual variables that are to be solved for are pressure, enthalpy, and velocity. The Jacobian matrix is the partial derivative of each residual function with respect to each residual variable. This partial derivative can be calculated numerically by perturbing the residual variable. Since the system is linear, the solution is exact. A list of all of the residual variables and equations are built for each location in the domain. The Jacobian Matrix is then built by looping over these 2 lists using nested loops. To include 1D conduction into the Jacobian Matrix, a residual function and variable for each solid node position just need to be appended to this process. While the liquid solution can be either semi-implicit or fully implicit, the heat conduction is always fully implicit. The coupling between the solid and liquid sections of the Jacobian matrix can be made explicit or implicit.

Outcomes: *What was the result? Did you meet your objective?* WC(0)

Total: (407/400=101.75%)

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

A descriptive abstract should be placed here. Information should be provided on the research motivation, background, objective, technical approach, and outcomes. Please do not include figures and tables in the abstract. The abstract should be about 250 to 400 words. Limit the abstract to one page only.

**Keywords:** Four to five keywords here (For example: Flow regime transition, two-fluid model, turbulence, void fraction)