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Discrete element modelling of vibrating screens

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ABSTRACT

Screening is one of the most widely used unit operations in mineral processing plants. In crushing circuits, the proper selection and sizing, optimization and their operation as efficient as possible are essential in terms of the performance and profitability of the crushing circuit and the whole plant.

There are various empirical models used for the sizing and the performance prediction of the screening operation. Due to the high margin of errors during calculations and assumptions based on empirical models and owing to the continuous increase in the computational capacity of computers, the numerical methods such as discrete element method have been increasingly used for the simulation of screening. However, there is still a deficiency in the literature in the area of the pilot or industrial scale validation of simulation results.

In this study, the effects of various design and operating variables (namely, feed rate, deck inclination, vibration frequency, amplitude and direction, aperture size) on the efficiency of screening are investigated by means of DEM simulation of industrial vibrating screens. Spherical and irregularly shaped particles (multi-spheres) were used in the simulations. Additionally, the prediction capability of the simulator was revealed based on the validation tests conducted on a pilot scale vibrating screen.

1. Introduction

Screening is one of the most common unit operations in mineral processing plants. It is used for various purposes starting from the production at the mine site until making it suitable for use as a definite end-product. Classification, size limitation of crusher feed, dewatering, slime cleaning, solid recovery, washing and etc. are some of the main utilization purposes of screening in mineral processing plants (Mular et al., 2002). Screening is widely applied in ore preparation and many other areas (food, textile, etc.). The design, sizing and separation efficiency of screens has a direct effect on the quantity and properties of the target products, the total power consumption and the efficient operation of the crushers and consequently the profitability of the mineral processing plant.

The role and importance of screening in whole mineral processing operations had been resulted in many modelling attempts. There are different approaches to the modelling of the screening process. Probabilistic and kinetic models were one of the first attempts in the modelling of screening as a phenomenological process (Whiten, 1972) and (Ferrara and Perti, 1975). On the other hand, empirical or capacity models approach the screening process modelling by investigating the effect of different variables on the screening performance experimentally. Karra (1979)'s model is one of the most popular examples of these models. These kinds of models are used mostly by screen manufacturers and as they have been developed for a specific type of screen, they should be used as a guide only (Wills and Napier-Munn, 2006).

Limitations of phenomenological and empirical models in representing realistic simulations and increasing computational capacity of computers led to the popularity of particle-based simulation approaches such as the discrete element method (DEM) in mineral processing which was first introduced by Cundall (1971) and the details of which are given by Cundall and Strack (1979).

DEM is appropriate for screening operation because it is capable of reflecting dynamic processes associated with screening such as segregation, passage and transport by providing necessary parameters. As a result, it is possible to have a deep insight through screening, as well as optimizing operation and design parameters (Elskamp and Kruggel-Emden, 2015).

One of the first applications of DEM on screening was the studies of Shimosaka et al. (2000) where 3D batch simulations were performed with a limited number of particles. The first attempts to simulate continuous screens were performed by Li et al. (2002, 2003). In these studies, the effects of single particle size and near-mesh particles by the look to the thickness of the bulk particle layer in screening performance were investigated. Cleary investigated the performance of double deck banana screen at different acceleration values (Cleary et al., 2009a,b). Additionally, Dong and Brake (2009) simulated a multi-deck banana screen by studying the effects of operational conditions and geometry

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on the screening performance. The effects of screen motion parameters like vibration amplitude, frequency and direction for linear and circularly vibrating screens investigated by Chen and Tong (2010) and Zhao et al. (2011) respectively. Validation of obtained data from DEM simulations against experimental data without scaling up is rare in the literature and limited to the studies of Delaney et al. (2012) and Zhao et al. (2016). Also according to Elskamp and Kruggel-Emden (2015), Hilden (2007) validated DEM application to screening process successfully. Fernandez et al. (2011) and Dong and Yu (2012) tried to couple DEM with SPH (smoothed particle hydrodynamics) and CFD (computational fluid dynamics) to simulate wet banana screens and sieve bends respectively. There are some studies utilizing non-spherical particles to increase the reality of DEM simulations in recent years. Kruggel-Emden and Elskamp (2014), Elskamp and Kruggel-Emden (2015) and Zhao et al. (2017) used non-spherical particles and found more realistic results compared to the experimental data.

This study will address the effects of some operational and design parameters like feed flowrate, screen deck inclination, vibration amplitude, vibration frequency and vibration direction on the performance of an inclined vibrating pilot scale screen. Open source LIGGGHTS software was used for performing DEM simulations. During the simulations, both spherical and irregularly shaped particles were studied. The irregularly shaped particles were modelled using multi-spheres (sphere clumps). The effects of different parameters on screening performance were tried to be explained with familiar terms for minerals engineers (partition curve, screening efficiency, mean residence time of passing particles and etc.). The validity of the DEM simulations has been tested by experimental data. The actual (experimental) data was compared to the simulation results using screening efficiencies and partition coefficients.

