# FLOW BEHAVIOR OF GRANULAR MATERIALS IN PHARMACEUTICAL AND FOOD INDUSTRY

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## ABSTRACT

The present work deals with flow of granular materials out of hoppers. Bench-scale experiments were performed to demonstrate core and mass flow of granular materials out of hoppers. Influence of size, shape, density of particles and angle of repose of hopper was observed on the flow granular materials out of hoppers. Results of this study showed that density of the granular material and angle of repose significantly influence the flow of granular materials out of hoppers. The present work is significantly important in fabrication and designing of mixers and segregators used in pharmaceutical and food industry.

**KEY WORDS:** Core flow, mass flow, hopper, mixing, particulate technology.

## INTRODUCTION

Granular materials are found in abundance, universal in nature and are of various types. Granular materials play an important role in many applications such as chemical engineering, pharmaceutical industry, agriculture, mining, metallurgical processing and energy production (Lori, 2007). The industrial applications deal with the processing of granular materials with different particle properties such as size, density and non-uniformity in shape (Rathore et al., 2016). The physico-chemical characteristics of granular materials are different from bulk solids, liquids and gases. Industrial sectors including food, agriculture, pharmaceutical, biotechnology, oil, chemical, metallurgical, detergent, powder generation, paint and pigment, plastics and cosmetics industries incorporate two-third of products, which require granular feed-pastes, granular slurry, powders, etc. at one stage or the other (Hill et al., 1999). Proportionately, 1% of total electricity is used in the industry during the size reduction process. The share of particulate products in US economy was estimated to be around US$1 trillion (Rhodes, 2008). Manufacturing processes involving granular materials require consistent storage and transfer services, which avoid segregation of particles. In pharmaceutical industries, properly mixed particulate active feed with proportionate amount of inactive components are used for making pills and tablets. However, there are several instances where there were



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anomalies in mixing of active feed and with inactive component of drugs, leading to tremendous loss to pharmaceutical industry. Not only this, but also the inappropriate mixing of the two feeds/ components of drugs may be threat to human beings (Lori, 2007). The flow out of hoppers and mixing of granular materials is primarily dependent upon shape, size, density of granular material, wall friction with particles, cohesive and noncohesive character of granular particle and angle of repose of hoppers (Rathore et al., 2016; Mediana et al., 2000).

The two broad categories of granular flow are namely core flow and mass flow. In case of mass flow, all the particles in the vessel are in a solitary motion whenever any particle drawn from the outlet, whereas with core flow the granular particles flow in a channel made within itself during flow out of hoppers (Rao and Nott, 2016). In fact, in core flow the particles are not in a solitary movement when the outlet is drawn from the storage vessels. The factors which appreciably affect the flow pattern of the granular particles are angle of repose, density and size of granular material, the geometric ratio between the height of granular material (layer thickness) and hopper width, bed height and angle of the orifice (Franklin, 1955).

In our previous investigations (Rathore et al., 2016; Mishra et al., 2016), few demonstration experiments were performed to illustrate the segregation (Brazil and Reverse Brazil nut effect) and mixing of granular materials in two and three dimensional units. In lateral expansion of previous work, the present investigation aims at studying the influence of density and size of granular material, angle of repose and thickness of granular layers on the flow of granular materials out of hoppers.

## MATERIALS AND METHODS

Materials used in the present work were arhar dal, moong dal, rice and urad (splitted, with peel) (Table 1). Densities of all granular materials were calculated by measuring the volume of the liquid displaced in the measuring cylinder on immersing the granular materials (Table 1).

Table 1: Densities and sizes of various granular materials used in the present work

| **Granular Material** | **Density (mg/ml)** | ***Size (mm)** | **Shape** |
|---|---|---|---|
| Arhar Dal | 0.84 | 3–5 (diameter) | Half oval |
| Moong Dal | 1.98 | 2–4 (diameter) | Oval shaped |
| Urad (with | 1.2 | 1–2 (diameter) | Half oval |
| Rice | 0.20 | 4.8–5.2 (length) | Cylinder tapered at both the ends |

*size measured with Vernier calipers.

