# Comparison of MATRA-S and COBRA-SFS for Low Flow Subchannel Analysis

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## 1. Introduction

We have amended an explicit solver XSCHEM of MATRA-S to overcome the weakness of implicit solver that the implicit solver is usually unstable for solving low flow and low pressure problems[1]. And we have assessed MATRA-S with PNL 2x6 rod bundle test data[2] of steady state and flow reduction transient.

In this study, we compared the MATRA-S with COBRA-SFS for the PNL test because the COBRA-SFS is believed to be superior to MATRA-S for the low flow conditions. COBRA-SFS[2] code was developed for subchannel analysis of spent fuel storage system based on COBRA-3C, COBRA-4I, and COBRA-WC. As the code was designed to predict temperature and flow distributions in spent fuel storage system, it can analyze thermal hydraulic fields of natural convection as well as radiation and conduction heat transfer.

## 2. Comparison of Numerical Methods

XSCHEM of MATRA-S adopted the ACE(Advanced Continuous fluid Eulerian) method[3] whereas RECIRC of COBRA-SFS[4] was adapted from COBRA-WC and uses the Newton-Raphson method for their explicit scheme, respectively.

The ACE was developed to take account rapid density change in flow such as a liquid-vapor interface. The method finds the pressure change that will satisfy the balance in the modified energy equation with updated axial flow and cross flow.

$$\left(\tilde{m}\upsilon_j^* - \tilde{m}\upsilon_{j-1}^*\right) + \Delta x\left[D_c\right]^T\left\{\tilde{w}\upsilon^*\right\}_j - \left.\frac{\partial \upsilon}{\partial h}\right|_p Q_j^n = E_j \qquad (1)$$

The correct pressure change with the correct axial flow and crossflow will make residual $E_j$ as zero in the above equation.

$$\Delta p_j = -\frac{E_j}{dE/dp} \qquad (2)$$

The denominator of right hand side of Eq.(2) can be calculated from Eq.(1). And the numerator in Eq.(2) can be calculated by expanding the derivative as following relationship:

$$\frac{dE}{dp} = \frac{\partial E}{\partial \tilde{m}_j}\frac{d\tilde{m}_j}{dp_j} + \frac{\partial E}{\partial \tilde{m}_{j-1}}\frac{d\tilde{m}_{j-1}}{dp_j} + \frac{\partial E}{\partial \tilde{w}_j}\frac{d\tilde{w}_j}{dp_j} \qquad (3)$$

The RECIRC is designed to finds the pressure change that will satisfy the balance in the continuity equation with updated axial flow and cross flow.

$$\bar{A}\frac{\Delta x}{\Delta t}\left(\rho - \rho^n\right) + \tilde{m}_j - \tilde{m}_{j-1} + \Delta x\sum_{k\in i} e_{ik}\tilde{w} = E_j \qquad (4)$$

The relation of pressure change and change rate of the residual is

$$\delta p_{j-1} = \frac{-E_j}{dE_j / dp_{j-1}} \qquad (5)$$

In Eq.(5), the Eq.(4) gives denominator and the following Eq.(6) gives numerator.

$$\frac{dE_j}{dp_{j-1}} = \frac{\partial \tilde{m}_j}{\partial p_{j-1}} - \frac{\partial \tilde{m}_{j-1}}{\partial p_{j-1}} + \Delta x\sum_{k\in i} e_{ik}\frac{\partial \tilde{w}_j}{\partial p_{j-1}} \qquad (6)$$

Once the pressure change is found, new axial flow and cross flow are calculated from the axial momentum equation and lateral momentum equation respectively in the both of XCHEME and RECIRC. And the density can be found from the equation of state.

## 3. Comparison of Results

We compared MATRA-S and COBRA-SFS with the 38 cases of steady states and flow reduction transients at PNL 2x6 rod bundle[2].

For the steady state heated condition, Fig.1 shows the measured local flow velocity profile at outlet and the predicted subchannel averaged flow velocity of MATRA-S and COBRA-SFS.