2. Pilot-scale vibrating screen geometry and simulation conditions

In this study, a pilot-scale vibrating inclined screen, which is available in the mineral processing laboratory of Hacettepe University, was used to perform validation tests. The typical Hertz-Mindlin particle contact model is used in this work as described in details in (Jahani et al., 2015). Open source LIGGGHTS solver was used to perform DEM simulations. In order to run the simulations under the same conditions, 3D models of the screen was prepared. Fig. 1 shows real and CAD illustrations of the screen and available feeding system. This polyurethane screen surface consists of six square panels in length and two in width, which gives 90 × 30 cm dimensions. The opening of the screen is 10.5 mm and the inclination of the screen surface is 10° which is adjustable. The feeding system consists of a bunker and vibrating feeder, which can provide up to 15 tons per hour of dry feed below 30 mm. The data used for setting up the DEM simulations are summarized in Table 1.

Table 1
The data used in DEM simulations.

Particle size (mm)	26.6	20.6	15.7	12.1	9.5	6.7	4.7	2.8
Feed size distribution (%)	10	10	20	8	14	14	14	10
Feeder height (mm)	275							
Vibration type	Linear (oscillatory motion)							
Screen aperture (mm)	10.5							
Particle density (kg/m^3)	2700							
Young's modulus (N/m^2)	5×10^7							
Poisons ratio	0.45							
Coefficient of restitution	0.3							
Sliding friction coefficient	0.5							
Rolling friction coefficient	0.01							
Time Step (s)	5×10^{-6}							
Simulation Duration (s)	In the range of 25–35 s							

Several simulations were performed for the testing of the model parameters (such as Young's modulus, time-step, Poisson's ratio, etc.) in accordance with the former studies in the literature and also to maintain a reasonable time-step based on Rayleigh time step in order to achieve reasonable simulation times.

To investigate how different parameters affect screening performance, various simulations were carried out at various feed flowrate, screen deck inclination, vibration amplitude, vibration frequency and vibration direction values while keeping the other parameters constant. In the experimental tests, −30 mm crushed aggregate samples were used. During the initial simulations, the particles were assumed as spherical particles. Table 2 shows the values of parameters used in simulations.

A simulation begins by creating and discharging the particles from the feeder. The particles that reach the screen surface will either pass the surface or flow along the screen towards the discharge end. It is important to evaluate particles motion data after achieving macroscopic steady state at which the inlet flow rate is equal to the sum of the flowrates of oversize and undersize streams for each size fraction. Fig. 2 shows the typical illustration of simulations.

At the end of the simulations, precise information such as the coordinates of each particle at each time step, the residence time of a particle or particle size class on the screen surface, whether the screen is at steady state, etc. are obtained.

3. Results and discussion

The simulations produce huge amount of data such as location,

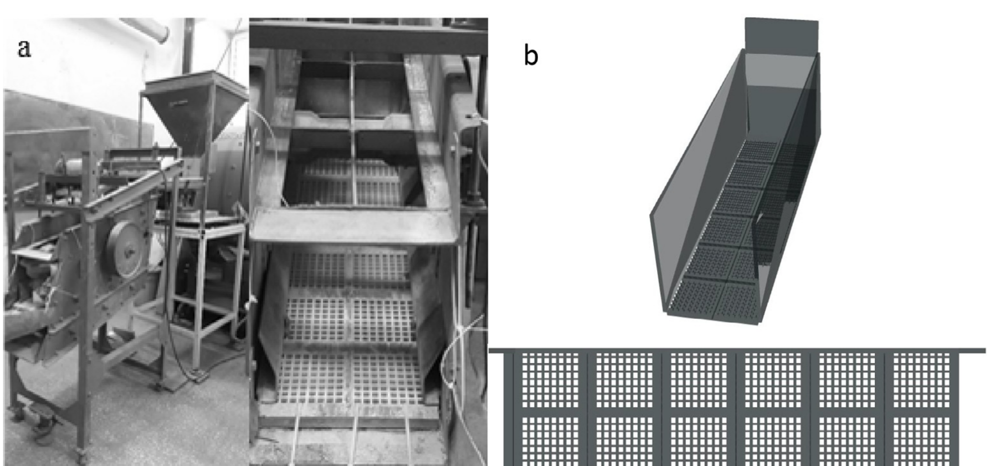

Fig. 1. Real (a) and CAD (b) versions of vibrating screen and feeder system.