Improvement of Numerical Stability of the MATRA Code by Using a Uniform Pressure Drop with an Effective Loss Coefficient

Kyong-Won Seo, Dae-Hyun Hwang, Chung-Chan Lee
Korea Atomic Energy Research Institute, 1045 Daedeokdaero, Yuseong, Daejeon, Korea, 305-600, Korea,
nulmiso@kaeri.re.kr

1. Introduction

Subchannel analysis codes usually solve a boundary value problem and use a multi-pass marching scheme to find flow and enthalpy fields for satisfying the boundary conditions at inlet and outlet. The multi-pass marching scheme may accumulate numerical errors during its iteration steps and numerical instabilities such as a numerical oscillation or loss of diagonal dominance may be induced. Yoo et al.[1] studied convergence criteria of the MATRA and other COBRA-family codes, such as TORC, COBRA3CP, and CORBRA-4I for CHF data from the Winfrith Establishment[2]. The axial length of the test bundle is 3m and the computational axial node size was uniformly 60mm. In a total of 123 cases, 29 cases are diverged and 2 cases are oscillated for low flow and low pressure. They found that the subchannel analysis codes are numerically unstable for the conditions of low pressure (< 100 bar) and low flow (< 300 kg/m^2-sec). Figure 1 shows a map of convergence and divergence or oscillation results of the MATRA code for the CHF data of Winfrith Establishment.

These days, advanced reactors which have a low power density and low flow are being proposed and studied. Subchannel anlalysis on these new reactors is basic and necessary to determine the CHFR, flowrate, thermal margin, and preliminary input for a safety analysis. Thus an improvement of the numerical stability of subchannel codes for low pressure and low flow is important for the design of these reactors.

2. Improvements of Numerical Stability

A common cause of a numerical instability was investigated for the low flow and/or low pressure conditions with CHF data of the Winfrith Establishment.

The implicit finite difference equation for a continuity of the MATRA is as follows:

$$\overline{A}_{i,j}\frac{\rho_{i,j}-\rho^{n}_{i,j}}{\Delta t}+\frac{m_{i,j}-m_{i,j-1}}{\Delta x_j}+\left\{D_c^T\right\}\left\{w_{k,j}\right\}=-\left\{D_c^T\right\}\left\{w'_{k,j}\right\} \qquad (1)$$

where $\left\{D_c^T\right\}$ is summation operator, $w_{k,j}$ is crossflow and $w'_{k,j}$ is turbulent mixing per unit length.

In a steady state, the axial flow in a channel increases by a summation of the crossflow and turbulent mixing from neighbor channels. For low pressure and low flow conditions, the void fraction in a channel may be developed suddenly in a short axial length. In this case, the axial flow decreases in a neighboring channel where the void fraction increases suddenly and crossflow increases as the calculation marches on axially. This may result in a negative axial flow and the MATRA code fails to solve an energy equation.

This numerical instability can be provisionally overcome by reducing the computational axial node size. The reduced axial node size decreases the crossflow relatively small with regard to the axial flow. For 31 cases that diverged or oscillated with an axial node size of 60 mm, five cases were converged with a half axial node size and one more case was converged with a quarter. Half sold symbols in Fig.1 are converged cases by decreasing the axial node size. However, the calculation time by this method is inversely proportional to the number of axial nodes.

Numerical stability may be increased by stabilizing the axial flow and crossflow by a uniform pressure drop between the channels at each axial plane for a low flow. The axial flow of the channels was redistributed to make a uniform pressure drop by using effective loss coefficients. The effective loss coefficient is evaluated from channel geometry as follows:

The pressure drop through a channel, *i*, will be the same as the core pressure drop;

$$\Delta P_i=\frac{1}{2}K_i'G_i^2=\frac{1}{2}K_C'G_C^2=\Delta P_C \qquad (2)$$

where $K'= K/\rho$ is the effective loss coefficient, K is the loss coefficient, ρ is the density, G is the mass flux, the

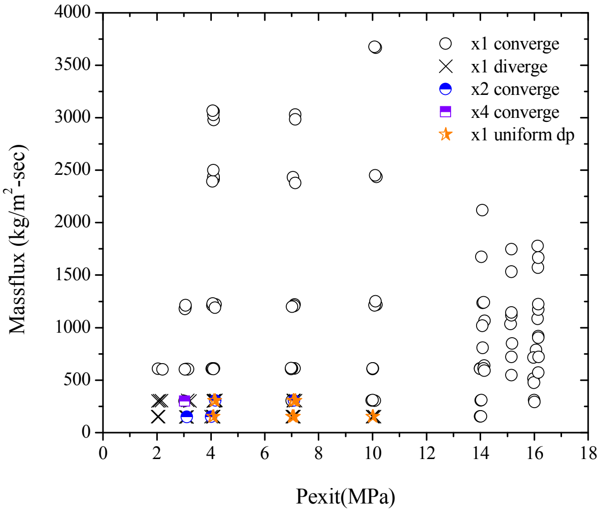

Fig. 1. Convergence Map of MATRA Code for Winfrith CHF Data.

