Screw feeder performance prediction using Discrete Element Method (DEM)

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Abstract: Screw feeders are widely used for transporting particulates at controlled and steady rates. These devices suitable for handling a wide variety of materials that have good flow ability characteristics. They are used in many bulk material applications in industries ranging from chemicals, cement, sand, industrial minerals, and food processing. In this paper the influence of screw diametric clearance and hopper filling level on the feeder performance is illustrated. A computational particle flow simulation of a Screw feeder is presented by applying the Discrete Element Method (DEM) with periodic boundary conditions. The DEM modelling gives predictions of screw feeder performance. The simulation tool allows the modelling of all relevant machine parts without expensive real manufacturing and to test their characteristics.

Key words: Clearance, DEM, Filling level, Mass Flow Rate, Screw feeder.

INTRODUCTION

Screw feeders are devices suitable for handling bulk materials from hoppers or bins in chemical, pharmaceutical, food and mining industries. They generally provide good output control and facilitate a level of environmental protection, not possible with belt conveyors. The typical configuration consists a helicoidal surface fitted on a shaft that rotates inside a fixed tube. The material inside the hopper withdraw by the helicoid flight in the direction of transport. The advantages of the screw feeder include the possibility of having different openings, each with its own shut-off organ for unloading the material.[5] While mechanically simple in principle, the behavior of material during the withdraw process and transport can be complex. If design is not adequate, certain problems can occur: unsteady flow rates, inaccurate metering, deformation of the granules, product degradation, excessive power draw, high start-up torques and high equipment wear, lower the quality of the final product. [2] The basic configuration of a typical screw feeder has three major components:

(1) Hopper or bin;
(2) Stationary screw casing;
(3) Rotating screw.

The considerable amount of research work has been carried out in the design and sizing of screw feeders and analysis of inside material flow using discrete element modelling approach. P.J Owen and P. W. Cleary studied operational performance of a screw conveyor including quantitative variation of flow characteristics with fill level, angle of inclination and rotational speed. [4] They examine how these operating conditions influence the performance of a screw conveyor by applying the Discrete Element Method (DEM). Marco Bortolamasi Johannes Fottner studied about Design and sizing of screw feeders. [5] Study is focused on design criteria for the screw feeders. Calculation of the nominal flow was done. Design and sizing of a screw feeder is a highly complex procedure. Researchers develop a general procedure to predict the performance of screw feeders of any specific geometry. As Starting torque has a direct influence on the correct selection of control devices a proper selection could mean a reduction up to 10% of the total cost. P.J. Owen, P. W. Cleary predicts the screw conveyor performance using the Discrete Element Method (DEM). [3] The performance of a screw conveyor is affected by the operating conditions, such as: the rotational speed of the screw; the inclination of the screw conveyor; and the volumetric fill level of the bulk material. DEM modelling gives predictions of screw conveyor performance in terms of variations of particle speeds, mass flow rate, energy dissipation and power consumption. Yongqin Yu investigates about the theoretical modelling and experimental investigation of the performance of the screw feeders. [6] They studied performance of single and twin screw feeder for volumetric efficiency, drawdown performance and torque or power requirements. Yoshiyuki Shimizu and Peter A. Cundall studied Three-dimensional DEM simulations of bulk handling by screw conveyors. [7] Numerical analysis is conducted to examine the performance of screw conveyors. The results are compared with previous work and empirical equations. Philip J. OWEN and Paul W. CLEARY investigated Screw conveyor performance: comparison of discrete element modelling with laboratory experiments. [8] The predicted mass flow rate was in excellent agreement with experimentally measured values for the horizontal and vertical configurations. They also focused on performance measures such as: particle speeds and power consumption that may vary due to changes in the properties of the particles. Here we extend this work to look at the performance of a screw feeder including quantitative variation of flow characteristics with mass flow rate.

MODEL DESCRIPTION

Discrete Element Method is used to simulate granular flow by tracking individual particles and predicting their interactions between each other and external objects such as the screw and hopper. The boundary geometry is created using a CAD package and imported as a triangular surface mesh into the DEM package. This provides unlimited flexibility in specifying the three dimensional geometries with which the particles interact. Here the particles are modelled as spheres. The laboratory scale screw feeder configuration used in this work. This is suitable for investigating the effects of changes in configuration. For industrial scale hoppers, the magnitude and extent of variation in the solids stresses will be much larger with greater loads acting on the feeders leading also to greater torque and power requirements. It is assumed that the screw feeder behaviors investigated here do not differ much from the laboratory to the industrial scale. [1] The hopper bin, screw casing and screw used for this study are shown in Fig 1 and Fig 2. The screw used in this study was a constant pitch, constant flight, and constant core diameter screw. The key geometric dimensions of the screw are given in Table 1.

