MODELING AND ANALYSIS OF DUST CONTROL HOPPER SYSTEM

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Abstract. Dust spread of bulk cargo loading is a potential environmental hazard, which can negatively affect human health and pollute environment. It is one of the most common ecological issues in city harbors and industrial areas, which are located close to residential areas and where large amount of granular materials is transferred. A significant amount of granular cargo is lost as dust, causing negative impact on the environment and the loading process costs. Dust spread is also a significant problem in agriculture, where granular materials are loaded for transportation or desiccation. In order to minimize the dust formation and eliminate dust spreading different types of dust suppression systems are used. In this paper several geometrical configurations of dust hopper constructions are modelled and analyzed. CFD and discrete element method software packages are used for analysis of granular particle flow through the dust control hopper system under different system parameters. Several types of granular materials are used for analysis of the hopper system. Granular material flow is analyzed with different hopper shape and granular material distribution loading parameters. Particle distribution at the hopper nozzle outlet is also analyzed under different vibration frequencies.

Keywords: dust control, numerical modeling, granular materials, hopper systems, optimization.

Introduction

Hopper systems are often used for quick transfer of granular bulk cargo. Granular material transferring process involves dust formation, which causes a negative effect on the surrounding environment as air pollution. Dust formation also reduces efficiency of the cargo loading process by losing significant amount of material. This issue is especially significant in industrial areas, such as harbors and terminals, where large amounts of granular materials are transferred every day. Granular material transfer is also a significant process in agriculture, where large amounts of products, such as grain, peas, corn and others, are transferred.

Dust control hopper (DCH) systems are used to prevent dust spread in environment during the bulk cargo transferring process. Different DCH types are used, depending on the type of the granular material, transfer distance and load amount. For long loading distances and slow cargo transferring speed closed construction DCH are used. For short distances, large amounts of cargo and limited working area open type DCH systems are the most common choice [1].

The main purpose of the DCH is to control the granular material flow by distributing articles at the hopper outlet nozzle, so that the small particles are concentrated in the center and large particles on the outside of the flow. Such particle distribution reduces smaller particle dispersion in the environment and therefore limits dust formation. Particle flow distribution in hopper systems depends on several important material properties – size distribution, shape, moisture content, volume of product, mechanical properties of the material and others [2].

Different methods can be used to analyze the granular material flow, including CFD and DEM software [3;4]. In this paper EDEM and Fluent [5] codes are used to analyze the dust control hopper system construction influence on the flow particle distribution under different conditions.

Dust control systems

Different dust control systems are used for transferring bulk cargo as load spouts, dust suppression hoppers and enclosures. Load spouts consist of series of telescopic cups or pipes that extend and retract. These systems are used to load vehicles with bulk cargo. This method requires-high precision, when operating compared with other dust control system methods, and is relatively expensive [6].

Another method used for preventing dust dispersion in environment is enclosures. Enclosure is a physical barrier, which limits dust dispersion in the breathing zone. Construction of enclosures is made from plastic strippings or curtains. This method creates restriction on the working area, since the loading area, where dust formation proceeds, must be closed [6].

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A more effective method for dust control is DCH. DCH is an opened system, where a stable particle flow is gained at the hopper outlet nozzle limiting dust formation. This system is supported with mechanical or electromagnetic control systems, which ensure stable cargo flow through the hopper [7].

Construction of DCH

DCH is used to gain a stable particle flow reducing small particle distribution in the environment. The DCH construction consists of a hopper cone, central plug and a mechanical or electromechanical control system, such as a spring or programmable logic controller, which regulates the gap between the plug and the hopper depending on the load amount in the hopper system, Fig. 1. Different types of materials are used for the hopper system construction; the most common is stainless steel and different plastic materials [6].

