Discussion on the Energy Conservation across a Sharp Gradient Junction in SPACE-CAP Code

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1. Introduction

SPACE code for RCS (Reactor Coolant System) analysis and CAP code for containment analysis are now under V&V (Validation & Verification). CAP code has undergone or will undergo so many test problems for following categories;

1) Fundamental phenomena.
2) Principle phenomena (mixing and transport) and components in containment.
3) Demonstration test by small, middle, large facilities and International Standard Problems.
4) Comparison with other containment codes such as GOTHIC or COMTEMPT.

CAP V&V is now in the category 3 above.

Most important demand for CAP code at this time is the capability of containment pressure and temperature analysis. Thus, the V&V for thermodynamics problems and energy conservation is extremely important. Energy conservation should be at times carefully examined in case of sharp gradient across a junction when the form of energy equation is based on the specific internal energy.

This paper discusses on the energy conservation across a sharp gradient junction.

2. Energy Equation of CAP

As mentioned in introduction energy equation of CAP is based on the specific internal energy[1]. For gas

$$
\begin{aligned}
&\frac{\partial}{\partial t}\left(\alpha_g \rho_g U_g\right)+\frac{1}{A}\frac{\partial}{\partial x}\left(\alpha_g \rho_g U_g u_g A\right) \\
&= -p\frac{\partial \alpha_g}{\partial t} - p\frac{1}{A}\frac{\partial}{\partial x}\left(\alpha_g u_g A\right)+\Phi_g \\
&+\left[\begin{array}{l}
-\dfrac{h_l^*}{\left(h_g^*-h_l^*\right)}\dfrac{p_v}{p}H_{gli\to g}\left(T^s\left(p_v\right)-T_g\right) \\
-\dfrac{h_g^*}{\left(h_g^*-h_l^*\right)}H_{gli\to l}\left(T^s\left(p_v\right)-T_l\right) \\
+\dfrac{p_n}{p}H_{l\to n}\left(T_l-T_g\right)
\end{array}\right] \\
&+\left[\begin{array}{l}
-\dfrac{h_d^*}{\left(h_g^*-h_d^*\right)}\dfrac{p_v}{p}H_{dgi\to g}\left(T^s\left(p_v\right)-T_g\right) \\
-\dfrac{h_g^*}{\left(h_g^*-h_d^*\right)}H_{dgi\to d}\left(T^s\left(p_v\right)-T_d\right) \\
+\dfrac{p_n}{p}H_{d\to n}\left(T_d-T_g\right)
\end{array}\right] \\
&+E_g^w+E_g
\end{aligned}
\qquad (1)
$$

The difference equation is the form of [2]

$$
\begin{aligned}
&LHS \\
&= \ldots + p^{(n)}\left(\tilde{\alpha}_{g,e}^{(n)}F_{g,e}^{(n+1)}+\tilde{\alpha}_{g,w}^{(n)}F_{g,w}^{(n+1)}\right)+\ldots \qquad (2)
\end{aligned}
$$

, where $F_{g,e}^{(n+1)} = u_{g,e}^{(n+1)}A_e$

3. Test for Adiabatic Expansion Problem

Test problem is shown in Fig. 1. Two inter connection volumes are filled with hydrogen and the junction is initially blocked and quick opens.

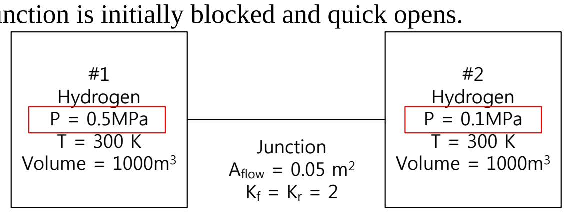

Fig. 1 Hydrogen Isothermal Expansion Problem

This process undergoes an adiabatic process and the final state can be calculated analytically.

T1 = 258.66K
T2 = 357.07 K

CAP prediction is presented CAP(PU)_ in Figs. 2 and 3

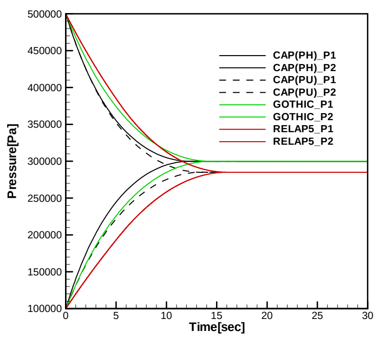

Fig. 2 Pressure behaviors

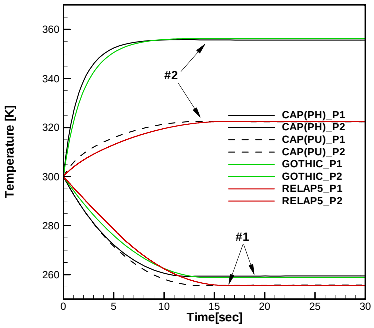

Fig. 3 Temperature behaviors

These results show much difference. And RELAP5[3] prediction is same to CAP(PU). But GOTHIC[4] is different from CAP(PU) and RELAP5, moreover it predicts exactly the analytic solution.

This is discussed in following sections.

4. Energy loss in junction

Equation (2) should be carefully observed. This term in energy equation means the expansion work and it is taken into account by boundary flows, because the gradient operator in equation reduced to surface integral in difference equation. In the equation (2) pressure takes the cell pressure, but void fraction and velocity take the values at junction. The values in junction are actually the upstream values. This is the meaning of the equation (2).

However, this does not reach sense, because of the mismatch of thermodynamic properties. This term is the sum of boundary flow properties, so all the value should takes the upstream values in order to conserve the delivered energy. So the pressure was set to take the upstream values.

In principle this makes the energy equation to change from the form of

$$= ... - p\nabla \cdot \left(\alpha_g \mathbf{v}_g\right) + ... \qquad (3)$$

to the form of

$$= ... - \nabla \cdot \left(p\alpha_g \mathbf{v}_g\right) + ... \qquad (4)$$

However, the energy equation (1) is rigorously derived from the conservation law of total energy without any assumptions. So such meaning is reflected only in the difference equation.

5. Results of modification and discussion

The results are presented in CAP(PH)_ in Figs. 2 and 3. It shows good agreement with analytic solution and GOTHIC results.

This is discussed in RELAP5. Junction option for PV term is related with this conservation. RELAP5 recommends;

The junction control flag e in jefvcahs is used to activate the modification to the energy flux term. This model is recommended for break junctions that connect to containment volumes that are modeled using regular volumes (not time-dependent volumes).

5. Conclusions

Through the slight modification in numerical development, energy conservation across sharp gradient junction was successfully implemented. Expansion term which includes Del operator slightly changes to take values in upstream.

ACKNOWLEDGMENTS

The authors would like to acknowledge the financial support from Ministry of Knowledge and Economics (MKE).

REFERENCES

[1] S.J. Hong, et al., Development of CAP Thermal Hydraulic Governing Equation, S06NX08-R-1-TR-25 Rev. 1 2010
[2] S.J. Hong, et al., Development of CAP Thermal Hydraulic Solver, S06NX08-R-1-TR-26 Rev. 0, 2009
[3] ISL, RELAP5/Mod3.3
[4] F. Rahn, GOTHIC Containment Analysis Package Technical Manual Version 7.2, Electric Power Research Institute, Inc, 2004