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FLOW OF GRANULAR MATTER OUT OF HOPPERS: DEMONSTRATION EXPERIMENTS

Ajay Rathore[1], Ankit Namdev[1], Jeeshan Ahmed[1], Munindra Bisen[1], Vishal Mishra[2]*

[1]Department of Chemical Engineering and Technology, Indian Institute of Technology (Banaras Hindu University), Varanasi, India.

[2]School of Biochemical Engineering, Indian Institute of Technology (Banaras Hindu University), Varanasi, India.

***Corresponding author: Dr. Vishal Mishra**, Assistant Professor, School of Biochemical Engineering, Indian Institute of Technology (Banaras Hindu University), Varanasi, India.
Email: vishal.bce@itbhu.ac.in

ABSTRACT

The flow behavior of granular matter is quite different than those of gases and liquids. Granular materials flow out of a hopper in the core- or mass-flow manners depending upon the cone angle of the hopper. This article present the basic concepts governing the flow behavior of granular matter and the details of simple experimental setup for demonstrating the core and mass flow behavior of particles out of hoppers.

KEY WORDS: Granular materials; Core flow; Mass flow; Hopper

INTRODUCTION

Granular materials are omnipresent in nature. Their physical and chemical properties are different from those of bulk solids, liquids and gases (Heinrich et al., 1996). Transportation of particulate materials like foodstuffs and grains, pharmaceuticals and coalthrough hoppers, chutes, and conveyor belts is one of the common operations in concerned industries. In nature, this is manifested in avalanches, planetary ring dynamics, soil liquefaction, river sedimentation and ice flow mechanics (Gray, 2003). In food, pharmaceutical, biotechnology, oil, chemical, metallurgical, detergent industries, powder generation, paint, plastics and cosmetics industries, two-third of products require granular feed - pastes, powders, etc. at one stage or the other. About 1% of total electricity usage in the industry is in size reduction processes. The impact of particulate products to US economy was estimated to be around US$1 trillion (Rhodes 2008). Manufacturing processes involving solids require reliable storage and transfer facilities without segregation. In pharmaceutical industries properly mixed particulate feed active and inactive components are used for making pills and tablets. The ratio of different compounds in all the tablets or drugs is a matter of life and death. If the particulate flow is not proper then this ratio gets altered and different batches of the drug may not have the same amount of the active component. There are innumerable instances where pharmaceutical companies had to withdraw their drugs due to improper composition caused by segregation during the flow of particulates which cost them millions of dollars. Indians and other oriental communities have been using difference in the behavior of granular materials in cleaning and separating grains since ages.

PARTICULATE FLOW VERSUS GAS AND LIQUID FLOW

The flow behavior of liquids and gases is well understood, but in the case of granular matter, engineers and technologists try to make some predictions about their flow using intuition primarily based on their knowledge of liquids and gases. However, flow behavior of solids is often counterintuitive. The viscous forces are completely absent in granular flow, unlike the gases and liquids where it plays a crucial role. Segregation occurs due to the difference in motion of individual particles resulting out of the difference in their size, shape, composition, etc., (Medina et al., 2000). Such segregation does not take place in gases/liquids. Practically the compressibility of liquids and gases change, but for the granularmatter, it remains same throughout the bulk.

FLOW OF GRANULAR MATERIALS

Different types of laws govern the flow of gases and liquids. These laws may or may not be applicable for the flow of granular matter. In this article, the flow behavior of granular matter is discussed. In addition to this, effect of discharge orifice in the hopper, or converging section beneath a storage vessel (silos) for granular matter has also been demonstrated using suitable 2 dimensional hoppers.

The flow of particulates can be differentiated into the two broad categories namely ***mass flow*** and ***core flow*** **“**figure 1”. In mass flow, all the particles in the storage vessel are in a single motion whenever any of it is drawn from the outlet **“**figure 1a”. In core flow as the name suggests, the particles flow in a channel made within itself i.e. all the particles are not in a single motion when the outlet is drawn from it **“**figure 1b” (Rhodes 2008).

FLOW MECHANISM

There is a common tendency to think that whenever there is a vertical flow the most effective force is gravity. But this is not the case always. In particulate flow, the gravitational forces are not that effective as assumed. Cohesive forces (forces between same types of particles), adhesive forces (forces between different type of particles including that between the solid particulates and the wall) and van der Wall’s forces are also the effective forces which come into picture when the flow takes place (Medina et al., 2000). Due to all these, flow of the same granular matter from hoppers is likely to exhibit different behavior depending upon the design, wall material, etc. This difference can be easily demonstrated through simple bench scale experiments.

