IMMERSED BOUNDARY - LATTICE BOLTZMANN METHOD FOR 2D PARTICLE SEDIMENTATION IN POWER-LAW FLUIDS

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Because particles motion and particles collisions play an important role in the performance of many industrial processes involving suspension flows, several studies regarding the settling mechanisms of particles have been performed in the last decades. Over the years, analytical solutions, empirical and numerical correlations for particles terminal velocity and drag force have been developed [1]. In oil and gas industry, one of the most important functions of a drilling fluid is to carry cuttings out of the drill region as quickly as possible. Generally, cuttings tend to settle and travel with a lower velocity than the drilling fluid due its greater density when compared with drilling fluid. For efficient hole cleaning, much effort has been done to improve the drilling fluid ability to transport cuttings from the bottom to the surface of the well. It is therefore important to predict accurately the settling and transport of particles moving through a drilling fluid. Recently, lattice - Boltzmann method (LBM) has been a promising alternative over the conventional CFD schemes that solves macroscopic variables such as velocity and pressure fields using the discretized Navier-Stokes equations. Further, the common feature of using the Cartesian grid motivates the coupling of LBM and immersed boundary method (IBM), which is a non-body-conformal grid method that adds a force density term in the governing equation in order to satisfy the no-slip boundary condition on the boundary. The first coupled immersed boundary - lattice Boltzmann method (IB-LBM) was propoused by Feng and Michaelides (2004) to simulate the motion of rigid particles. Their approach is similar to the feedback forcing method of Peskin (1977) but insted of solve NSe they used Lattice Boltzmann equation. In the same way that it happened after the work published by Peskin, many studies involving IB-LBM arose just after Feng and Michaelides work. The exploration of this new branch in the LBM has brought out several new different ways of approaching the particle-fluid coupling by the immersed boundary method in the LBM framework, in which the forcing term can be evaluated using feedback-forcing method or direct forcing method and the interface schemes can be sharp or diffuse and can be evaluated explicity or implicity [4].

In this work, a numerical solution for particle settling in non-Newtonian fluid is propose. The problem consists of a 2D particle released from the rest in a quiescent non-Newtonian media within a rectangular container of height H and length L, as shown in Figure 1. The particle of diameter d exerts a downward shear force on the fluid medium due gravitational effects. The 2D particle is a rigid circumference with geometrical dimensions and density (ρ_p) considered to be constant. The problem is treat two-dimensional in a Cartesian coordinate system (x,y), where x and y are the horizontal and vertical coordinates, respectively, and gravity $\mathbf{g}$ is pointing to the $-y$ direction. The non-Newtonian behaviour is represented by a power-law fluid type in which the apparent viscosity is given by:

$$\eta(\dot{\gamma}) = m\dot{\gamma}^{n-1} \;\; where\, if \begin{cases} n > 1 \Rightarrow Shear-thickening \\ n = 1 \Rightarrow Newtonian \\ n < 1 \Rightarrow Shear-thinning \end{cases} \tag{1}$$

m is the consistency index and n is the power-law index

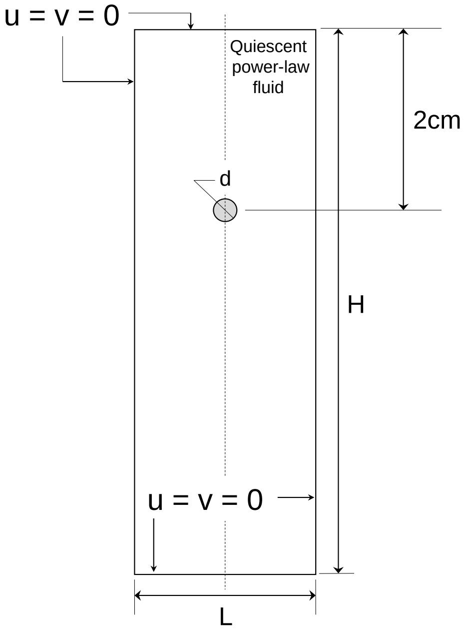

Figure 1: Geometry and boundary conditions for particle settling in power-law fluid.

