УДК 66.074

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RESEARCH OF THE MECHANISM O F SHOCK-INERTIAL DEPOSITION OF DISPERSED PARTICLES FROM GAS FLOW

Keywords: blade impeller; the liquid level; the effectiveness of gas purification; gas stream; scrubbing liquid; the diameter of particles; shock-inertial deposition.

The analytical dependence describing the effectiveness of shock-inertial deposition of particulate matter. Depending on the properties of trapped particulate material and operating parameters of gas purification. The design of the new device shock inertial action that allows optimizing the cleaning process gases taking into account the characteristics of components.

Ключевые слова: лопасть рабочего колеса; уровень жидкости; эффективность очистки газа, поток газа; очищающая жидкость, диаметр частиц, ударно-инерционное осаждение.

Получена аналитическая зависимость описывающая эффективность ударно-инерционного осаждения твердых частиц зависимости от свойств захваченных частиц и эксплуатационных параметров процесса очистки газа. Сконструировано новое устройство ударно-инерциального действия, которое позволяет оптимизировать процесс очистки газов с учетом характеристик компонентов.

Introduction

Comparative analysis of the main known dust separators of shock-inertial action shows that many designs work in small range of speed variation of gas in contact channels. Such apparatuses are used in industrial production for clearing of gases from large-dispersed dust in systems aspiration auxiliaries.

Known apparatuses are very sensitive to change of gas load to contact channel and the level of liquid. Insignificant deviations of these parameters from optimum values result in a unstable operating mode and efficiency reduction dust separation.

Because of low speeds of gas in contact channels such devices have big dimensions. These deficiencies, as well as weak level of scrutiny of processes proceeding in apparatuses, make difficult development of new rational designs of wet dust collectors of given type. Absence of reliable methods of their calculation hinders wide implementation to production [1, 2].

In connection with that there is necessity of more detailed theoretical and experimental studying shock-inertia-type deduster for use of the most effective designs in the purification systems of industrial gases.

Development of the rotoklon

Developed and patented design rotoklon, capable to solve the problem an effective separation of dust from gas flow [3]. At the same time supply of water to contact zones is implemented as a result of her circulation inside apparatus itself.

Rotoklon presented on fig.1 contains case 3 with pipe branches for entrance 7 and exit 5 gases, in which the pair of blades of sine wave profile are installed. Moving of top blades 2 is implemented with the aid of screw hoist 6, bottom blades 1 are fixed on axis 8 with opportunity of their turn. The angle of rotation of bottom blades is determined such that of constancy of speeds of dust-laden flow.

For regulation of the angle of rotation of output part of bottom blades 1 flywheels are provided. Amount blades pair is defined of output of the device and the dust content of dust-laden flow, that is, the mode of steady work of the device. In lower part of the case there is a pipe of outlet for slurry 9. Before pipe branch for gas exit 5 is installed labyrinth drip pan 4

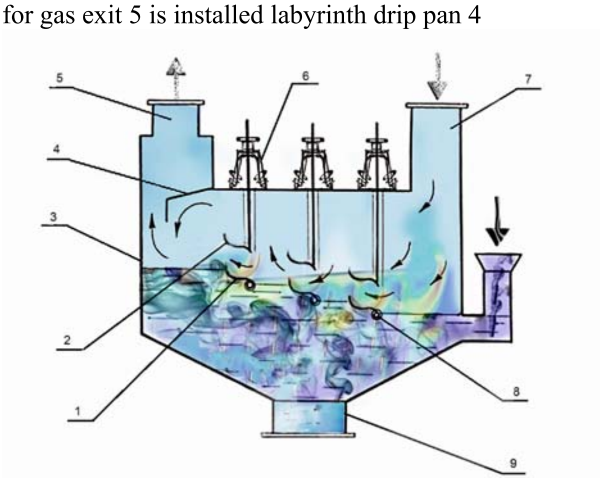

Fig. 1 - General view of the Rotoklon: bottom 1 and top 2 blades; case 3; labyrinth drip pan 4; pipe branches for entrance 7 and exit 5 gases; screw jack actuators 6; axis 8; outlet for slurry 9