MASS FLOW VERSUS CORE FLOW

The mass flow is uniform throughout the unit which is really making it simple to understand and estimate different required properties which explain the flow of any material. As the flow is uniform in the whole region the stresses on the walls and particles are uniform throughout the bulk. The bulk density is also uniform as there are no stagnant regions. Segregation is not a significant problem as it is in core flow. Due to friction between the walls and particulates, the silo walls erode resulting in contamination of the bulk feed, which has to be avoided (Rhodes 2008).

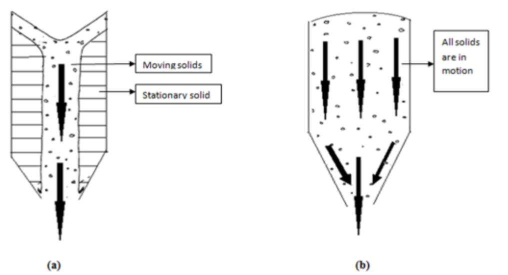

Figure 1. Core flow and mass flow in hoppers: (a) Core flow, (b) Mass flow (Based on Rhodes, 2008)

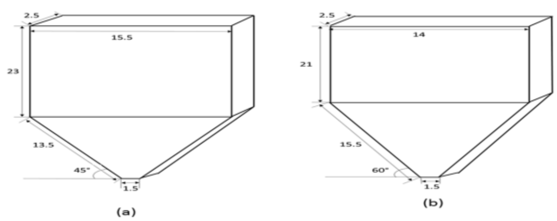

Figure 3 (a) The 2-dimensional silo with 45° hopper (all dimensions are in cm) **(b)** The 2-dimensional silo with 60° hopper (all

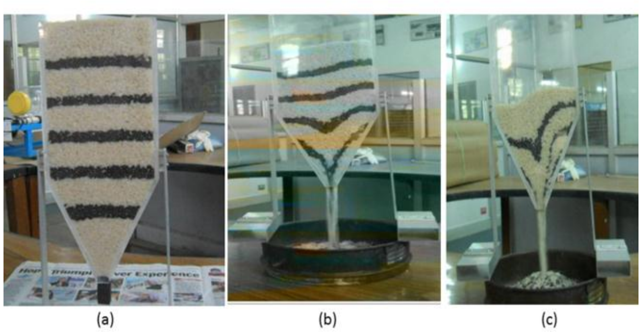

Figure 5. Flow out of 2-dimensional hopper with 60° cone (a) at time t = 0 s (b) at time t = 2 s (c) at time t = 5 s.

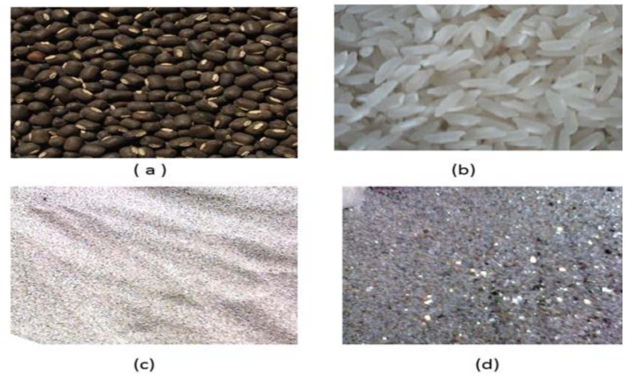

Figure 2. Photographs of granular materials used (a) black pulse (b) rice (c) white sand (d) black sand

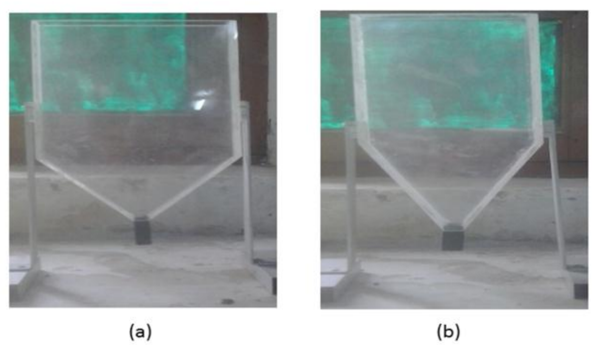

Figure 4. Photographs of blank hoppers (a) 45° hopper (b) 60° hopper

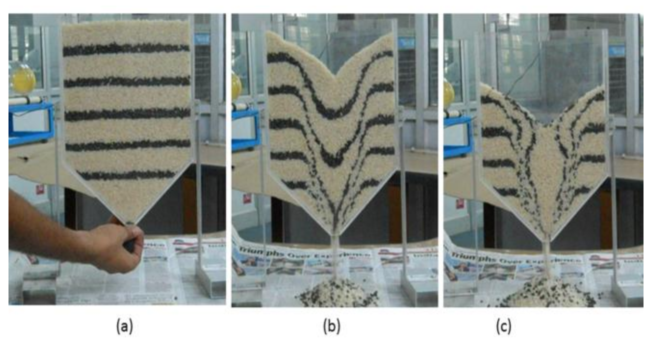

Figure 6. Flow out of 2-dimensional hopper with 45° cone (a) at time t = 0 s (b) at time t = 3 s (c) at time t = 7 s.

