Solid Particles Transport and Deposition Prediction in a Turbulent Impinging Jet Using the Lattice Boltzmann Method and a Probabilistic Model on GPU

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Abstract : Solid particle distribution on an impingement surface has been simulated utilizing a graphical processing unit (GPU). In-house computational fluid dynamics (CFD) code has been developed to investigate a 3D turbulent impinging jet using the lattice Boltzmann method (LBM) in conjunction with large eddy simulation (LES) and the multiple relaxation time (MRT) models. This paper proposed an improvement in the LBM-cellular automata (LBM-CA) probabilistic method. In the current model, the fluid flow utilizes the D3Q19 lattice, while the particle model employs the D3Q27 lattice. The particle numbers are defined at the same regular LBM nodes, and transport of particles from one node to its neighboring nodes are determined in accordance with the particle bulk density and velocity by considering all the external forces. The previous models distribute particles at each time step without considering the local velocity and the number of particles at each node. The present model overcomes the deficiencies of the previous LBM-CA models and, therefore, can better capture the dynamic interaction between particles and the surrounding turbulent flow field. Despite the increasing popularity of LBM-MRT-CA model in simulating complex multiphase fluid flows, this approach is still expensive in term of memory size and computational time required to perform 3D simulations. To improve the throughput of each simulation, a single GeForce GTX TITAN X GPU is used in the present work. The CUDA parallel programming platform and the CuRAND library are utilized to form an efficient LBM-CA algorithm. The methodology was first validated against a benchmark test case involving particle deposition on a square cylinder confined in a duct. The flow was unsteady and laminar at Re=200 (Re is the Reynolds number), and simulations were conducted for different Stokes numbers. The present LBM solutions agree well with other results available in the open literature. The GPU code was then used to simulate the particle transport and deposition in a turbulent impinging jet at Re=10,000. The simulations were conducted for L/D=2,4 and 6, where L is the nozzle-to-surface distance and D is the jet diameter. The effect of changing the Stokes number on the particle deposition profile was studied at different L/D ratios. For comparative studies, another in-house serial CPU code was also developed, coupling LBM with the classical Lagrangian particle dispersion model. Agreement between results obtained with LBM-CA and LBM-Lagrangian models and the experimental data is generally good. The present GPU approach achieves a speedup ratio of about 350 against the serial code running on a single CPU.

Keywords : CUDA, GPU parallel programming, LES, lattice Boltzmann method, MRT, multi-phase flow, probabilistic model
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