Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 29-30, 2014

Development of outer-iteration free scheme for MATRA code

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1. Introduction

General governing equations of subchannel code applying the thermo-hydraulic design are nonlinear like other equations based on the Navier-Stokes equation. The nonlinear requires solving a system of nonlinear algebraic equations at each iteration step. Such nonlinearities are handled in MATRA code using outer-iteration with Picard scheme. The Picard scheme involves successive updating of the coefficient on the previously calculated values. The outer-iteration is terminated at that time being satisfied with boundary condition on which a lateral pressure difference between subchannels is even at exit plane.

Diversion cross flow is generated to reduce the lateral pressure difference at each axial node. The physics can be numerically implemented with using approximation to force the lateral pressure difference to be the zero. The idea is firstly realized by prediction-correction method by C. Chiu[1]. In this code, two-step method is adopted to approximate the lateral pressure difference term using diversion cross flow. The approximation allows the outer-iteration free scheme.

The outer-iteration free scheme is expected to improve the calculation effectiveness of MATRA code rather than calculation with reference numerical scheme using outer-iteration. The present study describes the implementation of outer-iteration free scheme, called non-iterative prediction-correction method into MATRA code.

2. Methods and Results

2.1 Prediction-Correction scheme

Original numerical scheme in MATRA code is consisted of the 2-inner iteration and 1-outer-iteration as shown in Fig. 1. In this calculation, it first assumes the zero lateral pressure difference at all axial location and uses a combined axial and lateral momentum equations to evaluate the diversion cross flows and in turn axial mass flow rates for each axial node from the core inlet to the core exit. Then, it uses the axial momentum equation considering the recent calculated cross flow to update lateral pressure difference and advance the axial node. The exit boundary condition is applied when the axial marching reached at the exit node. Iteration terminates when the difference of subchannel flow rates between two consecutive iteration is less than a specified value.

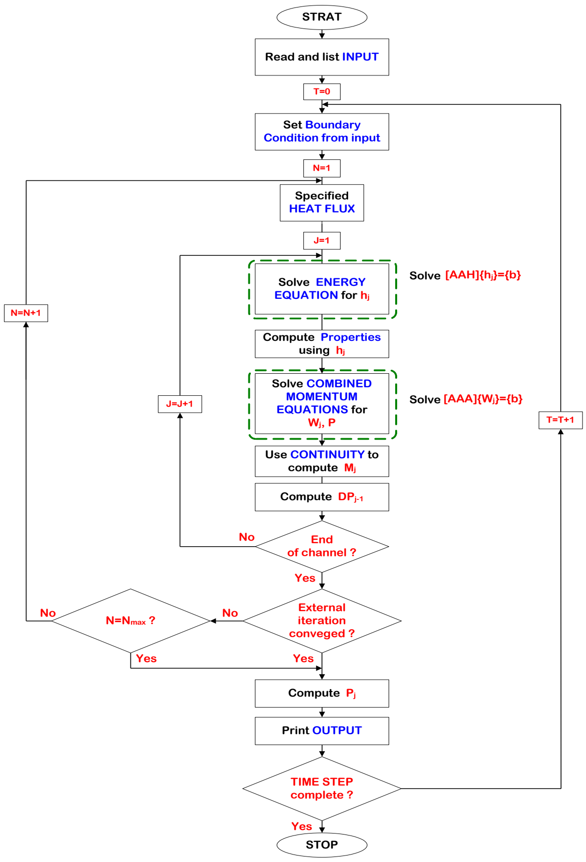


Fig.1. Original numerical scheme in MATRA code

The outer-iteration free scheme is basically same method as the non-iterative prediction-correction method implemented in CETOP code[1]. The original CETOP algorithm was applied only two channel problem. The present algorithm expands the original one to the multichannel problem. Figure 2 shows how to apply the non-iteration algorithm to the multichannel problem.

The transverse or lateral pressure difference is updated using the 'guessed' diversion cross flow that substituted the outer-iteration. The accuracy of this method lies in the fact the guessed diversion cross flow is a good approximation of the lateral pressure difference updated from outer-iteration. The procedures of this method for each finite difference axial, location, J, is briefly described as follows.