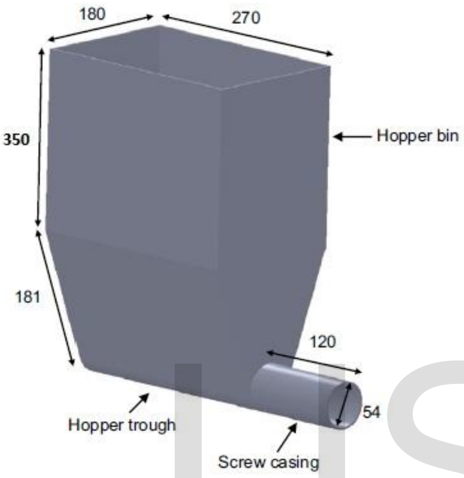

Fig 1: Hopper bin, screw casing

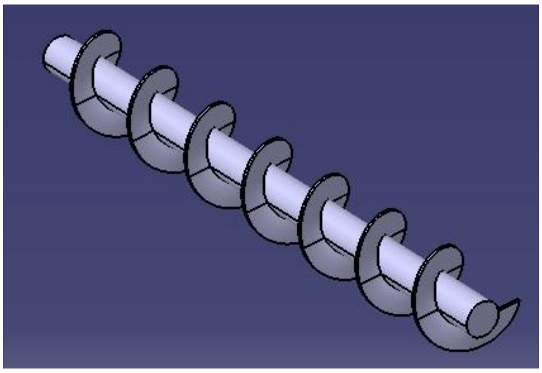

Fig 2: Screw

Table 1. Screw Dimensions

Screw Dimensions	
Outside Blade Diameter (D)(mm)	52.5
Outer shaft diameter (d)(mm)	22.5
Pitch (P)(mm)	52.5
Maximum Screw Clearance (c)(mm)	0.75

In this study, we investigated effect of screw diametric clearance and hopper filling level on feeder performance. Past literature indicates that clearance is an important constructional feature affecting output of the screw feeder. [4] Clearance is necessary to prevent metallic contact from taking place during rotation due to various adverse factors such as shaft deflection, minor manufacturing eccentricities, and tolerance on screw and through. [6] In the screw feeder configuration hopper bin acts as a storage as well as source of material. Filling level of hopper is height up to which material filled inside hopper. [9] Effect of filling level on mass flow rate investigated in this study.

MATERIAL PROPERTIES

The hopper bin was filled to approximately 60% full with 5 mm diameter spherical grains. A 1% variation was used for the diameter range to prevent unrealistic crystallization from occurring. The solid density of the particles was 1400 kg/m3. These are generic simple type of material intended to be reasonably representative of bulk materials so that the analysis is not overly complex but the modelling conclusions are reasonably broadly applicable. The coefficient of friction between particles, hopper wall and screw face were 0.6, 0.45 and 0.364, respectively. [1] In particular, the screw face friction (0.364) is often lower than the hopper wall friction (0.45) as the screw is polished either purposefully or by the flow of particles. These frictional coefficients were chosen based on typical values found in industry as measured using a Jenike shear tester. The maximum overlap between particles is determined by the normal spring stiffness. Typically, average overlaps of 0.1–0.5% are desirable, requiring a spring constant of 1000 N/m for this type of simulation.

DEM SIMULATIONS

The Discrete Element Method (DEM) is a well-documented numerical tool. In discrete element simulation of granular flows, the collision interactions of particles with each other and with their environment are detected and modelled using a suitable contact force law. Equations of motion are then solved for the particle motions and for the motion of any boundary objects. DEM simulates granular flow by tracking individual particles and predicting their interactions between each other and external objects. [7] The particles are permitted to overlap each other and boundary objects and when coupled with a contact law, predict contact force allowing the prediction of instantaneous positions, orientations, velocities and particle spin.[10] The present study uses a linear- spring dashpot model. The overlap scaled by a spring constant, provides a repulsive force coupled with a dashpot to dissipate a proportion of the normal energy in a collision. In a similar way, the tangential force has an incremental spring based on the tangential displacement and a dashpot to dissipate tangential energy. The DEM modelling gave predictions of the changes in the screw feeder performance due to changes in the parameters. It was assume that after some time, system reaches to steady state & gives constant output.

A. Comparison with Experimental Results

For Validating the Output given by computational study, results are compared with Millet seed experiment performed by Roberts and Wills. Effect of screw rotational speed on the screw conveyor output was evaluated by selecting four levels of rotational speeds.[3] Model used in the experiment was

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created and imported as triangular surface mesh in DEM package. Boundary conditions were applied and mass flow rate was calculated for each speed. The values of mass flow rate for the experimental and simulated results are plotted against screw rotation. There is excellent agreement between DEM and Experimental Results.

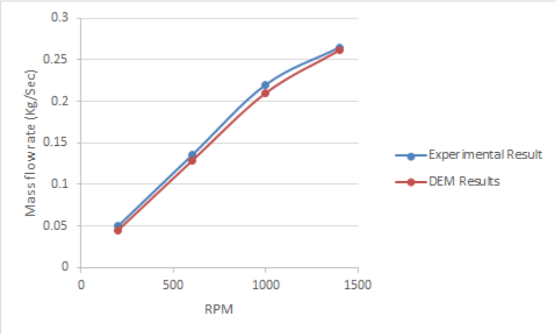

Fig 3: Comparison of DEM and Experimental Results

A series of DEM simulations was carried out to investigate selected parameters. Particles were modelled as spherical grains. After importing the CAD model in to DEM package, suitable boundary conditions were applied. Simulation run in a DEM solver. Depending on the complexity of the problem time taken by the solver may different. After solver phase, the simulations were ready for the post processing.

