Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 26-27, 2017

Flow mal-distribution and Maximum Crossflow Analysis on a basis of Fuel Assemblies in SMART core

Juhyung Lee*, S. J. Kim, K. W. Seo, H. Kwon, D. H. Hwang,
SMART Reactor Design Division, Korea Atomic Energy Research Institute,
989-111, Daedeok-daero, Yuseong-gu, Daejeon, 34057, Korea
**Corresponding author: juhyunglee@kaeri.re.kr*

1. Introduction

A non-uniform flow can be induced by complex upstream core structures and maintained for a while when it is passing through core in nuclear reactor. Since non-uniform flow, so called flow maldistribution can cause lateral vibrations of fuel assemblies (FAs) due to large amount of crossflow generation and strong uplift forces exerting on FA due to unbalanced axial-averaged flow and pressure drop within FAs. Therefore, an assessment of the effect of flow maldistribution is one of the essential processes in the core hydraulic and FA design for nuclear reactor such as SMART[1].

In the T/H subchannel code, MATRA-S[2], which is developed for SMART application, the following axial and lateral momentum equations and turbulent mixing model are closely related to simulate flow distribution in the reactor core:

- Axial momentum

$$\frac{\partial \dot{m}_i}{\partial t}+\frac{\partial}{\partial z}\left(\frac{\dot{m}_i^{\,2} v'}{A_i}\right)+\sum_j w_{ij}u^* + f_T\sum_j w_{ij}'\left(u_i-u_j\right) = -A_i\frac{\partial P}{\partial z}-F_z \qquad (1)$$

- Lateral momentum

$$\frac{\partial w_{ij}}{\partial t}+\frac{\partial}{\partial z}\left(w_{ij}u_i\right)+\frac{1}{l}\sum_j w_{ij}v_i = \frac{s_{ij}}{l}\left(P_i-P_j\right)-\frac{1}{2}K_{ij}\frac{w_{ij}\left|w_{ij}\right|}{\rho^* s_{ij} l} \qquad (2)$$

- Turbulent mixing

$$w_{ij}' = \beta\cdot s_{ij}\cdot G_{avg} \qquad (3)$$

In this study, the 57 lumped channel model using MATRA-S has been presented for evaluation of the maximum crossflow and flow mal-distribution factor in SMART core. A comparative study with comparison of the results from whole core pin-by-pin model[3] has been also conducted to validate this model. Generally, a representative axial power shape (APS) and radial power distribution of FAs has been used for analysis of flow mal-distribution in core hydraulic design. Here, possible APSs and FA power distributions in life time of SMART core, which are covering a variety of burn-up states (870 EFPD/5 cycles) have been adopted to investigate non-isothermal effects on maximum crossflow and flow maldistribution using proposed 57 lumped channel model.

2. Methods and Results

2.1 57 lumped channel model

SMART flow model test has been performed with 1/5 scaled experimental reactor rig to measure inlet flow non-uniformity of SMART core[4]. From measurements of inlet flow distribution on a basis of FA units, it is expected that the maximum flow peaking and cross flow occurs in the 55th FA channel (or D-9 FA) due to the largest inlet flow (21% higher based on average value). Measured inlet flow distribution has been adopted as inlet boundary condition for this analysis regard to flow fields throughout the core.

For simplification of problem and efficient assessment, the 57 lumped channel model has been intended for flow maldistribution analysis of SMART core, which considers one FA as one channel and one single imaginary rod (Figure 1). In this subchannel model, all amount of heat which is generated from 264 pins is considered as being generated from one imaginary single rod for satisfying energy balances for operating conditions. In addition, connections and geometrical boundaries between adjacent FAs are simplified such that 17 fuel pins at the most outer edges of FAs are placed on boundaries and the interaction between two adjacent subchannels can occur only through the gaps between those fuel pins, as schematically shown in the Figure 1.

