GESA
GLOCAL ENVIRONMENT & SOCIAL ASSOCIATION

International Journal of Biological Innovations
http: //ijbi.org.in | http://www.gesa.org.in/journals.php
Doi: https://doi.org/10.46505/IJBI.2021.3216
IJBI 3(2): 355-359 **(2021)**
E-ISSN: 2582-1032

FLOW OF GRANULAR MATERIAL OUT OF HOPPER: APPLICATION IN FOOD, AGRICULTURE AND PHARMACEUTICAL INDUSTRY

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Article Info:
Research Article
Received
10.09.2021
Reviewed
25.09.2021
Accepted
03.10.2021

Abstract: A new type of arching and rat-holding free hopper was designed for the flow of granular material by using the Discrete Element Method. Such hoppers are immensely helpful in the food, biopharmaceutical and agriculture industries. The DEM is a complex method that resolves the problem of storage and flow of granular material in a hopper. It is a time taking procedure as the granular particles search for the contact between each other. Initially, when the particles are filled in the hopper, the velocity is greater; however, at the time of discharging material out of the hopper the velocity of flow of granular material at the orifice end is smaller. The total particles are discharged within 0.17 second, having different diameters and velocities.

Keywords: Agriculture, Discrete element method, Granular particles, Hopper, Pharmaceuticals.

INTRODUCTION

In the field of mining, pharma industry, mineral processing, the flow of granular material through hopper is crucial. In industries, lots of problems happened related to the flow of granular material through hopper like ratholing, arching, bridging, erratic flow, segregation etc. The storage and the flow of granular material through hoppers are very important in pharma, mining and chemical industries (Langston *et al.*, 1995). The flow of granular material through hopper has been popular modelling for many years.The simulation of granular material through hopper is done by the using Discrete Element Method (DEM), which is also known as the Distinct Element Method. This is a numerical method for computing the effect of a large number of small particles and the effect of motion (Cleary and Sawley, 2002).

In DEM, the particles are used as monodisperse or polydisperse. DEM models can qualitatively predict mass flow, precise prognosis of funnel flow and another phenomenon such as arching, ratholing etc. In this model, discharge mass flow rate, change in the flow pattern, discharge velocity is derived (Yuan and Saxén, 2011). The DEM is a very advanced and complex method for studying the behavior of granular material which flows through the hopper.

The simulation of different geometrically-complex industrial applications, 3D simulation of large particles, which cause issues in the industry (Cleary and Sawley, 2002) is studied. The DEM neglecting because it affects the inter-particle cohesion and the particle shape (Yuan and Saxén, 2011). At the time of filling hopper, the velocity of flow of granular material is greater but at the time of discharging the velocity of flow of granular material is smaller (Yuan *et al.*, 2016). By using the software EDEM, one can simulate a large number of granular materials through the hopper and get different results. In this paper, authors tried to describe the simulation of the flow of different sizes of granular material through the new structured hopper.

MATERIALS AND METHODS

For the computer simulation of granular materials through the hopper, the new model of hopper was planned with the help of AutoCAD software by providing the different proportions (table 1).

Table 1: The dimensions of Hopper in AutoCAD software.

Sl. No.	Outer diameter (cm)	Inner diameter (cm)	Height (cm)	Thickness (cm)	Orifice diameter	Angle (degree)
1.	18.0	17.0	25	0.5	4.0	30°

