Case Study for the Numerical Instabilities of the MATRA at Low Flow and Low Pressure Conditions

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1. Introduction

Subchannel analysis codes are very useful and have important roles in analyzing the thermal performance of nuclear reactors. The COBRA and its descendants, including the MATRA[1], have been widely used as a subchannel analysis code. These codes are known to be unstable for certain conditions.

There have been many efforts to resolve unstableness and increase the stability of the subchannel analysis codes. Cuta et al.[2] assessed the stabilities of subchannel analysis codes, VIPRE-01, COBRA-3C, COBRA-IV-I, and LYNX-T with five different experimental data. They found that those codes are unstable for certain cases in a steady state. And they suggested that the cause of unstableness of those codes is the way the lateral pressure difference is updated in the momentum equation. They introduced the crossflow parameter as a measure of the relative numerical stability. The crossflow parameter is sums of average absolute values of the crossflow for the whole nodes:

$$\overline{w} = \frac{\sum_{j=2}^{NDX+1}\sum_{k=1}^{NK1}\left|w_{k,j}\right|}{NDX \times NK} \tag{1}$$

where NDX is the number of axial nodes, NK is the number of gaps and $w_{k,j}$ is the crossflow through gap k at the jth axial node. The crossflow parameter oscillates when a subchannel analysis code was unstable. But the oscillation of the crossflow parameter was not always an indicator of a poor solution.

Yoo et al.[3] assessed the MATRA and other COBRA-family codes, such as TORC, COBRA-3CP, and COBRA-IV-I with CHF data from the Winfrith Establishment[4]. They found that the COBRA-family subchannel analysis codes are commonly unstable for low pressure (< 100 bar) and low flow (< 300 kg/m2-sec) conditions.

These codes use multi-pass marching scheme to find flow and enthalpy fields that satisfy the boundary conditions. During an axial marching, inner iteration, the scheme solves enthalpy, cross flow, axial flow, and pressure at each axial plane from the inlet to outlet. The scheme iterates the axial marching until the errors of the cross flow and axial flow meet the convergence criteria. In this approach, numerical errors may be accumulated during iterations and may induce numerical instabilities especially under low-pressure and low-flow conditions.

2. Unstable Cases

We studied the cases when the MATRA becomes unstable in a steady state calculation. We found some reasons for the instabilities.

The first case of the numerical instabilities is an occurrence of negative axial flow. The finite difference equation for the continuity of the MATRA is as follows:

$$\overline{A}_{i,j}\frac{\rho_{i,j}-\rho_{i,j}^{n}}{\Delta t}+\frac{m_{i,j}-m_{i,j-1}}{\Delta x_j}+\left\{D_c^T\right\}\left\{w_{k,j}\right\}=-\left\{D_c^T\right\}\left\{w'_{k,j}\right\} \tag{2}$$

where $\left\{D_c^T\right\}$ is the summation operator, $w_{k,j}$ is the crossflow per unit length and $w'_{k,j}$ is the turbulent mixing per unit length. In a steady state, the crossflow and the turbulent mixing from neighboring subchannels are added to the axial flow of a subchannel. The turbulent mixing term is usually very small to the axial flow. The crossflow term may be large to the axial flow for certain conditions. For the low pressure and low flow conditions, a void fraction in a subchannel may be increased suddenly within an axial node. Then the crossflow increases and the axial flow decreases in the neighboring subchannels during inner iterations as shown in Fig.1. This may result in a negative axial flow and the MATRA fails to get solutions. Figure 1 shows the axial flows of corner subchannels (subchannel 1, 6, 31, and 36) become negative as iteration step is increased.