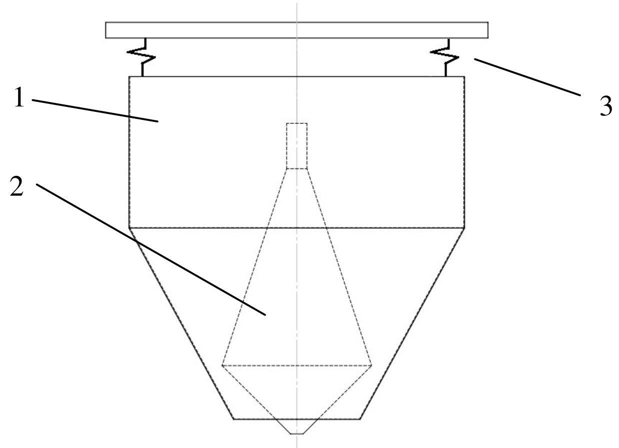

Fig.1. **Dust suppression system**: 1 – hopper; 2 – plug; 3 — springs

DCH systems are used for transferring different granular materials as grain, sands, coal, minerals etc. In a real cargo transfer process particles have different sizes, which can vary several times, and also different particle shapes, which could be irregular [8].

Contact models of particles

Different particle contact models are available for simulation of particle interaction and motion of the flow. The most commonly used contact model in DEM simulations is the Hertz-Mindlin contact model, Fig.2. This contact model in a non–linear elastic model, which uses spring – dashpot response to normal contact between particles – particles and optionally between particles – equipment geometry. The model uses Coulomb friction for shear interactions and second spring – dashpot response to tangential or rolling friction interaction [9].

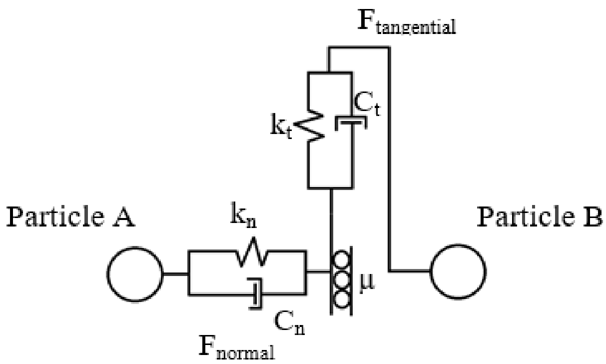

Fig. 2. **Hertz – Mindlin contact model**

Normal force (1) and damping force (2) acting between particles can be calculated based on particle overlap.

$$F_n = \frac{4}{3}\gamma\sqrt{R d_n^{\frac{3}{2}}}\ , \tag{1}$$

where γ – equivalent Young's modulus, N·mm^{-2};
R – equivalent radius, m;
d – normal overlap, m.

$$F_n^d = -2\sqrt{\frac{5}{6}}\beta\sqrt{s_n m v_n}\ , \tag{2}$$

where β – damping constant,
s_n – normal stiffness, N·m^{-1};
m – equivalent mass, kg;
v_n – relative velocity, m·s^{-1}.

The other commonly used contact model in DEM numerical calculations is the Linear Spring Dashpot model. For this model assumption is used that the displacement is directly proportional to the applied force (3). To obtain the contact force in this method the overlap velocity is required as an input parameter [9].

$$F_n = kd + c\dot{d}\ , \tag{3}$$

where k – linear spring stiffness, N·m^{-1};
c – damping coefficient, Ns·m^{-1};
$\dot{d}$– overlap velocity, m·s^{-1}.

Numerical model and simulation of DCH system

Firstly, a 3D model of DCH has been created using CAD software. Then the model is implemented in DEM analysis software, where the particle flow and restrictions are defined. In this paper model the particle flow has been simplified and the flow through the hopper is considered as mixture of two different size particles, which have the same mechanical properties. Particle shape in DEM simulation can be defined as sphere or as continuous sphere combination, which can be used to replace flow elements with irregular shape. Particles (Fig.3) are treated as spheres, to reduce the computational time.

a) b)