The problem was solved via direct force IB - LBM with an implicit diffuse interface scheme in which a 2-point discrete delta function was applied. The non-Newtonian effect was incorporated into the program via adaptive viscosity method. The implementation was done via Fortran language. Resutls for particle settling velocity and vertical trajectory were compared with those present in literature for particle settling in Newtonian fluids. As shown in Figure 2 the obtained results are in good agreement with those from literature [4][5][6]. For particle settling in power law fluid the obtained results were compared with the literature for different power-law index. Results are again in good agreement with the literature [6] as shown in Figure 3.

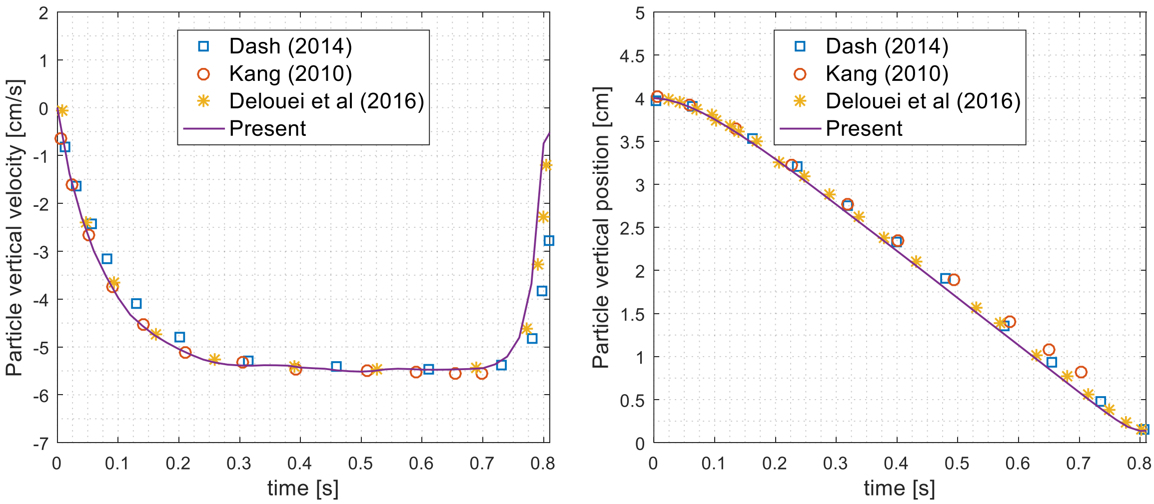

Figure 2: Comparison with literature of temporal evolution of particle settling velocity and particle position for Newtonian fluid.

Results for particle terminal settling generalized Reynolds number $Re_{pl,T}$ and drag coefficient $C_{D,T}$ were obtained as a function of generalized Arquimedes number Ar_{pl}. As shown in Figure 4 curves for different n for $Re_{pl,T} \times Ar_{pl}$ tend to pass through a common point. For a given value of Ar_{pl} above this point an increase on n causes a decrease on $Re_{pl,T}$. On the other hand, for Ar_{pl} values below the common point,

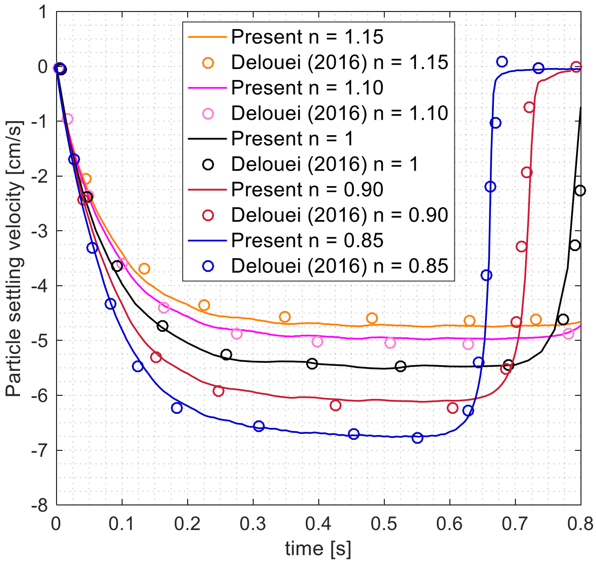

Figure 3: Comparison of temporal evolution of particle settling velocity with literature for different values of n.

