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SIMULATION OF FRACTIONATION PROCESSES IN CYCLONE DEVICES

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Abstract. *The article shows and studies the process of separating bulk materials in a centrifugal field, formulating the foundations for constructing its mathematical model. Based on the analysis of the processes occurring inside the cyclone apparatus, a hierarchical structure of the process has been compiled. A mathematical description of the determination of the rate of settling of fine particles, a mathematical description of the determination of the limiting particle size, and the determination of the number of particles deposited in the apparatus are obtained. A comparative analysis of the mathematical description of the determination of the limiting particle size with the mathematical descriptions in which is given in the literature data was carried out, on the basis of which an insignificant difference between them was established.*

Keywords: *separation, centrifugal force, gas-air flow, particle acceleration, matlab.*

Introduction

In industry, there are a number of devices for separating inhomogeneous systems under the action of centrifugal force, differing in design and principle of operation, depending on the method of creating centrifugal force, two classes of devices are distinguished. These are cyclones, where centrifugal force arises due to the swirling of a flow moving at high speed in a spiral, and settling centrifuges, in which centrifugal force arises due to the rotation of the rotor. Typically, gas-solid systems are separated in cyclones. The use of centrifugal force makes it possible to significantly increase the limits of separation of inhomogeneous systems. Despite the fact that cyclones have been widely used in industry for several decades, the process of separation of inhomogeneous systems going on in them has not yet been sufficiently studied due to the complexity of the hydrodynamic situation.

The most effective method for analyzing the separation process is a study on a mathematical model. The study has the ability to analyze the most complete information about the mechanism of influence of factors in a wide range. When compiling a mathematical model of the process of separation of bulk materials in a centrifugal field, the main stage is the study of the features of the processes occurring inside the apparatus.

Methods for pneumoseparation of bulk materials are widely used in many industries due to the simplicity of the design of the devices used, low energy consumption and the ability to work in various weather conditions., for many cases, the application is necessary.

AThe task of developing new pneumoseparation devices with higher technical parameters, adapted to specific operating conditions, becomes relevant [1-3]. Nevertheless

The principle of operation of pneumatic separation cyclones is based on the centrifugal separation of a mixture of dust and air. The dusty air flow is given a rotational motion, which creates a strong field of centrifugal forces of inertia, leading to the deposition of dust particles on the walls of the cyclone installation and then moving them to a special hopper, thereby pneumoseparating dispersed particles [4-5].

An increase in the degree of separation of the dispersed material is due to the creation of kinematic conditions for the emergence of additional centrifugal forces acting on the aerodisperse flow in the plane of its vertical section. The fractions of the dispersed material are provided with movement along trajectories with different radii of curvature [6–11]. In addition, an increase in the degree of separation, as well as a decrease in energy consumption, is facilitated by the rotational movement of the outer boundary of the confuser space, which, in addition to an increase in inertial forces and kinetic moment, ensures the laminization of the aerodisperse flow [12–14].

However, there are certain difficulties on the way to creating more advanced cyclones and units, mainly caused by the lack of accurate methods for calculating and predicting the performance of future devices, taking into account specific operating conditions [15–18]. The existing methods for the general calculation of cyclones have a narrow scope and do not allow predicting the parameters of cyclones [19–24].

To solve practical problems of improving the cyclone air separation devices and devices, theoretical methods are of great importance, the use of which, using mathematical and computer modeling, numerical methods with modern computer technology, allows you to quickly and with a high degree of reliability determine the parameters of the investigated process of air separation and air separation devices. , which determines the relevance of the article.

The aim of the study is to simulate the path of deposition during the movement of a particle in a pneumoseparation apparatus, with various parameters affecting the separation process.

Research methods

This article discusses pneumoseparation devices used for pneumoseparation of bulk materials from the air of the working area [25], for which a mathematical and computer model was created in the Matlab application environment [25]. The methods of mathematical and computer modeling are applied to describe the emerging physical processes inside the air separation unit and, in particular, with moving particles. This allows us to predict the behavior of a real object [26,27].

