DEM Investigation of separation performance and stress analysis of a five-deck industrial screen

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Abstract. In the Iron-making process, to achieve effective reducibility and porosity inside the blast furnace, pellets of definite size distribution i.e., (-16 +6.3) mm are required. For this, a multisizer screen made up of five decks with aperture sizes 25, 20, 17, 11 and 8 mm of wire mesh media are used. However, due to poor separation efficiency of screen, misplacement of fines increases in product. These excess fines return to the pellet making process reducing the net pellet production. So higher the fines, higher are the losses. Furthermore, wire mesh panels used in screens have a low average life leading to considerable loss of production hours. In screening, the ease of separation and particle flow is governed by particle-particle and particle-screen interactions. Therefore, a fundamental approach is required which can track these microscopic events and convert them into usable information to optimize the events at macroscopic level. The Discrete Element modelling (DEM) is such a technique used to simulate and predict bulk material trajectory flow. The current study started with modelling of existing process through Discrete Element Method (DEM) tool and validation of the model with plant data. For better reliability of the DEM model, the model input parameters were determined experimentally as well as through DEM calibration approach. Study of effects of vibration parameters (viz. amplitude and frequency) was done to find optimum values for maximum efficiency. On increasing frequency, overall efficiency of bottom deck increased. Due to increase in frequency, better percolation of fines through particle bed was observed which resulted in reducing the misplacement of fines. Total force calculations on each deck were carried out to identify areas which are more prone to damage. It was observed that feed part of top deck experienced the highest impact force and breakage mostly occurred in this part. This helped in better designing of screen panels for improved life.

1 Introduction

Screening is the most widely used method for sizing of various kinds of bulk/ granular materials. It is a probability driven process which is governed by numerous factors. In literature, Discrete Element Method (DEM) has been extensively used to model large scale screening operations and optimize vibrating parameters like frequency and amplitude [1, 2, 3, 4 & 5]. Particles in a vibrating screen experience a saltating/dancing/leaping motion rather than sliding [6, 7]. Vibrations facilitate in-situ bed stratification of particles by enabling finer particles to migrate towards screen apertures across a bed of coarser particles and finally percolate down. The vibration frequency and amplitude should be chosen such that trajectory movement of particles is according to their size. Finer particles should have smaller displacement to have increased encounter with screen surface whereas, larger particles have larger relative displacement, so that they pass through screen quickly. In addition to very high vibrations should be avoided as it may damage the screen panel [8, 9, 10].

The current project aims at solving two major problems in screening of bulk materials i.e., poor separation performance and low life of screen panels through DEM methodology.

2 Numerical Modeling

2.1 Discrete Element Modeling

Discrete element method is a popular tool which tracks the motion of all individual particles using Newton's second law of motion [11]. Here, we use the Hertz-Mindlin no-slip contact model to model the collisions between different particles. At any point of time, considering contact between spherical particles, the force balance and torque balance on the ith particle which is in contact with k number of particles can be expressed as

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

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

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 centre 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 actual wire mesh as shown in Fig 1 (a), was constructed in the Ansys Space Claim software by replicating hollow cylinders presented in Fig.1 (b). A comparative figure of the five-deck screen in 2-D drawing and designed 3-D model is given in Fig. 2 (a) & 2 (b). The key geometric parameters of the screen are provided in Table 1.

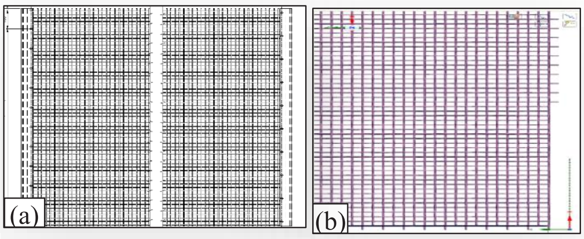

Fig.1(a) Actual Design of Wire Mesh screen panel used in plant; **(b)** 3-D design of the wire mesh used in simulation

