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Modelling of Separation and Pneumatic Classification Processes of Airodisperse Systems in the Shelf Device

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Abstract. The following paper considers the process of classification of polydisperse free-flowing material according to granulometric composition using a gravitational air classificator. There were considered the problems of the purity of separation of polydisperse bulk materials and methods for increasing the degree of separation of particles. There were presented and analyzed obtained the results of the comparison, the data of experimental research and computer simulation of two-phase hydrodynamics flow by CFD methods. The versatility of this complex allowed carrying out simulation of the process using various parameters. As a result, were obtained optimal operating parameters, which were experimentally verified. Based on the obtained data as a result of numerical modelling, the possibility of increasing gas flow influence to the polydispersed material were found, as well as organization along the walls of coarse fraction downward flow by dint of the optimizing the devise design (specifically through the organization of additional inlets for airflow) were obtained.

Keywords: pneumatic classification, grading, bulk material, polydisperse material, two-phase flow, degree of separation.

1 Introduction

In the chemical, mining, building and other industries, the feed stock or finished products are the dispersed materials, the high requirements for fractional composition of which are set. The quality of products obtained as dry chemical, coarse material or granules essentially depends on their homogeneity. The separation of a polydisperse material into narrow fractions with a given grain composition is provided by carrying out the technological process of gravitational pneumatic classification. Fractionation of granular materials is used to remove finely dispersed fractions and to obtain dust-free products, as well as to remove coarse fractions and to obtain a finely dispersed product, and to separate the particulate material from the desired fraction by the particle boundary size, or to separate more than two fractions from the polydisperse material with a predetermined grain size composition. This method is widely used in producing mineral fertilizers, electrode, food, grain processing and other industries.

2 Literature Review

Pneumatic classification is based on the difference in the velocities of the flittering of particles of different fractions in the air stream, as a result of which the initial material is divided into fractions according to the set of the following mechanical properties of particles: size, shape, surface roughness and density, and the possibility to obtain products in dry form reduces the energy capacity of the technological processes that are conducted. The change in the shape of the device's working volume increases the quality of separation, the hydraulic resistance decreases, and consequently the specific productivity and efficiency of the pneumatic classification process increases [1]. It was also found that the continuous supply of material to the device reduces the efficiency of the classification process, at which point the flow is raised by the jet of air will not dissipate. Therefore, clusters of fractions are created, which include both coarse and fine fractions that increases the energy intensity of the installation due to the formation of a sufficient lift [2]. For the rational use of the working space and more effective means and methods of influencing the flow of bulk material, a hardware model has been developed that provides a significant improvement of the separation quality [3]. A high degree of separation in the process of classifying dispersed materials affects not only the consumption rates of raw materials and their quality. However, it determines the own efficiency and the efficiency of other machines and devices in the technological scheme, which ultimately affects the technical and economic indicators of the production in a whole. Processing phosphorites in the production of phosphoric mineral fertilizers, and raw materials with coarser particles (more than 0.2-0.3 mm) requires longer time for acid decomposition, but with smaller (less than 0.05-0.06 mm) leads to intense dusting in the places of overload. Therefore, such technologies require an additional stage of separation, which are realized in one volume of the device for the pneumatic classification [4]. It has been experimentally determined the optimal design of the bulk material feeding unit in a conical pneumatic classification. The obtained results show the need to install an inclined perforated plate at an angle 30º to the vertical opposite the inlet nozzle of the original mixture, that allows increasing the velocity of the air carrier and reducing the hydraulic resistance. This allowed stabilizing the process of classification, reducing the time to enter the operating mode, and increasing the purity of the bottom product [5]. As a result of carrying out mathematical modelling of the classification process, the calculated dependencies connecting the distribution curve and the dispersed composition of the fission products with the design and regime parameters of the apparatus were obtained. Classifier's operating results and characteristics of the dispersed composition were calculated based on the calculated values of the functions [6]. Finally, due to the need of increasing requirements to the quality of products and saving of raw materials, the development of new principles for organizing the process of gravitational pneumatic classification and developing its theoretical foundations and instrumentation are the topical issue.

