CLUSTER FORMATION AND BREAKAGE OF WET GRANULATES UNDER SHEAR

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by

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I would like to dedicate this thesis to my loving wife and daughter...

CERTIFICATE

The thesis entitled "**Cluster formation and breakage of wet granulates under shear**" being submitted by Mr. Dheerendra Dubey to Indian Institute of Technology, Delhi for award of degree of doctor of philosophy is a record of original bonafide research work carried out by him. He has worked under my guidance and supervision, and fulfilled the requirement for the submission of this thesis, which has attained the standard required for a Ph.D. degree of this institute. The results represented in this thesis have not been submitted elsewhere for the award of any degree or diploma.

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Abstract

Granular materials have their wide presence on earth, almost all raw materials for daily usage and industrial applications come in the form of solid granular material. Clustering of particles has also found to play an important role in industries involving food-pharmaceutical processing, mineral extraction via froth flotation, waste water treatment, construction material production, catalyst generation etc. While in waste water treatment and froth floatation enough particle clusters are essential to the method, controlled agglomeration is found to give better physical properties like flowability, porosity enhancement, lower abrasion to the food and manufacturing processes, where excessive agglomeration can lead to just the opposite namely lumping. Thus, clustering of particles in wet granulates can also be considered to have a significant role in altering the rheological and physical characteristics of the material and it is essential not only to understand why and how these clusters are formed but it is equally important to understand the behavior of these clusters upon shear. Study of wet granulates under shear flow is required for improving several commercial processes and design. Wet granulates may be present in the form of a lump (single big cluster) or as a disperse phase. The wet granulates can as well be polydisperse in nature. The present thesis has been aimed to understand the effect of shear on these wet granulates under different assembly. The behavior of a single cluster aggregate made up of sticky wet granulates inside a Couette cell under constant shear has been numerically studied with the help of a Lattice Boltzmann model. Cluster composition and ratio of shear to capillary force (F_s/F_b) present in the clusters have been found to be the two important factors in determining

cluster behavior. Clusters having size below a critical value are found to exhibit rigid translational and rotational movement; above this critical value, the cluster breaks. Two broad failure regimes have been identified based on the relative magnitude of shear and capillary forces. For low values of the force ratio, the clusters are seen to undergo ductile failure either by thinning at the middle or from the peripheral area of the cluster due to severe coiling-recoiling action. At very high force ratios the clusters cannot withstand any shear and almost immediately break to form debris-like structures. Failure in these clusters is found to bring down the stress levels in the fluid. The increase in mass, less hysteresis in capillary forces, shear thinning base fluid and intrinsic voidage present in the clusters are found to make cluster-aggregates more susceptible to breakage. Monodisperse phase wet granulates under shear have been studied to understand the non-Newtonian rheological characteristics these granulates bring to the underlying flow system which otherwise is Newtonian in nature. Shear helps the dispersed particles to come together and form clusters. As the force ratio increases the dispersed phase particles are seen to form multiple clusters with lower cluster size, which leads to a shear thinning behavior. A moderate force ratio leads to shear banding phenomenon where the clusters are seen to agglomerate near the top and bottom wall in the form of a layered structure. Two kinds of shear banding phenomena were observed; for higher masses loose disperse phase banding was observed where with increased shear led to lower cluster sizes as in the case of lower force ratio but they were now confined to the said layers. In agglomerated banding found for lower masses, the cluster size increased and formed layered chain structures. At very high force ratio the dispersed particles in the absence of any strong capillary force were found unable to form clusters and remained dispersed even upon shearing. Polydispersity in the system based on size or density was found to decrease the average cluster size and thereby was found to lower the fluid behavioral index. This could be attributed to the presence of various masses in the system which induced a very high moment of inertia and made the clusters prone to breakage.

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F_s: Induced shear force on the particles, $mu.lu^{-2}$

F_b: Capillary bridge force between the particles, $mu.lu^{-2}$

ρ: Density of fluid, $mu.lu^{-3}$

υ: Kinematic viscosity of fluid, $lu^2.ts^{-1}$

G: Applied Shear rate over the fluid due to wall movement, ts^{-1}

τ: Relaxation parameter

Ω : Inverse of Relaxation parameter (τ:=1/ Ω)

D: Diameter of particle in, lu

σ: Force per unit length, $mu.lu^{-3}$

F_R: Repulsion force between the particles, $mu.Lu^{-2}$

ε is the depth of the potential well

g is the finite distance at which the inter particle potential is zero

μ: Dynamic viscosity of fluid, $mu.lu^{-1}.ts^{-1}$

L: Length of the simulation box, lu

D_p: Diameter of the particle, lu.

Re: Reynolds number

U_W: Wall velocity, lu.ts^{-1}

$M_{P,ref}$: Reference mass of the particle, 1916 mlu

$G_{,ref}$: Reference share rate, 0.0000775 ts^{-1}

$F_{b,ref}$: Reference capillary bridge force, 0.35 mu.lu^{-2}

$\overline{M_P}$: Non dimensional mass i.e. ratio of mass of particle to the Reference mass of the particle

$\bar{G}$: Non dimensional share rate i.e. ratio of share rate to the Reference share rate

$\overline{F_b}$: Non dimensional capillary bridge force i.e ratio of capillary bridge force to the Reference capillary bridge force

N_{c} : Critical number of particles

$G \times T$: Non-Dimensional time

$\bar{\rho}$: Non-dimensional density of particles, i.e. Ratio of density of particle to the base density of particles

$\overline{A_f}$: Fractional average coverage area by particles i.e. ratio of Area covered by particles to the total system's dimensional area

$\overline{M_s}$: Non dimensional mass of the system i.e. Ratio of total mass of system to the Reference mass of the particle

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