Rotoklon works as follows. Depending on the dust content of пылегазового flow top blades 5 by means of screw jack actuators 6, and bottom blades 1 with the aid of flywheels are installed to angle determined by the device operating mode. Dust-laden flow arrives to entrance pipe branch 7 at the top of the case of 3 apparatuses. Impacting of liquid surface, he changes his direction and passes to slot channel formed by top 2 and bottom 1 blades. Due to high speed of movement cleared gas seizes a top liquid layer and will crush him to smallest drops and lather with highly developed surface.

After sequential passing of all slot channels gas passes through labyrinth drip pan 4 and through outlet 5 is removed to atmosphere. Caught dust settles in the bunker rotoklon and through pipe of outlet for slurry 9, together with liquid, is removed periodically from apparatus.

Rotoklon is characterized by presence of three of slot channels formed by top and bottom blades, and in each channel subsequent in the course gas bottom blade is installed higher than the previous. Such arrangement promotes a gradual entrance of gas-liquid flow to slot channels and lowers thereby a hydraulic resistance of the device. The arrangement of entrance part of blades on axis with opportunity of their turn allows to create core of diffusion.

Consistently located slot channels create in diffusion zone formed by the blades angle of rotation, a hydrodynamic zone of active coating of dust particles. In accordance with moving of flow through liquid curtain, opportunity of repeated stay of particles of dust in hydrodynamic core is supplied that considerably increases efficiency dust separation and ensures the functioning device in wide ranges of the dust content of gas flow.

Noted features of the design do not allow to use correctly present decisions on hydrodynamics of dust-laden flow for developed design. In connection with that, for justified description of processes occurring in the apparatus, necessity of execution of experimental researches arose.

Description of experimental installation and the technique of execution of experiment

Rotoklon represents reservoir with water, to surface of which on the pipe branch of enter of dusty gas dust-laden mix arrives. Above water surface gas is displayed, and dust containing in gas on inertia they penetrate to liquid. Turn of impeller blades is produced manually, relatively each other on threaded connection by means of flywheels. Blades angle of inclination was installed in the interval 25°-45° to the axis.

Under study rotoklon had 3 slot channels, speed of gas in which accounted for up to 15 m/s. At this speed rotoklon had a hydraulic resistance 800 Pa. Working in such mode , he supplied dust trapping efficiency with entrance concentration 0,5 g/nm^3 and density 600 kg/m^3 on the level 96,3 % [1].

As model system air and powder of talc with size of particles d=2÷30 microns were used. The apparatus case was filled in water to level h_l=0,175m. Dust content of dust-laden mix was defined by direct method. On direct sections of the pipeline before and after apparatus sampling of dust-laden mix was produced. After establishing of the appropriate operating mode of the apparatus, tests of gas were selected with the aid of intake pipes. For observance isokinetic sampling on intake pipes replaceable tips of various diameters were applied.

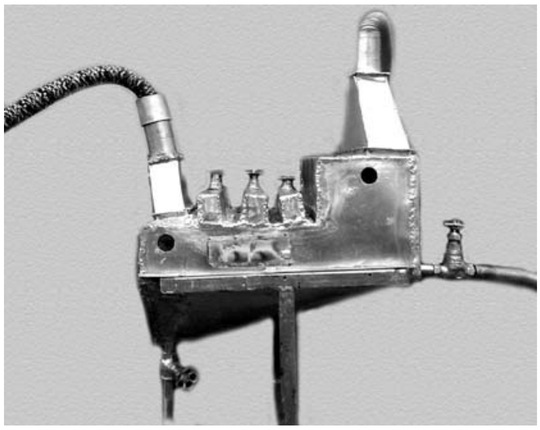

Fig. 2 - Experimental installation "Rotoklon"

Total trapping of dust containing in selected test of dust-laden mix, was produced by the way of external filtration with the aid of dust aspirator EA-55 through special analytical filters AFA-10 which were inserted to filtering cartridges. The time of selection was fixed on stop-watch, and speed - rotameter. Water discharge is defined by losses of her to evaporation and with removed slurry. Run-down of water is produced by small portions from bunker supplied by pneumatic gate.

