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Prediction of screw conveyor performance using the Discrete Element Method (DEM)

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ABSTRACT

Screw conveyors are used extensively in agriculture and industry for transporting and/or elevating bulk materials over short to medium distances. They are very effective conveying devices for dry particulate solids, giving good control over the throughput. Despite their apparent simplicity, the mechanics of the transportation action is very complex and designers have tended to rely heavily on empirical performance data. 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. In this paper we examine how these operating conditions influence the performance of a screw conveyor by applying the Discrete Element Method (DEM) to simulate a single-pitch screw conveyor with periodic boundary conditions. The DEM modelling gives predictions of screw conveyor performance in terms of variations of: particle speeds, mass flow rate, energy dissipation and power consumption, due to changes in the operating conditions.

1. Introduction

Screw conveyors are widely used for transporting and/or elevating particulates at controlled and steady rates. They are used in many bulk material applications in industries ranging from industrial minerals, agriculture (grains), pharmaceuticals, chemicals, pigments, plastics, cement, sand, salt and food processing. They are also used for metering (measuring the flow rate) from storage bins and adding small controlled amounts of trace materials (dosing) such as pigments to granular materials or powders. If not designed properly for the transported material, problems experienced include: surging and unsteady flow rates, inaccurate metering and dosing, inhomogeneity of the product, product degradation, excessive power consumption, high start-up torques, high equipment wear and variable residence time and segregation.

The basic design of a typical screw conveyor has three major components:

(1) a hopper or bin;
(2) a stationary screw casing (tubular, open or covered trough); and
(3) a rotating screw.

Fig. 1 shows a 45° inclined screw conveyor with a tubular screw casing. The rotating screw draws down the bulk material from the hopper and transports it along the cylindrical tube to the discharge opening. A summary of current design methods and problems experienced for screw conveyors can be found in Bortolamasi and Fottner [1]. The description of the theoretical behaviour of screw conveyors can be found in articles by Yu and Arnold [2], and Roberts [3].

In this paper, we will use the Discrete Element Method (DEM) to analyse the performance of a screw conveyor in terms of: particle speed, mass flow rate, energy dissipation and power consumption. We also analyse the change in performance due to changes in the operating conditions. DEM modelling of particulate flow in a screw conveyor was first reported by Shimizu and Cundall [4]. They examined the performance of horizontal and vertical screw conveyors and compared their results with previous work and empirical equations. Owen et al. [5] introduced the use of a periodic slice model to explore the performance of a long screw conveyor. Cleary [6] used DEM to study draw down patterns from a hopper by a 45° inclined screw conveyor (as shown in Fig. 1). Cleary [7] extended this work to examine the effect of particle shape on the draw down flow from the hopper and on the transport characteristics of the screw conveyor. Here we extend the original work of Owen et al. [5] to look at the detailed operational performance of a screw conveyor including quantitative variation of flow characteristics with fill level, angle of inclination and rotational speed.

2. Model description

DEM simulations involve following the motion of every particle (coarser than some cut-off size) and modelling each collision between the particles and between the particles and their environment (e.g. the internal surface of the screw casing and the surface of the rotating screw). The boundary geometry is built using a CAD package and imported as a triangular surface mesh into the DEM package. This

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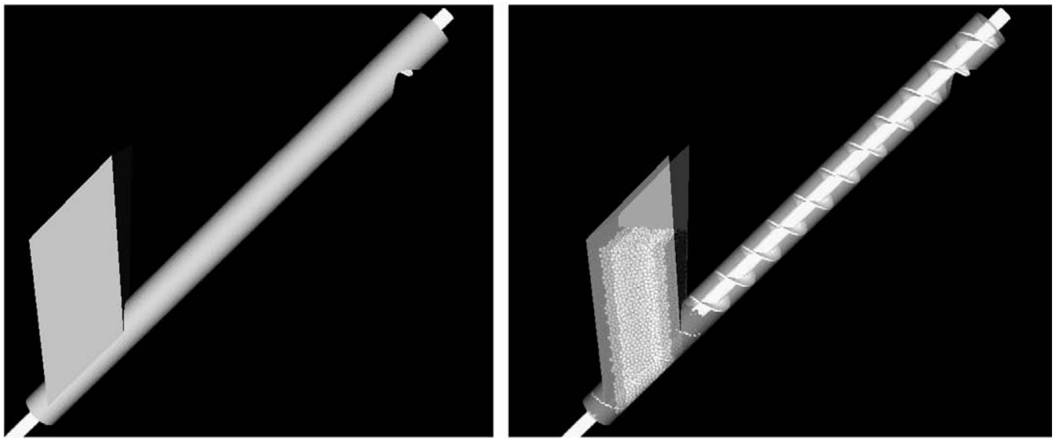

Fig. 1. Inclined screw conveyor: (left) external view showing hopper and screw casing, (right) internal view showing screw and particulate material.

provides unlimited flexibility in specifying the three dimensional geometries with which the particles interact. Here the particles are modelled as spheres. The DEM code used here is described in more detail in Cleary [6,8,9].

