INTELLIGENT CALCULATION OF THE NUMBER OF REVOLUTIONS OF PARTICLES DURING CYCLONE DUST-AIR LAYER

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Abstract. *The aim of the study is to develop a method for calculating the number of revolutions of accelerated motion of a particle in a turbulent dust-gas flow in the field of centrifugal forces of the cyclone apparatus. The modeling of the process of pneumatic separation is carried out with various influencing parameters on the particle.On the basis of systems thinking, the technological structure of the process of concentrating bulk materials in the field of centrifugal forces is analyzed.The hierarchical structure of the system and the interconnected constituent elements have been determined.The examples show the curves of the dependence of the distance traveled by a particle with a size of 0.2 μm from the inner radius of 0.15 m to the outer 0.35 m of the cyclone device and the number of revolutions of the particle in the dust-gas flow. It was found that in the field of centrifugal forces the particle makes accelerating motion. It travels from the inner radius of 0.15 m to the outer 0.35 m in 0.21 seconds. During this time, it makes 0.3 turns inside the cyclone installation. Research results show a large share of accelerating motion of particles in cyclones. They will make it possible to calculate in a new way various apparatus for cycloning bulk materials.*

Keywords: *particle, motion, calculate, apparatus, cycloning bulk materials.*

Introduction

Due to their simplicity of design, low energy consumption and the ability to work in conditions of high temperatures and pressures, installations of centrifugal pneumatic separation of particles are used in many industries.

In connection with the tightening of requirements for pneumatic separation of particles and dedusting of process air, the task of developing new models of cyclones with higher technical parameters, adapted for specific operating conditions, becomes urgent [1-3].Nevertheless, for many cases, the use of cyclones is necessary [4,5].

An increase in the degree of separation of dispersed material is due to the creation of kinematic conditions for the emergence of centrifugal forces acting on the aerodispersed flow in the plane of its vertical section.Particles of 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 provision of rotational movement of the outer boundary of the confuser space, which allows, in addition to an increase in inertial forces and angular momentum, to provide laminarization of the aerodispersed flow [12-14].

However, there are certain difficulties on the way of creating more advanced cyclones and units, caused mainly by the lack of accurate methods for calculating and predicting the performance of devices, taking into account specific operating conditions [19-23].The existing methods for the general calculation of cyclones have a narrow field of application and do not allow predicting the parameters of cyclones [24-30].

To solve practical problems of improving cyclone pneumatic separation devices, theoretical methods are of great importance, the use of which, with the use of mathematical and computer modeling, numerical methods and means of modern computing technology, makes it possible to quickly and with a high degree of reliability determine the optimal parameters of the process under study, which is relevant. task.A cyclone device that separates particles from a dust and gas flow in the working area is considered.

The aim of the study is to develop a method for calculating the number of revolutions of a particle in the field of centrifugal forces in a cyclone apparatus based on modeling, with various parameters affecting the separation process.

Research methods

The methods of systems thinking are recommended on[15-19].A systematic approach to the concentration of bulk materials, which plays an important role in the analysis, modeling and search for optimal solutions for the process of particle motion in a cyclone unit, makes it possible to establish cause-and-effect relationships that characterize the course of the process by defining the hierarchical structure of the system.

Methods of mathematical and computer modeling, methods of using the Matlab application environment [31].Methods of mathematical and computer modeling have been applied to describe the arising physical processes inside the cycloning unit and, in particular, with moving particles [32, 33].This allows us to predict the behavior of a real object.

The system for concentrating bulk materials in the field of centrifugal forces has a number of methods for determining processes, these are:

- feeding the initial mixture through the injection mixer,
- rotation of the dust - gas flow around the inner axis of the cyclone - separator,
- movement of particles to the wall of the inner wall of the cyclone body - separator separation of solid particles from the gas flow. In turn, the movement of dispersed particles is divided into the movement of individual particles of different sizes and densities.
- sliding of particles removed from the gas flow down the inner wall of the cyclone body,
- outlet of the gas stream partially freed from solid particles,
- accumulation of removed particles in the lower part of the cyclone,
- finally, the removal of accumulated particles.

