Recording of the Particular Matter Behaviour when Leaving a Container

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Abstract

The article focuses on behaviour of particular matter depending on marginal conditions with application of the PIV (Particle Image Velocimetry) and DEM (Discrete Element Method). The Discrete Element Method was used for validation of the particular matter behaviour. The research on the bulk material behaviour concentrated on detection of changes of velocity in experimental materials under constant marginal conditions. The marginal condition is an obstacle on the bottom of the storage tank. As experimental material, we selected glass balls of various sizes. The diameter of the particles was 5 and 3 mm. These particles were mixed in a 50/50 proportion up to the capacity of the experimental sample. The output velocity was recorded by a high-speed camera and compared with numerical simulation in the DEM program. The resulting values of the particle velocity in both the PIV and DEM method were compared. The agreement between the experimental outputs and the numerical method in comparison of the flow velocity was on a high level. From results is possible to detect the period when all particles left the tested zone from charts illustrating the average velocity of all particles in the selected areas during drainage of the tank. By comparison of the locations with the period of the flow's termination in the individual zones we can declare that in the course of the flow, the matter leaves the higher delimited zones earlier than zones closer to the outlet hole. The time difference of the mutually successive zones then becomes shorter while approaching the outlet hole. To summarize the whole experiment complexly, we can declare that the particular matter is accelerated towards the outlet hole by action of the 30° incline of the hopper wall. In an area outside the outlet hole, this acceleration occurs especially in the x axis before the matter arrives above the discharge hole, where the core flow is under way and the direction of the matter's acceleration changes from the x axis to the y axis.

Keywords: discrete element method, particles, bulk solids, Hopper

Introduction

The man constantly observes events around him, tries to understand why they occur and on what laws they are based. However, the human sense of observation is limited. Thus, it was necessary to develop new technologies able to detect and illustrate the events so that we could evaluate them through abilities with which the nature endowed us. In this way, we managed to develop microscopes for observation of the microcosmos or high-speed recording for observation of events faster than the human eye is able to capture. Thanks to these technologies and the acquired expertise, we can obtain new information in the area of particular matter.

Now we know that particular matter is a predecessor of planets in the space, which developed by clustering of dust particles into agglomerates that solidified into rocks by action of mutual collisions and hardening [1, 2]. The rocks continued to collide, forming larger boulders, which continued colliding until they formed the planet. This understanding makes us declare that particular matter was present at the birth of each rock planet. In our solar system, these planets include Mercury, Venus, the Earth and Mars. This sphere of research on particular matter is so broad that we are standing at the very onset of understanding the particular matter in the whole universe.

This essay thus answers the question: how will the particular matter behave when leaving a tank through a 30° hopper?

The essay studies the effect of the tank shape on behaviour of the particular matter during the discharge process. To achieve this goal, we used high-speed recording (PIV), which enables detailed analysis of the individual particle's movement. A suitable tool for prediction of behaviour of the particular matter is mathematic modelling with application of the DEM method.

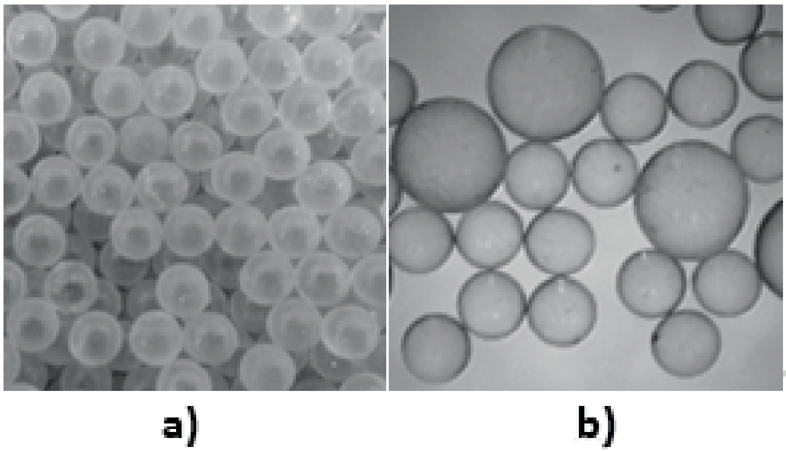

Fig. 1. Selected experimental material a) 5 mm diameter b) mixture of 5 mm and 3 mm
Rys. 1. Wybrany materiał badawczy o wielkości: a) 5 mm b) mieszanka 5 mm i 3 mm

