APROS Thermal Hydraulics: Five Equation Model

The non-iterating 5-equation model has its origin in nuclear safety analysis and training simulator applications. It is based on the conservation equations of mass and energy for liquid and gas phases and the momentum equation for mixture of gas and liquid. The wall friction of mixture, wall heat transfer for liquid and gas separately, interfacial heat and mass transfer and phase separation by the drift flux phase separation need constitutive equations in addition to the basic conservation equations.

The discretized forms of the conservation equations are solved via a sparse matrix solution giving the pressure, the liquid enthalpy and the vapour enthalpy distribution in the nodes, the mixture velocity distribution in branches and the prediction for the new void fraction distribution in the nodes. The void fraction prediction includes the effect of the phase separation, which is calculated by a drift flux formula.

The pressure and mixture velocity distributions include the effect of the wall friction. The Blasius equation is applied for the turbulent flow area and a laminar approach is used for the low flow velocities.

The solution of the momentum conservation equation includes the limitation of the critical flow. The frozen sound speed of mixture has been used as a limitation for the mixture velocity.

The drift flux model has two parameters, the basic drift velocity and the radial void distribution factor for the fitting of the mathematical model into the physical data. These coefficients are derived by using the EPRI full range correlation. The correlation includes the effect of the counter current flow limitation, which is included as an additional limiter in the formulation.

The wall heat transfer correlation is selected on the basis of the wall temperature, the saturation temperature, the critical heat flux and the Leidenfrost temperature. The forced convection into the single phase liquid and gas is solved by the Dittus-Boelter correlation. Boiling occurs above the saturation temperature and Chen correlation has been used for this heat transfer regime. The critical heat flux model combines Zuber-Griffith, Biasi and Westinghouse correlations on their validity range. The additional heat transfer for the dry wall due to the inverted annular film boiling is calculated by Bromley correlation. The transient boiling heat transfer is calculated by the interpolation between the critical heat flux point and the minimum film boiling point. Additionally, an effect of the wall condensation is calculated, when the wall temperature is below the saturation temperature and surrounded by steam. All the heat transfer correlations, except Dittus-Boelter are programmed as multiparameter functions resulting in a full range correlation over the whole expected parameter range.

The interfacial heat transfer includes the flashing of the superheated liquid and the steam condensation into the subcooled liquid. For the condensation two approaches are included: the low condensation rate through a water level and high condensation between droplets and gas.

Summary:

§ The 5-equation model is a best estimate thermal hydraulic flow model providing engineering and safety analysis type calculations comparable to nuclear safety analysis codes.

§ The model is a non-iterating, non-equilibrium, non-homogeneous, two-phase flow model able to accurately represent a variety of transients including small and large loss-of-coolant accidents in nuclear power plants.

§ The model is able to handle transport of non-condensable gases in the flowing fluid.

§ The model is closely coupled to the nuclear core model, and generates detailed power-void mapping.

§ The model is able to simulate a ”cold water front” in the vessel from incoming cold feedwater.

§ The model is capable of simulating degassing of the reactor tank.