Development of Pipe Model for GPASS Code

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1. Introduction

Development of the General Plant Analyzer and System Simulation (GPASS) code is underway for an analysis of LMR plant transients.

In the current version of the GPASS code, a loop consists of a collection of components, where the outlet of each component connects to the inlet of another component such that a closed circuit component connection is realized. However, the flow travels along the loop of the reactor, and the fluid system temperature response will be delayed due to fluid transportation and heat transfer between the fluid and pipe wall.

This paper describes the models and numerical solution scheme for the pipe component of the GPASS code. The validation results for the pipe model are described. Transients involve a null-transient and 5% ramp change in the inlet temperature for an OTSG.

2. Methods and Results

The governing equations required to model the pipe are the mass, momentum, energy balances for the flow, and only the energy balance for the pipe wall. The last equation describes the heat transport between the flow and wall, which is required to simulate the transient, especially during a cold start-up.

2.1 Conservation Equation and Solution Scheme

With the chain rule for the rate of change in density, mass accumulation can be expressed in the form of enthalpy and pressure base. The mass conservation equation is obtained as

$$V\left(\frac{\partial\rho}{\partial h}\frac{\partial h}{\partial t}+\frac{\partial\rho}{\partial p}\frac{\partial p}{\partial t}\right)=\dot{m}_{in}-\dot{m}_{out}$$

The momentum conservation equation for a control volume is obtained as

$$\frac{d\dot{m}}{dt}=\frac{[(p+\rho v^2)A]_{in}-[(p+\rho v^2)A]_{out}}{L}+\rho\frac{v}{L}gcos\theta-\frac{f}{D_h}\frac{\rho v^2}{2}A-K\frac{\rho v^2}{2}\frac{A}{L}$$

The energy conservation equation is obtained as

$$V\left[\left(h\frac{\partial\rho}{\partial h}+\rho\right)\frac{\partial h}{\partial t}+\left(h\frac{\partial\rho}{\partial p}-1\right)\frac{\partial p}{\partial t}\right]=(\dot{m}h)_{in}-(\dot{m}h)_{out}-htcA_w(T-T_w)$$

Energy conservation equation of a pipe wall incorporates a heat transfer model between the wall and fluid, and heat storage, since heat (or thermal energy) is transported from the fluid to the pipe wall during the transient. For the transient simulation of a pipe, the energy conservation equation should be solved with the governing equations of the fluid given in the previous sections. The wall temperature of the pipe can be modeled with a constant temperature as a lumped element model in the radial direction for simplification. It is assumed that there is negligible thermal conduction in the axial direction, and no heat loss at the outer surface of the pipe. The energy balance equation is obtained from the previous equations as shown below.

$$\mathrm{mc}\frac{dT_m}{dt}=\frac{T_{hot}-T_{sm}}{\frac{1}{htcA_w}+\frac{L_{eff}/2}{kA_{eff}}}$$

A schematic nodalization of the heat exchanger is illustrated in Fig.1. For each nodal zone, there are two control volumes for the fluid and pipe wall. Thus, there are four equations and four unknowns to be solved for each zone. The unknowns are the mass flow rate ($\dot{m}$), pressure (p), specific enthalpy (h) at the surface of the control volumes, and the lumped temperature of the tube wall (T_{sm}).

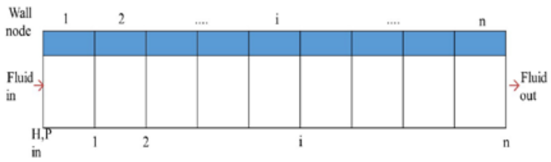

Fig. 1. Schematic Nodalization of Pipe for the 4-equation pipe model.

The unknowns are initialized with the initial guess, or the results of the previous time step. The Newton-Raphson method is used to solve the system of algebraic equations to satisfy the governing equations and boundary conditions. The average mass flow rate, pressure, and specific enthalpy (for fluid control volume) and temperature (for pipe control volume) are calculated, and are used then for obtaining the property and transport coefficients required to assess each term of governing equations.

2.2 Results

In this section, the solution to a sample problem is given to demonstrate the ability of the 4-equation pipe model. It is applied to the OTSG SG geometry with an extended tube length of 10 fold. The length of the pipe was 158.8 m, and the thickness of the wall was 0.864 mm. The working fluid is water. The pipe was modeled with 20 equal length nodes. The results of a null transient simulation are shown in Fig. 2. The figure shows that the temperatures, heat transfer rate, and pressure are invariant after a few seconds.

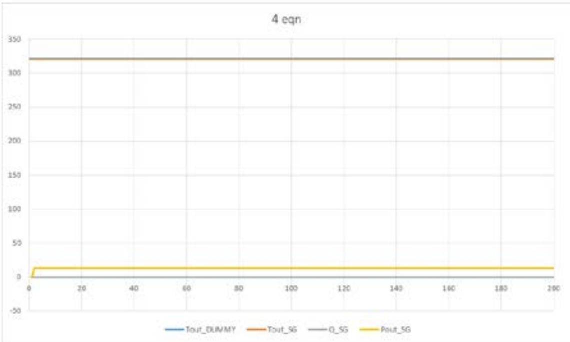

Fig. 2. Temperature, heat transfer rate, and pressure Response of 4-Equations Model during null transient.