3 Research Methodology

3.1 Procedure of laboratory experiment

At the unit (Fig. 1), a series of experiments was carried out using a two-component mixture of fractions -0.315 + 0.2 mm and –0.63 + 0.4 mm.

The initial mixture of bulk material in the amount 0.03 kg/s from the batch hopper 3 and transferred by the belt doser 4 to the lower section of the pneumatic classificator 2. Airflow enters the lower section of the device at a velocity 2.6 m/s, which flow rate is measured by the fill valve 6. Separation airflow is generated using the gas pump 8 by air-sweeping through the device. During the separation process, the fraction is caught by the airflow and settled on them while flowing over inclined shelves.

Further, the dust-air flow enters cyclone 1, where the purified air is discharged into the atmosphere, and the fine particles are trapped and released into the fine fraction collecting hopper 7.

The coarse fraction comes in the lower section of the device to the collecting hopper for the heavy fraction 5. After the separation process, the selected samples are classified into fractions using a set of scalpers. The obtained fractions are weighed. Thus, the degree of mixture separation into fractions is determined.

The photo of the experimental unit is given below.

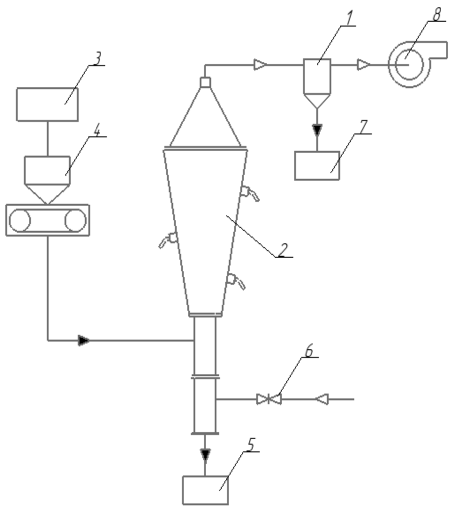


Figure 1 — Technological scheme of the pneumatic classification unit

Figure 2 — Assembled representation of the laboratory unit for pneumatic classification [7]

The results of the experiments are shown in Fig. 3.

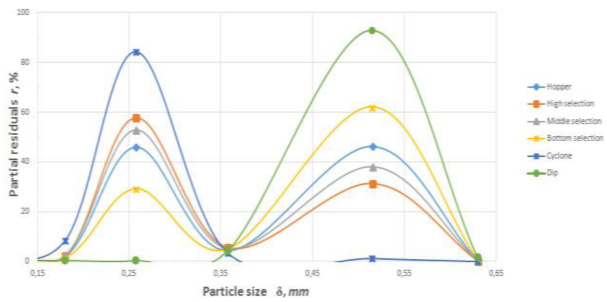


Figure 3 – Sieving curves of initial mixture particles, its entertainment, dip, and material from intermediate selections

3.2 Conducting a computer modelling

The computer modelling of the classification process was used to compare data that were got during the experiment, as well as calculated sizes, construction design of the pneumatic classificator's flow part and sufficient quality of bulk separation in accordance with requirements of the technological regulations with the help of universal software complex ANSYS Workbench.

The calculation of airflow hydrodynamics and determination of the optimum process parameters are conducted with the help of universal software complex ANSYS Workbench and its module "Fluent Flow". All the calculations are based on the finite volume method. In the general case, the equation of motion of polydisperse particles is considered due to the following forces: hydrodynamic resistance from the side of the carrier gas flow, gravity, particles collision with the device's walls and contact elements, particles hitting with each other, particles rotation and their interaction with the gas flow.

The structure of the device's flow affects the dispersed fraction distribution process. The efficiency of the shelf pneumatic classificator is substantially determined by the flow field of the gas stream, which vice versa affects the concentration of the solid phase in the two-phase flow. Considering the character of gas flow is important for establishing the regularities of its interaction with the solid phase that determines the motion speed and particle residence time in the device's operating volume [8].

