International Journal of Research in Engineering and Applied Sciences(IJREAS)
Available online at http://euroasiapub.org
Vol. 9 Issue 5, May-2019,
ISSN (O): 2249-3905, ISSN(P): 2349-6525 | Impact Factor: 7.196 |

Microstructure of dilatant suspensions: A Critical Study

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ABSTRACT

For better understand the microstructure of dilatant suspension, a 2Dliquid-particle-suspension couette-flow is studied along with suspension microstructure in share flow, shear thickness and momentum transfer. The liquid-particle suspension's rheological behaviour shows various complex phenomena as discussed in article.

INTRODUCTION

In this article we examine the Couette flow's 'dilatant' rheological behaviour suspensions of liquid's particle. The article objective is to review the reasonsregarding thickening of the shear and the effects of suspension microstructure. Using numerical simulations, we studied momentum transfer as well as shear stress regarding two-dimensional suspensions of liquid's particles.

COUETTE FLOW OF LIQUID-PARTICLE SUSPENSION

The liquid-particle suspension Couette flow geometry (shear flow) is important for many applications and appears in popular viscometers. The underlying two-phase character is frequently overlooked in such functional flow problems and the suspension regarded as a fluid which is non-Newtonian. This method can be valuable for homogeneous, dilute, isotropic suspension along with small regular-shaped particles. Dense suspensions, however, cannot ignore their 2 phase existence. This is due to the importance of other momentum transfer mechanisms besides viscous stress in fluid phase. Such processes involve interactions betweenparticle-particle and within particles tension. Furthermore, the effects of complicated microstructures or boundaries such as clustering[1] as well as layering[2] of particles may

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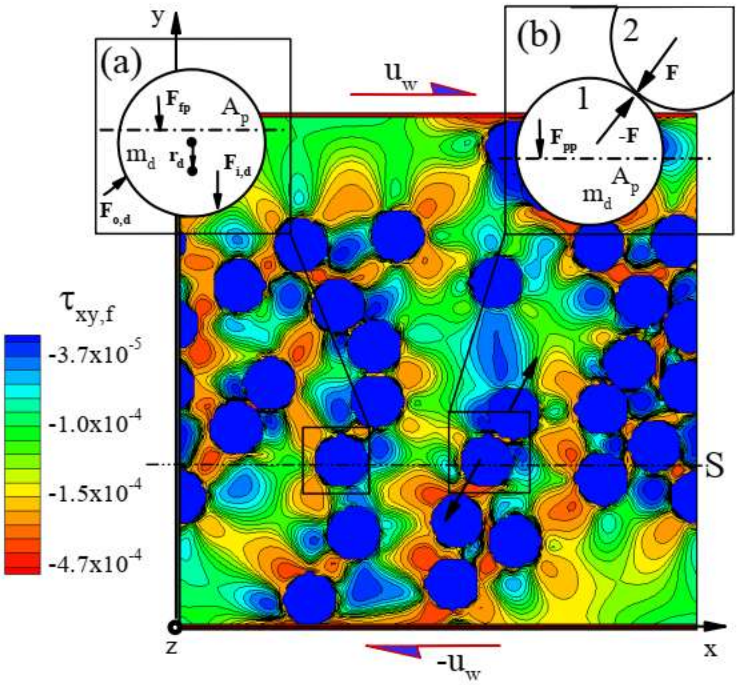
form the 2 phase flow non-isotropic or non-homogeneous, depending on the size of the data. To analyse the mesoscopic mechanisms which lead to total measurable shear stress, the apparent viscosity regardingsuspension of liquid's particle, stresses of various phases as well as momentum fluxes were studied. In this article we focus on the mechanisms responsible for the solid's volume fraction as well as viscosity dependence number Reynolds. In article we only consider cased of zero-gravity.The carrier liquid's Couette flow is solved by lattice-Boltzmann when moving cylindrical (2D) as well as spherical (3D) radius particlesnewtonian mechanics control radius suspended in fluid. The suspension is positioned between two moving solid, x-oriented wallshaving H distance away from each other. The walls move torwarddifferent poles which are opposite in direction. Thus, conditions of couette-flow are generated with the mean shear rate $\gamma_w=2u_w / H$. The x-direction applies periodic boundary conditions. The simulation grid is rectangular, normally 128x128 lattice points. In certain instances, 384x384 and 256x256 lattice points and the proportion of diametertenparticulate units as well as their composition (including core fluid and solid matrix) about 3.5 times carrier fluid density. This particular one density ratio value was chosen for pigment suspensions used in paper coating. The particle volume fraction (area fraction) ranges from 12 percent and 52 percent and the Reynolds shear number from 0.14 to 11.7. Simulations start by configuration of a particle which is distributed randomly (Figure 1) along with resting fluid (only moving walls).

Figure 1 A picture or snapshot of a 2-Dsuspension of liquid's particle couette-flow solved by method of Lattice-Boltzmann. Color coding shows fluid phase viscous shear stress. Both insets display the forces used to quantify internal particle tension.



