International Journal of Mining Science and Technology 22 (2012) 357–362

Contents lists available at SciVerse ScienceDirect

International Journal of Mining Science and Technology

journal homepage: www.elsevier.com/locate/ijmst

Particle stratification and penetration of a linear vibrating screen by the discrete element method

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ARTICLE INFO

Article history:
Received 12 September 2011
Received in revised form 6 October 2011
Accepted 25 November 2011
Available online 4 May 2012

Keywords:
Fine particle ratio
Stratification
Penetration
Structural parameter

ABSTRACT

A simulation of stratification and penetration was performed over a range of structural parameters that included screen width, aperture size, inclination angle, and wire diameter. The discrete element method (DEM) was used for the simulations. The terms stratification and penetration are defined and the change in fine particle concentration is discussed. Mathematical models relating fine particle ratio to time are established using the least squares method. The effect of structural parameters on fine particle ratio is analyzed. Stratification and penetration rate are discussed by considering the time derivative of the fine particle ratio. The conclusions are: an increase in inclination or wire diameter has a positive effect on particle stratifying; The optimal screen width is 40 mm for particle stratification; The inclination angle has a negative effect on the penetration; The effect of wire diameter and screen width on the penetration rate is negligible.

1. Introduction

Stratification and penetration are the two main processes that occur during particle screening. At the start of sieving, these two processes happen immediately but there is a change in proportion as particles move along the screen length. In previous work, stratification was defined as the fine particles passing through the big particles to form the particle segregation layers. The process whereby the particles pass through the apertures to become undersize particles was defined as penetration. This paper focuses on studying the movement of fine particles during stratification and penetration.

Screening is composed of two regions: a "crowded" region and a "separated" region [1,2]. This is similar to the processes of stratification and penetration. Stratification in a vibrated bed with different particle sizes, and the transport of fine material into and out of the bottom layer, has been studied [3]. Early works explored particle properties and their impact on stratification and penetration. These properties included shape, size, and size distribution. Soldinger established a model to account for the effects of material loading and particle size distribution on stratification and separation [4]. He explained the influence of fine particles, and the material layer thickness, on stratification rate and particle passage through the apertures. Rosato and Kunio described the crucial effects of discrete particle motion on screening efficiency and identified how grain segregation occurs in the material layer and how undersized particulates approach and ultimately pass through the apertures [5,6]. Khan experimented with binary mixtures of sand particles [7]. Lawrence and Beddow determined the effect of particle shape and density on stratification in a mould [8]. Rao has presented several factors that influence the stratification process, such as particle size, shape, and density [9].

The process of stratification and penetration has also been studied in terms of vibration parameters and screen length. Subasinghe divided the screen length into three regions and explored the phenomenon of stratification and penetration in each of the three regions [10]. Li studied the effect of particle bed depth on the screen length in a penetration screening operation [11]. Li also divided the screen length into 10 parts and then examined the number of particles passing through the apertures in these different regions along the screen [12]. Dong has presented a numerical study of particle flow on a banana screen as a function of vibration parameters including frequency, amplitude, and type of vibratory motion [13]. DEM was used for that study and the role of each parameter on screening efficiency was determined. Jiao and Zhao study the particles screening with DEM simulations [14]. They further discussed the penetration behavior of particles in a screen plate [15]. Chen and Tong also explored the relationship between vibration parameters and screen efficiency based on DEM simulations [16].

2. Simulations

2.1. Simulation model

As shown in Fig. 1, a 3D model was used to simulate particle screening. During simulation particles were generated by the par-

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2095-2686/$ - see front matter © 2012 Published by Elsevier B.V. on behalf of China University of Mining & Technology.
http://dx.doi.org/10.1016/j.ijmst.2012.04.013

ticle factory to fall on the screen surface under the influence of gravity. This study employed a mixture of two different sized, spherical particles. The particles had a bimodal, normal distribution with individual mean diameters of 0.5 and 1.0 mm. The standard deviation of the two particle sizes was 0.45. The particle density was 2678 kg/m^3, which is similar in density to sand. During each simulation 30,000 particles were generated by the factory. The initial velocity of particles is calculated according to the set feeding rate. The particle velocities in the x, y, and z directions were assumed to be $v_x = v_y = 0$ and $v_z = -0.01$ m/s. However, velocities in all three dimensions change due to the vibration.

A series of simulations was carried out where screen width, aperture size, inclination, and wire diameter were varied. The conditions and parameters are listed in Table 1. Four groups of structural parameter simulations were performed. Each group of simulations only changed one parameter value while the other parameters were kept constant. The first group used various screen widths, which included widths of 20, 30, 40, 50, and 60 mm. The second group varied the aperture size and included apertures of 0.4×0.4, 0.5×0.5, 0.6×0.6, 0.8×0.8, 0.9×0.9, and 1.0×1.0 mm^2 size. The third group of simulations involved a range of wire diameters including 0.3, 0.5, 0.75, 1.0, 1.2, and 1.5 mm in diameter. The last group varied the screen inclination over the values 10°, 15°, 25°, 30°, 35°, 40°, and 45°.