The hoppers used in present work were made up of perspex sheet and fastened on metallic stand. The two angle of repose used in present work were 45° and 60°. The rubber stopper was used to close the outlet of hopper. The detailed geometry and design (engineering drawing) of the hopper has been discussed in ref. (Mishra et al., 2016). The thickness of granular material layer ranged from 2 to 3.5 cm. Rice is common in all the experiments. All the experiments were repeated in thrice. The photographs of flow of granular materials were taken at time interval at 1 sec, 3 sec, 5 sec and 7 seconds. The picture of granular materials



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used in the present work has been shown in Figure 1.


Figure 1: Photograph of granular materials used in present work.

## RESULTS AND DISCUSSION

Figure 2 (a-d) and figure 2 (e-h) show the influence of density, size and thickness of layer (of rice and urad dal), angle of repose on the flow of granular materials out of hoppers (45 and 60° angle of repose). In figure 2 (a-d), the thickness of rice layer is 3.5 cm and the thickness of urad dal layer is 2 cm.

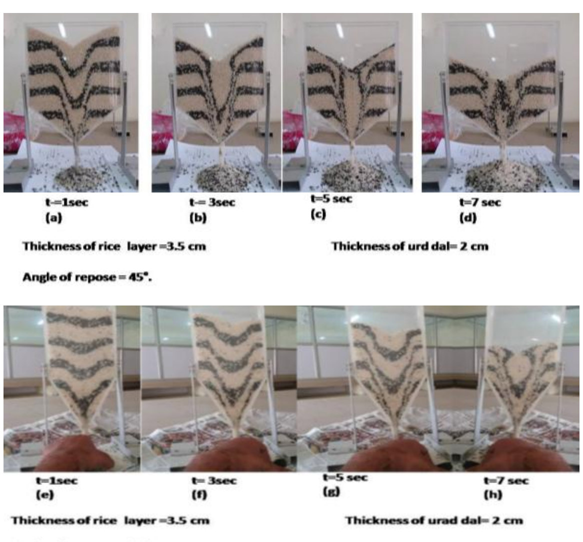


Figure 2: Flow of granular materials out of hopper with an angle of repose 45° and 60°.

It became evident from figure 2 (a-d) and figure 2 (e-h) that at 45° and 60° of angle of repose the core flow of granular materials out of hoppers was observed. The results showed that the angle of repose do not significantly influence the flow of granular materials, which are packed in symmetrical fashion in hoppers and when the shape, size and densities of granular materials were consistent in both the experiments.

Figure 3 (a-d) and figure 3 (e-h) show the influence of density, size and thickness of layer (of rice and urad dal), angle of repose on the flow of granular materials out of hoppers (45° and 60° angle of repose). In figure 3 (a-d) and figure 3 (e-h) the thickness of rice layer is 2 cm and the thickness of urad dal layer is 3.5 cm.

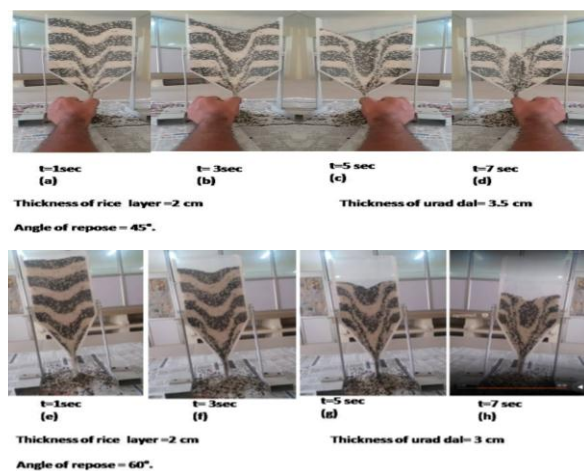


Figure 3: Flow of granular materials out of hopper with an angle of repose 45° and 60°.

