Journal of Applied and Computational Sciences in Mechanics, Vol. 28, No. 1, 2017.

Simulation of Particle Motion in Non-Newtonian fluids by Immersed Boundary- Lattice Boltzmann Method

A. Amiri Delouei[1], M.H. Kayhani[2], M. Nazari[3]

1. Introduction

Particle flows have wide applications in various industries and sciences such as chemistry, biology, geology, environmental sciences and so on. Although numerous studies have been carried out in the field of particle flow, a few research studies have considered non-Newtonian behaviors. It is worth noting that most of the work done on particle motion phenomena in both Newtonian and non-Newtonian fields are in the circular geometry. In real applications, non-circular geometries have also contributed to the field and it is necessary to investigate the motion of particles with different geometries, such as square particles.

2. Numerical Method

The lattice Boltzmann method is used to simulate non-Newtonian fluid flow and the immersed boundary method is utilized to model the motion of particle in fluid flow. Generally, the immersed boundary method can be defined as a non-body-conformal grid method that satisfies the no-slip boundary condition by implementing a force density term to the flow governing equation. In order to study the effects of immersed body, the direct-forcing algorithm is applied. Since the forcing nodes are placed on the computational points and they are not located on solid boundaries, an interface algorithm is needed for achieving the velocity on computational nodes. In the current study, the four-point interpolation scheme is applied to link between the Eulerian fluid nodes and Lagrangian particle points. The general forces acting on the particle are, (1) the forces acting on the surface of fixed particle and (2) the force resulting from accelerated mass.

3. Validation

To validate the proposed method, a step by step process is used. The validation consists of three benchmark problems i.e. (1) non-Newtonian fluid flow in a channel, (2) Newtonian fluid flow over an infinite cylinder with square cross-section, (3) falling of circular particle in a channel filled with Newtonian fluid. The current results have a good agreements with the previous study on all of the above-mentioned problems.

[1] Corresponding author: Mechanical Engineering Department, University of Bojnord, Bojnord, Iran. amiri@ub.ac.ir

[2,3] Mechanical Engineering Department, Shahrood University of Technology, Shahrood, Iran.

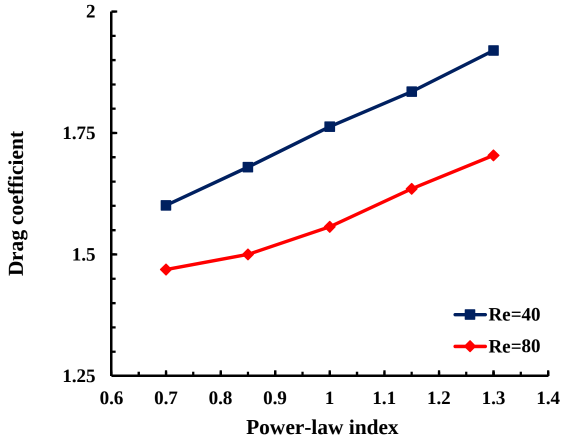

Fig. 1: Drag coefficient for Newtonian and non-Newtonian fluid flow over the square cylinder in steady (Re=40) and unsteady flows (Re=80).

4. Results and Discussion

Two different geometries including non-Newtonian flow over a stationary cylinder and falling particle in a channel filled with non-Newtonian fluids are considered.

4-1- Non-Newtonian flow over an infinite stationary cylinder with square cross-section

Fig. 1 shows the variation of drag coefficient with respect to non-Newtonian behavior index in Newtonian and non-Newtonian fluid flow over a square obstacle. Fig. 1 is depicted for both steady (Re=40) and unsteady (Re=80) flows. According to this Figure, the drag coefficient increases with the growth of non-Newtonian behavior index.

4.2. Falling of square particle in different power-law fluids

Fig. 2 shows the stream lines near the moving square cylinder in different shear-thinning, Newtonian and shear-thickening fluids after 50 seconds of beginning of motion. The differences of streamlines for different non-Newtonian behavior indices are considerable.

Also, the time histories of longitudinal velocity and position for a falling square particle in different power-law fluids are presented in Figures 3 and 4, respectively. Although the differences in the variation of power-law index in Figs. 3 and 4 are rather small, they have remarkable variations on the presented results. This shows the significant effect of non-Newtonian behavior on particle motion.