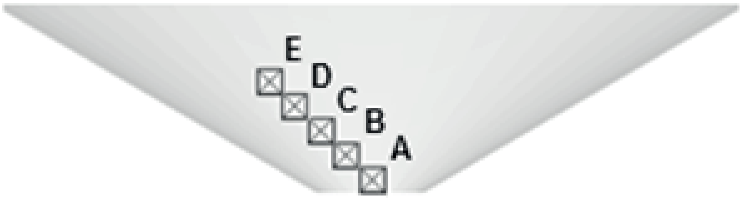

Fig. 2. Marking of the average velocity measurement zones during the simulation and high-speed PIV recording
Rys. 2. Oznaczenie strefy pomiaru średniej prędkości w czasie symulacji i nagrywania szybką kamerą PIV

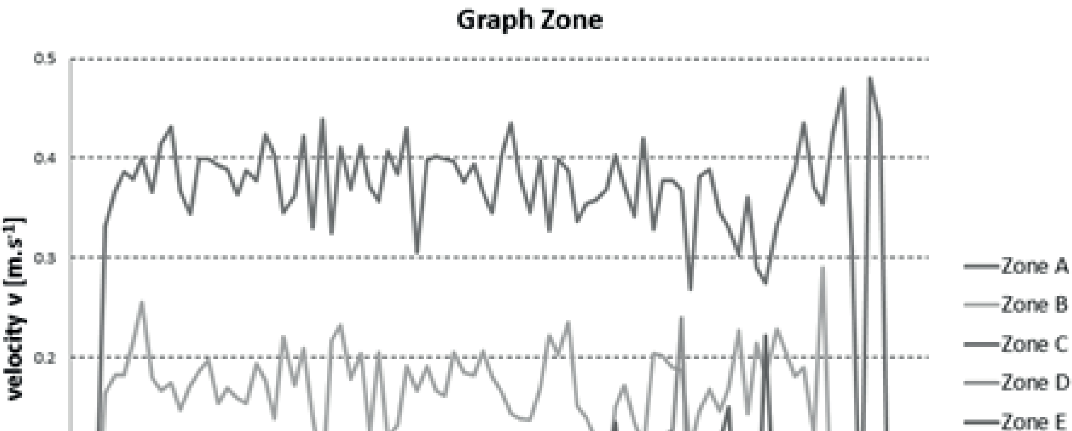

Fig. 3. A chart illustrating the average velocity in the centre of the hopper
Fig. 3. Średnia prędkość wewnątrz zasobnika

Description of the simulation

The definition of simulation includes imitation of a real thing or a process.

Here, the simulation process concerns behaviour of a flow of the particular matter down a hopper with a 30° incline of the wall.

To achieve an adequate simulation by a program support, it is necessary to correctly define basic parameters of each fraction from which the resulting particular matter is composed.

The EDEM simulation program is divided into three parts. Each part concentrates on a partial problem (the creator, the analyser and the simulator). First, it is necessary to define the input parameters of the environment and the particular matter by means of the creator. It is possible to import a 3D model of the tank crated for example in the Inventor program. The simulation models are based on the basic spherical shape of the particle. This particle is now assigned material properties based on the solid particle's own structure. These parameters include a shear module of the material's elasticity, the Poisson constant and the volumetric weight.

The other important parameters include properties of the particle in interaction with a different material. In this case, the particle of the particular matter can come into interaction with the wall of the tank and another particle. Thus, it is necessary to define interaction coefficients for both types of interaction. These coefficients comprise the coefficient of restitution, coefficient of static friction and the rolling resistance coefficient [3].

To explore the problem, we used a numerical simulation for validation of the experiment, where we focused on recording output velocity of the particular matter during flow through the hopper.

A problem involving particular matter in the storage application is reflection of the bulk material properties in environment restricted by marginal conditions [4].

The marginal conditions include the shape of the tank, the material of the tank and other impacts entering the storage and discharge process.

Thanks to validation comparison of the experiment with the numerical simulation, we can detect dissimilarities in the resulting velocities [5].

Description of the material

Particular matter is an aggregate containing a certain amount of solid particles in a mutual interaction. The actual contacts between the individual solid particles can be intensified by various bonds between the individual particles [2]. We chose glass granules as the experimental material in Fig. 1.

To set up the geometry of the experimental model correctly, it was necessary measure mechanical-physical properties of this material [6]. The basic mechanical-physical properties include granularity, the volumetric weight, the repose angle and the angle of internal and external friction with the contact materials by [7]. To enter input parameters of bulk materials in the EDEM program, it is also important to perform particular measurements of the real material to obtain information on the individual coefficients, which are included in description of the simulation. The values of the mechanical-physical measurements were measured in the Laboratory of Bulk Materials at VSB-TU Ostrava. The instruments used for the measurements included the shear machine RST-01[8] and the Jenike shear tester, which uses a linear principle of measurement.

The glass granules had two sizes, i.e. 5 mm and 3 mm particles. The measured volumetric weight for the 5mm material was 1992 $kg.m^{-3}$, the angle of repose was 21°, the angle of internal friction was 26° and the angle of external friction in contact with plastic of the model was 6°.