Gate closing is implemented by quick pressure rise of air in the gate chamber, opening - pressure relief. A small decrease of the level quickly is compensated topping up the level м through the pipe branch of enter of liquid. At periodic run-down of condensing slurry water discharge is defined by slurry consistence and averages up to 10 g. by 1 m^3 air, and at constant run-down charge does not exceed 100-200 g. by 1 m^3 air. Filling rotoklon with water was adjusted with the aid of level gauge. Maintenance of constant water level has essential value, as his oscillations involve an appreciable change both of efficiency, and productivity of the device.

Results of experiment

In rotoklon process of interaction of gas, liquid and firm phases is realized, as a result of which firm phase (dust), dispersed in gas, goes to liquid. Hydrodynamic processes proceeding at the same time can be distributed to following consistently proceeding stages: at the inlet to impeller blade grab of liquid with gas flow takes place; active liquid splitting with gas flow with formation of liquid curtain; coagulation of dispersed particles by liquid drops; separation of drops of liquid from gas in labyrinth drip pan.

At supervision through observation port it is given an impression that all working volume of the apparatus is filled with gas-liquid lather and splashes. However this effect is characteristic only for layer directly contiguous to observation port, he can be explained by deceleration of the flow at butt wall. Consideration of slowed down shooting allows to establish a true flow picture. Gas flow goes on the trajectory of least way, trying to strive through liquid. The impeller blades worth consistently under these conditions limit dissemination of air jet, forcing her sharply to change their direction that favors process of separation.

Qualitative dust separation will be reached only in the case of effective grab of liquid with gas flow, otherwise it will not be supplied of effective interaction of phases in contact channels. In such a manner, grab of liquid with gas flow at sequential passing of impeller blades is one of the most important phases of hydrodynamic process in rotoklon.

Process of grab of liquid layer with gas flow is realized due to presence of turbulent fluctuations which are formed on the boundary of the section of gas and liquid phases. By the preconditions for occurrence of turbulent vortexes they can serve distinction in flows viscosity, surface tension of liquid phase, as well as presence on gradient interface of speeds of phases.

The evaluation of gas purification efficiency

Quantitative evaluation of efficiency of grab in the apparatuses of shock-inertial type with inside circulation of liquid expediently to conduct with the aid of $n = L_l / L_g$, m^3/m^3 gas equal to attitude of volumes of liquid and gas phases in contact channels and characterizing specific irrigation gas channels. It is evident that size n, primarily, will be defined of gas flow velocity at the inlet to contact channel [4]. Following important parameter is the level of liquid at the inlet to contact channel which can change channel section and to influence speed of gas:

$$\frac{\vartheta_g}{S} = \frac{\vartheta_g}{bh_c - bh_l} - \frac{\vartheta_g}{b(h_c - h_l)}$$

where S —is an effective area of contact channel; b— is distance between impeller blades; h_c — is channel height; h_l — is the level of liquid. In such a manner, for definition of efficiency of grab of liquid with gas flow in contact channels rotoklon it is enough to receive experimentally following dependence:

$$n = f(\vartheta_g \cdot h_l)$$

As it was installed experimentally, from size of liquid drops to a large extent dust particles trapping efficiency depends: with reduction of size of drops efficiency dust separation is increased. In such a manner, given stage of hydrodynamic phases interaction is quite important. For calculation of middle diameter of drops formed at passing of impeller blades, empirical dependence is received:

$$d = \frac{585 \cdot 10^3 \sqrt{\varsigma}}{\vartheta_o} + 21.375 \cdot \left(\frac{\mu_l}{\sqrt{\rho_l \varsigma}}\right)^{0,73} \frac{L_l}{L_g}$$

where ϑ_o —there is relative velocity of gases in the channel, m / s; ς — factor of surface tension of liquid, N/m; ρ_l —there is fluid density, kg/m^3; μ_l — there is viscosity of liquid, Pa / s; L_l— is volumetric flow rate of liquid, m^3/s; L_g— is volumetric flow rate of gas, m^3/s.