The screw conveyor used in this study was a standard pitch, single flight screw conveyor with dimensions similar to the one used by Roberts and Willis [10] in their experiments. The pitch of the screw is defined as the length, along the drive shaft, of one turn of the helical blade, as shown in Fig. 2. A standard pitch screw has its pitch equal to the outer diameter of the helical blade.

The DEM model was simplified by applying periodic boundary conditions to a single pitch of the screw as shown in Fig. 2. The diameter and the pitch of the screw were 38 mm, the diameter of the screw shaft was 13 mm, and the blade thickness was approximately 1 mm. The internal diameter for tubular case was 40 mm, giving a gap of about 1 mm between the outer edge of screw blade and the internal surface of the casing.

Roberts and Willis [10] used millet (a grain that is very close to spherical in shape) for the dry particulates in their experiments. The diameters of the spherical particles used here ranged from 2 mm to 3 mm, were uniformly distributed on a mass weighted basis, and had a density of 700 kg/m^3 to best match the millet used in these experiments. The particle–particle and particle–boundary frictions used for these DEM simulations were 0.7 and 0.5, respectively; and the particle–particle and particle–boundary coefficients of restitution were 0.1 and 0.3, respectively. 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.

A series of DEM simulations was carried out for a range of screw conveyor operating conditions. Three different rotational speeds and three different volumetric fill levels were used, and the inclination of the screw conveyor was varied from 0° to 90° in steps of 10°. Table 1 summaries the series of operating conditions simulated in this study. The DEM modelling gave predictions of the changes in the screw conveyor performance due to changes in the operating conditions in terms of variations of: particle speed, mass flow rate, energy dissipation and power consumption.

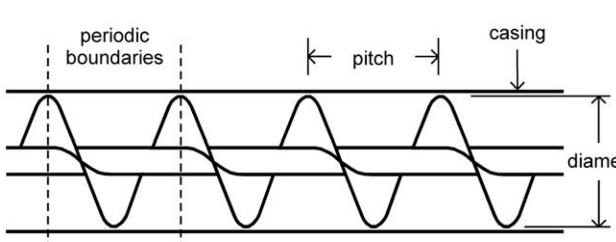

Fig. 2. Standard pitch — single flight screw conveyor (pitch equal to diameter).

3. Particle distributions within the screw conveyor

Fig. 3 shows the distribution of the particles inside the screw conveyor for a 30% by volume fill level and with the screw rotating at 1000 rpm for angles ranging from horizontal to vertical. The particles are coloured according to their diameter, with the smaller particles (~2 mm diameter) being light grey and the larger particles (~3 mm diameter) coloured dark grey. Note that the change inclination was obtained by changing the orientation of the gravity vector. The screw therefore remains in the same position and orientation in the pictures allowing easier comparison of the flow patterns. The first frame, Fig. 3 (a), shows the particle distribution inside a horizontal screw conveyor. In each subsequent frame the inclination is increased until the screw conveyor is vertical in the last frame, Fig. 3(f).

For the horizontal screw conveyor (Fig. 3(a)) the particles form a heap against the leading face of the screw. After reaching the top of the screw most of the particles tumble down the surface of the heap and a few particles fall behind the screw shaft as pictured. There is a slightly higher concentration of smaller (lighter grey) particles in contact with the leading face of the screw and a higher concentration of larger (darker grey) particles in the outer parts of the heap. This indicates that the particles have become mildly size segregated due to shear generated by the face of the screw. The extent of the size segregation reported by Owen et al., [5] for a larger (125 mm) screw conveyor rotating at 60 rpm with particle sizes ranging from 2 mm to 5 mm, was more pronounced than it is for this screw conveyor.

The next three frames of Fig. 3 show the changes in the distribution of the particles as the inclination of the screw conveyor is increased to 30° in 10° steps. Fig. 3(b), (c) and (d) shows the heap in front of the leading face of the screw blade progressively redistributing as the inclination of the screw increases, with less material at the bottom near the casing and more material near the top. The free surface of the bed of particles becomes increasingly aligned with the angle of the screw blade. As the inclination of the screw increases more particles

Table 1
Screw conveyor operating conditions.

rpm	Fill level (%)	Number of particles	Screw conveyor inclination to horizontal
600	30	907	0° to 90° in steps of 10°
1000	30	907	0° to 90° in steps of 10°
1400	30	907	0° to 90° in steps of 10°
1000	50	1440	0° to 90° in steps of 10°
1000	70	2012	0° to 90° in steps of 10°