Computational Modelling of Dense, Viscoplastic Suspensions using Coupled Lattice Boltzmann-Discrete Element Methods

Christopher R. Leonardi[‡†], Wojciech Regulski[‡§]*, Bruce D. Jones[†] and John R. Williams[†]

[‡]School of Mechanical and Mining Engineering, The University of Queensland
The University of Queensland, Brisbane, QLD 4072, Australia
email: c.leonardi@uq.edu.au, wojciech.regulski@uq.edu.au

[§] Institute of Aeronautics and Applied Mechanics, Warsaw University of Technology
Nowowiejska 21/25, Warszawa, 00-665, Poland
email: wregulski@meil.pw.edu.pl

[†]Department of Civil and Environmental Engineering, Massachusetts Institute of Technology
77 Massachusetts Avenue, Cambridge, MA 02139, USA
email: chrisleo@mit.edu, bdjones@mit.edu, jrw@mit.edu

ABSTRACT

A computational model has been developed which facilitates the simulation of dense particle suspensions. The model employs the discrete element method (DEM) to represent a range of particle geometries, while the fluid phase is captured using a single-relaxation-time (SRT) formulation of the lattice Boltzmann method (LBM). Full hydrodynamic coupling of the LBM and DEM is achieved using an immersed moving boundary condition [1, 2]. The developed model has the ability to simulate Navier-Stokes hydrodynamics, turbulence, Reynolds lubrication and electromagnetic forces.

This paper presents progress on the extension of the LBM-DEM framework, in particular, the development of a computational material model which captures the rheology of viscoplastic fluids. This work leverages previous research [3] on the numerical rheometry of non-Newtonian fluids and granular suspensions, where it was shown that shear-thinning, power-law fluids can mimic the behaviour of viscoplastic fluids to some degree. Ultimately, though, they are unable to capture the finite stress, zero strain behaviour which is the defining characteristic of viscoplastic fluids.

Non-Newtonian fluid behaviour in the LBM can be included either by strain-rate-dependent adjustment of the collision process or modification of the LBM equilibrium functions [3]. The former is more straightforward to implement but requires the inclusion of a multiple-relaxation-time (MRT) collision operator to improve stability [4]. The latter requires the non-local calculation of velocity gradients for modification of LBM equilibrium functions. The ability to calculate these gradients in the presence of the tortuous voids which develop and evolve in dense, three-dimensional suspensions is a critical aspect of this research.

Numerical illustration and validation of the developed model is presented via simulations of dense suspensions in rheometry and channel flow geometries. The success of this study will represent a significant contribution to both the fundamental and applied state of the art, with relevance in fields such as petroleum engineering, biology, and pharmaceuticals.

REFERENCES

[1] B.K. Cook, D.R. Noble, and J.R. Williams. "A direct simulation method for particle-fluid systems". *Int. J. Num. Meth. Engng.*, **21**(2/3/4): 151-168 (2004).

[2] D.R.J. Owen, C.R. Leonardi, and Y.T. Feng. "An efficient framework for fluid-structure interaction using the lattice Boltzmann method and immersed moving boundaries". *Int. J. Num. Meth. Engng.*, **87**(1-5): 66-95 (2011).

[3] C.R. Leonardi, D.R.J. Owen, and Y.T. Feng. "Numerical rheometry of bulk materials using a power law fluid and the lattice Boltzmann method". *J. Non-Newton. Fluid*, **166**(12-13): 628-638 (2011).

[4] S.G. Chen, C.H. Zhang, Q.C. Sun, and F. Jin. "Coupled LBM-DEM modeling of Bingham fluids with suspended particles", In *Geomechanics from Micro to Macro: Proceedings of the International Symposium on Geomechanics from Micro to Macro*, 479-484 (2015), CRC Press.