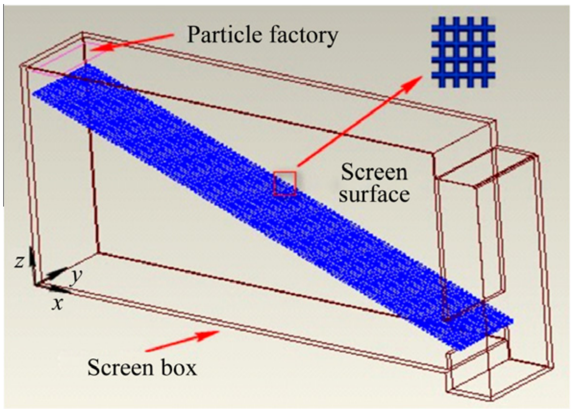

Fig. 1. Schematic view of the vibrating screen model.

Table 1
Summary of simulation conditions.

Material property	Poisson's ratio	Shear modulus	Density
Particle	0.3	23 MPa	2678 kg/m^3
Screen	0.29	79.92 GPa	7861 kg/m^3
Collision properties	Coefficient of restitution	Coefficient of static friction	Coefficient of rolling friction
Particle–particle	0.1	0.545	0.01
Particle–screen	0.2	0.5	0.01
Particle diameter	Mean 0.5 and 1.0 mm	Particle generation rate	50,000 particle/s
	Std Dev 0.45	Total number	30,000
Amplitude (mm)	2.55	Particle generate position	Particle factory
Screen width (mm)	20, 30, 40, 50, 60	Aperture size (mm)	0.4, 0.5, 0.6, 0.8, 0.9, 1.0
Wire diameter (mm)	0.3, 0.5, 0.75, 1.0, 1.2, 1.5	Inclination (°)	10, 15, 25, 30, 35, 40, 45

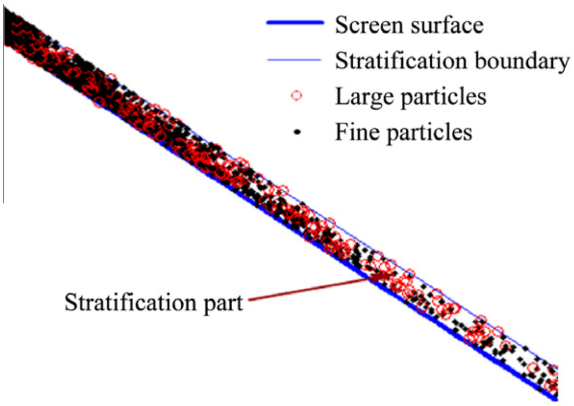

Fig. 2. The stratification.

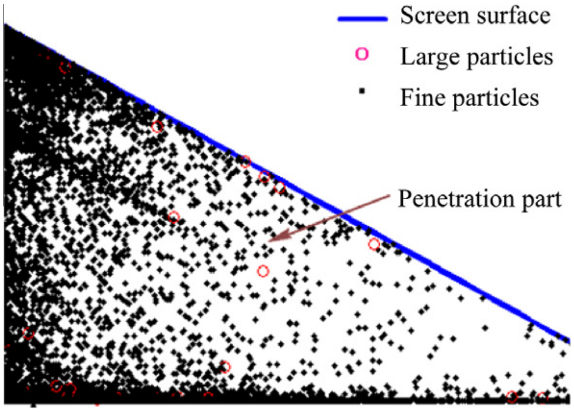

Fig. 3. The penetration.

2.2. Definition of stratification and penetration rate

In this study particles smaller than 0.5 mm in diameter are defined as fine particles. The fine particle ratio of stratification, or penetration, is the proportion of fine particles in the stratified region, or in the penetration zone, to the total number of fine particles. These values reflect the change of fine particle content during the screening. The fine particle ratio is used to study the stratification and the penetration processes.

The stratification is defined as a certain thickness of material that contains more than 90% of the particles on the screen surface, as shown in Fig. 2. The stratification rate is the derivative of the fine particle ratio with respect to time:

$$v_s = \dot{S} \tag{1}$$

where v_s is the stratification rate, S is the fine particle ratio of stratification, and $\dot{S}$ is the derivative of S with respect to time.

The penetration occurs in a bottom layer of material where the particles pass through the apertures to become the undersize classified particles as shown in Fig. 3. Similar to the stratification rate, the penetration rate is defined as:

$$v_p = \dot{P} \tag{2}$$

where v_p is the penetration rate, P is the fine particle ratio of penetration, and $\dot{P}$ is the derivative of P with respect to time.