A pneumoseparation apparatus was considered, with an inner radius, while air is supplied through the inlet pipe of the cross section. Such devices of pneumoseparation, as a rule, have a vertical axis z, and dust particles are removed from the flow due to their movement to the wall of the pneumoseparation device under the action of inertia forces (in this case, directed towards the axis of the cyclone and, therefore, hereinafter referred to as centrifugal) [28]. The movement of particles down along the outer wall of the pneumoseparation apparatus occurs due to the axial component of the velocity of the gas-dispersed flow and under the action of gravity [29].

Using the method of system analysis, it has been established that the cyclone itself is conditionally divided into 4 zones. In the first zone, under the action of centrifugal force and depending on the flow velocity, particles with larger fractions are immediately deposited. In the second zone of the cyclone, the flow passes in a circle around the outlet pipe and moves downward spirally and the dust particle, which is in the most favorable conditions for settling, moves in the cyclone with the gas flow, and here the larger particles are deposited. In the third zone of the cyclone, the flow "g-t" moves in the annular space between the walls of the separator casing, here it is planned to decrease the flow velocity and centrifugal force and increase the resistance force of the medium. In the fourth zone of the separator, the flow "g-t" moves spirally down the casing wall and then up into the outlet pipe. The diameter of the ascending spiral flow is almost equal to the diameter of the outlet pipe. In this zone, an increase in flow velocity and centrifugal force is planned.

When implementing a systematic approach to the study of the process of pneumoseparation of bulk materials, it is necessary to identify the type of air supply, the method of evacuation of the incoming flow, the scheme of interaction of flows in the cyclone apparatus, and also to evaluate the contribution of each step of the hierarchy to the total process of pneumoseparation, i.e. it is necessary to substantiate the general physical picture of the process under study.

The actual process of pneumoseparation of bulk materials in the field of centrifugal forces is divided into subprocesses:

- supply of the initial mixture through an injection mixer, rotation of the dust-gas flow around the axis of the separator, separation of the gas flow from solid particles, removal of the gas flow freed from solid particles, sliding of particles removed from the gas flow down the casing wall, accumulation of removed particles in the lower part of the cyclone and, finally, the removal of accumulated particles.

The subprocess of dust-gas flow cycling around the circumference of the outlet pipe is divided into the following elementary components:

1) movement of the gas phase;

2) movement of fine particles;

In turn, the process of particle movement is divided into the movement of individual particles of different sizes and densities.

At the next stage of the analysis of the technological process, the decomposition of the system into interconnected constituent elements is required, i.e. determination of the hierarchical structure of the substages of the processes under consideration, taking into account the hydrodynamic structure of the interacting flows.

The analysis of the hierarchical structure starts from the lowest level of the hierarchy:

1. The first step of the hierarchy is the level of displacement of an individual particle. At this level, the motion of a particle during cyclonication is analyzed. The particle under the action of centrifugal force, depending on its speed, size and density, moves inside the separation unit and begins to settle. Usually, for each cyclone apparatus of certain geometric dimensions, there is a certain limiting particle size for trapping it.

As the main parameters characterizing the behavior of the subsystem at a given level of detail, we can take the size of the particle and its density.

Phenomena at this level are controlled by changing the size and density of the particle. A mathematical description of the phenomena at this level can be obtained in the process of solving the problem of determining the limiting particle size.

2. The second level of the hierarchy includes the phenomena and effects of the movement of particles of the dispersed phase and continuous gas flow in the field of centrifugal forces. Particles entering the cyclone, under the action of inertial forces, move at the initial moment of time along rectilinear trajectories, and then entraining effects of the rotating gas flow bend their resulting trajectory, and the larger, the greater the distance from the entry point of the particles to the outer wall of the cyclone. The initial section is characterized by intensive separation of the largest particles, further the process is determined by a continuous change in the vector of the tangential component of the gas velocity. In this case, the particles located in the sedimentation zone, depending on their size and density, have different sedimentation rates.