The computer-aided design system SolidWorks 2017, which tools allowed simulating vessel's flow part is used for building the computer model. The obtained device's geometry applies to ANSYS "Design Modeler" that is set as geometry editor for existing CAD models, as well as for their preliminary processing. ANSYS "Meshing" provides the flexible design of the computational grid that allows generating a qualitative grid with respect to the device's geometry using the three-dimensional tetrahedral, hexahedral and pyramidal elements (Fig. 4). For further simulation process the, Fluent preprocessor is applied for setting the process parameters. The "Pressure-based" solver method is chosen that allows using the Navier-Stokes algorithm based on a pressure parameter. The "Transient" time dependence is set that indicates the non-stationary process running. The calculation process is conducted using the k-ε turbulence model. The k-ε RNG model improves accuracy for whirling flows because it relies on the whirl effect on the turbulence and is more accurate and reliable for a wider class of flows than the standard model. The function "Standard Wall Functions" determines the wall processing that is applied for airflow turbulence simulation. To calculate the flow of dispersed particles in the device's volume, the "Discrete Phase Model" is used. This approach allows setting parameters related to the calculation of the particles discrete phase. The determination of the particle sorting percentage with density 2600 kg/m^3 is carried out in the established channel of particle diameter 0.200-0.315 mm and 0.40-0.63 mm at the air rate 2.6 m/s. The boundary conditions at the input (Inlet 1) for the polydisperse phase discharge 0.03 kg/s; at the inlet (Inlet 2) by the airflow velocity 2.6 m/s (Fig. 3) are set.

The calculation of the process based on the pressure is carried out using the ANSYS "Fluent". The pressure equation is derived from the continuity equation and conservation of momentum. As far as the control equations are not linear and related to each other, the process of solution involves iterations, where the whole set of control equations is solved multiply until the solution converges.

The ANSYS "CFD-Post" allows obtaining the values of the main parameters (gas velocity, solid particles, hydraulic resistance and distribution of the solid phase in the vessel's volume).

Sizing	
Size Function	Curvature
Relevance Center	Coarse
Max Face Size	3,e-003 m
Mesh Defeaturing	Yes
Defeature Size	Default (1,5e-005 m)
Transition	Slow
Growth Rate	Default (1,20)
Span Angle Center	Fine
Min Size	Default (3,e-005 m)
Max Tet Size	Default (6,e-003 m)
Curvature Normal Angle	Default (18,0 œ)
Bounding Box Diagonal	1,73210 m
Minimum Edge Length	2,e-003 m
Quality	
Target Skewness	Default (0.900000)
Smoothing	Medium
Mesh Metric	Skewness
Min	1,3057e-010
Max	0,95538
Average	0,33389
Standard Deviation	0,1964

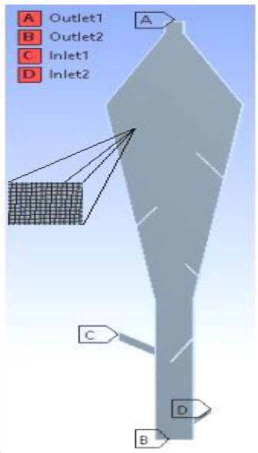
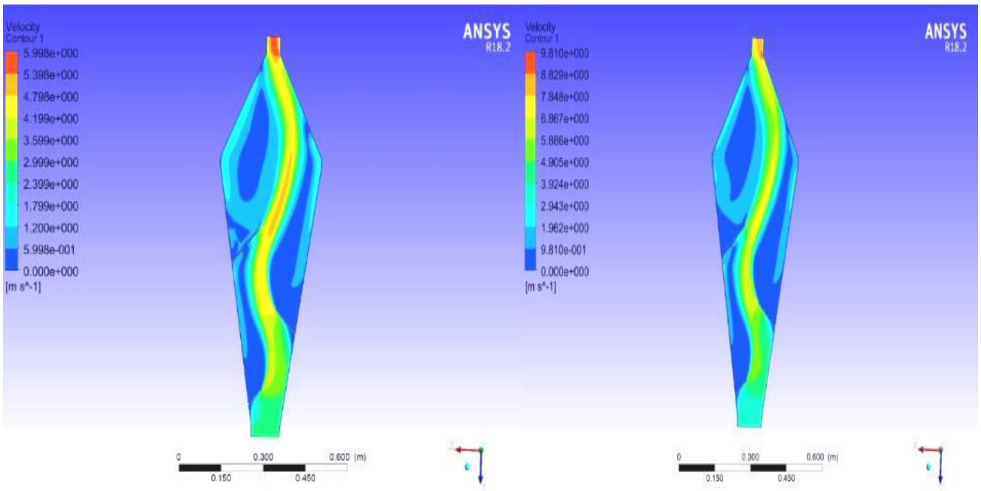


