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Employing DEM to study the impact of different parameters on the screening efficiency and mesh wear

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A B S T R A C T

Discrete element method (DEM) was employed in modeling vibrating screen, in order to study the effects of different parameters on the process efficiency and the mesh wear. A review was provided about modeling the contact force between colliding bodies. However, Hertz elastic and Kelvin–Voigt viscoelastic models were combined for the purpose of this study. Gear's approach was used in the numerical integration of the governing equations. The required programs were developed to perform the simulations using an open source code. Factors affecting numerical computations were tuned to achieve suitable values and obtain reliable results in the numerical studies. In the section of numerical studies, several simulations were built to reveal the effects of mesh slope, vibration frequency and excitation direction on the screening efficiency and wear of the screen mesh. Results related to the dependence of the efficiency on vibration frequency, excitation angle and mesh inclination were in agreement with those of data reported in open literature. However, no comparable data was seen with regards to the wear of the screen mesh. It was observed that most of the introduced parameters affect the efficiency and wear. The results were appropriately discussed and were presented graphically using diagrams and graphs. The conclusions and methodology of this study can be employed in both practical and theoretical fields.

1. Introduction

Screening, or in other words sorting the particles in terms of their sizes, is a common process in many industries such as petrochemical, agricultural, pharmaceutical and mineral processing plants. As a practical example, this equipment is used for sorting iron pellets in different sizes so as to feed the rest of the production lines. Clearly, adequate knowledge of the process enables us to design screening devices with higher efficiency and service life. Moreover, such information can be used in setting machines working parameters to achieve higher efficiency. According to the literature review, many researchers have studied screening processes and devices, employing different approaches. Experimental approach is reliable but expensive and difficult to perform due to requirement of special equipment with the potential of tuning influential parameters. On the other hand, analytical methods for modeling granular media take a limited number of particles into account while generally a huge number of particles participate in a real process. Alternatively, numerical methods such as discrete element method (DEM), also referred to as molecular dynamics (MD), can be employed in simulating processes containing large numbers of particles and complex domains. In fact, such method acts as a virtual experimental setup providing quasi-experimental data with acceptable accuracy. However, requirement of powerful computer hardware and long simulation time are hindrances in applying such technique. Nonetheless, recent developments in electronics and computer technology, and the introduction of new programming techniques such as parallel computing have helped to overcome the aforementioned problems.

Actually, the progress in computer science has recently facilitated the application of DEM which was itself developed many years ago [1]. Among the first publications regarding the numerical simulation of screen, Li and co-workers studied the effects of input charge and screen length on the process efficiency by means of discrete element method [2]. Chen and Tong employed DEM to study the effects of screen length and vibration frequency on the screen efficiency [3]. Based on their results, with increasing the vibration frequency, screen efficiency is reduced. According to DEM results reported by the same researchers, the relationship between linear vibration frequency and efficiency of the screen is almost exponential [4]. Dong and co-workers simulated a multi deck screen to numerically study the influence of vibration frequency, amplitude and excitation type on the screen efficiency [5]. In summary, based on their results, decreasing of vibration frequency and amplitude led to an increase in the screening efficiency. Furthermore, they showed that rotational vibration provides a better efficiency compared with linear vibration. Cleary and co-workers employed DEM to study the effects of acceleration on the kinetic energy of particles in a multi deck screen [6]. Guifeng and Xin showed that the screen efficiency increases with the rise in the screen length [7]. They proved that screen length has no strong effect on the efficiency for low excitation

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frequencies. Employing DEM, Zhao and co-workers and later Xiao and Tong showed that increasing of the screen mesh slope leads to a decrease in the screening efficiency [8,9]. Dong and Yu simulated the flow of granular materials on a screen mesh using DEM, and evaluated the effects of horizontal and vertical vibration on the screen efficiency [10]. They concluded that the amount of underflow particles increases by reducing the vibration frequency. Delaney and co-workers employed experimental approach and DEM to study the effects of different parameters on the screening processes [11]. They concluded that for low flow rates, DEM results are close to experimental ones. Furthermore, they showed that using spherical particles might be inadequate to model non-spherical realistic particles, especially for high flow rates. Emden and Elskamp made non-spherical particles by clustering spherical shapes to simulate screening of such particles using DEM [12,13]. They indicated that the screening rate is higher for spheres than cylinders and double cones while they have equivalent volume.

