A Study on the Space-time Behaviors of Fluidized Fuel Reactors; AMBIKIN2D Algorithm

Y.J. Lee, H.S. Kim, S.K. Oh

Dep. of Energy Studied Ajou Univ., Suwon si, Kyunggi do,

tearingtree@hanmail.net, Korea

1. Introduction

Fluidized-fuel nuclear systems are grouped in accordance with the nature of moving fuel material in the reactor, and include MSR and PBMR for the GEN IV candidates, ADS for some HLW transmutation, and other special purpose reactors for isotope production and separation. Pyro-chemical reactor systems designed for spent-fuel reprocessing can be included to this category. Because of enabling to timely control isotopic compositions in fuel stream, the fluidized-fuel reactor systems are in favor of advanced reactor concepts. Nevertheless, unlikely the fixed-fuel nuclear systems, such as LWR, HWR, and LMFBR, tools of nuclear and thermal-hydraulic design studies for the fluidized-fuel reactors are not popular. Computer codes to resolve space-time problems frequently arisen in nuclear safety assessment of the reactor are more seldom for which AMBIKIN2D-code is being developed.

2. Theory and Model

2.1 2-D and 2-G Neutron Kinetics with Z-directional Fuel-flows

2 group neutron kinetics equations in an r-z geometry reactor where the fuel materials flow upwardly can be derived as follows:

$$\frac{1}{\upsilon_i}\frac{\partial \phi_i}{\partial t} = \nabla D_i \nabla \phi_i + (1-\beta)\nu\chi_i \sum_{k=1}^{NG} \Sigma_{f,k}\phi_k - \Sigma_{tot}\,\phi_i + \chi \sum_{j=1}^{J} \lambda_j C_j$$

$$\frac{\partial C_j}{\partial t} = \beta_j \nu \sum_{k=1}^{NG} \Sigma_{f,k}\phi_k - \lambda_j C - u_z(t)\frac{\partial C_j}{\partial z},\ j = 1..J \quad (1)$$

2.2 Modeling of time-dependent fuel material properties with perturbation insertions

Cross-section changes due to fuel-flows were approximated by introducing a pseudo-nuclide model as follows:.

$$\frac{\partial \Sigma_{mi}}{\partial t} = (A_{mi} + B_{mi}\psi_i)\Sigma_{mi} - u_z(t)\frac{\partial \Sigma_{mi}}{\partial z} + \Delta_{mi}(t) \quad (2)$$

2.3 Implicit method and quasi-static scheme for numerical solution

For solving the finite difference approximation of Eq. (1), we first determine the steady state solutions iteratively converged with given flow velocity. Starting with this as initial conditions, implicit scheme of

$$\frac{\phi^{n+1} - \phi^n}{\Delta t} = \alpha B \phi^{n-1} + (1-\alpha) B \phi^n \quad (3)$$

was applied where α was the over-relaxation factor.

As cross-sections generally changes as slow as flow velocity, a quasi-static approximation might be accurate enough, so that,

$$\Sigma_{mi}^{k+1} = \Sigma_{mi}^{k} \exp\{-(A_{mi} + B_{mi}\psi_i^k)\Delta t\} + \Delta_{mi}(t)\Delta t$$

$$\frac{\Sigma_{mi,l}^{k'+1} - \Sigma_{mi,l}^{k'}}{\Delta\tau} = -u_z^{k'}\frac{\Sigma_{mi,l}^{k'+1} - \Sigma_{mi,l-1}^{k'+1}}{\Delta z} \quad (4)$$

Here, the $\Delta_{mi}(t)\Delta t$ term is considered as perturbation insertion by means of adding fuel material into the reactor, by re-cycling the reprocessed fuel, and so forth. Reactivity feedback model of thermal-hydraulic condition changes are not incorporated in the code yet.

2.4 Validations and verification

For V&V studies of AMBIKIN2D, we attempted to reproduce theoretical and experimental dynamic analysis of MSRE using the developed MATLAB-Simulink MSRE model equipped with point-kinetics. After confirming differences between the experiments and the simulations acceptable, the reversal attempt was made for the AMBIDEXTER nuclear energy system with its AMBIKIN2D and MATLAB-Simulink models.

Effects of fuel-flows on steady state flux distributions were examined. As shown in Figs. 1 and 2, axial distributions of fast and thermal neutron fluxes are shifted upwardly to -1~2% comparing with no flow case. Flow-induced reactivity loss mainly due to entrained-loss of delayed-neutron precursors was estimated to about 1.5mk.

In sinusoidal reactivity insertion of 0.3mk and 1rad, difference rate of one point model and AMBIKEN2D is 4~5.8%.

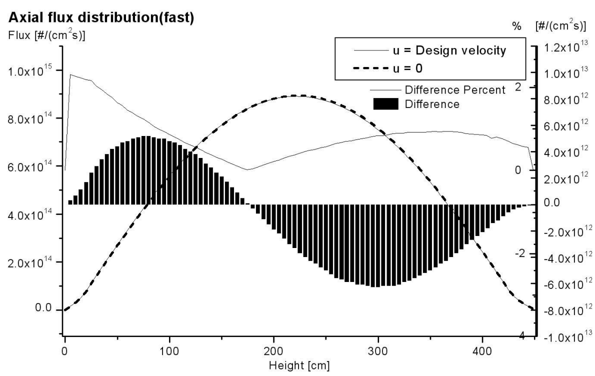

Figure 1.Difference of thermal neutron flux distributions depending on velocity in axial direction.

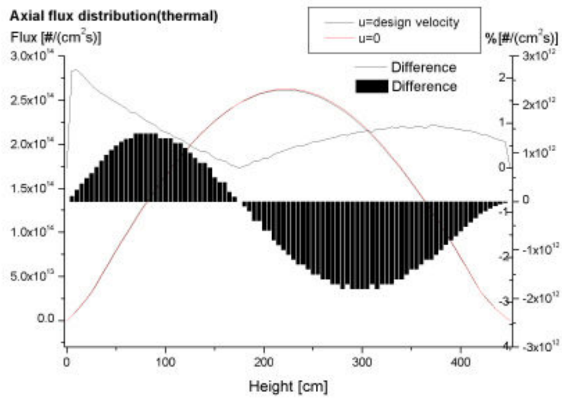

Figure 2. Difference of thermal neutron flux distributions depending on velocity in axial direction.

3. Conclusion

AMBIKIN2D code was developed for analyzing various transient cases of the fluidized-fuel nuclear energy systems. Also its verification and validation for the purpose has been examined using theoretical and experimental dynamic analysis data of the MSRE.

For the future works, acceleration techniques to improve its iteration scheme are going to be evaluated. And reactivity feedback models of thermal-hydraulic condition changes are also to be incorporated.

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