Paper: Flow of particulates, toners and carriers in a housing cavity

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Abstract

Flow of small particles micron in size is important in several industrial applications such as digital imaging, polymer processing, powder coating and in dispersing fertilizers to name a few. In digital imaging toner particles surrounded by silica or titanium are triboelectrically mixed with carrier particles to form developer particles. The toner particles are then separated from carrier particles by electric field and conveyed to photoreceptor for development. Optimum flow rates of both toner particles and of developer particles are essential for development process. Inter-particle forces, bulk properties (compressibility and cohesion) and stresses (frictional, cohesive and viscous stresses) are used to analyze powder flow. In inter-particle forces, the presence of humidity can result in capillary forces (surface tension) being important along with both electrostatic and van der Waal forces in affecting toner and developer flow. Several models can be put forth to explain the mechanisms of charges on toner and developer particles and their effect on flow. Correspondingly, hardness and modulus of a particle or particles are important material variables in van der Waal forces. Flow of toner particles and developers in a housing is analyzed by considering driving force from applied shear energy (rotating augers) against constraints of extrinsic constraints (consolidation, boundary) and intrinsic constraints(cohesion, compressibility and inter-particle forces). Both Discrete Element Method(DEM) and Continuum Models have been used to analyze powder flow with DEM uses models at particle level and is therefore requires costly computation where as Continuum Models are less accurate for complicated geometries and free surfaces. Empirical correlations are costly to obtain for predicting developer flow from frequent bench experiments (Freeman tester, Jenike shear cell and Seville tester) and tests in fixtures and housings.

Introduction:

Theoretical and experimental work on granular matter especially cohesive granular matter has diverse applications varying from digital imaging to fertilizer distribution. In digital imaging, toner mixed with external additives is triboelectrically charged with polymer coated carrier beads. An amine type coupling agent is surface coated on silica, titania or alumina and is used as an external additive to give proper charge and flow to a toner (1). There is some evidence to show that an amorphous hydrophobic titanium dioxide instead of a crystalline titanium dioxide when surface treated with alkyl trialkoxy silane gives toner more charge and flow stability to a toner(2).The content of the above-described large-particle size inorganic fine particles comprising 50% by volume or more of particles having a particle size of from 100 to 583.9 nm is preferably from 0.01 to 5 parts by weight, more preferably from 0.05 to 3 parts by weight, based on 100 parts by weight of the toner before the treatment with the external additive (untreated toner).

Although the reason why the effects of the present invention can be obtained by these constituents has not been clear, it is thought that the effects are obtained as a result of a combination of various factors as follows. The van der Waals forces between the toner and the toner carrying member or the like can be uniformly controlled by adding large-particle size inorganic fine particles having a specific particle size distribution; embedment and detachment of the large-particle size inorganic fine particles due to the stress in a non-contact development method are subtly balanced by adjusting the BET specific surface area of the large-particle size inorganic fine particles within a specific range; and the like(3).

Toner adhesion

While the conventional electrostatic transfer process works well with large toner particles, difficulties arise as the size of the toner particles is reduced. Smaller toner particles are necessary for images of high resolution and low granularity. It is known that as the particle size of the toner falls below about 8 micrometers, however, the surface forces holding the toner particles to the element tend to dominate over the electrostatic force that can be applied to the particles to assist their transfer to the receiver. Thus, less toner transfers and image quality suffers. In addition, as the particle size decreases, Coulombic repulsion between the particles tends to scatter the particles, causing loss in image resolution and increase in graininess and mottle. Thus, high resolution images require very small particles, but high resolution images without image defects have not been achievable using electrostatic transfer (4).

