Multi-Particle Sedimentation under Vibration

Navid Pirzae Khabazi[1], Houshang. Alamdari[2] and Seyed Mohammad Taghavi[3]
1. PhD. Student
Aluminium Research Centre REGAL, Dept. of Mining, Materials and Metallurgical Engineering, Laval University, Quebec, Canada
2. Professor
Dept. of Mining, Materials and Metallurgical Engineering, Laval University, Quebec, Canada
3. Professor
Chemical Engineering Department, Laval University, Quebec, Canada
Corresponding author: nkhabazi@ut.ac.ir

Abstract

In the aluminum smelting process in production of aluminum, the anodes used are formed through compaction of a paste composed of coarse particles of petroleum coke and binder matrix. The latter is a non-Newtonian material. One of the rheological features of the binder is the presence of a yield stress, which is the focus of our work. One of aspect of the complicated process of vibro-compaction can be seen as sedimentation of numerous particles (coke) in a yield stress material (binder), through applying vibration to the container. In this work, the effects of the vibration of container on the sedimentation of multiple particles in yield stress fluids are numerically studied, and the results are compared with the Newtonian counterparts. It is found that in Newtonian fluids vibration of the container does not necessarily cause the particles to fall faster. Indeed, the vibration may cause the particles to fall slower at higher frequencies. In yield stress fluids, vibration of the container may have a significant effect on the speed of the sedimentation of the particles in a way that higher frequencies cause the particles to fall faster. This effect becomes more pronounced in yield stress fluids with higher yield stresses.

Keywords: Aluminum smelting process; vibro-compaction; yield stress; numerical simulation.1

1. Introduction

Sedimentation of the particles involved in many industrial projects including slurry flows, fluidization, etc. Particles sedimentation under vibration of the container is one of the main steps of making anode in the process of the production of aluminum (which we explained in the abstract). Numerous researches have been focused on the particles sedimentation in yield stress fluids (e.g. see [1-3]), but to best of our knowledge there is no study related to the effect of the vibration of the container on the sedimentation of the particles.

2. Problem description and results

The system that we consider has been scaled compared to the industrial application. We consider the problem of many particles sedimentation in Newtonian fluids as well as yield stress fluids in container that oscillates vertically with:

$$y = 0.04\sin(2\pi f\, t)\ (cm) \tag{1}$$

where: y position of the bottom of the container, cm

f frequency of oscillation of the container, $1/s$

t time, s

Schematic of the particles and their initial position is shown in Figure 1. The channel is assumed to have a width of $1\ (cm)$ and a height of $4\ (cm)$. Initial position of the particles is chosen in a

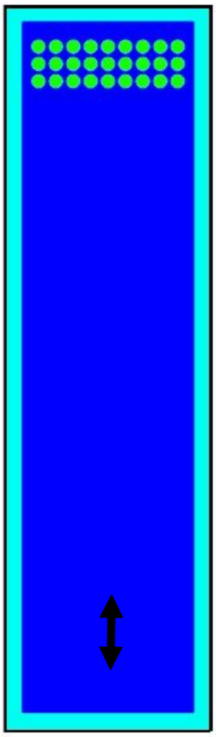

Figure 1. Initial position of the particles.

way to have their center of mass at height of $3.85\ (cm)$ (see Figure 1). The distance between the centers of each two particles is chosen to be $0.1\,(cm)$. Fluid density is $\rho_f = 1\,(g/cm^3)$, and kinematic viscosity of the fluid is assumed to be $0.01\,(cm^2/s)$. Solid density is $\rho_s = 1.25\ (g/cm^3)$. Diameter of the particles are $D = 0.07\ (cm)$. The whole domain and the particles are initially at rest and the container start to oscillate at $t = 0\ (s)$, at different frequencies.