To analyze the technological process of concentrating bulk materials in the field of centrifugal forces, it is necessary to determine the hierarchical structure and related constituent elements, i.e. to determine the hierarchical structure of the risers of the systems under consideration, taking into account the hydrodynamic structure of the interacting flows.

System analysis of cyclone device

The analysis of the hierarchical structure of the cyclone apparatus is carried out starting from the lower level of the hierarchy:

1. The first level of the hierarchy is the level of an individual particle. This level analyzes the movement of a particle during cycloning. A 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 capturing it.

As the main parameters characterizing the behavior of the subsystem at a given level of detail, one can take the particle size 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 - determining the limiting particle size.

2. The second level of the hierarchy includes the particle flow. Here, the phenomena and effects of motion of particles of a dispersed phase and a continuous gas flow in the field of centrifugal forces are considered: Particles entering the cyclone, under the action of inertial forces, move at the initial time along rectilinear trajectories, and then the entraining effects of a rotating gas flow distort their resulting trajectory, moreover, 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, and then the process is determined by a continuous change in the vector of the tangential component of the gas velocity. In this case, the particles in the deposition zone, depending on their size and density, have a different deposition rate.

3. The third level of the hierarchy includes a continuous gas phase. The gas flow at the cyclone inlet moves in the annular space between the walls of the cyclone casing and the outlet pipe.

Based on the foregoing, the gas velocity, as well as the hydrodynamic modes of the interacting flows, can be taken as the main parameters characterizing the behavior of the functional subsystem at this level.

Phenomena at this level are controlled by changing the flow rate. A mathematical description of this level can be obtained by finding the deposition rate of various particles of a material with different densities.

4. The fourth level of the hierarchy includes the dust and gas flow. The dusty gas flow enters the cyclone through a branch pipe located tangentially to the cylindrical dust collection chamber. It then runs in a circle around the outlet pipe and moves along the wall of the cone to the outlet pipe. In parallel with the rotation of the dust and gas flow around the circumference, the process of deposition of particles with different sizes and densities takes place.

The mathematical description of the phenomena is an expression that determines the number of particles deposited and leaving the apparatus, depending on the aerodynamics of the flow or particles. The aerodynamic structure of flows is determined by the Reynolds number. It determines the relative importance of the effect of viscosity versus the effect of inertia. The Reynolds number is proportional to the force of inertia and inversely proportional to the force of viscosity.

- laminarif$Re<2300$
- intermediate if$2300 < Re <4000$*(иногдауказывают 10000)*
- turbulentif$4000<Re$

In our case, the parameters for calculating the aerodynamic structure of flows are given:

Air consumption – 0,035 м3/с

Cycloning device radius: R1=0.35; R2=0.15;

Height of the gas-air supply – 200 мм

Air inlet width – 200 мм

Particle size– 0,2 мкм

Particle density– 1246 кг/м3

Air density 1,36 кг/м3

Air viscosity– 0,0000185Н • с / м2). [37],

obtained the Reynolds number equal to12 864

Thus, the particle is in the zone of a turbulent gas and dust flow. For such a hydrodynamic regime, the drag coefficient can be taken equal to 0.44.

The next stage of the system analysis is the formalization of the properties andphenomena of the corresponding levels of the hierarchy, the cumulative modeling of the process as a whole, and, if necessary, the adaptation of the model to the changed conditions of cycloning.