Toner Flow

M A S Quintanilla etal. analyzed transitional behavior of avalanches in cohesive granular materials and tested the behaviour of xerographic developers, consisting of a mixture of toner particles and carrier beads, the latter being used to disperse the toner particles and to control them. This ensemble of carrier beads, each with about a monolayer of toner particles, is used in the electrophotographic development process, hence the term xerographic developer. Toner particles, which form the actual xerographic image, are made of pigmented resin, and are typically 10 μm in diameter. Spherical carrier beads are ~ 100 μm in diameter or less and are made of a variety of materials (originally lacquer-coated sand was used but modern formulations consist of ferrite, or equivalent magnetic material, with a polymer coating to provide the appropriate triboelectric relationship to the toner polymer). When blended together, the toner particles and the ferrite beads undergo triboelectric charge exchange, and are then held together by electrostatic and van der Waals forces. Developer cohesiveness arises mainly from van der Waals attractive forces between toner particles and depends on the manufacturing process known as `housing', where the developer is subjected to strong compressive stresses (6).

For powders with primary particle size usually less than 30 µm, the interparticle forces are generally of the same order of magnitude or larger than the gravitational or hydrodynamic forces on the particles. The dominant interaction forces between particles in a dry powder are the electrostatic or van der Waals forces of attraction between molecules. The **van der Waals attraction forces** for macroscopic bodies such as two spherical particles are dependent on A is Hamakers constant, h is the Lifshitz-van der Waals constant (values for most solids in air range from 1 to 10 eV), H is the hardness of the softer of the materials in contact, a is the surface separation which is of the order of the intermolecular spacing (0.165 to 0.4 nm) and R is the radius of the spherical particle. The inter-particle forces depend more on the particles surface properties than on the bulk, and a number of researchers have concluded that a measure of the particles surface asperities (usually taken as 0.1 µm) should be used instead of the particles radius R. The effects of particle size, size distribution and pre-consolidation on bulk flow are not apparent from single-particle characterization; rather these bulk effects depend on

particle packing. Linkage between micro-scale particle properties and bulk powder flow offers parallels between micro-scale analyses of inter-particle friction and bulk flow yield loci. The dynamic motion and mechanical interactions between toner particles can be modeled. The mechanical interactions are due to collisions, friction, adhesion, and electromagnetic forces. The discrete element method (DEM) is used as the simulation tool for a quantitative description of the system. The interaction rules are determined for the toner particles and the surfaces of the development rollers. In the discrete element method (DEM), all toner particles are considered discrete elements. Each element interacts with its neighboring elements and its surroundings. Every time step, the forces that act on a particle are summed and, from this, the speed and the displacement of the particle is calculated by integration of Newton's second law of motion. The macroscopic behavior of the toner flow and print output can thus be simulated using DEM. The dominant forces in the developer roll toner assembly are normal and tangential collision forces between particles themselves and between particles and rollers, adhesive and cohesive forces, magnetic forces on toner particles due to the magnet within the imaging roller and due to the presence of magnetized particles, and electric forces between particles and the rollers. Jenike shear cell, Sevilla powder tester and Freeman shear cell are aften used to characterize flow properties of powders. Automated shear testers have gained widespread acceptance in the industry. comparative measurements with different shear testers show a dependency of flow on the bulk solid with. no significant difference in shear tester for easy flowing bulk solids. An influence of the shear tester is observed for poor flowing, compressible bulk solids. Experiments have shown that test procedure and shear cell design (tester geometry) affect the measurements considerably.

Jenike shear cell has usually been used to test granular particles in pharmacetical industry. Distinct element simulation methods (DEM) and contact dynamics (CD)have been used to analyze influence of particle elasticity for non-cohesive granular matter in shear testers Including Jenike Shear Cell (7). Jenike shear cell has been particularly applied to a study of flow patterns and stress distribution in silos. Limitation of a Jenike Shear Cell lies in showing non-uniform stress distribution and vertical force is limited to maximum of about 200psi.