Offered formula allows to produce calculation with the account of physical specifications of phases and control parameters of process of gas purification. Fig. 3 shows the calculated values of middle diameter of drops formed are presented at passing of impeller blades, from speed of gas in contact channels and specific irrigation of gas. At calculation the values of physical properties of water were accepted at temperature 20° C: ρ_l = 998 kg / m^3; μ_l = 1,002·10^{-3} N·S/m^2 ; ς =72,86 10^{-3} N/ m.

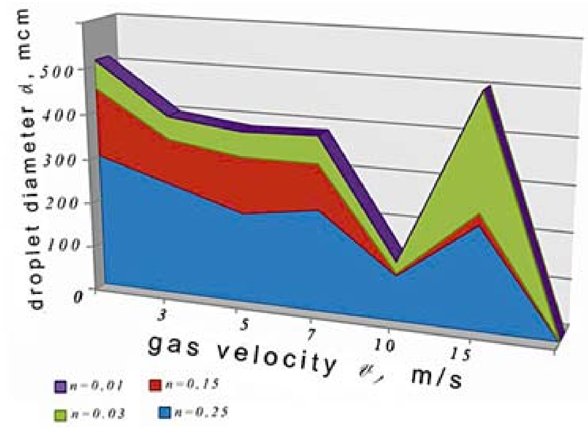

Fig. 3 - Calculated dependence of size of drops from flow rate and specific irrigation

Received dependences testify that of the most important control parameters, from which average size of drops in contact channels rotoklon depends, gas flow velocity ϑ_o and specific charge of liquid to humidifying of gas n are. Exactly these parameters define a hydrodynamic structure of formed gas-liquid flow.

Degree of clearing of gas emissions in the apparatuses of shock-inertial action can be found only on the basis of empirical information on particular apparatuses designs. Methods of calculations which found use in practice of designing, are based on the assumption of opportunity of linear approximation of dependence of degree of clearing from diameter of particles in probability-logarithmic coordinate system. Calculations on probability method are executed on the same outline, as for the apparatuses of dry gases clearing [1, 2].

Shock-inertial deposition of dust particles takes place at flow of liquid drops with dusty flow, therefore the particles having inertia, continue to move across bent gases streamlines, drops surfaces reach and deposit on them.

Efficiency of shock-inertial deposition η_u is function of following dimensionless criterion:

$$\eta_i = f\left(\frac{m_p}{\xi} \cdot \frac{\vartheta_p}{d_0}\right)$$

where m_p — is mass besieged particle; ϑ_p — is speed of the particle; ξ —particle movement drag coefficient; d_0 — is diameter of the drop section. For globe-shaped particles, movement which obeys the Stokes law, this criterion has following type:

$$\frac{m_p \vartheta_p}{\xi d_0} = \frac{1}{18} \cdot \frac{d_g^2 \vartheta_p \rho_p C}{\mu_g d_0}$$

The complex $d_p^2 \vartheta_p \rho_p C / (18 \mu_g d_0)$ is Stokes parameter (fig.4)

$$\eta_i = f(Stk) = f\left(\frac{d_p^2 \vartheta_p \rho_p C}{18 \mu_g d_0}\right)$$

In such a manner, dust particles trapping efficiency in rotoklon to inertial model depends mainly from specification caught dust (size and density caught particles) and control parameters, most important of which gas flow velocity is at passing through impellers blade.