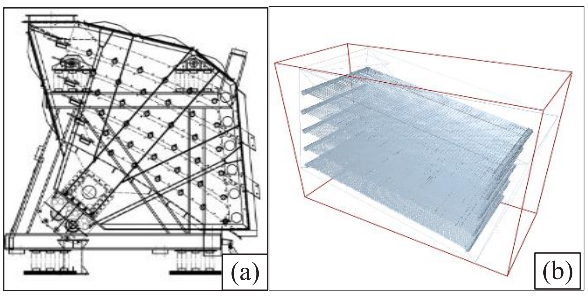

Fig. 2. (a) 2-D drawing of the five-deck screen **(b)** 3-D Model of the five-deck screen used in DEM simulation

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

S. No.	Parameters	Value	
1	Screen length	2.7 m	
2	Screen width	1.22m	
3	No of Decks	5	
5	Vibration frequency	12.5 Hz	
6	Vibration amplitude	30 mm	
7	Vibration type	Linear	
8	Feed rate	600 tonnes per hour	
9	Screen Inclination	12 ° with horizontal line	
10	Screen Panel Type	Wire mesh	
11	Particle size distribution	Size (mm)	Weight %
		+16	26
		-16+6.3	71
		-6.3	3

Since pellet particles are roughly spherical in shape, spherical particles have been used simulations to represent them. The DEM material parameters for both particle-to-particle and particle-to-screen deck used in the simulations are listed in Table 2. The values are taken from previous studies [12 & 13] where detailed work on the calculation and calibration of the material parameters was done.

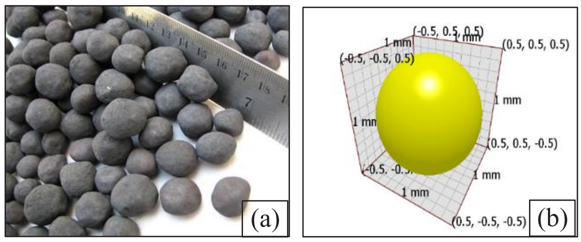

Fig. 3. (a) Real pellet particles; **(b)** 3-D replica of pellet particles used in DEM simulations

Table 2. DEM input parameters used in simulations.

Parameters	Value (Inter Particle)	Particle-Deck
Solids Density (ρ, kg/m^3)	3700	7800
Poisson's ratio (υ)	0.25	0.2
Coefficient of restitution (ε)	0.6	0.5
Coefficient of static friction (μ_s)	0.49	0.8
Coefficient of rolling friction (μ_r)	0.06	0.06

A total of 10 simulations, one of the existing process and others with varying vibration parameters i.e., amplitude and frequency were performed in this study. The values for amplitude were 12.5 mm, 25 mm and 50 mm whereas frequency was tested at 5 Hz, 10 Hz and 15 Hz with throughput being same in all simulations. To provide linear motion to the screen, sinusoidal translation motion was chosen with the X-Y plane as the screen plane with amplitude/ displacement in perpendicular direction (Z-axis).

3 Results & discussion

3.1 DEM model of existing process

DEM tool facilitated the true replication of existing process (Fig. 4(a)) with the values of frequency and amplitude mentioned in Table 1. Validation of DEM model was done by comparing the product size distribution of plant data with simulation data which shows a good match as given in Fig. 4 (b).

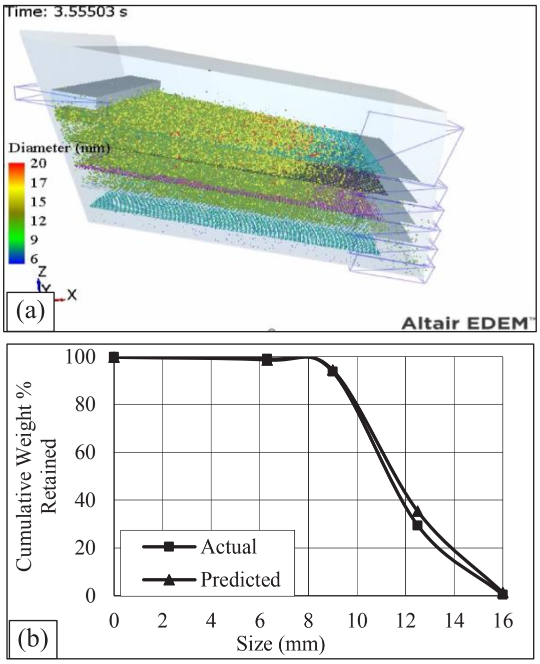

Fig. 4. (a) Snapshot of DEM simulation for existing process; **(b)** Validation of DEM model with plant data.