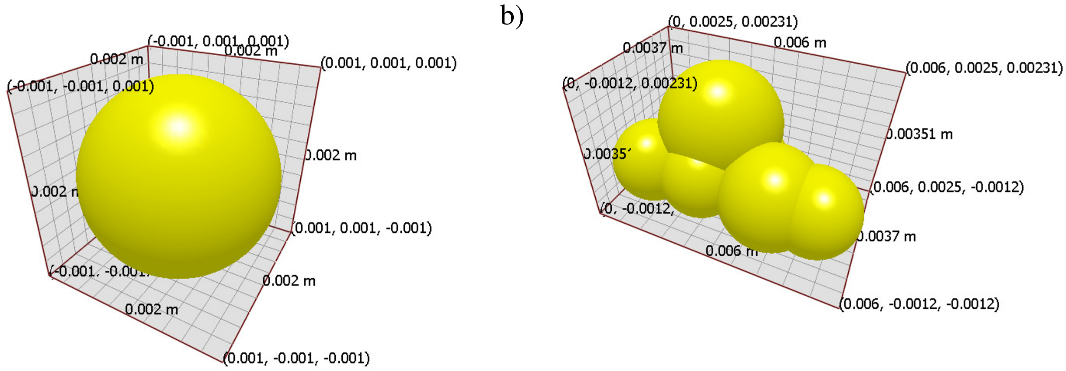

Fig. 3. **Geometry of particle:** a – regular particle, b – irregular particle

As previously discussed, the Hertz – Mindlin contact model is used to define the contact forces for particles – particles and particles – geometry. It is assumed that particles have uniform distribution at DCH inlet. Numerical model used for calculation is simplified and the springs acting in the DCH construction are neglected, therefore the simulation results obtained can be used for analysis only for the condition with constant opening at the DCH construction outlet nozzle. To take into account hopper oscillations EDEM simulation results can be imported in multi-body dynamics code ADAMS and then co-simulation can be implemented [5]. This is a very time consuming procedure and for optimization purposes the metamodeling approach [10] will be performed.

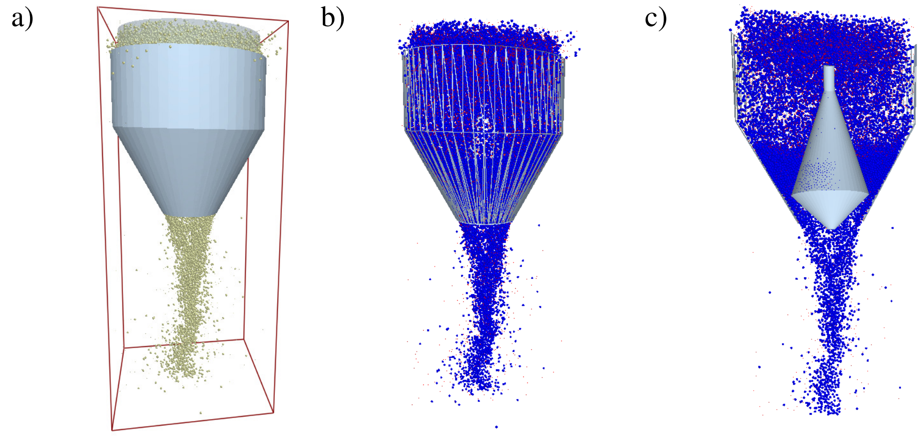

Fig. 4. **Particle flow through DCH:** a – calculation domain with geometrical model of DCH; b – particle distribution in 3D-model; c – particle distribution in cross-section

