

Investigation of effect of particle shape on the screening performance of vibratory screens using the DEM approach

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Abstract. The efficiency of a screening process affects the efficiency of downstream processes, reduces variability in system, improves throughput and quality, reduces waste generation and cost. Among the factors affecting screening efficiency of bulk materials, particle shape is a major one. The particle shape influences particle bed formation and its packing. This in turn decides the porosity and permeability of the bed. It influences two key mechanisms of screening process i.e., particle stratification and passage of fine particles. For obtaining higher screening efficiency, better stratification and higher passage rate is required. Stratification of particles, where larger particles rise to the bed and finer particles migrate down and finally pass through it, depends on vibrating conditions of screen. The effect produced by these vibrations on the particle bed depends on particle characteristics as well as inter-particle and particle-screen interactions. Particle shape is important as different shapes may behave differently under similar vibrating conditions. In this work, a comparative study of behavior of particle shapes for multiple vibrating parameters is done. The varying vibration parameters include different vibration motion types (linear, circular and elliptical). Using DEM methodology, the microscopic parameters like residence time and particle-deck collisions were studied. This microscopic information is used to predict the macroscopic screening performance for different particles' shape.

1 Introduction

Screens play a critical role in a wide range of industries. The process is affected by numerous factors which include material properties, design parameters and vibration parameters [1 & 2]. Discrete Element modelling (DEM) is one of the modelling approaches used to study screening process [3, 4, 5 & 6]. It is known for its ability to capture microscopic events (inter-particle interaction forces) and convert them into macroscopic events like particle flow, separation by size etc. Previously, studies involving the effect of vibration motions during screening have been conducted [7, 8, 9, 10 & 11]. In addition, scientists have used non-spherical particles in their simulations [10, 11 & 12]. However, these studies do not present a clear picture regarding the effect of different vibration motions on sieving behavior of particles of different shapes. So, the current work aims to present a comparative analysis of screening process under three vibration modes (linear, circular, elliptical) for different particle shapes using DEM.

2 Numerical Modeling

2.1 Discrete Element Modeling

Discrete element method is a computational technique which treats the material as discrete, individual particles and tracks motion of all individual particles over small time steps. It is governed by Newton's second law of motion and Euler's second law of motion for rotational motion of particles [13]. In this case, the Hertz-Mindlin no-slip contact model has been used. At any point of time, considering contact between spherical particles, the force balance and torque balance on the *i*th particle which is in contact with *k* number of particles can be expressed as

$$m_i \frac{d\vec{v}_i}{dt} = m_i \vec{g} + \sum_{j=1}^k (F_{cn,ij} + F_{dn,ij}) \hat{n}_{ij} + \sum_{j=1}^k (F_{ct,ij} + F_{dt,ij}) \hat{t}_{ij} \quad (1)$$

$$I_i \frac{d\vec{\omega}_i}{dt} = \sum_{j=1}^k (\vec{T}_{t,ij} + \vec{T}_{r,ij}) \quad (2)$$

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where m_i , v_i , I_i and ω_i represent mass, velocity, moment of inertia and angular velocity respectively of the i^{th} particle. The collision force between any two particles is divided into two components i.e., normal force (acting along direction of vector joining the center of particles) and tangential force (acting in direction perpendicular to normal force). Both these forces are modelled as a spring and a dashpot in parallel. The spring represents elastic part and dashpot represents damping part of the force. So, $F_{cn,ij}$ and $F_{dn,ij}$ represent elastic component and damping component of normal force respectively, and similarly $F_{ct,ij}$ and $F_{dt,ij}$ for tangential force. Additionally, $\vec{T}_{t,ij}$ and $\vec{T}_{r,ij}$ represent torque due to tangential force and rolling friction respectively.

2.2 Simulation Conditions

The 3-D model of the screen panel with circular apertures of diameter 10 mm and the screen set-up used in simulations is shown in Fig 1 (a) & Fig 1 (b) respectively.