3.2 Optimization of Vibration parameters

Screening efficiency of lowest deck i.e., bottom deck (8 mm) where fines get separated was calculated at different values of vibration parameters [7] and presented in Fig. 5(a) & 5(b). It shows that frequency of vibration has a positive effect on efficiency of the bottom screen i.e., on increasing frequency, efficiency increases. While amplitude does not affect the screening efficiency much. The same can be observed for the velocity profile of the material during screening for different vibration conditions from Fig. 6 (a, b &c). The material flow is quite low when vibrations are low while material gets fluidized due to high vibrations. The preferred condition is case (6b) with increased frequency and same amplitude

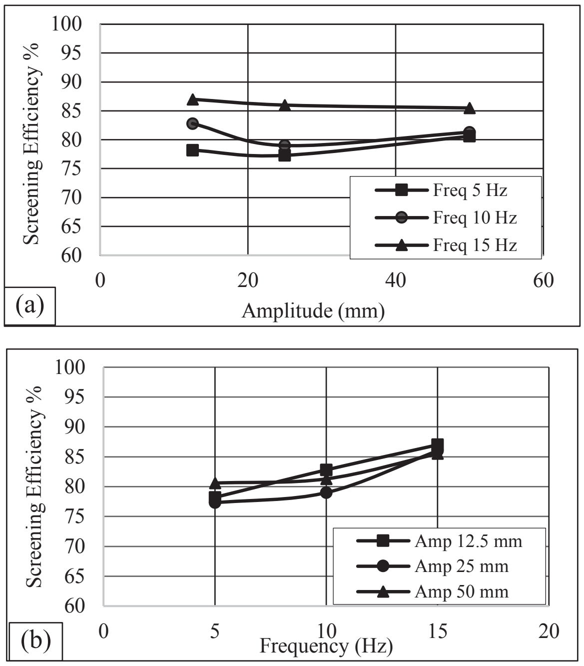

Fig. 5. (a) Effect of frequency at different amplitudes; **(b)** Effect of amplitude at different frequencies.

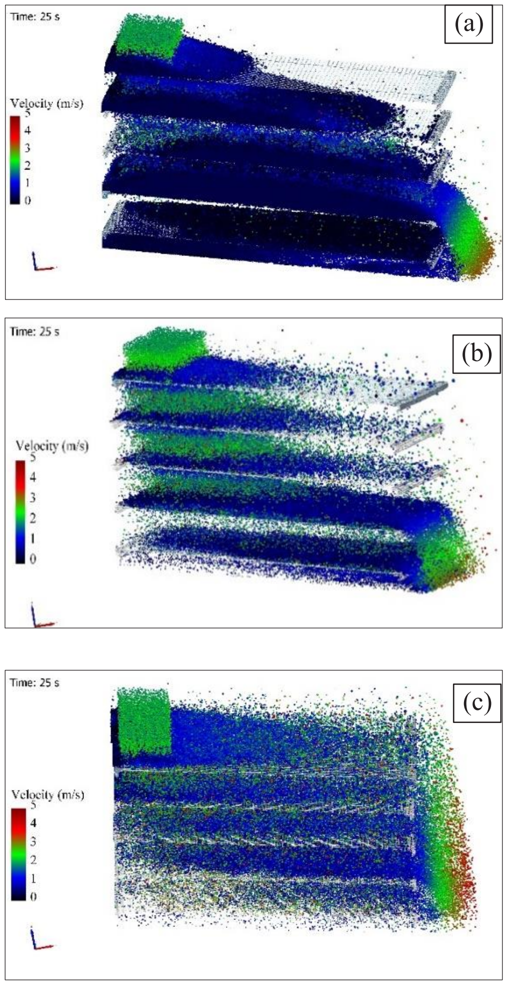

Fig. 6. Velocity profile for different vibration conditions: **(a)** low frequency & low amplitude; **(b)** high frequency & low amplitude & **(c)** high frequency & high amplitude.