It became evident from figure 3 (a-d) that the flow of granular materials out of hopper with an angle of repose 45° was core flow. However, in figure 3 (e-h) the flow of granular materials partially shifted (very initial stage) to the mass flow, which is ultimately followed by core flow on the later stage of process. The findings reported in



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figure 3 (e-h) showed that the angle of repose and the thickness of granular layer influenced and changed the flow behavior of granular materials. The partial mass flow followed by the core flow at 60° angle of repose (figure 3 e-h) was due to the high input force exerted by one layer of granular material over the another layer. The high input force might be due to higher thickness of layers made up of urad dal than the layers of rice and the density of urad dal is higher (6 folds) than of rice.

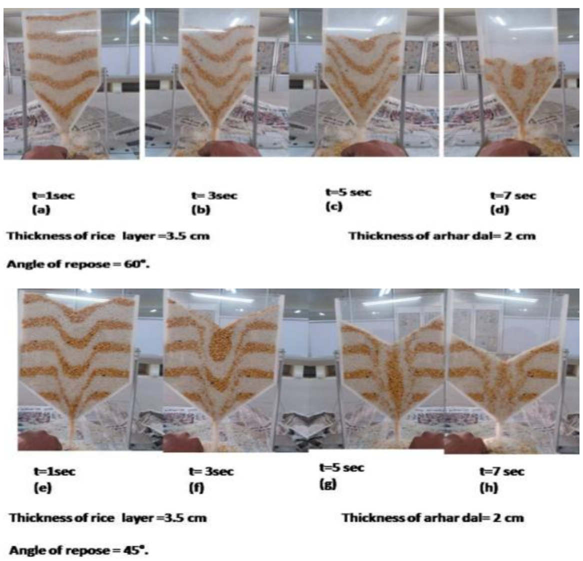


Figure 4: Flow of granular materials out of hopper with an angle of repose 45° and 60°.

Figure 4 (a-d) and figure 4 (e-h) show the influence of density, size and thickness of layer (of rice and arhar dal), angle of repose on the flow of granular materials out of hoppers (45° and 60° angle of repose). In figure 4 (a-d) and figure 4 (e-h) the thickness of rice layer is 3.5 cm and the thickness of arhar dal layer is 2 cm. It became evident from figure 4 (a-d) and figure 4 (e-h) that at 45° and 60° of angle of repose the core flow of granular materials out of hoppers was observed. The results showed that the angle of repose do not significantly influence the flow of granular materials, which are packed in symmetrical fashion in hoppers and when the shape, size and densities of granular materials were consistent in both the experiments.

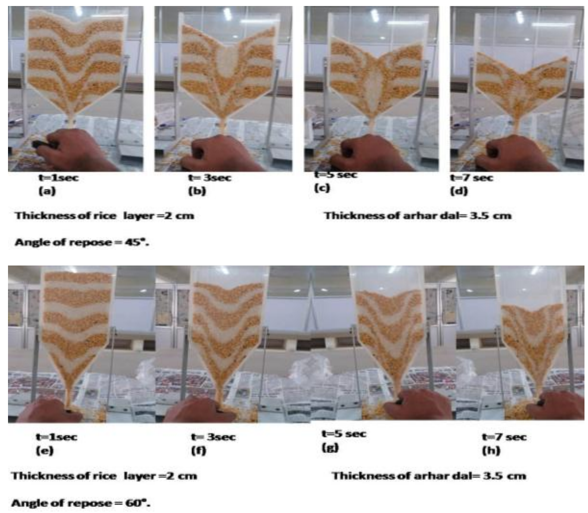


Figure 5: Flow of granular materials out of hopper with an angle of repose 45° and 60°.

