§16. Large-scale In-silico Experiment for Thermal-hydraulic and Thermo-mechanic Characteristic of Pebble Bed

Ebara, S., Yokomine, T. (Kyushu Univ.),
Sagara, A.

Performance of a fusion reactor using pebble bed in its blanket depends on averaged properties such as packing density of the bed. On the other hand, crucial phenomena that affect safety issues, e.g., stress concentration in the pebble bed, blockage of flow area and the outset of a heat spot caused by thermal creep of constituent particles, depend on local properties of the bed. Conventional researches for pebble bed have been done in terms of average operation or coarse graining of the bed and can never capture the above local phenomena. In this study, the pebble bed is not coarse-grained but is treated such that small scale phenomena are treated as they are. Large-eddy simulation is used for simulation of turbulent flow in microscopic pore scale of pebble bed. Dynamic mixed model[1] is used for the subgrid-scale stress and Lagrangian average[2] is adopted for stabilizing the dynamic procedure. In the present simulation, the stabilized finite element formulations[3] based on SUPG (streamline-upwind/Petrov-Galerkin) and PSPG (pressure-stabilization/Petrov-Galerkin) are implemented in parallel using MPI, and flow regime in the bed is simulated. Pebble bed is assumed to have body-centered cubic structure and a part of the bed with unbounded region is computed. More specifically, the periodic boundary is imposed on every computational boundary in the simulation and the flow is driven by applied average pressure gradient in the flow direction, which is given by Ergun's expression[4] (Eq. (1)) in the simulation, is where f' nondimensional pressure gradient, ε is porosity of the bed, Re is Reynolds number based on macroscopic (averaged) fluid velocity and pebble diameter, respectively.

$$f' = 150 + 1.75\frac{\mathrm{Re}}{1-\varepsilon} \qquad (1)$$

Fig. 1 shows the computational model of the pebble bed.

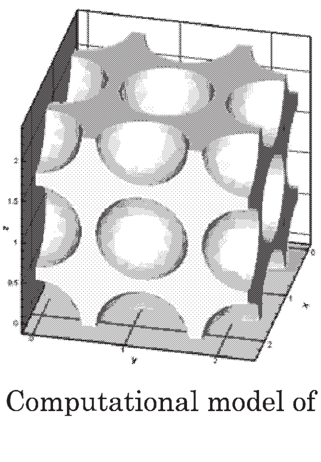

Fig. 1 Computational model of pebble bed

Fluid flows in the pebble bed, circumventing pebbles as blockage So, flow path alternates between bifurcation and confluence. In the body-centered packing used in the simulation, there are some paths which run straight through from entrance to exit. Fig. 2, 3 show the velocity vector on the cross section parallel to the flow direction. In Fig. 2, there are two "open" paths where fluid goes straight without circumvention. The width of the paths repeatedly becomes wide and narrow, but flow resistance is relatively small and the paths become the bypass of flow in the bed. On the other hand, there is not any bypass in Fig. 3. Flow velocity is partially allowed to become large. When a pore is large in the pebble bed but does not connect the bypass of flow, the pore cannot contribute the flow in the bed. It is found from the figure that there are many regions which has almost nothing to do with the flow in the bed.

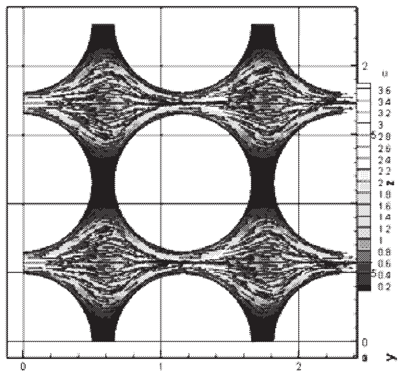

Fig. 2 Velocity vector in bypass channels in the bed

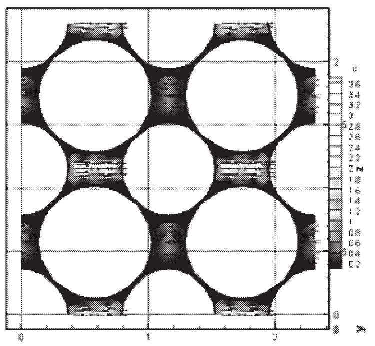

Fig. 3 Velocity vector in the disjunct channel

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(3) T. E. Tezduyar et al., Incompressible flow computations with stabilized bilinear and linear equal-order-interpolation velocity-pressure elements, Comput. Methods Appl. Mech. Eng. 95 (1992) 221-242.
(4) S. Ergun, Chemical Engineering Progress, 48 (1952) 89-94.