increasing n implies a increase of $Re_{pl,R}$. A similar tendency is observed for $C_{D,T}$ as a function of Ar_{pl} in Figure 5. There is a common point for all the curves in which values of Ar_{pl} above it imply a reduction of the $C_{D,T}$ with the increase of n and for Ar_{pl} below it $C_{D,T}$ is increased by increasing n.

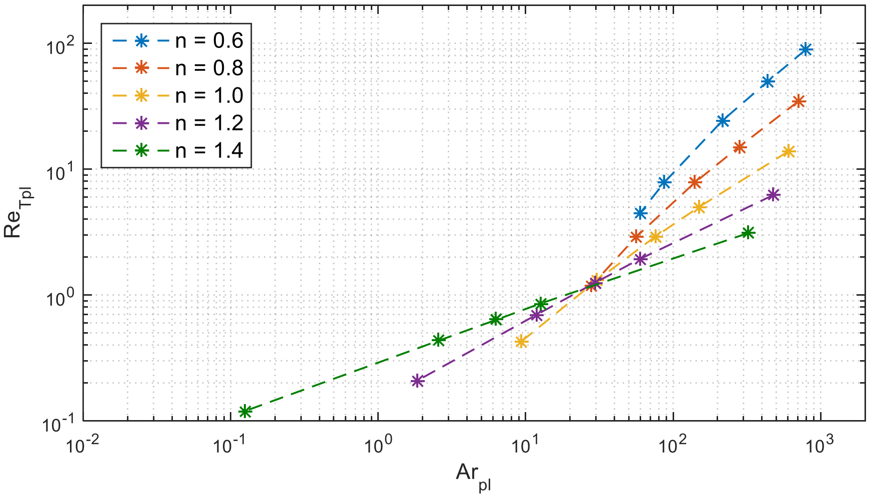

Figure 4: Drag coefficient experienced by the particle at its terminal settling velocity as a function of Ar_{pl}

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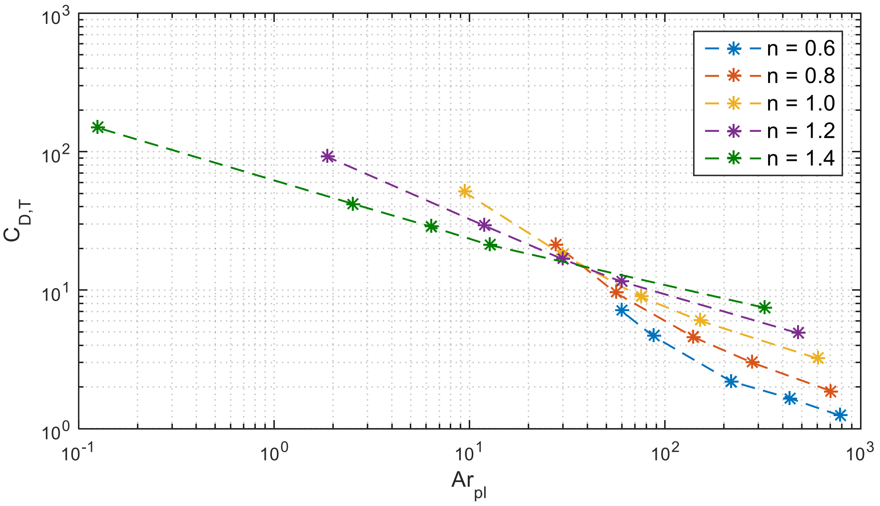

Figure 5: Terminal settling Reynolds as a function of Ar_{pl}.

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