The second case of the numerical instabilities is an oscillation from a density oscillation. For the low flow condition, a gravitational pressure loss is more dominant than other pressure loss components. The density oscillation results in an oscillation of the gravitational pressure loss. In a node where it belongs to a subcooled region and a saturated region, the density in the subchannel may oscillate widely. Then gravitational pressure loss and frictional pressure loss also oscillates because of a uniform exit pressure boundary condition. And the axial flow also fluctuates to meet the pressure loss and the other fluid properties fluctuate sequentially. It adds more divergence for an axial flow and thus MATRA can't obtain a converged solution. This numerical instability is presented in Fig.2. The solid line shows the gravitational pressure loss per unit length and it represents the density oscillation well. The dotted line shows this oscillation is damped by a relaxation factor of 0.7.

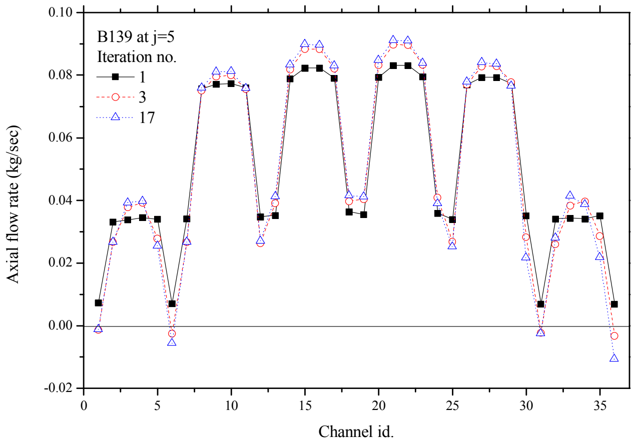

Fig.1. Numerical Instability due to a Negative Axial Flow.

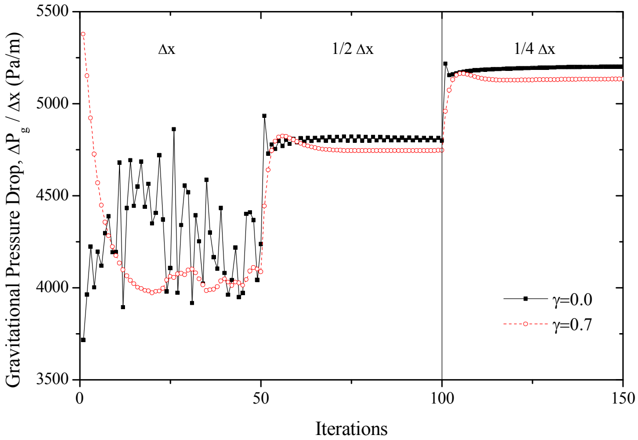

Fig.2. Flowchart of the New Scheme.

This type of oscillation can be provisionally reduced by a relaxation factor or by reducing an axial node size. The relaxation factor can limit a sudden change of values during iterations. Reduction of an axial node size can decrease an amount of change of values during axial marching from the j-1th to the jth axial nodes.

3. Conclusion

We studied unstable cases of the MATRA with Winfrith CHF data. The numerical instabilities are mainly induced by a relatively large crossflow to axial flow ratio and density oscillation for a low pressure and low flow. The first numerical instability can be resolved by uniform pressure drop boundary condition which redistributes axial flow forcedly. And the second numerical instability can by resolved by a relaxation factor or by reducing the axial node size to make the crossflow small enough for an axial flow.

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REFERENCES

1. Y. J. Yoo and D. H. Hwang, Development of a Subchannel Analysis Code MATRA (Ver. α), KAERI/TR-1033/98, KAERI (1998).
2. J. M. CUTA et al., VIPRE-01: A Thermal-Hydraulic Code for Reactor Cores, Volume 4: Applications, NP-2511-CCM-Vol.5, EPRI (1987).
3. Y. J. Yoo and D. H. Hwang, "A Study on the Numerical Instability of COBRA-Series Subchannel Analysis Codes at Low-Pressure and Low-Flow Conditions," *Proc. of the Korea Nuclear Society Spring Meeting,* Jeju, Korea (2001).
4. 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 (1987).