FACTORS INFLUENCING THE FLOW BEHAVIOR

The factors which significantly affect the flow behavior of the granular solid are angle of repose, density and diameter of granular material, the geometric ratio between the height of granular material and hopper width, bed height and angle of the orifice (Franklin and Johanson, 1996; Nguyen et al., 1980).

DEMONSTRATION EXPERIMENTS

Materials

Two types of particles of different colors were first sieved with standard sieves of appropriate sizes to obtain particles of the same average size. Pulse (Black moong grains), rice, white sand, and black colored white sand were used as thegranular material. The average size of moong dal grains was around 2-4 mm and that of rice was 1-3 mm. The white sand was of 100 to 1000 microns in size. Sieves were used to obtain the particles of same average sizes. Sand of two different colors having identical particle density, size and shape was used in the experiment. The black sand was prepared by coloring the white sand. Figure 2 shows the picture of the granular materials used the in demonstration experiments. Two-dimensional transparent silos were constructed from 5 mm thick Perspex sheet. Their dimensional details are shown in Figure 3 (a) and 3 (b). Perspex silos were made having particular dimensions and bottom angles of 45° and 60° "figure 4a" and "figure 4b". The metallic stand was used for their standing and stopper was used for theclosing of the bottom orifice.

A Simple Experimental set-up for Demonstration of Core Flow and Mass Flow of Particulate Matter

To ensure the involvement of these forces a simple experiment was performed using two- dimensional Perspex units with a conical bottom having an angle of inclination of 45° and 60°.

Alternate layers of these particles (each approx. 2 cm thick) were formed one above the other, as shown in "figure 5a" and "figure 6a". The stopper was removed and the flow of the particles was observed. The experiments were done with hoppers having the conical bottom of angles of 45° and 60° (Rathore, 2014). It is seen from Figure 5 (b and c) and Figure 6 (b and c) that the flow from the hopper with 45° conical bottom is core flow and that from the hopper with 60° conical bottom is mass flow. Figure 7 and 8 represents the flow of sand particles out of hoppers.

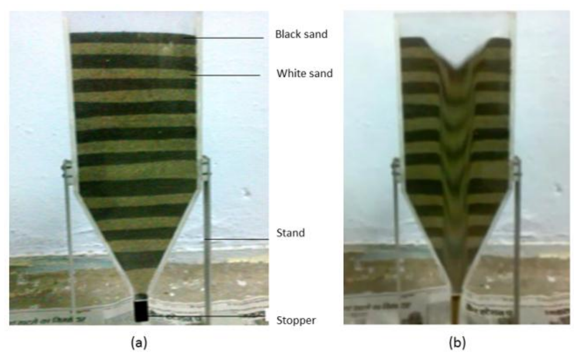

Figure 7. Flow out of 2-dimensional hopper with 60° cone (a) at time t = 0 s (b) at time t = 2 s.

This behavior can be explained on the basis of the fact that the gravitational forces are not that effective in the flow of granules. Adhesive and cohesive forces and shape and size of the solid granules have a vital role to play in giving rise to core flow and mass flow. However, Fedler and Gerogy (1989) reported no significant correlation of angle of repose with mass flow of dried granular material through the horizontal orifice.

Similarly, the study on flow of wheat, barley, flax and rapeseed through orifice showed direct exact correlation between flow rate-cum-type of flow (mass flow and core flow) and angle of repose (Mosey et al., 1988).

Figure 8. Flow out of 2-dimensional hopper with 45° cone (a) at time t = 0 s (b) at time t = 2 s.

CONCLUSION

The flow of granular matter is less dependent upon the density and gravitational effect but more on the shape and size of granular solids (Rhodes, 2008). The type is also dependent on the hopper characteristics like converging angle, loading etc. Using cheap and simple bench-scale setups, it is possible to demonstrate the difference in core and mass flow behavior of granular materials as well as the effects of shape and size.

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CONFLICT OF INTEREST

None of the authors have any conflict of interest in the mutual submission of manuscript.

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