Yield stress fluid during this study is assumed to be the Bingham model which is the most widely used model for this kind of fluids. Such materials become yielded and flow when a certain yield stress is exceeded. For any stress lower than this critical stress the material is un-yielded. Constitutive law of the Bingham model can be written as [4]:

$$\begin{cases} \tau_{ij} = 2\left(\dfrac{\tau_y}{\dot{\gamma}} + \mu_p\right) d_{ij} = 2\eta(\dot{\gamma}) d_{ij} & for \quad \tau_{ij} \geq \tau_y \\ 2d_{ij} = 0 & for \quad \tau_{ij} < \tau_y \end{cases} \tag{2}$$

where: d_{ij} rate of deformation tensor

τ_y yield stress

μ_p plastic viscosity

$\dot{\gamma}$ deformation rate ($\dot{\gamma} = \sqrt{d_{ij} d_{ij}}$)

$\eta(\dot{\gamma})$ apparent viscosity of the Bingham model

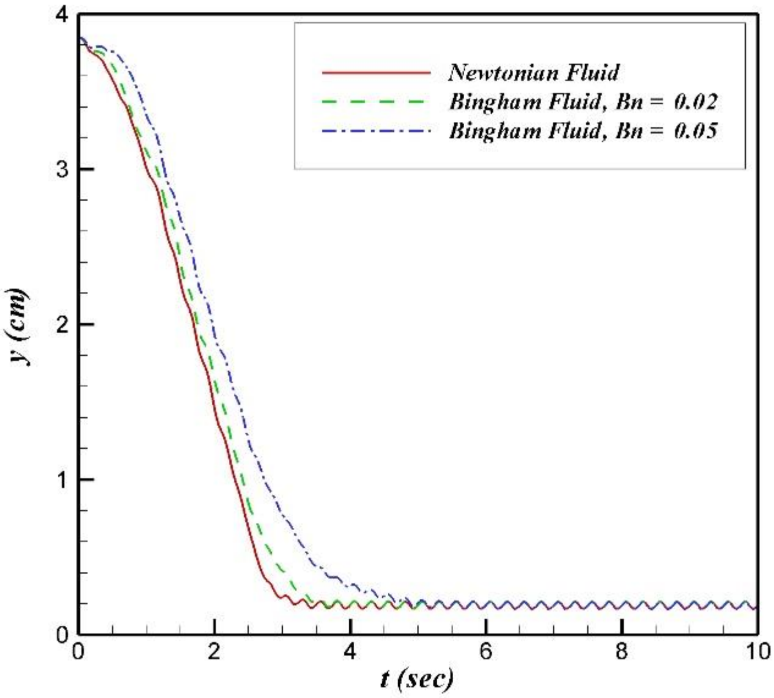

Figure 6. Y-location of the center of gravity of the particles in the container with oscillation with f=4(1/s).

3. Conclusion

It can be concluded that vibrating the container to speed up the falling of the particles is crucially important in the case of yield stress fluids. Our findings have interesting applications in the vibro-compaction process of the paste in a mold box. For example, it was interestingly shown that, counter-intuitively, the presence of a yield stress may actually help the sedimentation process by vibration. Thus, the presence of yield stress in binder may be the reason why the vibro-compaction is in fact an effective industrial process. Further study is needed to include the huge number of the particles with different shapes and also consider the presence of the gas bubbles in the binder.

4. References

1. R.W. Ansley, T.N. Smith, Motion of spherical particles in a Bingham plastic, *AICHE Journal* 13 (1967) 1193.
2. A.N. Beris, J.A. Tsamopoulos, R.C. Armstrong, R.A. Brown, Creeping motion of a sphere through a Bingham plastic, *Journal of Fluid Mechanics* 158 (1985) 219-244.
3. Prashant, J. Derksen, Direct simulations of spherical particle motion in Bingham liquids, *Computers and Chemical Engineering* 35 (2011) 1200-1214.
4. R.B. Bird, R.C. Armstrong, and O. Hassager, *Dynamics of Polymeric Liquids*, vols. I and II, Wiley, New York, 1987.
5. N.P. Khabazi, S.M. Taghavi, K. Sadeghy, Peristaltic flow of Bingham fluids at large Reynolds numbers: A numerical study, *Journal of Non-Newtonian Fluid Mechanics* 227 (2016) 30-44.
6. N.P. Khabazi, K. Sadeghy, Simulating Peristaltic Transport of Solid Particles Immersed in a Viscoplastic Fluid using the LBM/SPM Numerical Method, *submitted to Journal of Non-Newtonian Fluid Mechanics*.