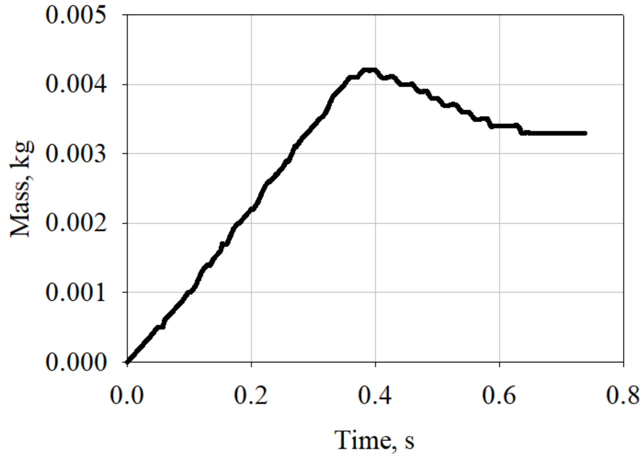

Fig. 5. Dust flow through DCH

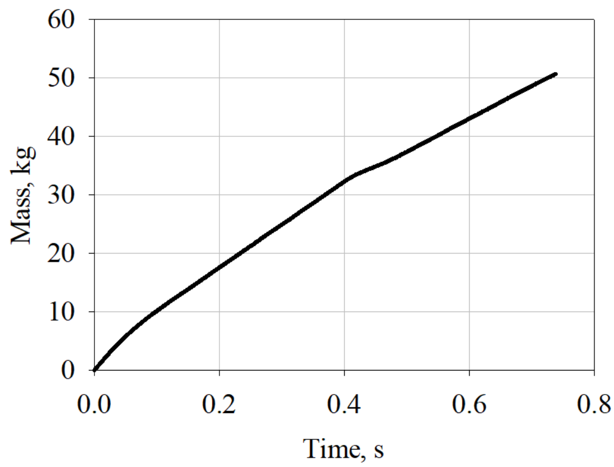

Fig. 6. **Large particle flow through DCH**

Results and discussion

The performed preliminary numerical simulation of DCH shows segregation of particles in the hopper and at the hopper outlet nozzle, Fig.4. If the mechanical spring system is not applied to DCH, particle accumulation in the construction occurs. Particle flow analysis through the hopper construction indicates that largest particle accumulation continues to increase, Fig.6, but the small particle amounts, Fig.5, in the hopper system have variable character during the particle flow process.

The main effect of particle segregation is captured also using simplified 2D hopper models, which are solved by another multi-body dynamics software WorkingModel [11]. Due to the symmetry in Fig. 7 is shown only half of the 2D model and two sized circles as particles. Essential importance for capturing segregation effect is taking into account the aerodynamic drag force acting on particles. In Fig.7.b a tendency is visible of red dust particles to concentrate at the middle of outflow, near the vertical symmetry axle.

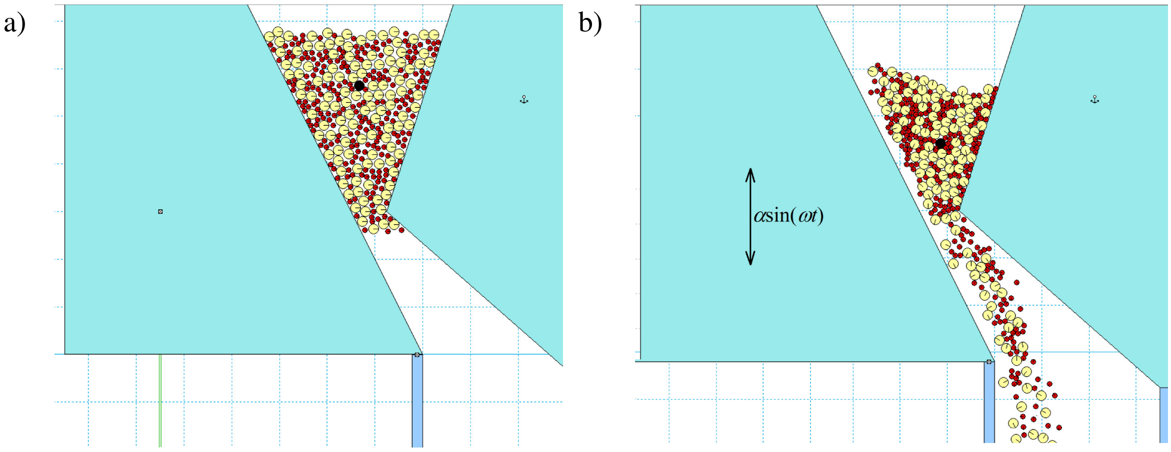

Fig. 7. **2D particle flow through ½ DCH:** a – WorkingModel setup at initial time moment; b – position of particles after 0.3 s of simulation (vibration frequency 50Hz, amplitude 1mm)