Figure 5 (a-d) and figure 5 (e-h) show the influence of density, size and thickness of layer (of rice and arhar dal), angle of repose on the flow of granular materials out of hoppers (45° and 60° angle of repose). In figure 5 (a-d) and figure 5 (e-h) the thickness of rice layer is 2 cm and the thickness of arhar dal layer is 3.5 cm. It became evident from figure 5(a-d) that at 45° of angle of repose the core flow of granular materials out of hoppers was observed. In figure 5 (e-h) the flow of granular materials partially shifted (very initial stage) to the mass flow, which is ultimately followed by core flow on the later stage of process. The findings reported in figure 5 (e-h) showed that the angle of repose and the thickness of granular layer influenced and changed the flow behavior of granular materials. The partial mass flow followed by the core flow at 60° angle of repose (figure 5 e-h) was due to the high input force exerted by one layer of granular



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material over the another layer. The high input force was might be due to the reason that thickness of layer made up of moong dal is higher than the layer of rice and the density of arhar dal is far more (4 folds) higher than the density of rice.

t=1 sec (a) t=3 sec (b) t=5 sec (c) t=7 sec (d)

Thickness of rice layer = 2 cm Thickness of Moong Dal=3.5 cm

Angle of repose = 45°

t=1 sec (a) t=3 sec (b) t=5 sec (c) t=7 sec (d)

Thickness of rice layer = 2 cm Thickness of Moong Dal=3.5 cm

Angle of repose = 60°

Figure 6: Flow of granular materials out of hopper with an angle of repose 45° and 60°.

Figure 6 (a-d) and figure 6 (e-h) show the influence of density, size and thickness of layer (of rice and moong dal), angle of repose on the flow of granular materials out of hoppers (45° and 60° angle of repose). In figure 6 (a-d) and figure 6 (e-h) the thickness of rice layer is 2 cm and the thickness of moong dal layer is 3.5 cm. It became evident from figure 6 (a-d) that at 45° of angle of repose the core flow of granular materials out of hoppers was observed. In figure 6 (e-h) the flow of granular materials partially shifted (very initial stage) to the mass flow, which is ultimately followed by core flow on the later stage of process. The findings reported in figure 6 (e-h) showed that the angle of repose and the thickness of granular layer influenced and changed the flow behavior of granular materials. The partial mass flow followed by the core flow at 60° angle of repose (figure 6 e-h) was due to the high input force exerted by one layer of granular material over the another layer. The high input force was might be due to the reason that thickness of layer made up of moong dal is higher than the layer of rice and the density of moong dal is far more (almost 10 folds) higher than the density of rice.

t=1 sec (a) t=3 sec (b) t=5 sec (c) t=7 sec (d)

Thickness of rice layer = 3.5 cm Thickness of Moong Dal=2 cm

Angle of repose = 45°

t=1 sec (a) t=3 sec (b) t=5 sec (c) t=7 sec (d)

Thickness of rice layer = 3.5 cm Thickness of Moong Dal=2 cm

Angle of repose = 60°

Figure 7: Flow of granular materials out of hopper with an angle of repose 45° and 60°.

Figure 7 (a-d) and figure 7 (e-h) show the influence of density, size and thickness of layer (of rice and moong dal), angle of repose on the flow of granular materials out of hoppers (45° and 60° angle of repose). In figure 7 (a-d) and figure 7 (e-h) the thickness of rice layer is 3.5 cm and the thickness of moong dal layer is 2 cm. It became evident from figure 7(a-d) and figure 7 (e-h) that at 45° and 60° of angle of repose the core flow of granular materials out of hoppers was observed. The results showed that the angle of repose do not significantly influence the flow of granular



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materials, which are packed in symmetrical fashion in hoppers and when the shape, size and densities of granular materials were consistent in both the experiments.

## CONCLUSION

The flow of granular materials is significantly influenced by density of granular materials, thickness of granular layer, loading capacity and angle of repose of hoppers. Furthermore, in the present work, it was demonstrated that by using simple batch scale experimental set up, it is easy to demonstrate the various types of flows of granular materials.

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## CONFLICT OF INTEREST

Authors of the manuscript declare no conflict of interest.

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