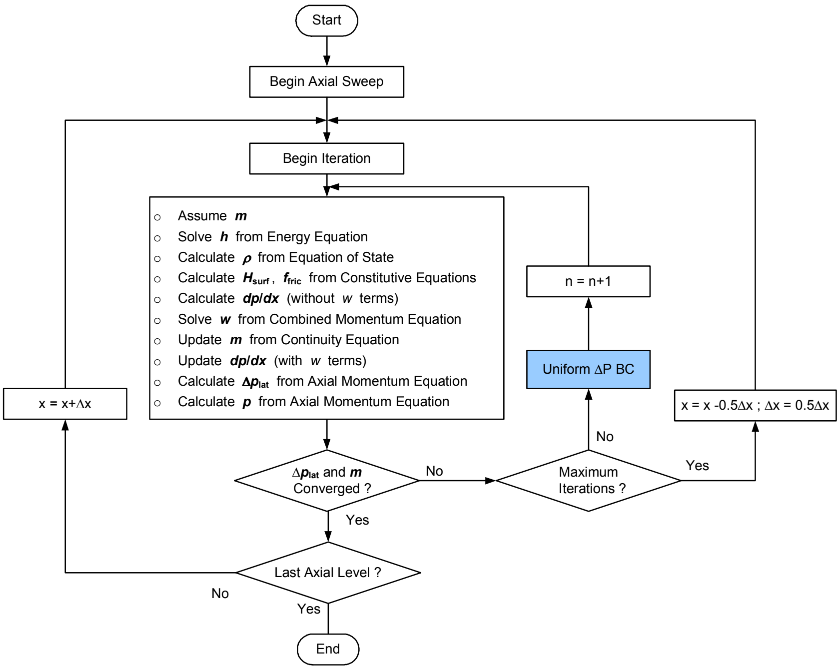

Fig. 2. Algorithm of Uniform Pressure Drop at Each Axial Plane.

subscript i means a channel, and the subscript C means the core average.

The relative inlet flow for the core flow can be calculated from eq.(2);

$$G_i / G_C = \sqrt{K'_C / K'_i} \ . \tag{3}$$

The continuity equation results in

$$\sum_i G_i A_i = G_C \sum_i A_i \ . \tag{4}$$

The effective loss coefficient of the core is derived from eqs.(2) and (3)

$$K'_C = \left\{ \sum_i A_i \bigg/ \sum_i \frac{A_i}{\sqrt{K'_i}} \right\}^2 . \tag{5}$$

And then the axial flow of each channel can be updated by Eq.(3).

The assumption of a uniform pressure drop at each axial plane was validated first in comparisons with the multi-pass marching scheme at high-pressure and high-flow conditions. The results of a uniform pressure drop at each axial plane were good agreement with those of the multi-pass marching scheme.

For 31 cases that were diverged or oscillated for the original setup, 16 cases were converged with a uniform pressure drop boundary condition. The results include 6 cases (stars in Fig.1) which were converged by reducing the axial node size. That is 10 more cases were converged with a uniform pressure drop boundary condition than by increasing the axial node size without increasing the calculation time.

3. Conclusion

Numerical instability of the MATRA code was mainly induced by a relatively large crossflow to axial flow ratio for a low pressure and low flow. The numerical stability can be improved by reducing the axial node size to make the crossflow small enough for an axial flow. This method doubles the calculation time as it reduces the axial node size by half. Flow redistribution by an effective loss coefficient under the assumption of uniform pressure drop at each axial plane was implemented in the MATRA code. By this method, the numerical stability can be improved without increasing the calculation time.

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REFERENCES

[1] Yeon-Jong Yoo et al., "A Study on the Numerical Instability of COBRA-Series Subchannel Analysis Codes at Low-Pressure and Low-Flow Conditions," *Proc. of the Korean Nuclear Society Spring Meeting*, Korea, 2001.

[2] F. H. Bowditch and D. J. Mogford, "An Experimental and Analytical Study of Fluid Flow and Critical Heat Flux in PWR Fuel Elements," AEEW-R2050, AEE Winfrith, February (1987).