Mathematical description of the motion of a particle in a cyclone

The forces acting on a suspended particle in a stream rotating inside a cyclone of a gas-dispersed phase are based on the method for calculating the particle velocity in the Matlab application program. This is the centrifugal force, the force of resistance of the gas-dust flow, the forces of gravity, the Archimedean force and the force of inertia acting on the accelerating motion of the particle in the flow [30, 31]:

To obtain a mathematical description of the process of motion of a particle in a cyclone, the forces acting on a suspended particle in a flow rotating inside a gas-dispersed phase are considered:

1) centrifugal force- $F_{ц} = \frac{mV^2}{R}$; (1)
2) gravity force– Fт $=Mg$; (2)
3) the force of resistance of the air gas-dispersed phase

$$F_c = \varepsilon \frac{\pi d^2{}_ч}{4} \frac{W^2{}_{oc}}{2} P_r \, , \quad (3)$$

here: R - radius of the device; dч - particle diameter, ε - hydraulic resistance coefficient, ρг - gas density, V - gas flow rate, m – particle mass, ε - hydraulic resistance coefficient, Woc - particle settling rate.

To determine the speed of movement of a particle in a cyclone and the duration of the separation process of inhomogeneous systems "gas-solid", it is necessary to compare the action of the centrifugal force and the force of resistance of the medium.

If we assume that sedimentation is characterized by the general law of resistance, then the force of centrifugal acceleration and the force of resistance tend to balance. The driving force for the accelerated motion of a particle (neglecting the force of gravity of the particle, the Archimedean force) is equal to the difference between the centrifugal force and the force of the movement of the particle in the flow,

$$\Delta F = (F_U - F_{тр}) = m \cdot a \quad (4)$$

Here, a - the acceleration of the particle. The Archimedean force is very insignificant and can be neglected. Then, the acceleration of the particle

$$a = \frac{\Delta F}{m} \quad (5),$$

Where, the particle mass is known as:

$$m = \rho V_ч \;\; = \frac{3\pi d^3}{4} \rho \quad (6)$$

Comparing the centrifugal force and the resistance force, we get:

$$\Delta F = ma = \frac{mV^2}{R} - \varepsilon \frac{\pi d^2{}_{ч} W^2{}_{oc}}{4*2} P_r \quad (7)$$

Acceleration is determined by the difference in speed over time:

$$a = \frac{dW_{oc}}{d\tau} \quad (8)$$

Hence, the equation for the accelerated motion of a particle in the field of centrifugal motion of a dust-gas mixture was obtained:

$$m\frac{dW_{oc}}{d\tau} = \frac{mV^2}{R} - \varepsilon \frac{\pi d^2{}_{ч}}{8} \rho_r W_{oc}^2 \quad (9)$$

To formalize the computer model, transforming equation (12) of the accelerated motion of a particle in the field of centrifugal motion of a dust-gas mixture, the velocity of motion of particles with acceleration was obtained

$$\frac{dW_{oc}}{d\tau} = \frac{V^2}{R} - \varepsilon \frac{\pi d^2{}_{ч}}{8.m} \rho_r W_{oc}^2 \quad (10)$$

To calculate the sedimentation rate of a particle, we apply the following formula

$$W_{oc} = \frac{dL_{oc}}{d\tau}, \quad (11)$$

and to calculate the path of the particle, we use

$$L_{oc} = dW_{oc} * d\tau \quad (12)$$

The residence time of particles in the apparatus is determined by the following expression:

$$\tau = \frac{L}{V_p} = \frac{2\pi R}{V_p} n \quad (13),$$

here$L$ – apparatus length; m – the number of revolutions of the dust-gas flow,

$$\tau = \frac{Loc}{W}. \quad (14)$$

Equating equations (18) and (19), the required number of cyclone revolutions is determined, which ensures complete sedimentation of the particle with the specified parameters and, transforming, is expressed in the form:

$$n = \frac{VL}{2\pi RW} \quad (15)$$

From equations (10-15), a computer model of the distance traveled and the number of revolutions of the particle in the field of centrifugal forces in the cyclone apparatus was obtained (Fig. 1).