3. The level of movement of a continuous gas phase. When analyzing the movement of the air flow in cyclone-type apparatuses, it is necessary to maintain a constant speed of the initial flow. The tangential component of the gas velocity is actually a function of the radial distance . The gas flow at the cyclone inlet moves with acceleration in the annular space between the walls of the cyclone casing and the outlet pipe. The kinetic energy of the annular flow is dissipated as a result of the exchange of momentum with reverse flows that occur at the boundaries of stagnant zones.

Based on the foregoing, as the main parameters characterizing the behavior of the functional subsystem at a given level, one can take the speed and pressure of the gas, as well as the hydrodynamic modes of movement of the interacting flows. Phenomena at this level are controlled by changing the flow rate or pressure of the gas. A mathematical description of this level can be obtained by finding the settling rate of various particles of material with different densities. 4. Cyclone dust-gas flow. The dusty gas flow enters the cyclone through a branch pipe located tangentially to the cylindrical dust settling chamber, then passes in a circle around the outlet pipe and moves spirally down the cone wall and then up to the outlet pipe. The diameter of the ascending spiral flow is almost equal to the diameter of the outlet pipe.

The mathematical description of the phenomena is an expression that determines the amount of particles deposited and leaving the apparatus.

The last stage of the system analysis is the formalization of the properties and phenomena of the corresponding levels of the hierarchy, the cumulative modeling of the process as a whole, checking the adequacy of the model to the real process and, if necessary, adapting the model to the changed conditions of the object.

Research as a whole predetermines the feasibility of the following sequence of study of its parts in relation to the developed mathematical description of the process of pneumoseparation of bulk materials:

- formalization of the properties of individual particles;
- formalization of the hydrodynamic structure of interacting flows;
- determination of the amount of trapped particles in the apparatus;
- determination of the total amount of the resulting product;
- formation of a closed or generalized mathematical model of the process under study as a whole;
- selection of the process efficiency criterion;
- formulation and solution of the problem of process optimization;

General mathematical model of the process of separation of bulk materials in a centrifugal field:

$$W_{oc} = \sqrt{\frac{4\rho_ч \ Vp^2}{3(R_2 + R_1)\xi \ P_Г}\delta} \quad ; \quad \textbf{(1)}$$

$$r = \frac{2\pi R}{Vp} \ \textbf{(2)}$$

$$\delta_0 = \frac{3\xi \ \rho_Г}{4\pi^2 \rho_ч}\left[\frac{\overline{4R_2} - \overline{4R_1}}{m}\right]^2 \ \textbf{(3)}$$

$$G_{1b} = G_{0b} - G_{m1b} \quad \textbf{(4)}$$

$$G_{m1b} = G_{m10b} + G_{m11b} \quad (5)$$

$$G_{0b} = G_0 * X_{0b} \quad (6)$$

$$G_{m10b} = \frac{G_0 * \Pi * (R_1 + R_2) * m}{3(R_2 - R_1)(\delta_{\max} - \delta_{\min})} \sqrt{\frac{32 * \rho_ч}{3\xi \rho_Г}} \left[\delta^2{}_{0b} - \delta^2{}_{b\min}\right] + \frac{\pi \rho_w}{\rho} \left[\delta_0{}^2 - \delta^2{}_{\min}\right] m \quad (7)$$

$$G_{m11b} = \frac{\delta_{\max} - \delta_0}{\delta_{\max} - \delta_{\min}} G_0 \quad (8)$$

Conclusions

Implemented process research software. Based on the results of the research, the distribution curves of the deposition rate Woc of particles over time t were constructed and analyzed. The influence of the distribution of particle diameters, air pressure, etc. on the separation of bulk materials is determined. It has been established that the degree of separation of bulk material is very significantly affected by the degree of dispersion of particle diameters from their limiting value captured by precipitation.

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