SUSPENSION MICROSTRUCTURE IN SHARE FLOW

Monodisperse suspensions showed various structuresbased on interaction between particles, shear strength and concentration. For example, repulsion between particles of long-range tends to make the system ordered, whereas repulsive forces between particles having short range can cause fluid-like structure of system [5]. Figure 2 represent the profiles of the suspension 's average U velocity, as well as the local particle volume's fraction, between moving plates for Re_γ =1.5, in macroscopically stationary flow as well as for 2 systems having different particle volume's fractions. Figure 2a showed the relatively diluted suspension in which the particles tend to be concentrated close to the channel core and observed as thin and very diffuse layering near walls. A velocity profile deviation is very less from the linear one and has shallow form in a way that the shear rate near the middle is low. Most remarkable phenomenon for the denser suspension (Figure 2b) is the heavy layering of the particles between the walls. Except this even in the channel's central region weaker layering is noticeable. Notice that Hoffman had also found such layering in light-diffraction experiments[3].

Figure 2 Local particle volume fraction and mean velocity profile suspension through channel width is H for suspension havingRe_γ =1,5as well assolid mean volume fractions ϕ

=twenvepercent(a) and ϕ =forty eight percent (b). The thick solid line reveals volume fraction while thin solid line reveals suspension velocity separated by wall velocity i.e. (uw). Linear velocity profile represented by dashed line.

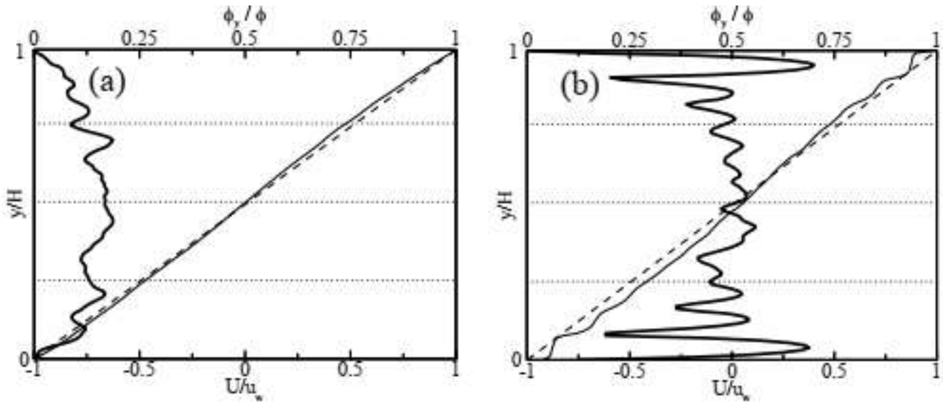
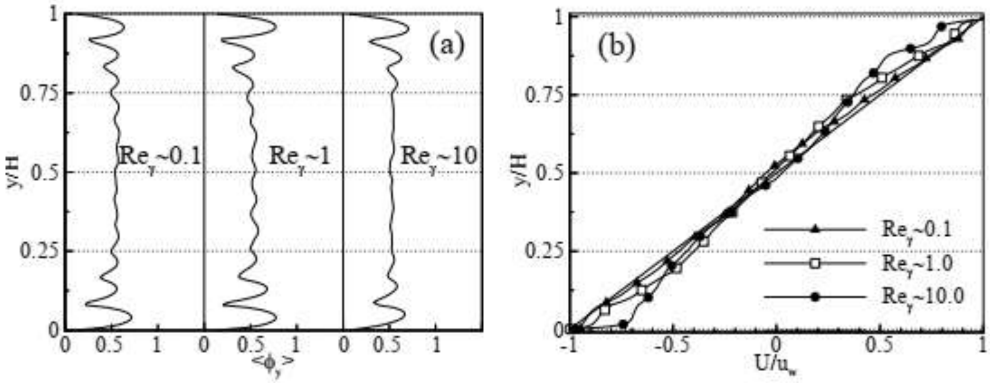


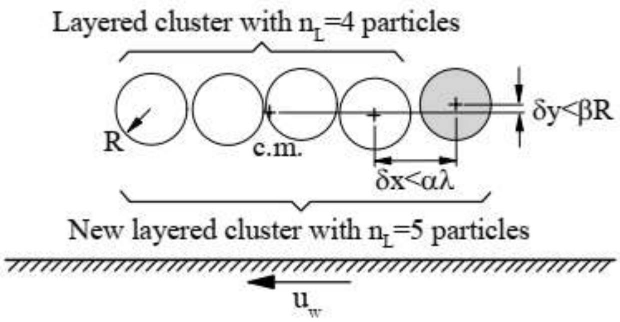
Figure 3a shows a fraction of the particles' local volume and Figure 3b shows the mean suspension velocity profile while suspension in Newtonian flow regime has Reynolds low shear number area (Re_γ = 0.1) as well as velocity profile is very linear. As predicted, heavy particlelayeringis seen along the walls and appeared for all 3shear numbers of Reynolds. Even in the channel's central region, weaker layering is noticeable. There remains a narrow zone between the first layer and the wall having almost entirely fluid nature. Experiments too sometimes showed such layer of pure fluid in gaphaving length less than a particles' radius which decreases in order to increase concentration[4]. ForRe_γ = 1.0, the layering tends to be much more highlightened near the walls of the channel relative to the other two cases. The velocity profile begins to get nonlinear in this regime (Figure 3b). The concentration profile in the channels' middle tends to flatten out by increase their shearing rate beyond $Re_\gamma >$ 1.0(Figure 3a).