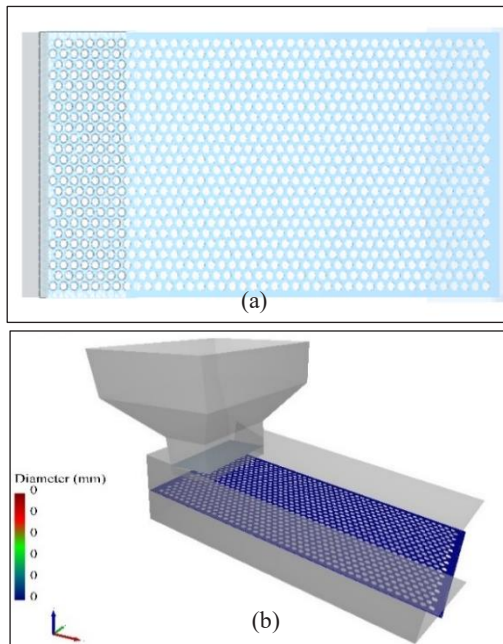


Fig.1: (a) 3-D Design of screen panel used in simulation; (b) 3-D set-up of the screening system used in simulation.

The key geometric parameters of the screen are provided in Table 1.

Table 1. Key Geometric parameters of the screen (existing process)

S. No.	Parameters	Value
1	Screen length	610 mm
2	Screen width	305 mm
3	Vibration frequency	11.63 Hz
4	Vibration type	Linear, circular & elliptical
5	Feed rate	600 tones per hour
6	Screen Inclination	10 ° with horizontal line

As pellet particles are roughly spherical in shape, hence they have been used as spherical particles in simulations whereas sinter particles are non-spherical particles (Fig 2(a & b) & Fig 2(c & d)). The DEM material parameters for both types of particles used in simulations are listed in Table 2. The values are taken from previous studies [14] where detailed work on calculation and calibration of material parameters was done.

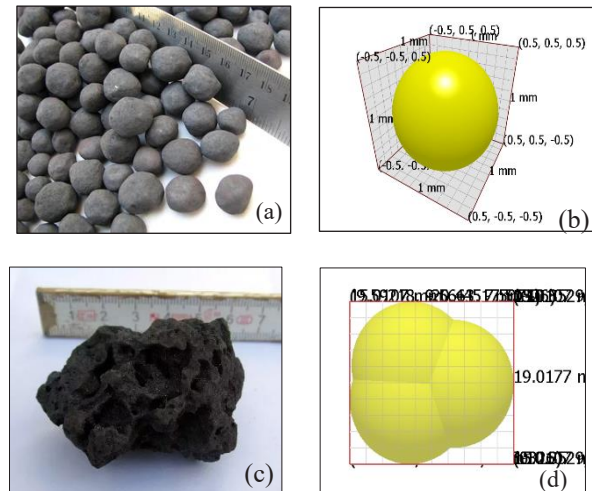


Fig. 2 (a) Real spherical particles: pellet particles; (b) 3-D model of spherical particles; (c) real non-spherical particles: sinter particles & (d) 3-D model of non-spherical particles

Table 2. DEM input parameters both material specific (particle-particle) and interaction parameters (particle-screen deck) used in DEM simulations.

Parameters	Pellet-pellet	Pellet-Deck	Sinter-sinter	Sinter-deck
Solids Density (ρ , kg/m ³)	3700	7800	3700	7800
Poisson's ratio (ν)	0.25	0.2	0.25	0.2
Coefficient of restitution (ϵ)	0.6	0.5	0.4	0.5
Coefficient of static friction (μ_s)	0.49	0.8	0.7	0.38
Coefficient of rolling friction (μ_r)	0.06	0.06	0.12	0.12

The same feed size distribution as given in Figure 3 have been used for both the particle shapes. It shows the high percentage of near-mesh particles in the feed. Same set of simulations are performed for both the particle types. In the present study, the X-Y plane was taken as screen plane with Z-axis perpendicular to it. This means that during linear motion displacement is only in Z-direction i.e., perpendicular to screen plane and no displacement along screen plane (X-Y plane). Though, for circular and elliptical motions, the displacement was in both directions i.e., perpendicular to screen plane (Z-direction) plus along screen plane (X-direction).

However, for circular motion the value of displacement in both planes is equal whereas for elliptical motion these are unequal. So, the key difference in the three vibration motions is value as well as direction of displacement [15]. Following this, the sinusoidal translation motion was chosen with fixed frequency and amplitude/ displacement in selected axes during the simulations. The details of the vibration motions are given in Fig. 4.