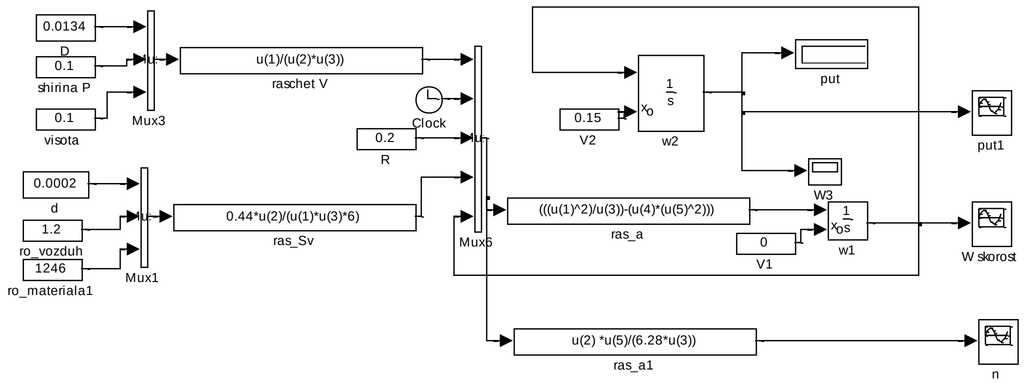

Fig. 1. Computer model for calculating the number of revolutions of a particle with different sizes in the field of centrifugal forces in the cyclone apparatus.

Transforming equation (18), a computer model of the number of revolutions of particles in the field of centrifugal forces in the cyclone apparatus was obtained (Fig. 1).

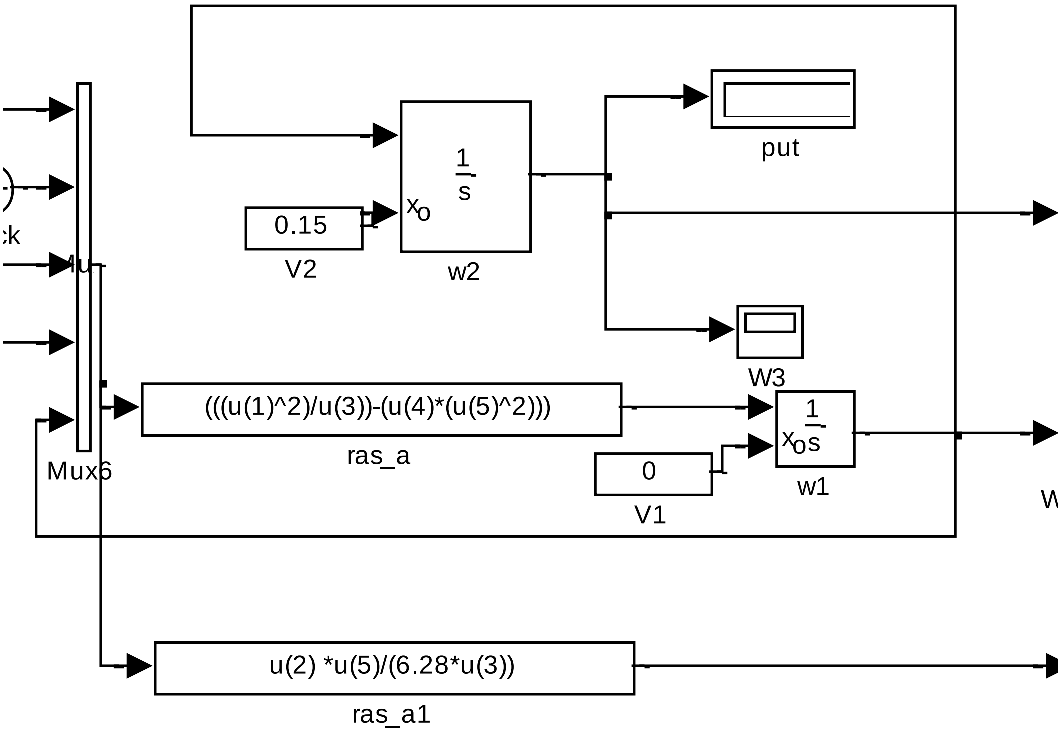

Fig. 6. Block for calculating the number of revolutions of a dust and gas flow with a particle

The results of studies on a computer model, in particular, on the time variation of the velocity above the intended particle of the dust and gas flow are presented.