2. Problem description

Fig. 1 indicates the schematic of the screen mesh and its associated parameters. As depicted, the mesh surface has the inclination angle of β with respect to the horizontal plane. Harmonic excitation with the angle of α creates a linear vibration with frequency of ω (rad/s) or f (Hz). The particles are spherical with various diameters; drop on the left side of the mesh with square shape apertures, and the overflow particles go out at the right side of the screen along the 'X' direction. The objective of the current study is to study the process efficiency and the wear of the screen mesh. In this regard, the influence of different tunable parameters including linear vibration frequency, excitation angle and the mesh slope were numerically studied.

3. Modeling

As a matter of fact, particles participating in the screening process interact with each other, the mesh surface and screen walls. Based on the theory of molecular dynamics (MD) or in other words, discrete element method (DEM), potential functions were introduced to represent the interacting forces between the particles. It is noted that the name DEM is used in conditions that only direct contact forces exist in the system, such as the current case. In classical mechanics, six kinetic equilibrium equations exist for each particle and can be presented in the following mathematical forms for ith particle.

$$\ddot{\vec{r}}_i = \frac{1}{m_i}\vec{F}_i; \quad (i \neq j = 1, \ldots, N) \tag{1a}$$

$$\ddot{\vec{\varphi}}_i = \frac{1}{J_i}\vec{M}_i \quad (i \neq j = 1, \ldots, N). \tag{1b}$$

In the above equations, $\vec{r}_i$, $\vec{\varphi}_i$, m_i and J_i represent, respectively the position vector, rotation vector, mass and moment of inertia pertaining to the ith particle. Moreover, $\vec{F}_i$ and $\vec{M}_i$ are the vectors of the resultant force and moment exerted on ith particle. It should be noted that the resultant contact force and moment on ith particle are the sum of the forces and moments exerted by other particles and walls as follows:

$$\vec{F}_i = \sum_{j=1, j\neq i}^{N'} \vec{F}_{ij} \tag{2a}$$

$$\vec{M}_i = \sum_{j=1, j\neq i}^{N'} \vec{M}_{ij}. \tag{2b}$$

In the above, $\vec{F}_{ij}$ and $\vec{M}_{ij}$ are the force and moment vectors exerted on the ith particle from the jth particle or wall element, and N' is the number of neighbor particles and wall segments in contact with ith particle. Consequently, since there are six governing equations for each particle, a set of 6N ordinary differential equations is formed for the system of N particles. Solution of these equations provides the history of position, velocity, and acceleration vectors of each particle with respect to time. It is worth mentioning that the knowledge of exerted forces and moments on all particles is an essential requirement for the development of the governing equations. In the next subsection, the methodology for determining the contact force is explained.

3.1. Contact force

Due to the elastic and/or damping properties of the particles, they become deformed when they collide and a contact zone is formed as shown in Fig. 2. During the collision, a normal interacting force is

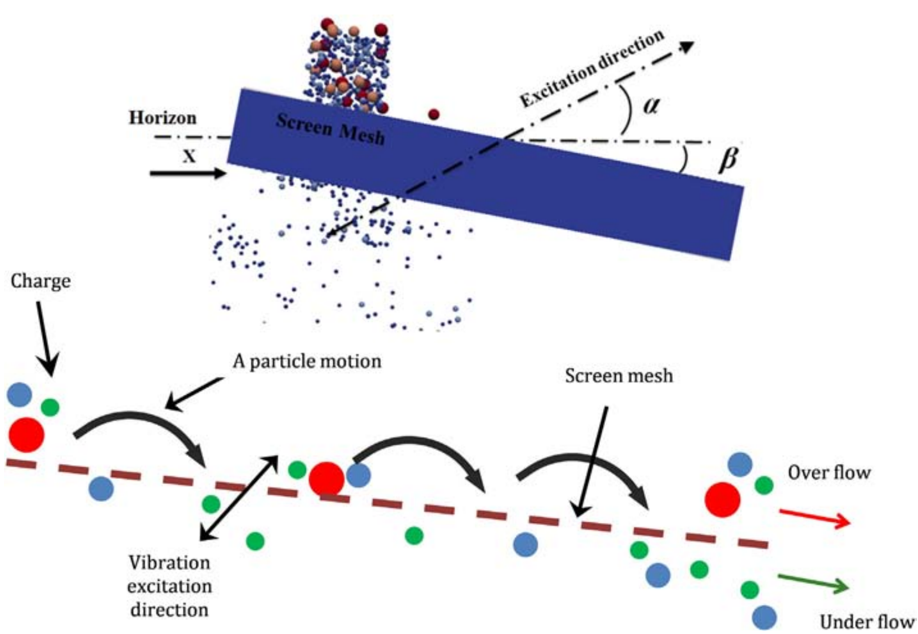

Fig. 1. Schematic side view of the screen mesh and particles.