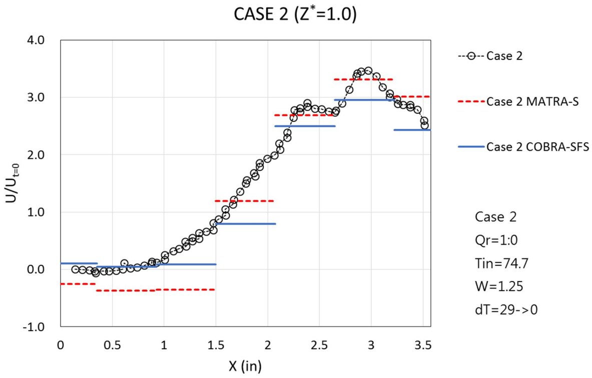


Fig.1 Steady State Flow Velocity Profile

The above results are measured along subchannels from 1 to 7 and only the six rods at right half side are heated as shown in Fig.2.

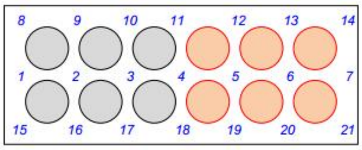


Fig.2 Cross-sectional View of PNL Test

It is hard to directly compare the measured local flow velocity and the result of subchannel analysis code. The result shows MATRA-S slightly under-predicted the flow velocity at cold channels(subchannel 2 and 3) and slightly over-predicted at hot channels (subchannel 5 and 6). COBRA-SFS under-predicted flow velocity at hot channels.

For the 150 seconds flow reduction transient, Fig.3 shows the local flow velocity measured at subchannel centerline and the predicted subchannel average flow velocity of MATRA-S and COBRA-SFS.

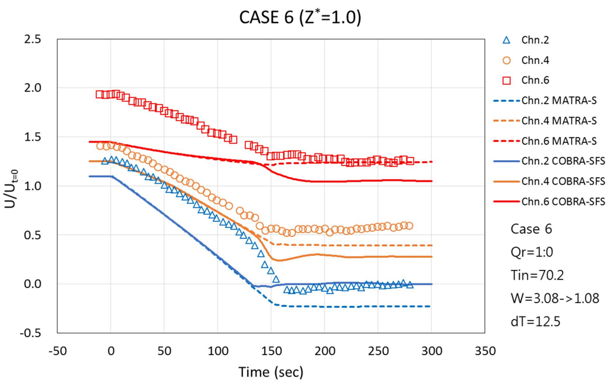


Fig.3 Transient Flow Velocity

The measured data at the subchannel centerline can't be directly compared to the results of subchannel analysis code. Although the centerline to average flow velocity varies about 1.2 to 2 depending flow regimes, it can tell us the trends of transient. MATRA-S showed ability to predict negative flow at the cold subchannel 2. COBRA-SFS also showed it can predict negative flow and recirculation, but it showed overshooting behaviors in the channel 4 and 6 after the end of 150 seconds transient.

Fig. 4 shows the normalized temperature rise at the subchannels 2, 4, and 6. MATRA-S failed to predict temperature rise at cold subchannel 2 after end of flow reduction because it didn't treat the income boundary conditions from the outlet. COBRA-SFS has several options to treat these cases and it could predict the temperature rise from recirculated flow.

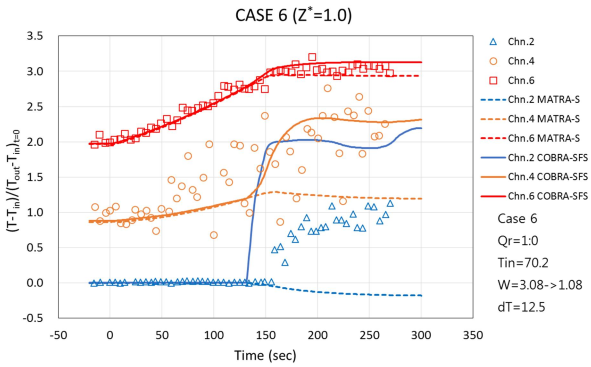


Fig.4 Normalized Temperature Rise

## CONCLUSION

In the way of improving XSHCME of MATRA-S to be applicable to low flow problems, we compared MATRA-S XSCHEM and COBRA-SFS RECIRC for steady state and flow transient. Both methods use similar algorithms to solve pressure, axial flow and cross flow. MATRA-S XSCHEM predicted flow velocity profile well even negative flow in recirculation flow. It showed that it needs further improvements in treatment of boundary conditions such as recirculation flow.

## ACKNOWLEGEMENT

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