For correct definition of the simulation model, the measured coefficient of restitution was 0.89, the rest friction coefficient was 0.3 and the rolling friction coefficient was 0.005.

For the 3 mm granules, the measured volumetric weight was 2095 $kg.m^{-3}$, the angle of repose was 19°, the angle of internal friction was 24° and the angle of external friction in contact with plastic of the model was 6°.

Experiments

The experiment focused on behaviour of the particular matter during its flow through a hopper located in the bottom part of the tank. The bulk material was moved to the outlet hole by the particles' own weight.

A special semi-circular tank for the experiment was prepared. In the bottom, it had a hopper with the wall incline of 30°. The outlet hole was dimensioned for the diameter D = 40 mm with regard to the 5 mm particles.

The model of the hopper was attached to the bottom of the tank and secured against movement. We put a sliding closure under the outlet hole, which opened backwards from the recording plane of the model. The height of the model tank was H = 400 mm. The hopper was h = 125 mm. Before filling of the tank, the closure was put in the closed position. The material was fed through the centre of the tank. After filling the tank, we set the recording by the PIV method.

The recording was adjusted to the frequency of 300 Hz, which corresponds to the period of 10 s at the maximum number of frames, i.e 3,000.

When the recording started, the space under the hopper was released by opening of the sliding closure and the flow of the bulk material through the hopper was recorded by the high-speed camera. The container discharge period can be detected from the chart in Fig. 6; it oscillates around 9 seconds.

Results and discussion

The numerical simulations were executed to validate the experiment. We focused the sphere of research on monitoring of the particle velocity under defined marginal conditions. The measured values entered in the DEM program, such as the coefficient of restitution, the rest friction and the rolling friction, can have a great impact on the simulation process and the final results of the individual particle's movement in the flow process.

Consequently, we measured the values of all coefficients and entered them in the DEM program; see the chapter describing the material. The correct adjustment of input parameters for the bulk material and the marginal conditions resulted in outcomes corresponding with outcomes obtained in the PIV measurement.

The experimental results focused on velocity were validated by the Discrete Element Method with a high level of accuracy (the maximum difference was 0.02 $m.s^{-1}$). Based on comparison of the outcomes, we can declare that other partial parameters, which cannot be gained experimentally or validated, can be obtained by application of the mathematical model.

For the experiment, we chose a semi-circular tank, which allowed observation of the process inside the container. The observation focused on a 30° hopper and its impact on the particular matter behaviour during its passage through the outlet hole.

During the experiment, we measured the average velocity of the particles' movement on the outlet from the tank.

The blue marked squares in Fig. 2 are zones where the average velocity of the particles was measured in relation to the discharge period.

It is possible to record velocities of the particles' movement by an experiment. If we know the weight of each particle, we can calculate momentum of the particle and the whole aggregate.

In this chart in Fig. 3, can be observed the progress of the particles' velocity in the measurement zone, where the average velocity oscillates within 0.33–0.43 $m.s^{-1}$. It can be further observed that the process is not entirely linear, but small pulsations of the particles' velocity occur when the faster and the slower particles fluctuate within 0.33–0.43 $m.s^{-1}$. In the chart, we can see that the flow velocity is reduced in the second zone marked B. This area shows more frequent contacts between the individual particles without a chance to be released into the open space, as it occurs directly in the bottom zone. This chart better illustrates the discernible pulsations of the faster and slower particles, which move within the speeds of 0.08–0.25 $m.s^{-1}$. The highest velocity measured in the B zone corresponds to the lowest value in the A zone. This fact shows that the speed spectrums of these two zones do not overlap. This chart illustrates a reference that the movement of the particles in the C zone is terminated earlier than it can occur at the bottom of the tank. The zone is located above the outlet hole and particles from this zone need not move in the x axis to the outlet hole. The speed oscillates within 0.025 and 0.15 $m.s^{-1}$. From this range it is apparent that the velocity spectrum of the B and C zones overlaps. The D zone is not located directly over the outlet hole and particles from this zone must move in the x axis. A hopper with the wall incline of 30° produces a core flow; this is why particles from the D zone must move to this core of the flow. If the velocity resultant was divided into two components vx and vy, the vx velocity would be higher than the vy velocity in many cases. The character of the curve is totally different from the previous zones A, B and C. There is no rapid increase of velocity into the area of average velocity over the entire area, but the velocity of the particles rises slowly together with the emerging pulsations in a smaller extent than in A, B and C zones above the outlet hole.The E zone is comparable with the D zone. It is located outside the outlet hole, but still further in the x axis than the D zone. This suggests that the particles must cover a larger distance in the x axis. The relocation of the particle in the environment of other particles in the x axis within the gravitational field of the y axis is very complicated and particles limited to a rotational movement can thus become completely static, creating a dead zone. Dead zones in storage equipment are undesirable and all structural designs try to eliminate this effect. The character of the chart in the E zone is slightly rising, but it is the lowest of all of the monitored zones as regards the velocity spectrum.