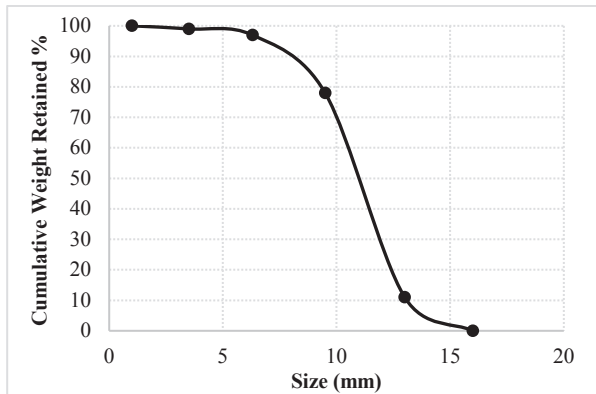


Fig. 3: Particle Size Distribution of the two samples

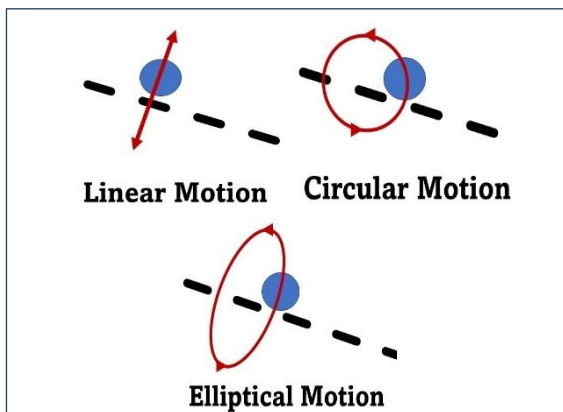


Fig. 4: Description of the three types of vibration motions

3 Results & discussion

The snapshots of the simulations for spherical and non-spherical particles are given in Fig. 5 (a) & 4(b) respectively. The sieving behavior of the particles can be observed in Fig. 6 which shows the screening efficiency for both the cases. In both cases, circular and elliptical motions give better results than linear motion. This is due to the different vibration force profile in each case. In linear motion, forces act on the particles only in the perpendicular direction to the surface of screen. However, in circular and elliptical motions, vibration forces act in all directions like the centripetal motion of a particle moving in a circle. This back-and-forth motion provides more residence time (Fig 7 (a) & (b)) for the particles on the screen which in turn results in higher encounters of the particles (Fig. 8) to the screen surface. Further, in this case where the feed is composed of high near-mesh particles, higher number of particle-deck

collisions leads to higher probability of passage of such hard to pass particles as per the screening theory [16 & 17]. Moreover, it can be observed from Table 2 that the coefficient of rolling friction of non-spherical particles is double the value of that for spherical particles. This means that spherical particles roll down the screen plane much faster than non-spherical particles. In literature it can be found that non-spherical particles undergo multiple orientations during screening which makes their probability of passage higher than spherical particles [18]. Thus, the combined effect of vibration motion type and particle shape result in maximum screening efficiency of non-spherical particles during circular and elliptical motions.

Previously, Miwa [19] & Dong [17] predicted the number of attempts (N_A) i.e., particle-deck collisions, required by a particle to pass through the screen surface in terms of various parameters like amplitude, frequency, particle diameter, aperture size and open area of screen surface. This shows that screen design parameters like the aperture shape and open area of the screens also affects the number of attempts and other related output parameters like mean residence time.

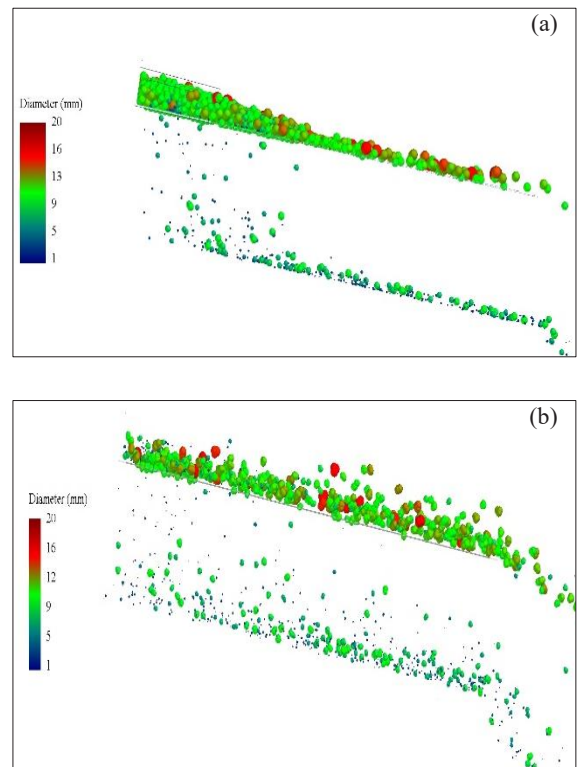


Fig. 5. Snapshot of DEM simulation for (a) spherical particles; (b) non-spherical particles.