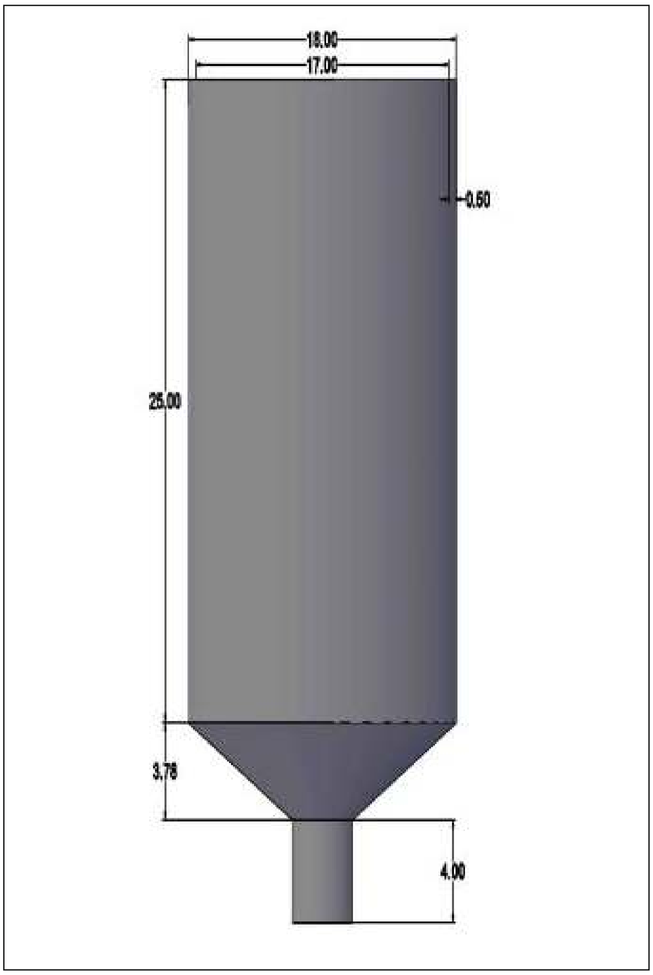

Fig. 1: Front view of hopper

By using different proportions, the new model of hopper had structured which have good competence for storage and flow of immensity amount of granular material. Figure 1 and figure 2 illustrate the different dimensions of the new modelled hopper.

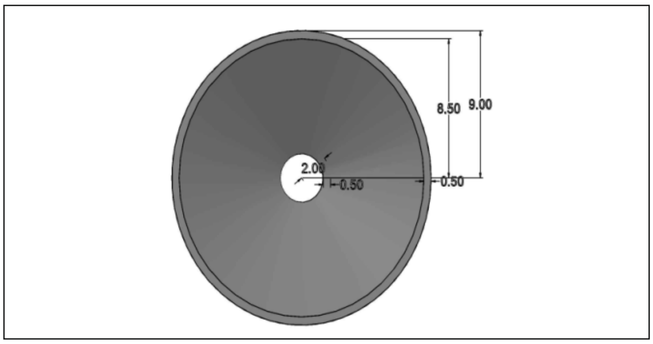

Fig. 2: Inner view of a hopper.

Granular materials and hopper

For simulation of granular material through the hopper, there are different parameters of granular material and different parameters of the hopper are set to steel, which is mentioned in table 2.

Table 2: Simulation parameters*.

Parameters	Value
Poisson's Ratio of material	0.35
Poisson's Ratio of steel	0.3
Particle shear modulus (Pa)	1e+ 10
Steel shear modulus (Pa)	1e+08
Particle and particle recovery restitution	0.5
Particle and steel restitution	0.5
Particle and particle coefficient rolling friction	0.2
Particle and steel coefficient rolling friction	0.05
Steel density (kg/m^3)	7850
Particle density (kg/m^3)	1300

*The different values were calculated for the simulation (Yuan and Saxén, 2011).

The simulation by discrete element method is time-consuming procedure because in these criteria there is a contact searching model procedure and for the motion of the particles, small time steps are required for solving the equation. So to reduce simulation time the model of granular material is appropriate and designed the hopper with suitable parameters. The particles consider in the hopper for simulation is approx. N= 1780 particles. The value of the radius of the particle varies from 0.03 to 0.05m, which gives the best and random uniformly motion. The granular materials such as Pigeon pea pulse, sand, salt etc. are used for the flow-through hopper so in the simulation model only single sphere is selected by providing radius and contact radius (fig. 3).