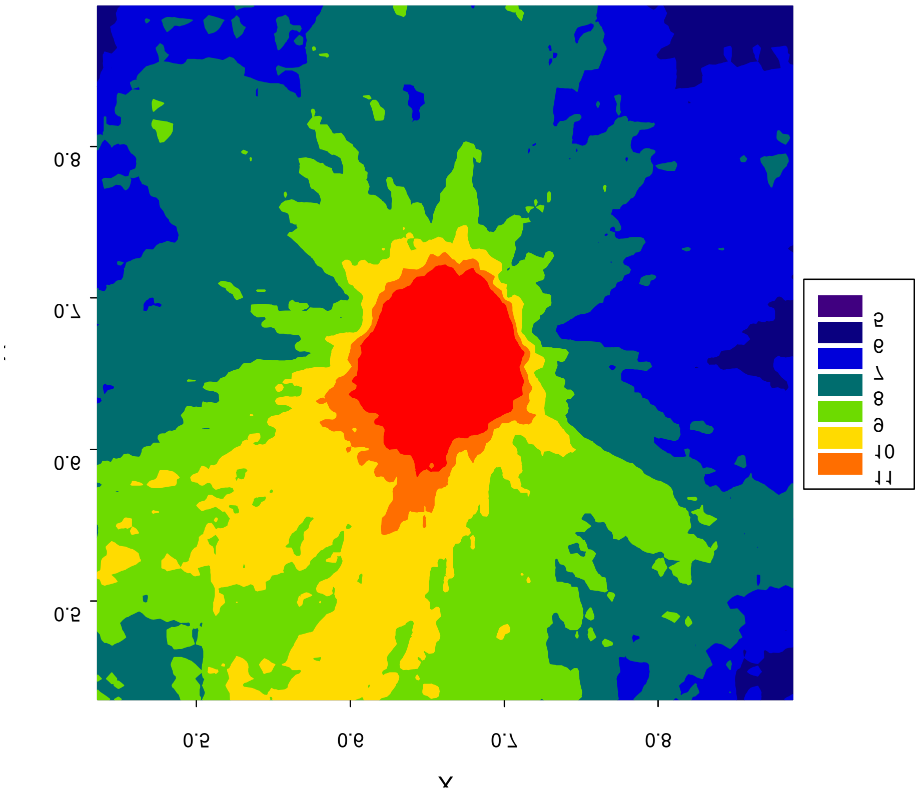

Fig. 8. **Relative density of dust particles in horizontal section of outflow**

The modeling results can be used in metamodel based shape optimization to obtain effective particle distribution through the outlet nozzle and reduce dust dispersion in environment during the loading process. For this, we need to numerically evaluate the distribution of the particles. Fig.8 shows the relative density of dust particles, which is calculated for small 1cm radius area circles at 10000 points in the horizontal section of the outlet as averaged ratio of the dust particle number to the total number of particles. In this case, dust particle concentration in the middle area of the section is more than two times larger than in the outer flow part.

Conclusions

1. The numerical calculation results show the dust amount in the hopper systems and at the hopper outlet nozzle. Depending on the particle size at DCH, if the outlet nozzle has constant opening through the particle flow, then material accumulation of large particles in DCH can be observed, while smaller particles continue to exit the DCH outlet nozzle. The performed calculation can be used for further analysis of the DCH system with applied mechanical control. Granular flow analysis is computational time consuming and requires powerful computer resources with multiple core processors.
2. The performed numerical analysis can be used for further investigation of shape optimization of the DCH construction to achieve the optimal shape of the hopper, which ensures minimal dust forming.

Acknowledgments

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