Sevilla PowderTester is a fluidized bed apparatus that enables one to test the bulk mechanical properties such as the yield stresses and compressibility of fine cohesive powders (8). Every measurement is preceded by driving the powder into the bubbling regime in which the material loses memory of its previous history. Then the gas flow is set to a given value to take the powder into a well defined and reproducible initial state of low consolidation. Reverse flow is used to exert high compressive stress. A cornerstone of this technique is that the procedure is automatized, thus making results operator insensitive. Besides being a practical tool to diagnose the flowability of experimental powders, the Sevilla Powder Tester (SPT) also provides us with a powerful technique to research fundamental problems in powder mechanics fluidized bed technique provides a convenient method of generating a reproducibly consolidated powder and can be adapted to measure the limiting shear stress of the powder subjected to a controlled and small consolidation stress. After initializing, shear stress is applied to the sample by slowly tilting the bed. As the angle of tilt increases, this generates a shear stress in the powder layer. For deep beds, the location of the shear plane and the angle of tilt a at which failure occurs depend on the width of the bed . At shallow layers, it is observed that the width of the bed has no major influence and that powder failure occurs near the base of the sample. From the angle at which the sample fails in shear, we calculate the coordinates of one point on the yield locus. In order to generate more data for the yield locus we need to be able to vary the compressive stress on a sample. For example, the Canon CLC700 magenta toner particles are able to pack in a more compact structure for the same consolidation stress. Also for a given normal stress, the critical shear stress needed to make the powder flow decreases when the flow additive is increased from decrease of adhesion force (yield locus of experimental toners (12.7 µm particle size, 0.02% and 0.2% by weight of Aerosil) determined by the tilted fluidized bed technique).

The FT4 Powder Rheometer provides dynamic flow properties for powders. Complimentary to these dynamic flow measurements, the shear cell accessory allows the FT4 to make precise and rapid shear measurements. Initial powder conditioning is to obtain a homogeneous, conditioned powder state to allow highly repeatable measurements to be made. A conditioning cycle comprises of the dynamic test blade slicing downward through the powder followed by an upward traverse that lifts the powder and drops it over the blade. This process helps to remove the effect of different sampling methodologies and powder storage times.The conditioned column of powder is compacted using a ventilated compaction piston (allowing entrained air to escape), with a force equal to that of the pre-shear normal stress. Critical consolidation is obtained by achieving incipient failure and the specimen is over-consolidated with respect to the normal stress applied during shearing. This is realised by reaching a critical consolidation level at steady state flow and then reducing the normal stress for shearing. For each pre-shear normal stress, five measurements are taken at the five normal stresses defined by the standard. A measurement of shear stress is also taken at the preshear normal stress level i.e. at 3, 6, 9 and 15kPa. The five measurements taken make up the yield loci for each pre-shear normal stress level. The yield loci are plotted on a shear stress *vs*. normal stress graph, from which Mohr's circles can be added in order to extrapolate various flow data. The dependence upon environmental factors commonly imposed on powders such as flow rate, the level of aeration and the amount of consolidation can be determined for materials. The results of investigation into flow properties of toners show that they are affected by a large number of variables, of which one of the most significant is the effect of aeration and de-aeration representing the transition from fluidisation consolidation(9).

Further work on FT4 using a shear cell shows that coefficient of friction for toner increases with increase in Tg. Coefficient of friction is made up of a bulk component which relates to tan delta, a surface energy component and a component due to roughness of the particle. Addition of external additives showed a decrease in coefficient of friction. Investigation into carrier beads show that carrier beads increase in coefficient of friction with decrease in carrier size and with polymer coating covering a carrier bead.

Conclusion:

Presence of small amounts of interstitial fluid in the system introduces another degree of complexity due to the cohesive forces between particles in addition to the core repulsion force and the friction force present for dry granular matter. Cohesive powders flow depends on van der Waal, electrostatic and capillary forces. As the particle size decreases and moisture increases, cohesive forces increase. Modulus and charge affect significantly flow behavior. Increase in dynamic coefficient of friction can result in segregation and clogging.

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Author Biography

Suresh Ahuja received MSc in 1962 in Ssoil Physics from the Indian Research Institute(1962) and PhD in Chemical Physics from Polytechnic Institute of Brooklyn University (1967). From 1970 to 2006 he actively worked at Xerox in Webster, NY and is now retired. He has numerous patents on toners and photoreceptors.. Besides patents he has over forty presentations and publications. He has been member of APS, ASME, SOR and IST.