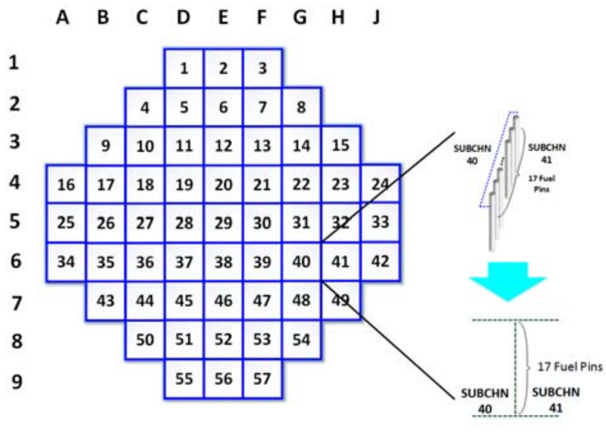

Figure. 1. 57 lumped channel model

Maximum crossflow, w_{ij} which is cross flow rate per unit length between channel i and j, and flow maldistribution factor which is the maximum value of ratio of axial-averaged mass flux within FA to radial-averaged mass flux, are evaluated from 57 lumped channel model using MATRA-S. It should be noted here that the cross-flow resistance coefficient, K_{ij} is set to be 0.5 in MATRA-S subchannel model.

2.2 Whole core channel model

As a reference model for the 57 lumped channel model, whole core channel model is also adopted for the evaluation of maximum cross flow and flow maldistribution factor. In this model, whole core pin-by-pin subchannel analysis for SMART core can be achieved using parallel algorithm for MATRA-S code[3]. Figure 2 shows one of results for axial distributions of flow rate in 51st, 55th and 56th assemblies, which are calculated from whole core model and 57 lumped channel model using MATRA-S. As seen in the figure, both subchannel models shows similar trends and good agreements between calculated flow rates, giving only small deviations (< 1.2 %), have been found in this assessment. It is expected based on mass balance, therefore, the maximum flow maldistribution factor and crossflow, which will occur in 55th FA (D-9) could be predicted with fairy high accuracy using 57 lumped model.

Comparative analysis results of the maximum crossflow and flow maldistribution factor for a variety of possible thermal conditions (300 cases) in SMART core between 57 lumped channel model and whole core model are summarized in Table 1. As seen in this table, the estimated maximum crossflow from 57 lumped channel model is 5.4 % (on average) higher than those calculated from whole core pin-by-pin model. For flow maldistribution factor, only 0.5 % of differences are expected when it is assessed with 57 lumped channel model, compared to whole core pin-by-pin model.

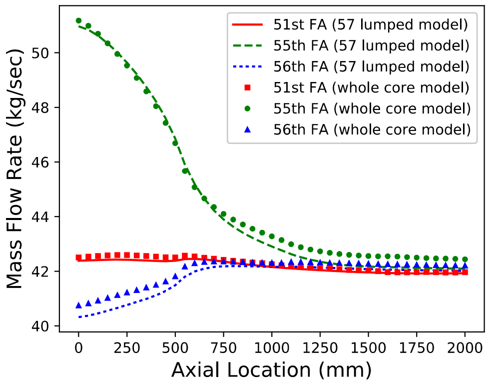

Figure. 2. 57 lumped channel model vs. Whole core model (axial flow distribution in 51st , 55th and 56th FAs)

Table 1. Ratio of predicted values between 57 lumped channel model and Whole core model

	Max. crossflow	Flow maldistribution factor
avg.	1.054	0.995
std.	0.000187	0.000035

2.3 Non-isothermal effects

Figure 3 shows calculation results of the maximum cross flow and flow mal-distribution factor versus core average burnup for each cycle of reactor operation, using 57 lumped channel model. Except for cycle 1, it shows that the maximum crossflow and flow peaking factor decrease as burnup increases. After cycle 3, trends of maximum crossflow and flow peaking factor are found to become almost identical in SMART core. In case of cycle 1 operation, however the maximum crossflow increases during changes from BOC to MOC and decreases when the life time of reactor transits from MOC to EOC. This kind of transition characteristics of maximum crossflow and flow maldistribution factor during life time of reactor should be related to changes of radial power distributions around 55th FA of rector core. As an example, the maximum cross flows are plotted against Fr differences between D-9 FA and E-9 FAs. As seen in the figure, the maximum crossflow increases with Fr differences between those two FAs. Since radial power around 55th FA becomes uniform while burnup increases in cycle 2~5, the maximum crossflow decreases in their life time. In case of cycle 1, however, Fr difference increases after startup of reactor and then start to decrease at MOC state.