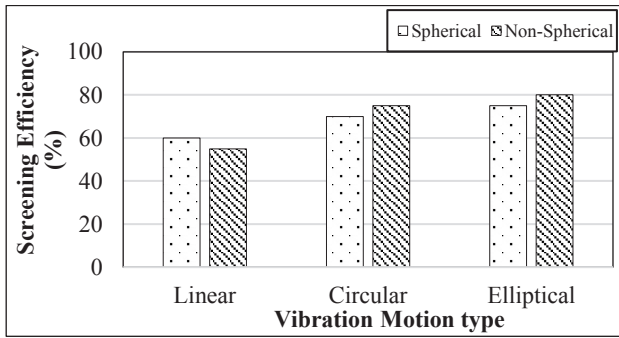


Fig. 6. Screening efficiency for spherical and non-spherical particles at different vibration motions.

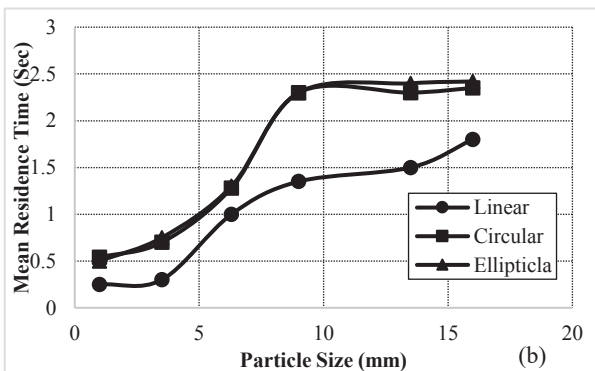
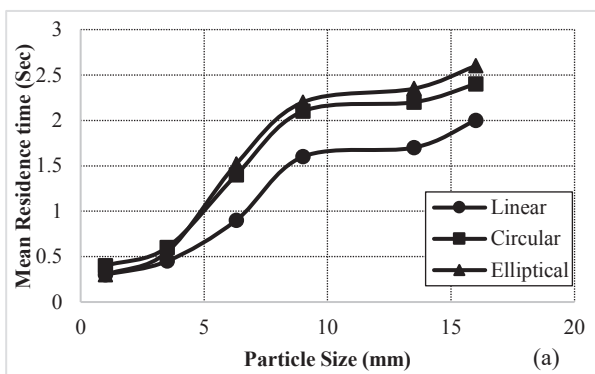


Fig. 7: Mean Residence Time Distribution (a) For Spherical Particles; (b) For Non-spherical particles.

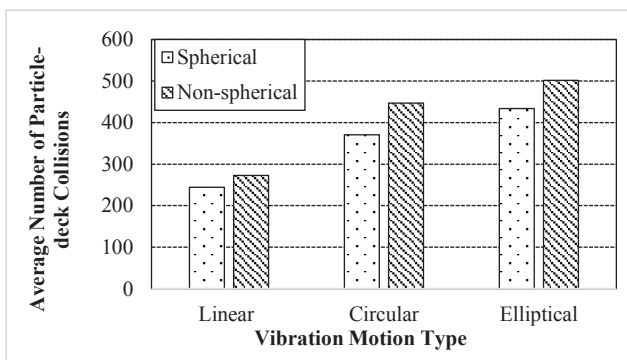


Fig. 8: Average number of particle-deck collisions for both particle shapes

4 Conclusion

The current study explored the impact of vibration motion types on the screening performance of two different particle shapes. The results that for both non-spherical and spherical particles circular and elliptical motions give better screening performance as compared to linear motion for a feed with higher near-mesh particles. This work acts as a framework for better selection of screen parameters as per the particle shape. However, further investigation is required to establish a relationship between parameters like the residence time or number of attempts for different motions considering the effect of screen design parameters as well.

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