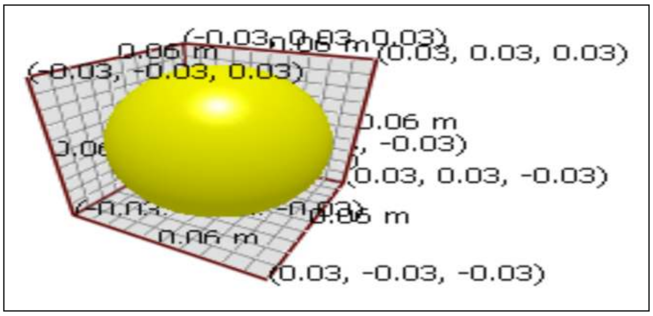

Fig. 3: The modelled granular material for the simulation.

Here, authors selected the contact model because it gives the best accuracy. There are nine contact models in EDEM software. For the flow of granular material, the Hertz- Mindlin contact model is selected because granular materials contain some amount of moisture.

Discrete Element Method (DEM)

The Discrete Element Model was proposed by Cundall and Strack (1979). In this method, motion is of two types: Rotational and Translational. The Rotational and translational motion of particle *I* with mass m_i and Inertial I_i, is derived from Newton's Second Law of motion (Larsson, 2019).

$$m_i \frac{dvi}{dt} = \sum_{j}^{c} Fij + \sum_{k}^{nc} Fik + Fi^9$$

and $$I_i \frac{d\omega i}{dt} = \sum_{j} Mij$$

Here, v_i and ϖ_i are the translational and angular velocities of the particle. The contact forces and torque acting on particle *i* by particle *j* are given by fij^c and M *ij*. (Larsson, 2019).

For the 3D simulation, the 2D objects are extruded in the CAD software and provide thickness to the object and generate the third dimension which is described by the finite element meshes, which can be designed in CAD using a commercial mesh generator. In 3D, the particles are modelled here are spheres. All particles are packed in the hopper without overlap of the particles after that particles settle down in the hopper and then the orifice end is opened then the particles are searching contact between each other and start discharging with the different diameter and velocity until the hopper was emptied as shown in fig. 4 and fig. 5.

Validation of the simulation

In industries, the particles flow from hopper has geometry complexity. Here, the authors have chosen the pre-processing software to implement the simulation procedure. The geometry is initially established using CAD software (*e.g.* AutoCAD) after that the 2D dimension geometry is extruded and provide the thickness through which the 3D structure of the hopper is derived. The geometry is then imported into a commercial mesh generator *e. g.* (FEMAP) to construct a finite element surface that will describe the object to code the DEM (for visualization purpose, a tetrahedral mesh is required which describes the geometry volume). There is most commercial software that is unable to distinguish the particles, which needed to be drawn and which not. Such a type of 3D simulation can take a long time to compute and visualize.

RESULTS AND DISCUSSION

The results drawn are as following:

1. The DEM is used for hopper discharging with different sizes of particle, has been successfully validated.
2. Different types of particles have the same velocities in the whole area of the hopper except the exit zone of the hopper, there the velocity value is very small as mentioned in

the result but the value of angular velocity is very large as compared to the velocity.

3. By the DEM the flow of hoppers is the mass flow, not the funnel flow. The particles do not stick in the side of the hopper by which discharging process is best which is very useful for the industry also.

Authors focused on the simulation of granular material, the behaviour of monosized granular material during the discharging and filling process and the analysis of the different velocities, count of the particles were done by the Discrete Element Method (DEM).