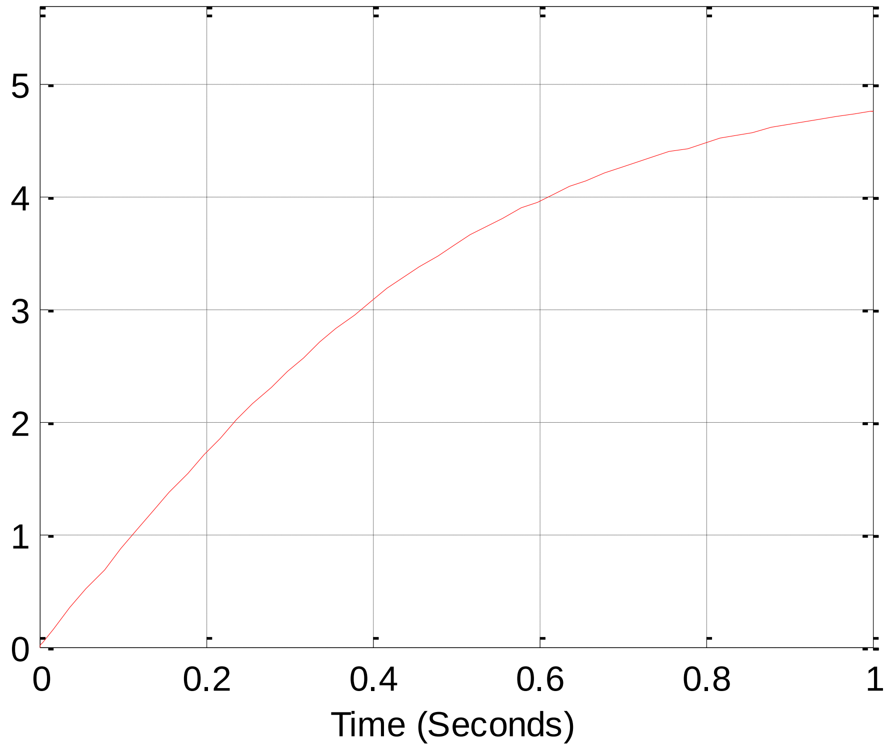

Fig. 8. Curve of the velocity of passage of a particle in a dispersed flow

Figure 8. shows the result of calculating the speed of passage of a particle in the field of centrifugal forces in the cyclone apparatus. In 1 second, the particle gains speed up to 5 m / s inside the quasi-cyclone apparatus.

The time dependence of the path of a particle of a dust-gas flow in a dispersed flow is determined.

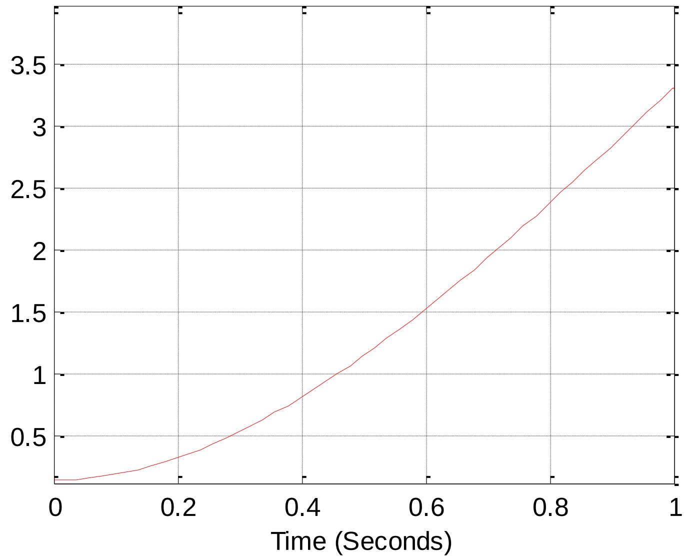

Fig. 9. Curve for calculating the path of passage of a particle in a dispersed flow

Figure 9 shows the result of calculating the path of passage of a particle in the field of centrifugal forces in a quasi-cyclone apparatus. In 1 second, the particle gains acceleration and travels, as it were, 3.4 meters inside the quasi-cycloning apparatus.