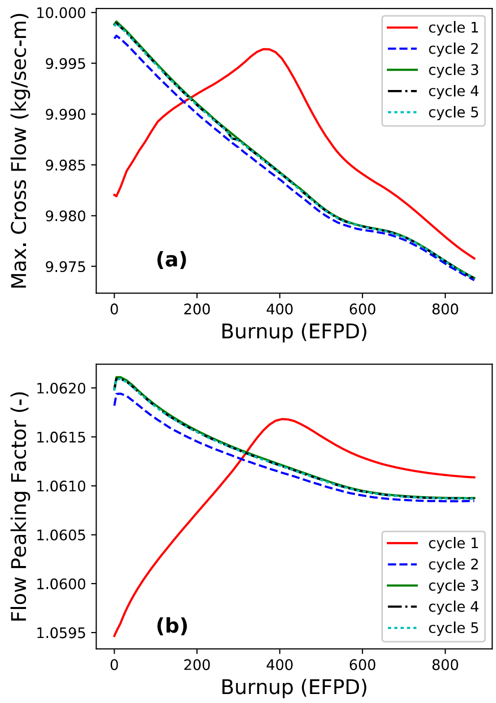

Figure. 3. 57 lumped Model results vs. Burnup
(a) Maximum cross flow and (b) Flow peaking factor

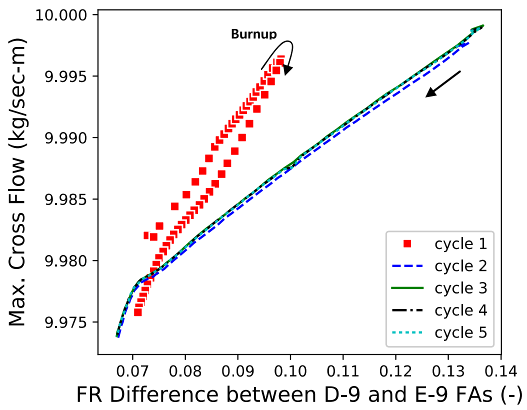

Figure. 4. Max. crossflow vs. Fr difference between D-9 and E-9 FAs

3. Conclusions

A 57 lumped channel model using MATRA-S has been suggested for the evaluation of flow maldistribution phenomena in reactor core, especially for SMART. Based on comparison with results from whole core pin-by pin model, it has been proved that this model can provide efficient and accurate ways for evaluation of flow maldistribution factor and maximum crossflow, which are essential parameters in T/H core and FA design. Using this 57 lumped channel model, transitions of flow maldistrubution factor and maximum cross flow through lifetime of reactor core has been explored. It shows that flow maldistribution is highly affected by the characteristics of radial power distribution around FA in which the maximum inlet flow involved.

NOMENCLATURE

A_i : channel flow area (m^2)
f_T : turbulent momentum factor
F_z : force exerted in axial direction per unit axial length (kg/sec^2)
G : mass flux (kg/m^2-sec)
K_{ij} : crossflow resistance factor
l : centroid distance between adjacent channels (m)
$\dot{m}_i$: mass flow rate of channel i (kg/sec)
P : pressure ($kg/m\text{-}sec^2$)
s_{ij} : gap between channel i and j (m)
t : time (sec)
u : axial flow velocity (m/sec)
v : lateral flow velocity (m/sec)
v' : effective specific volume (m^3/kg)
w_{ij} : cross flow channel i to j (kg/m-sec)
w_{ij}' : turbulent mixing flow rate per unit axial length (kg/m-sec)
z : axial distance (m)

Greek letters

β : turbulent mixing parameter

Subscripts

avg : averaged for i and j
i, j : channel index

Superscripts

$*$: donor channel property

REFERENCES

[1] SMART Standard Safety Analysis Report, Rev.1, KAERI, 2012.
[2] D. H. Hwang, et. al., Technical Report for MATRA-S code, 003-TR464-001 Rev.02, KAERI, 2011.
[3] S. J. Kim, et. al. Development of Parallel Algorithm for MATRA - Improving Parallelization of an Outer Iteration, TR-6185, KAERI, 2015.
[4] D. J. Euh, et. al., SMART Reactor Flow Distribution Test (SCOP-E-01), TR-4224, KAERI, 2010.