The simulation results from the 4-equation model were compared against the results produced by the 7-equation OTSG model of the GPASS code with a very small thermal conductivity of the tube wall to have a thermal insulation effect. The purpose of the simulation was to see the time delay effect of a long pipe and to compare the dynamic trends.

The 7-equation OTSG model of the GPASS code consists of conservation equations (mass, momentum and energy) of hot and cold fluids, and a metal energy conservation equation.

The results obtained with the 4-equation pipe model and the 7-equation OTSG model of the GPASS code are shown in Figs. 3 and 4. The simulation was conducted to let the inlet feed temperature change from the nominal value to 95% of this value during a 5 s period. As a result, both models have the same pressure drop of 0.226 MPa at a steady state.

It can be seen that the outlet temperature is changing after about 20 s from the change at the inlet temperature in Fig. 3. There is the same agreement between the two models in the trends show in Figs. 3 and 4. The trend of the two figures are similar, the time delay of the 7 equation model is about 5 s shorter than the 4 equation model. This is because the thermal conductivity of the 4 equation model has an effect on the heat transfer between the fluid and metal, whereas the 7 equation model does not owing to the almost zero thermal conductivity. The shortened time delay can also be seen if the thermal conductivity is set to ~0 in the 4 equation model.

Figs. 5 and 6 show the results in the case of sodium working fluid. Fig. 5 shows that the sodium containing pipe has a longer time delay effect than that in Fig. 3. Fig. 6 shows the same behavior as Fig. 4 owing to the non-heat transfer between the fluid and tube metal.

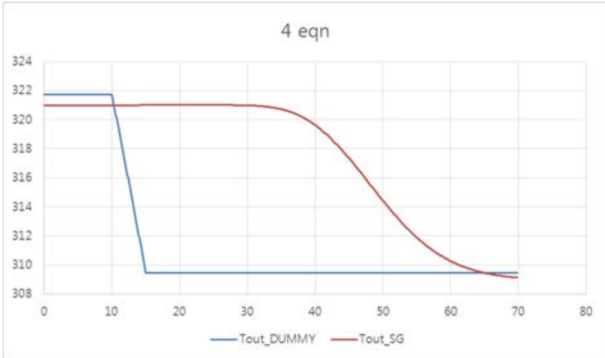

Fig. 3. Outlet Temperature Response of 4 Equation Model.

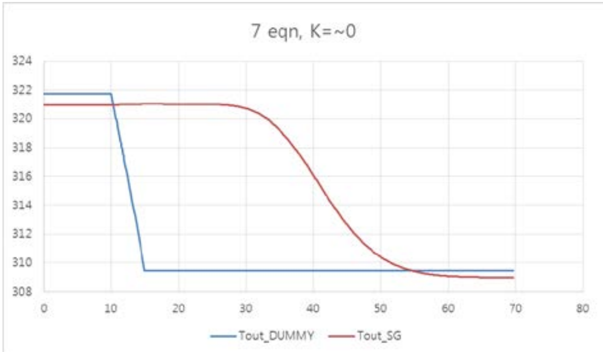

Fig. 4. Outlet Temperature Response of 7 Equation Model with almost Zero Thermal Conductivity.

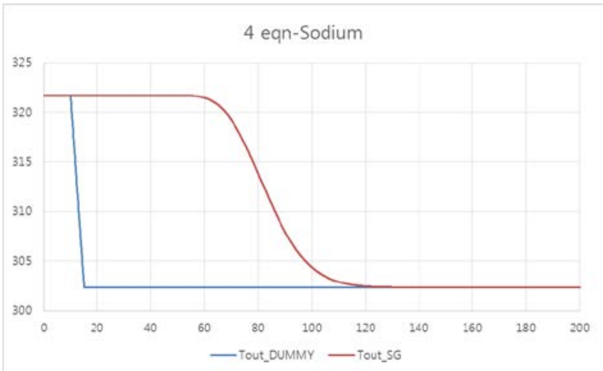

Fig. 5. Outlet Temperature Response of 4 Equation Model (Working Fluid: Sodium).

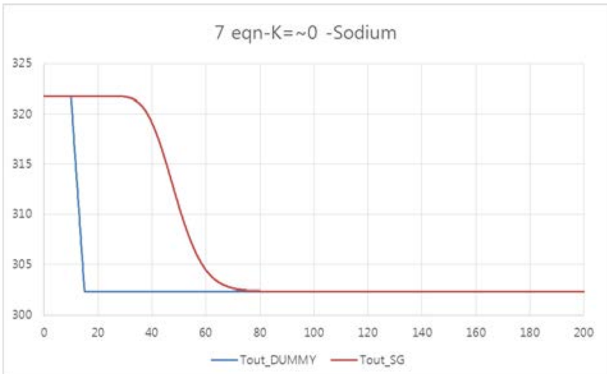

Fig. 6. Outlet Temperature Response of 7 Equation Model with almost Zero Thermal Conductivity (Working Fluid: Sodium).

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