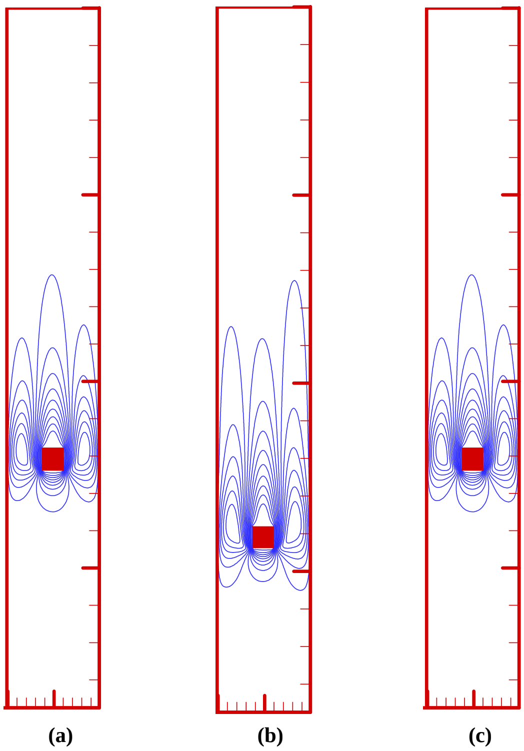

Fig. 2. stream lines near the square cylinder in channel filled with shear-thinning (n=0.9), Newtonian (n=1.0), and shear-thickening fluids (n=1.1), $Ar_{pl}=10^3$.

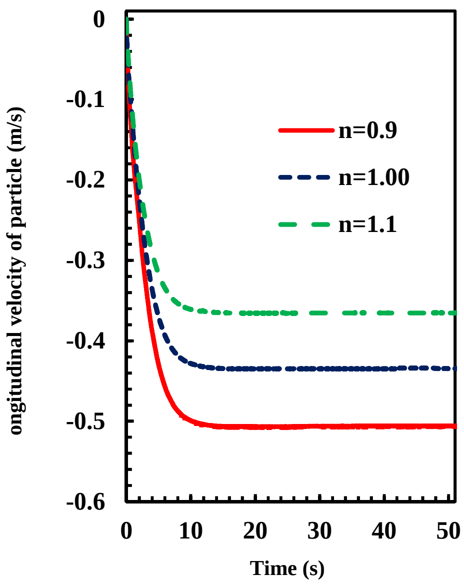

Fig. 3. Time evaluation of particles' longitudinal position for shear-thinning (n=0.9), Newtonian (n=1.0), and shear-thickening fluids (n=1.1).

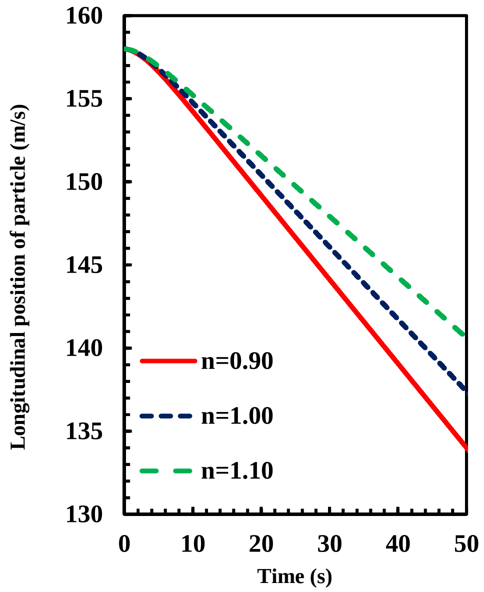

Fig. 4. Time evaluation of particles' longitudinal velocity for shear-thinning (n=0.9), Newtonian (n=1.0), and shear-thickening fluids (n=1.1).

5. **Conclusion**

The immersed boundary – non-Newtonian lattice Boltzmann method (IB-NLBM) is utilized to simulate the interface forces of fluid and solid structure. Two practical problems of non-Newtonian flow over stationary square obstacle and motion of square particle in non-Newtonian fluid are studied in details. The results show that the reduction of non-Newtonian behavior index leads to decreased accuracy of the problem. Also, the results indicate the significant effect of non-Newtonian behavior on forces acting on stationary square obstacles and velocity of moving particles. For the case of non-Newtonian fluid flow over a stationary square cylinder, drag coefficient is increased by the growth of non-Newtonian behavior index for both steady and unsteady flows. Also the periodic time of lift coefficient for unsteady flows over stationary cylinder reduces by diminishing of non-Newtonian behavior index. In the case of falling particle in non-Newtonian power-law fluid, the terminal velocity of the particle increases with a reduction of shear-thickening behavior.