Acknowledgemets

This paper was elaborated in the framework of the New creative teams project in priorities of scientic research, reg. no. CZ.1.07/2.3.00/30.0055, supported by Operational Programme Education for Competitiveness and cofinanced by the European Social Fund and the state budget of the Czech Republic. This paper was supported by research projects of the Ministry of Education, Youth and Sport of the Czech Republic: ENET CZ.1.05/2.1.00/03.0069. Measurements were performed in the Laboratory of Bulk Materials in Ostrava.

Literatura – References

1. ZEGZULKA, J. 2004. *Mechanika sypkých hmot*. Vyd. 1. Ostrava: VŠB - Technická univerzita.
2. ZEGZULKA, J. 2013. "The angle of internal friction as a measure of work loss in granular material flow." *Powder Technology* [online] 233: 347–353 [cit. 2015-08-21], doi: 10.1016/j.powtec.2012.06.047.
3. WENSRICH, C.M. a A. KATTERFELD. 2012. "Rolling friction as a technique for modelling particle shape in DEM." *Powder Technology* [online] 217: 409–417 [cit. 2015-08-21], doi: 10.1016/j.powtec.2011.10.057.
4. ZHU, H.P., Z.Y. ZHOU, R.Y. YANG a A.B. YU. 2008. "Discrete particle simulation of particulate systems: A review of major applications and findings." *Chemical Engineering Science* [online] 63(23): 5728–5770 [cit. 2015-08-21], doi: 10.1016/j.ces.2008.08.006.
5. COETZEE, C.J. a D.N.J. ELS. 2009. "Calibration of discrete element parameters and the modelling of silo discharge and bucket filling." *Computers and Electronics in Agriculture* [online] 65(2): 198–212 [cit. 2015-08-21], doi: 10.1016/j.compag.2008.10.002.
6. LANDI, G., D. BARLETTA a M. POLETTO. 2011. "Modelling and experiments on the effect of air humidity on the flow properties of glass powders." *Powder Technology* [online] 207(1–3): 437–443 [cit. 2015-08-21], doi: 10.1016/j.powtec.2010.11.033.
7. GANESAN, V., K. MUTHUKUMARAPPAN a K.A. ROSENTRATER. 2008. "Flow properties of DDGS with varying soluble and moisture contents using jenike shear testing." *Powder Technology* [online] 187(2): 130–137 [cit. 2015-08-21], doi: 10.1016/j.powtec.2008.02.003.
8. SCHULZE, D. 2011. "Round robin test on ring shear testers." *Advanced Powder Technology* [online] 22(2): 197–202 [cit. 2015-08-21], doi: 10.1016/j.apt.2010.10.015.

Zapis zachowania ziaren przy opuszczaniu zasobnika

W artykule skupiono się na zachowaniu pyłu zawieszonego w zależności od warunków brzegowych z użyciem anaklizatora obrazu cząstek (ang. skrót PIV – Particle Image Velocimetry) oraz metody elementów dyskretnych (ang. skrót DEM). Metody elementów dyskretnych użyto w celu określenia zachowania pyłu zawieszonego. Badanie materiału sypkiego skupione było na wykryciu zmian w prędkości materiału wysypującego się ze zbiornika, w stałych warunkach brzegowych. Jako materiał eksperymentalny użyto szklane kule o różnych średnicach. Średnice wynosiły 5 oraz 3 mm. Kule wymieszano w proporcji 50/50, aż do osiągnięcia objętości próbki eksperymentalnej. Prędkość wyjściowa została zarejestrowana przez kamerę i porównana z symulacją numeryczną w programie DEM. Porównano uzyskane wyniki określenia prędkości cząstek z obu metod PIV i DEM. Zalezność między wynikami eksperymentalnymi i prędkością strumienia wyznaczoną metodą numeryczną była na wysokim poziomie. Dzięki wynikom z wykresów przedstawiających średnią prędkość cząstek na wybranych powierzchniach można określić moment, w którym wszystkie cząstki opuściły badaną przestrzeń. Można stwierdzić, że w przepływ strumienia materiału opuszczającego zbiornik niejest jednolity. Można stwierdzić, że pył zawieszony przyspiesza w kierunku odbioru, przy 30° kącie nachylenia ściany zbiornika.

Słowa kluczowe: metoda elementów dyskretnych, ziarna, materiały sypkie, zasobnik