The dependence of the number of revolutions of a particle of a dust-gas flow in a dispersed flow over time has been determined.

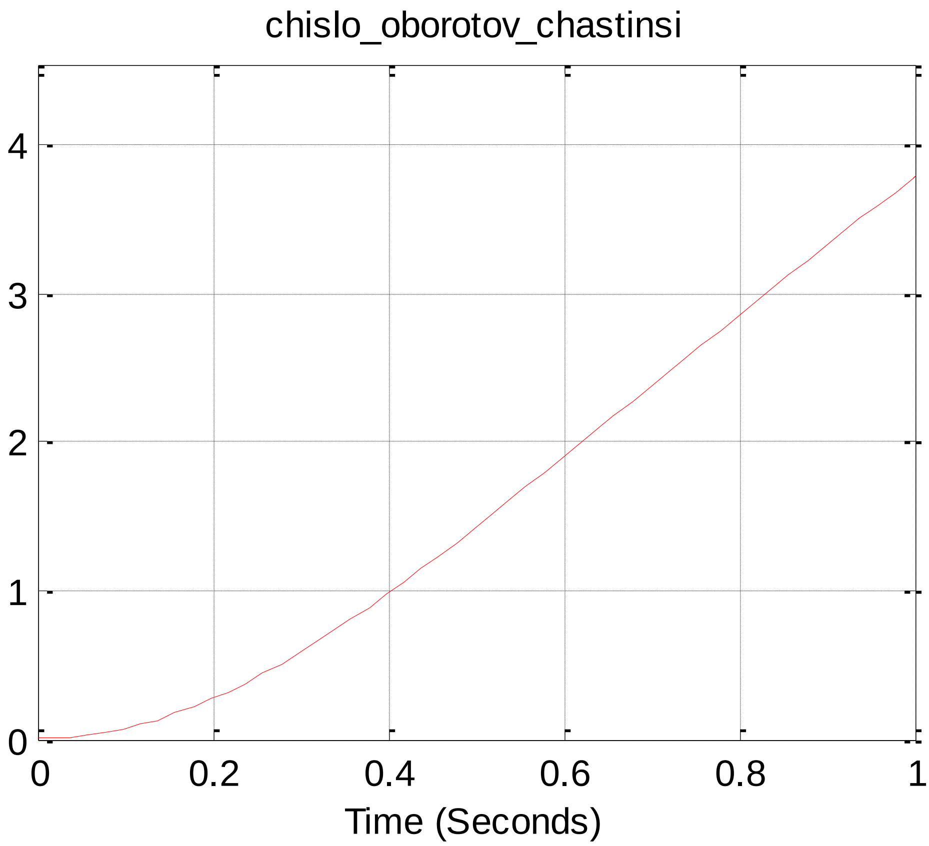

Fig. 10. Curve for calculating the number of revolutions of a particle in the field of centrifugal forces in a quasi-cyclone apparatus

In Figure 10, a graph of the result of calculating the number of revolutions of a particle in the field of centrifugal forces in a quasi-cycloning apparatus is indicated. In 1 second, the particle passes up to 4 revolutions inside the cyclone installation.