Figure 4 – The main parameters of the computational grid and boundary conditions of the computational model: A – outlet of the finely dispersed phase to the carryover; B – outlet of the coarse phase to the trough; C – inlet of the polydisperse material for separation; D – inlet of the airstream

4 Results and Discussion

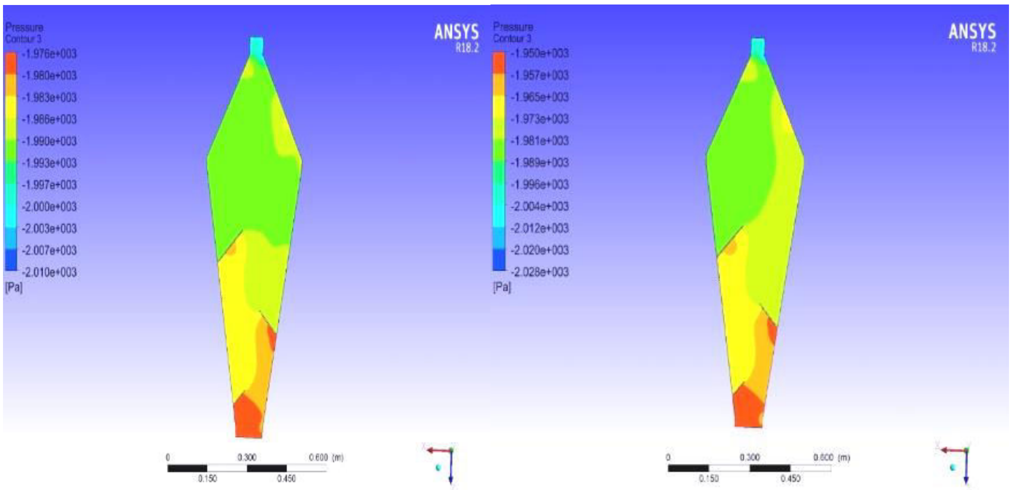
The pressure distribution (Fig. 6) and velocity fields (Fig. 5) were obtained as a result of computer modelling of classification process. These results made possible the determination of the device operation hydrodynamic features and their effect to the classification process efficiency. Confirmed optimum shape of the flow part contributes to the formation of stable vortices in the volume of the apparatus (Fig. 5). After carrying out experimental estimation the positive influence effect of the perforated contact elements to the air flow structure and the allocation of solid particles in the volume of devise were confirmed. The volume concentrations of the particles on the contact elements, as well as outgoing particles into the entrainment and dip were calculated during the simulation. The possibility of separating polydisperse materials in the volume of one device without the usage of sequentially located devices was confirmed comparing obtained and experimental data.

The air flow velocity field in the flow part of device was determined (Fig. 7). This approach allowed specifying operating, technological and design parameters for the classification process of polydispersed materials. This approach ensures an efficiency of the process and high-degree of separation in the shelf device.



