An Evaluation of Relative Pebble Flow Velocity in Pebble Bed Core

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1. Introduction

The pebbles flow down through the core by gravity and pressure of coolant in operation of pebble bed reactor. Pebble flow velocity at a location of pebble in the reactor core is changed by the various forces. The relative pebble velocity affects the burn-up distribution of the nuclear fuels. Therefore, the evaluation of reactor neutronic parameters can be distorted by the application of the incorrect pebble velocity. Though there are some methods to evaluate the pebble flow velocity, the pebble velocity evaluation was not successfully carried out for pebble bed reactor. In this study, a simulation method for the evaluation of relative pebble velocity is proposed. The results from the method developed were compared with the results of the MIT pebble flow experiments [1].

2. Methods and Results

The characteristics of pebble motion in the reactor core indicate that it can be studied under the theoretical constructs that have been successfully used in the past to characterize granular motion. The representative models are dynamic continuum model, dynamic discrete model, kinematic model, and cellular automata model. The methods with the models are well developed, however, these methods can cause errors and have limitations in the application into the pebble bed reactor core.

MIT Mathematics Department performed the pebble flow experiment [1] and compared the velocity profiles with the velocity profiles in using VSOP code [2] based on dynamic continuum model.

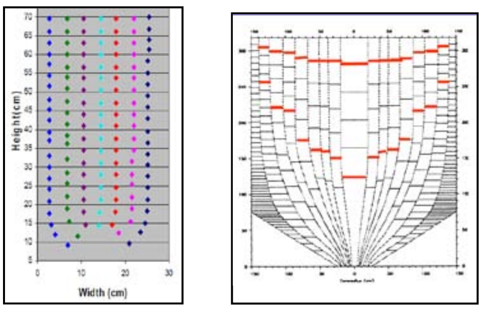

Fig. 1. Velocity Profiles from MIT Experiment and VSOP Code

While the relative velocities in each stream line from the MIT experiment do not severely differ, the each relative velocity evaluated by using VSOP code shows the respectable differences.

The PBMR core has a central graphite column, therefore, the pebbles are located in annular core. The existing models for the evaluation of the granular motion are extremely difficult to apply in the evaluation of annular core even though they are well matched with some experiments.

In this study, the simulation method of pebble flow was developed with the model proposed and the relative pebble velocity was evaluated.

2.1 Simulation Method of Relative Pebble Velocity

The core is divided into the two regions which are core and defuel cone region as shown in figure 2. Stream line is defined as the movement route of pebble. Each stream line in the core region starts from the top of reactor core and ends to the bottom of core region. The streams in the defule cone region are connected with the stream line in the core region. The stream lines are ended to the intersection point of center stream line and surface of defule cone. It is assumed that the pebbles move only through the stream line in this study.

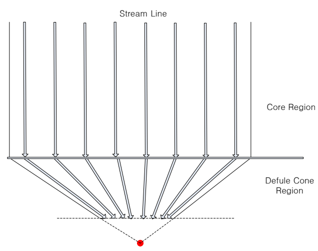

Fig. 2. Stream Lines for the Pebble Flow Simulation

Pebbles in the core are affected by the four forces i.e., gravity, helium gas pressure, wall fraction, and other pebbles. To apply the effects of the forces into the pebble move simulation, the pebble motions are assumed as below:

- Pebbles in any position take the equal z-axial force from the gravity and helium gas when the pebbles move downward. The adjacent pebbles do not temporally give the force to the pebble during the movement.
- Pebbles cannot move when the other pebbles are existed below the target pebble. Two layers are used for this assumption.

With the assumptions, the z-axial force is given by Eq. (1).

$$F_z(x,y) = \cos\phi(x,y)\cdot(\cos\phi(x,y)\cdot F_N - F_w(x,y)) \quad (1)$$

where, $\phi(x,y)$ *= orthogonal angle of stream line*
F_N *= normalized force of a pebble from gravity and helium gas*

The wall fraction of the core region is ignored because of the small normal force and coefficient of fraction. Wall fraction of pebbles in the defule cone region is given by Eq. (2).

$$F_w(x,y) = \mu_w N_w(x,y) \quad (2)$$

$$N_w(x,y) = F_N \cdot \sin\phi(x,y) \quad (3)$$

where, μ_w *= coefficient of graphite fraction*
$N_w(x,y)$ *= normal force of pebble at x,y stream line*

The change of velocity in $t+\Delta t$ is given by Eq. (4). The initial velocity is zero, therefore, the average velocity of pebble during Δt is given by Eq. (5).

$$v(t+\Delta t) = v(t) + \frac{1}{m}F(x,y)\cdot\Delta t \quad (4)$$

$$\bar{v}(\Delta t) = \frac{1}{2\cdot m}F(x,y)\cdot\Delta t \quad (5)$$

where, m = mass of a pebble

The relative velocity compared with the maximum velocity is given by Eq. (6).

$$R_v = \bar{v}(x,y)/\bar{v}_{\max} = F_z(x,y)/F_{z,\max} \quad (6)$$

By using these equations, simulation of void movement is performed. The voids on all stream lines are started from a hole of the defule chute in the simulation. The movement distance of void in each stream line is calculated by the simulation until a void arrives to the top of core. The relative velocity is calculated by the simulation results of the moving distance until the arrival time.

2.2 Result of Relative Pebble Flow Velocity

A simulation of relative pebble flow velocity is persued by using Matlab program in this study. The pebble radius is 0.3 cm and the radius of cylindrical core is 14.25cm. Cone angle is 30° and the core height is 63cm. The results were compared with the results of the MIT experiment [1]. The results are shown in figure 3.

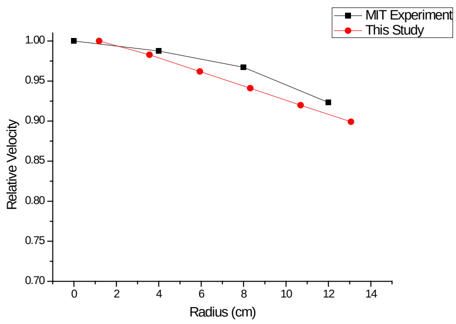

Fig. 3. Comparison Results of Relative Pebble Velocity between This Study and the MIT Experiment

The result shows that the method proposed in this study has a good agreement with the experiment result. However, the relative velocity distribution as the radial position was not smooth because the diffusions of the pebbles between stream lines were not considered and pitch between stream lines was assumed in this study.

3. Conclusions

This study is for the evaluation of relative pebble velocity in pebble bed core. A simulation method was proposed in this study. The stream line was assumed and the simulation of void movement was pursued. The evaluation result of relative velocity was compared with the MIT experiment. The result from the simulation method developed in this study gives a good agreement with the MIT experiment. This method can easily apply for the evaluation of the relative velocity in the annular core with good accuracy. It is thus expected that this simulation method can be utilized for relative velocity analysis of PBMR reactor after the few modifications of pebble motion.

Acknowledgment

This work was supported in part by the Ministry of Education, Science and Technology [MEST] of Korea through the Nuclear Hydrogen Development and Demonstration [NHDD] Project coordinated by Korea Atomic Energy Research Institute (M20406010002-05J0101-00212), and the Ministry of Knowledge Economy (2008-P-EP-HM-E-06-0000).

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