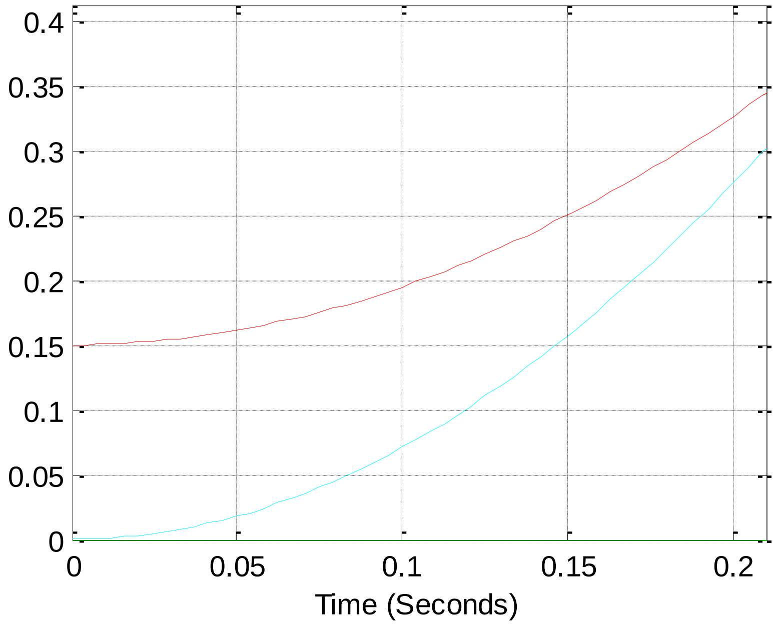

Fig. 10. Curves of the dependence of the distance traveled by the particle in time on the inner radius of the cyclone device and the number of revolutions of the particle in the dust-gas flow

Figure 11 shows the curves of the dependence of the distance traveled by a particle with a size of 0.2 μm from the inner radius of 0.15 m to the outer 0.35 m of the cyclone device and the number of revolutions of the particle in the dust-gas flow. As you can see, in the field of centrifugal forces in the cyclone apparatus for 0.21 second, the particle making accelerating motion travels a path from 0.15 to 0.35 m. During this time, it makes 0.3 revolutions inside the cyclone installation. Research results show a large share of accelerating motion of particles in cyclones. They will make it possible to calculate in a new way various apparatus for cycloning bulk materials.

Results and discussion

The analysis of the movement of a particle in a cyclone was based on a mathematical model, which gives an understanding of the ongoing physical processes in the cyclone apparatus. With the help of the created computer model in the environment of the MATLAB application program, where the processes occurring in the cyclone apparatus were recreated. Each process taking place inside the cyclone apparatus was built in stages in the form of several blocks with functional elements. Each unit directly initialized the tasks posed in the process of modeling accelerating and centrifugal forces, where the material was a particle gaining speed inside the cyclone apparatus, moving to the walls of the installation chamber under the influence of centrifugal force. In the elements inside the blocks, input and output parameters, functions and formulas were entered for each process taking place directly in one or another block of the cyclone apparatus model.

The final stage of modeling was the conclusion of the final result, in the form of accelerating and centrifugal processes, and also, as a result of modeling, the conclusion of the path of passage, acceleration and number of revolutions of the particle in the cyclone apparatus.

As can be seen from the result of our work, the particle has accelerated motion in the gas-dust flow, gaining acceleration under the given conditions, up to 2 seconds. According to the calculation data, during this time most of the particles reach the cyclone walls. This shows that the main process of making revolutions and sedimentation of particles in cyclones occurs during accelerated motion.

Conclusion

A computer model of a cyclone installation was developed, where analytical methods for evaluating the acceleration parameters and the main methods of numerical analysis of the dynamics of particle motion were carried out. Using the method of systems thinking and mathematical modeling in the development of a computer model in the Matlab environment, we have developed a detailed model for calculating the number of revolutions it makes in the field of centrifugal forces in the cyclone apparatus.

This showed that under the given conditions, the main advantage of up to 2 seconds is the accelerated motion of a particle in a gas-dust stream. So, the main process of sedimentation of particles in cyclones occurs during the accelerated movement of particles. During this time, most of the particles reach the cyclone walls and settle. the particle has an accelerated motion in the gas-dust flow, gaining acceleration under the given conditions, up to 2 seconds. According to the calculation data, during this time most of the particles reach the cyclone walls. This shows that the main process of making revolutions and sedimentation of particles in cyclones occurs during accelerated motion.

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