Step 1. Assuming axial mass flow rate at J+1 node

We first predict the coolant enthalpy at J+1 axial node using axial mass flow and diversion cross flow of previous node at J. For this purpose, we solve the additional energy equation to obtain the coolant enthalpy at J+1 node. Using the predicted enthalpy

$h_{I,J+1}$, fluid and coolant properties such as specific volume and friction factors are calculated.

Step 2. Prediction of Lateral pressure difference

We assume that the lateral pressure difference at axial node J+1 is even. The assumption is supported on the fact that the diversion cross flow is generated to reduce the lateral pressure difference at each axial node. If perfect cross flow is generated, lateral pressure difference will be going zero value.

In this step, the solving of combined momentum equation is added to obtain the cross flow at J+1 node. The cross flow is used to correct the cross flow at J node.

Step 3. Correction of diversion cross flow

In this step, diversion cross flow is corrected using the predicted cross flow at J+1 node. The lateral pressure difference term is updated with the outer-iteration in conventional iteration scheme described in Fig. 1. Provided the cross flow at J+1 node, the update by outer-iteration can be substituted from predicted diversion cross flow from step 2.

In correction step, the final cross flow at axial node J is calculated with the approximation for the lateral pressure difference.

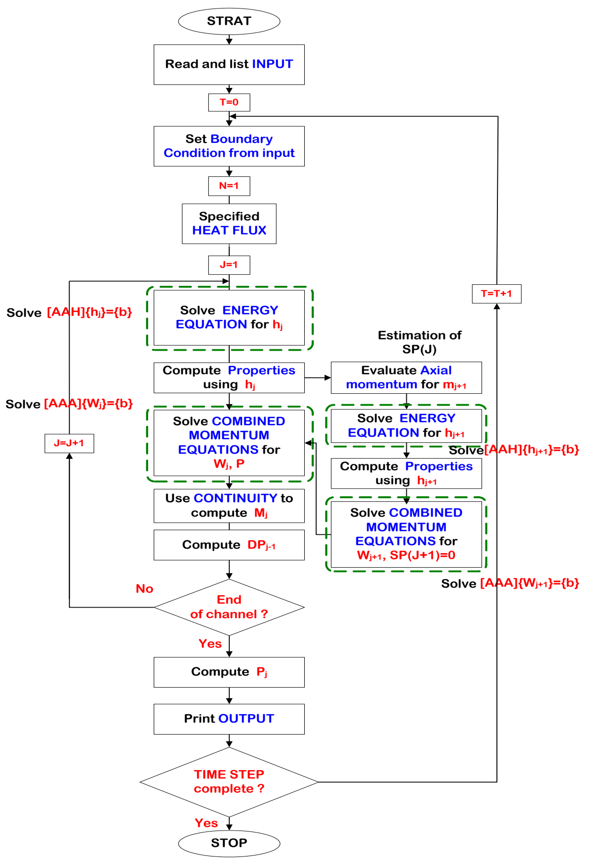


Fig.2. Outer-iteration free scheme(Prediction-Correction scheme)

2.2 Verification Problem

Verification of the non-iterative prediction-correction scheme is performed with the KSNP single assembly and 5x5 CHF test assembly. Verification cases to estimate performance of present method are as shown on Table 1.

Table 1: Verification problem case definition

Model	channel	Axial node	Operating Condition
SMT-CHF 5x5	36	40	Very low axial mass flux condition
KSNP-Single-ASS	284	50	KSNP Normal operating condition and varying mass flux

2.3 Results of subchannel analysis

The performance of prediction-correction method was tested on the aspect of calculation speed and low flow rate performance. Linear solver was calculated with the SOR algorithm fixed under relaxation factor with 1.6.

The calculation speed problem on the KSNP single assembly shows the efficiency of prediction-correction method remaining the accuracy as shown in Table 2. MDNBR of prediction-correction method is slightly low compared with the original method. The difference may be resulted in that the cross flow calculated by prediction-correction method is smaller than that of original method.