3.3 Stress analysis on screen deck

Under stress analysis, most vulnerable points/ areas were identified by calculating the average force exerted by particles on the screen surface. Force calculations showed that feed part of top screen experienced most of the impact force (>65 N) and breakage (Fig. 7(a)) mostly occur in this part (as shown in Fig. 7(b) & (c)). On second deck forces in the feed end and mid end are also high but lower than that compared to first deck. Forces on 17 mm and 11 mm decks are somewhat same throughout the length as most stratification and separation take place on these decks.

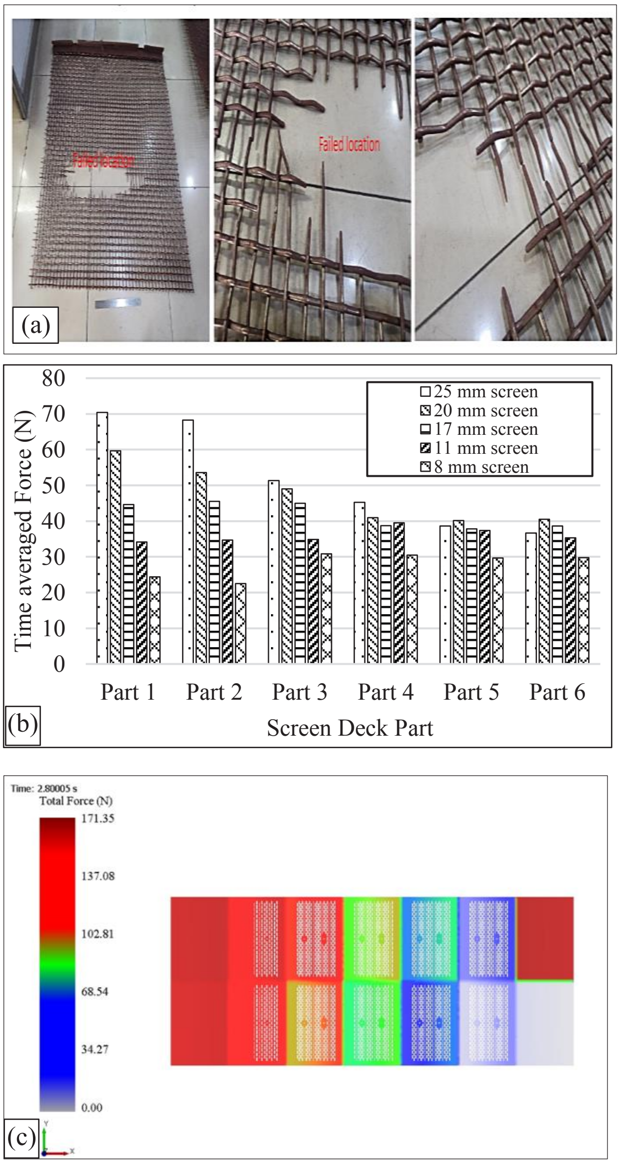

Fig. 7. (a) Failures in the screen panel; (b) Force calculation in different parts of the screen for each deck and (c) Force analysis on the top deck: Red parts have the maximum force concentrations.

4 Conclusion

Based on simulation results it was recommended that frequency should be increased without increasing amplitude, for better separation of -6.3 mm. To increase the average life of screen, panels with higher grade material and thicker diameter should be used for feed part of top two decks. Based on these recommendations, new screen panel with double welded wire mesh arrangement made of higher strength material was designed and used which increased the life of panels by 30%.

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