Figure 3 Variation of particle mass fraction (a) and mean velocity suspension profile (b), channel width (H) for 3 separate shear numbers Reynolds as well as average solid volume fraction ϕ=52%.



A 'layered cluster' is parallel with a channel-wall consists of particles having centres at a distance from a line that passes through cluster 's mass centre and parallel to wall, as well as whose closest-neighboring distances (between particles' centre) in the wall's direction (as see in Figure 4). The$\lambda = (HL / n)^{1/2}$ is the particle' mean free path where as n is particles' total number, α and β are the coefficients having 3/2 and 1/2 values respectively. Such description is developed in recursive search routine that remains in progress unless none of new particles was satisfied the descriptions for horizontal distance (maximum).

Figure 4 Schematic overview of cluster or recursive search-routine and 4 particles' clusterwhich is identified already and new (shaded) particle meets the description for the horizontal distance (maximum) between nearest neighboring centres as well as max.distance of particle centre from the horizontal line which passes via cluster's mass centre.



SHEAR THICKNESS

From the two-D simulations which described above, the total shear stress as a function of shear intensity on the channel walls also found. As shown in Figure 5, shear number

Reynolds for 6 concentrations. For solid's volume fractions above appox.thirty percent the relative viscosity starts to increase as shear number of Reynolds increasing at about Reγ ≈ 0.5, although before that value being more or less independent of Re_{γ}. For low concentrations, apparent viscosity increases at high shear rates and the dependency on apparent viscosity tends to be a power rule (not seen here). We can now partly related the layering to the apparent viscosity (relative), as well as plot the layering index in Figure 6 as a relative apparent viscosity' function for the 3 highest solid's volume fractions for which layering index was highestbut below Re_{γ} =1.

Figure 5 Relative apparent viscosity μ*r* asshear Reynolds number' function for 6 solid volume fractionsϕ. The corresponding values of wall Reynolds number also showed.

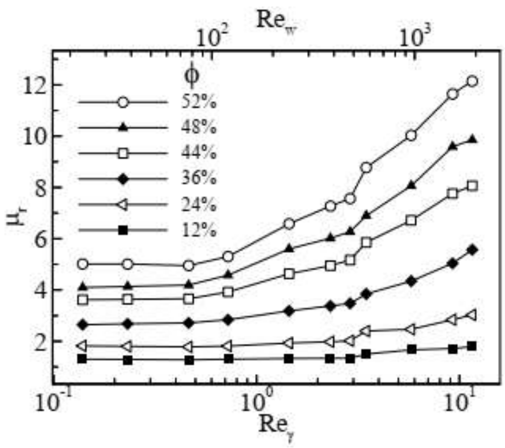
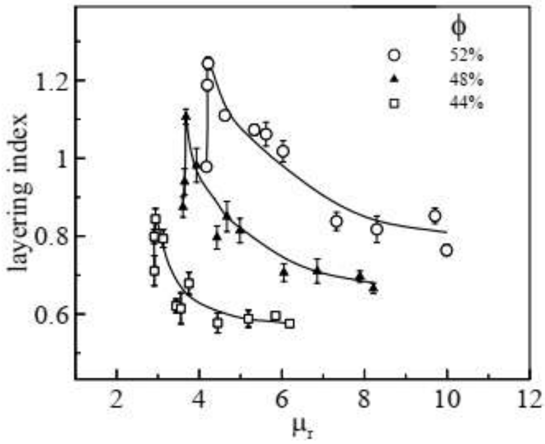


Figure 6 Variance of layering index by relative apparent viscosity μ_r for three concentrations. Strong lines are eye-guides.



MOMENTUM TRANSFER

Momentum transfer is a multi-scale process in multi-phase structures, such as particulate suspensions. The stress of various momentum fluxes as well as phases including the viscous stress of fluid’s phase, particles’ structural stress as well as inertial fluxes which arising in both phases from the pseudo-turbulent variations. Inside every particle the mean shear stress was calculated indirectly via forces of hydrodynamicwhich acting on particle’s surface. The measurement of hydrodynamic forces which acting on particles as well as stress in fluid’s phase,can be performed without relation to normal fluid-dynamic quantities like viscous stress tensor, since the Lattice-Boltzmann approach is not based on Navier-Stokes equations and traditional continuity, but on a discrete Boltzmann’s equation. Figure 1 provides a snapshot regarding the shear stress borne by the fluid, where there are high shear stress locationsamong the solid particles.

CONCLUSION

From the above content it can be conclude that the liquid-particle suspension's rheological behaviour shows complex phenomena such as nonlinear velocity profile, shear thickening, particle layering as well as apparent slip along solid walls. Momentum transfer showed that the shear thickening is associated with increase stress in solid-phase and decrease layering near walls. The apparent relative viscosity wasdepend, via a simple analytical term, only on the relative solid-phase stress.

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