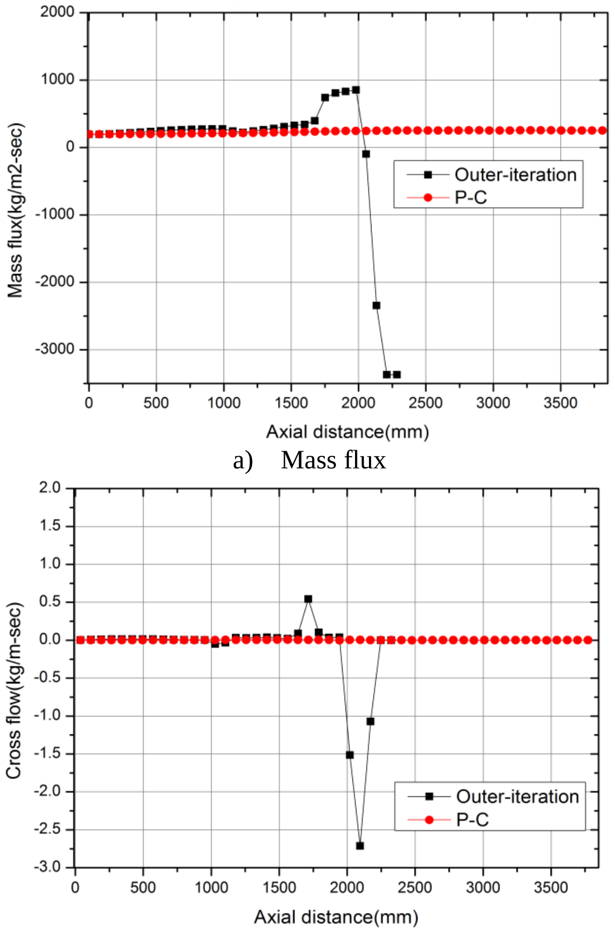
Table 2: Verification results on the KSNP single assembly problem

CASE	Mass flux (kg/m2-sec)	MDNBR		Cal. Time(sec)	
		P-C	Original	P-C	Original
1	3301	1.986	1.9836	4.14	17.86 (outer :9)
2	2050	1.093	1.0685	4.22	15.95 (outer :8)
3	800	0.1604	fail	4.14	Fail

The results for SMT-CHF are shown on Table. 2. Compared with conventional outer-iteration scheme, prediction-correction method is more robust under the low mass flux condition in which conventional method is breakdown. The sustainability on low mass flux condition can be explained with stable cross flow. In the case 1 in Table 3, the conventional algorithm is interrupted on the way of axial marching. A pressure drop of channel occurred at boiling is abruptly increased. Cross flow reduced to pressure imbalance is generated. The cross flow in conventional iteration method is overestimated at hot spot position. The overestimation is one of reasons of breakdown . The overestimated cross flow by conventional iteration method is shown in Fig. 3. The axial mass flow rate in the boiling channel is nearly dried up by the cross flow.

Table 3: Verification results on SMT-CHF 5 x 5 problem

CASE	Mass flux (kg/m2-sec)	MDNBR		Cal. Time(sec)	
		P-C	Original	P-C	Original
1	195.8	1.4914	Interrupted	0.188	Fail
2	165.5	0.3340	Fail	0.156	Fail
3	150.0	0.080	Fail	0.162	Fail



a) Mass flux

b) Cross flow

Fig.3. Comparisons for different under relaxation factor on the SMART whole core problem

3. Conclusions

Outer-iteration free algorithm is implemented into the subchannel code MATRA. Original prediction-correction method applied only two channel is successfully expanded into the multichannel application. In comparison with the convectional outer-iteration numerical scheme, the present algorithm showed the more efficient and compatible accuracy on the verification problems, such as SMT-5x5 problem and KSNP single assembly problem. In addition, outer-iteration free algorithm can be calculated in lower mass flow condition in which conventional scheme is breakdown.

REFERENCES

[1] C.Chiu, Three dimensional transport coefficient model and prediction-correction numerical method for thermal margin analysis of PWR cores, Nuclear Eng. And Design, Vol. 64, pp. 103-115, (1981).