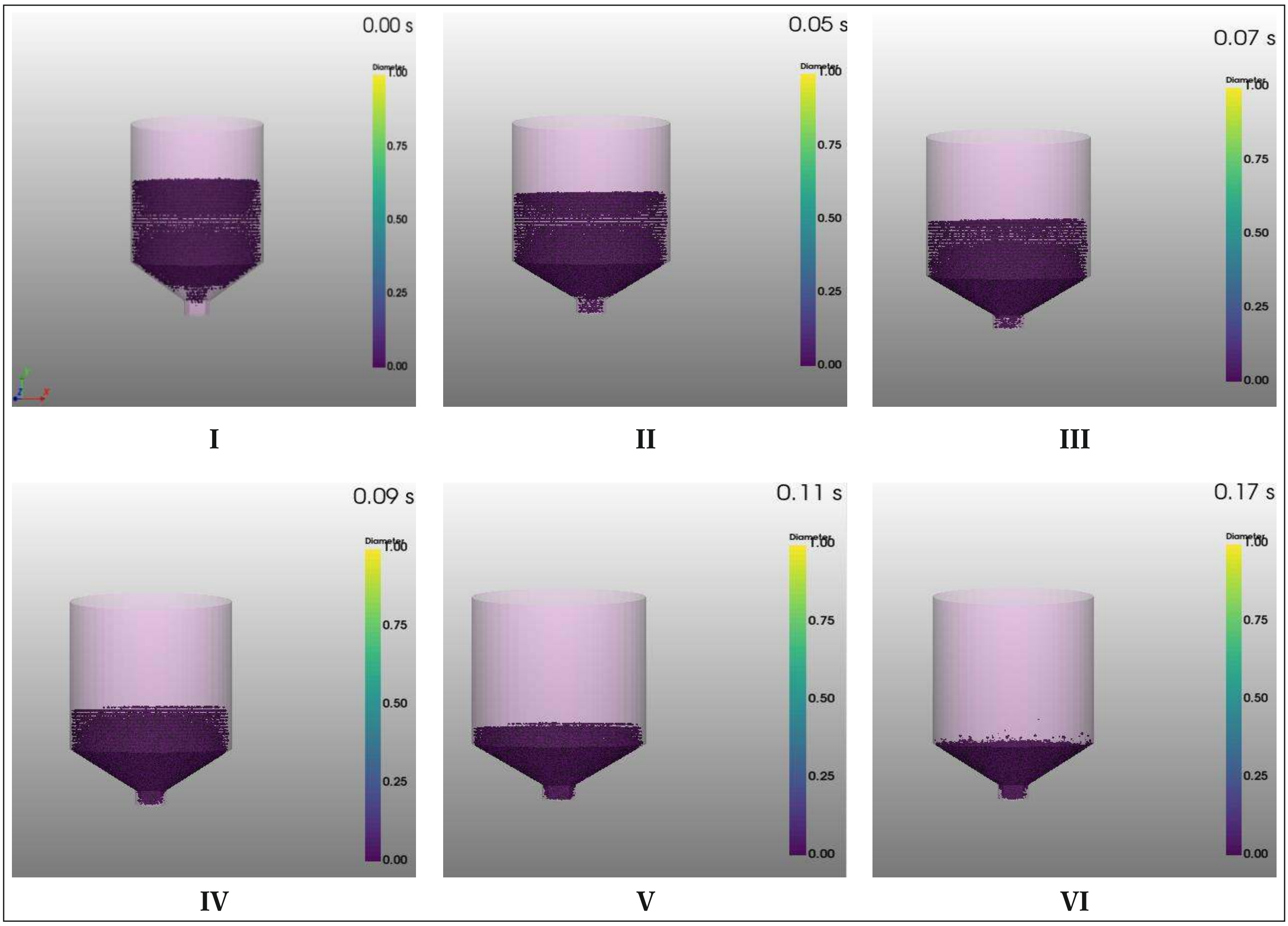

Fig. 4: The diameter distribution at different times during the discharging process.