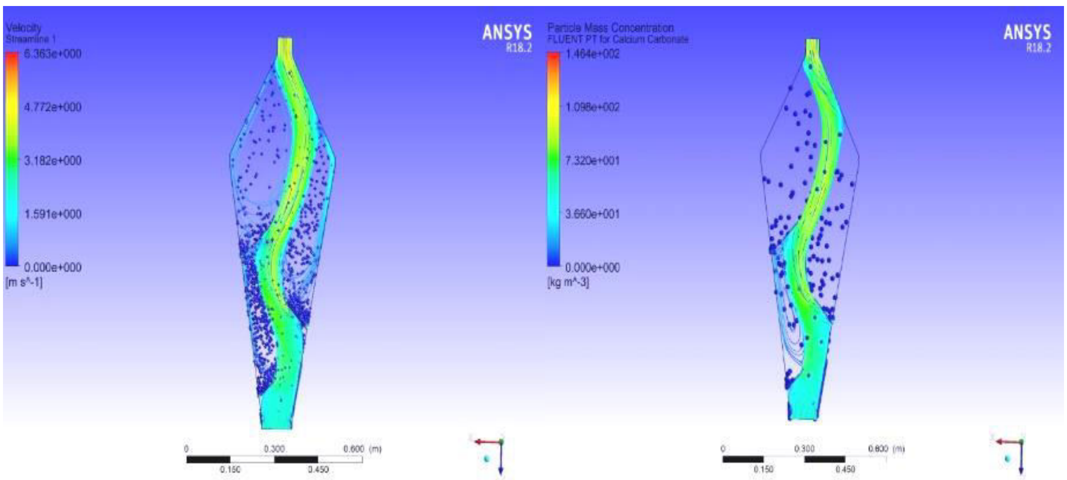
a b

Figure 5 – Contours of air flow velocity for particles d = -0.315 + 0.2 mm, V = 2,6 m/s (a), and d = –0.63 + 0.4 mm, V = 3.784 m/s (b)



a b

Figure 6 – Contours of internal pressure for particles d = -0.315 + 0.2 mm, V = 2,6 m/s (a), and d = –0.63 + 0.4 mm, V = 3.784 m/s (b)



a b

Figure 7 – Air flow velocity streamlines for particles d = -0.315 + 0.2 mm, V = 2.6 m/s (a), and d = –0.63 + 0.4 mm, V = 3.784 m/s (b)

5 Conclusions

Based on the obtained data as a result of numerical modelling, the possibility of increasing gas flow influence to the polydispersed material were found, as well as organization along the walls of coarse fraction downward flow by dint of the optimizing the devise design (specifically through the organization of additional inlets for airflow) were obtained. The future research will be aimed at using CFD simulation methods for testing the achieved results by the creation of a computational model with new design features.

6 Acknowledgements

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Моделювання процесів сепарації та пневмокласифікації аеродисперсних систем у поличковому апараті

Варуха Д. А.,[1], Смирнов В. А.[1], Едл М.[2], Дем'яненко М. М.[1], Юхименко М. П.[1], Павленко І. В.[1], Ляпощенко О. О.[1]

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Анотація. У представленій роботі розглядається процес класифікації полідисперсного сипучого матеріалу за заданим гранулометричним складом із використанням гравітаційного пневмокласcифікатора. Розглядались проблеми якості поділу полідисперсних сипучих матеріалів і способи підвищення ступеня поділу частинок. Представлені і проаналізовані отримані у результаті порівняння дані експериментального дослідження та комп'ютерного моделювання гідродинаміки двофазного потоку CFD-методами. Універсальність даного комплексу дозволила здійснити моделювання процесу з використанням варіювання параметрів. У результаті отримані оптимальні робочі параметри, які були експериментально апробовані. На підставі отриманих даних у результаті чисельного моделювання виявлена можливість збільшення впливу потоку газу на полідисперсний матеріал, а також його розподіл уздовж стінок потоку вниз по грубій фракції за рахунок оптимізації розробленої конструкції, зокрема через наявність додаткових впускних отворів для повітряного потоку.

Ключові слова: пневмокласcифікація, гранулометричний склад, сипучий матеріал, полідисперсний матеріал, двофазний потік, ступінь поділу.