B. Effect of Clearance

Clearance is the space between outer diameter of the screw and the casing. Clearance is necessary to prevent metallic contact during rotation. It is also essential to avoid nipping or wedging of particles which could cause the extreme contact Pressure. Clearance can be maintained either by increasing the casing size or by reducing screw diameter. It was observed during this study that both approaches having different effect on the output. In previous investigation effect of clearance by increasing casing size was studied and presented here for reference. In this study we reduced the screw outer diameter to vary space between screw and casing. A series of simulations were performed to examine the effect of clearance on output of the screw feeder. The clearance range were selected as 0.75 to 8 mm in the increment of 0.25. The angular velocity of the screw was 60 rpm. The response parameter measured was mass flow rate.

C. Effect of Filling level in hopper

In screw feeder operation, material removed from the hopper by screw rotation. Filling level is height up to which material filled inside the hopper. Hopper can be either wedge-shaped hopper or conical shaped hopper. In this study effect of filling level for the conical shaped hopper was investigated. In previous study effect of filling level for wedge shaped hopper was studied and presented here for reference. Series of DEM simulations were performed. The hopper bin was filled at different filling levels and mass flow rate was calculated for each level. Screw was rotated at 200 rpm.

Results and Discussion

The flow behavior inside the screw conveyor examine quantitatively by measuring the mass flow rates of the particles when they are transported along the screw feeder. The mass Flow rate was determined by recording the mass of each particle that has passed through a plane perpendicular to the axis of the screw. Fig. shows the average mass flow rate of the particles versus clearance to c/D ratio (Clearance to screw Diameter). As mention earlier, effect of clearance by increasing casing size presented here for reference.

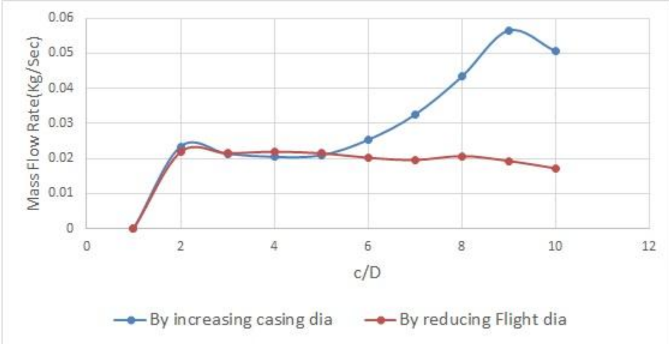

Fig 4: Mass Flow rate vs. Ratio c/D

In this study clearance was maintained by decreasing screw outer diameter. This approach does not show significant effect on the feeder output. Graph shows that, as clearance increases, output of the screw feeder remains almost constant and then decreased. As compared to earlier approach i.e.by increasing the casing size, for same c/D ratio we observed less mass flow rate by decreasing screw diameter. Output starts droping, when clearance value is much larger as compared with the grain size. To examine the effect of filling level of hopper, feeder output is plotted against filling level for conical shaped hopper.

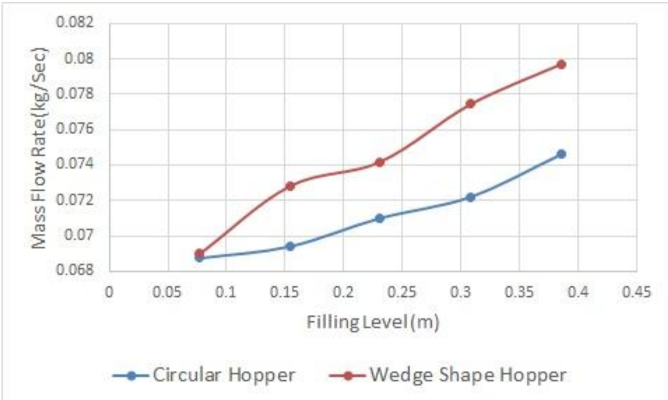

Fig 5: Mass Flow Rate vs. filling level

Effect of fiiling level for wedge shaped hopper is ploted here for reference. It was observe that with increase in filling level of hopper, feeder output increases. Conical hopper shows less output as compared to wedge shaped hopper.

CONCLUSION

This investigation shows that, the particle flow in screw feeder is reasonably sensitive to the parameters selected for study i.e. clearance and filling level. The output of the screw feeder for the different clearance values were studied and result compared with previous investigation. When screw diameter decreased to maintain the clearance, effective area also decreases hence results does not show significant increase in mass flow rate. For the much larger clearance values, slippage of the particles occurs in the clearance space and output starts dropping. Effect of level of bulk material inside the conical shaped hopper on mass flow rate was studied. Observation shows that mass flow rate increases slightly with increase in level of material inside hopper. On comparing result of conical shaped hopper with previous investigation, wedge shaped hopper shows higher mass flow rate.

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