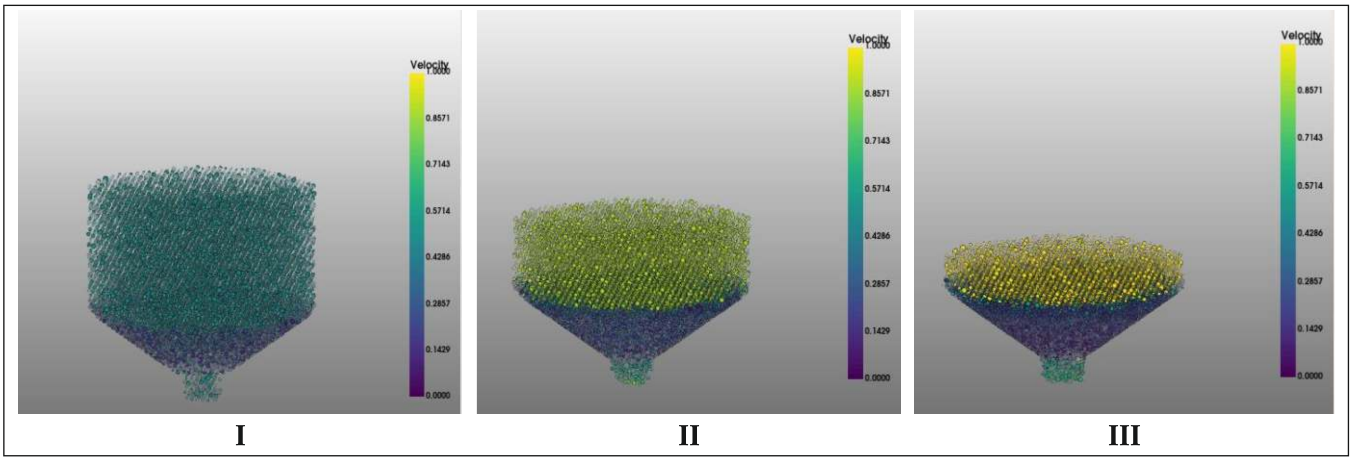

Fig. 5: The velocity distribution at different times during the discharging process.

During discharging process the velocity is the same in the bottom of a hopper but it changed in the exit zone of the hopper. There the velocity becomes smaller as compared to the bottom of the hopper.

In fig.6 and fig.7, the graphs illustrate that the particles simulate in hopper with the various diameter and velocity. In fig.6 initially the diameter of the particles increases gradually after that it declined and in fig.7 the velocity is equal in whole hopper only it changes at the exit zone of hopper.

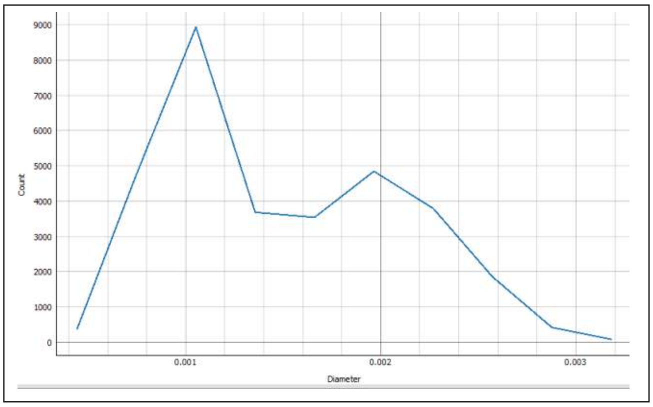

Fig. 6: Graph to show the count of particle and the diameter of the particle.

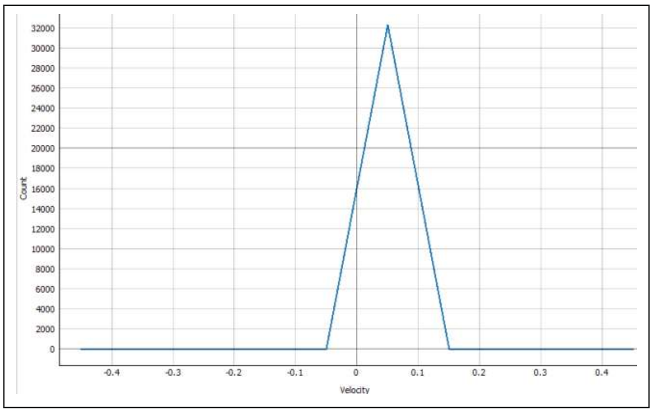

Fig. 7: Graph to show the count of particles and the distribution of velocities.

ACKNOWLEDGEMENTS

Authors are thankful to the Indian Institute of Technology (BHU), Varanasi and Council of Science and Technology, Lucknow, India (under the project: Flow and Segregation of granular materials out of hoppers and two and three-dimensional devices) for providing funding and instrumentation facilities to complete this work.

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