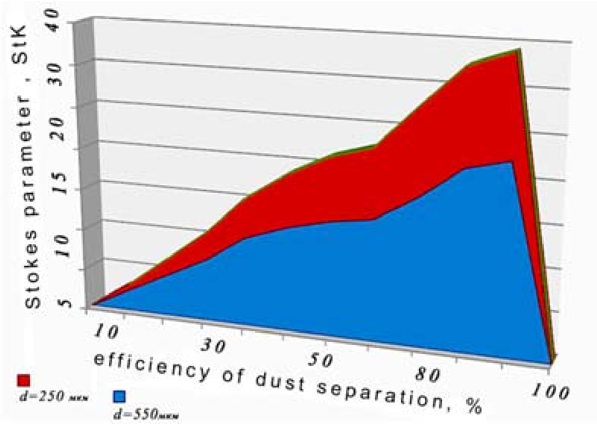

Fig. 4 - Dependence of efficiency of dust separation from criterion StK

Considered inertial model adequately characterizes physics of process proceeding in contact channels rotoklon.

Aerodynamic profiling of impeller blades

For reduction of hydraulic resistance expediently to apply a rational profiling of impeller blades. Formation to the blades of the impeller of sine wave profile allows to remove separator of flow on blades edges.

At the same time flow of entrance section of the profile of blades with big fixed speed and increase of ricochets from shaped part of blades takes place in view of which it is possible to predict an insignificant increase of gas sweeting efficiency. Outline of calculation of shaped blades is represented on the fig. 5.

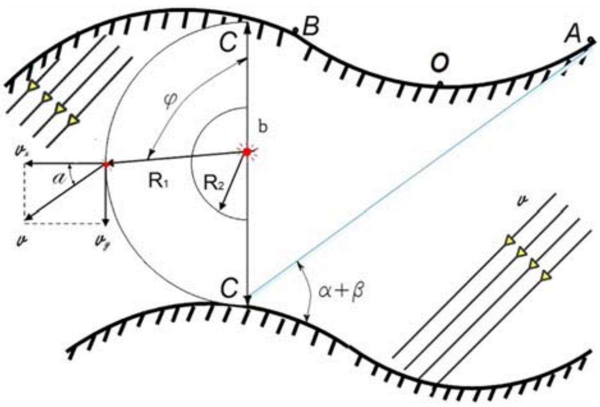

Fig. 5 – Design scheme shaped blades

In entrance part of dust-laden flow free jet boundaries are replaced by shaped impeller blades channels. In point of blow *O* ram air it will be crushed and flows about curvilinear surface of *AB*, at the same time speed reaches peak value ϑ_{max} and is preserved to constant by length of the whole section. In the section *C* flow it is possible to consider as uniform, driven with speed ϑ, and the impeller blades have a ultimate thickness, separator of flow from impeller blades does not take place. Flow is implemented lossless of pressure up to critical section *C-C,* after which static pressure in flow begins to drop. Hydrodynamic expediently profile the blades of the impeller in view of various values of speeds within the limits of slot channels. In such a manner, dust-laden flow can be revolved to any necessary angle without hydraulic losses.

As results of experiment showed, change of the angle α from 30° to 45° results in increase of passage area of flow $R_2 - R_1$ at change of the direction of gas movement and increase *b* after his turn. Passage area of flow *b* is increased on the average to 1,55 times. At the same time speed of gas at passing through impeller blade decreases that involves reduction of speed of dispersed particles tangent components ϑ_y. Centrifugal force of the inertia being in charge of separation of particles from gas flow and determining increment of radial components ϑ_x speed of particles, decreases at the same time. Expansion of the jet $R_2 - R_1$ promotes increase of the path of particles at separation, and it leads in turn to significant growth of secondary entrainment of dust.

Flow of dusty gas passing through impeller blade, can be schematized with flat flow of incompressible liquid which approaches to the lattice under angle α with speed ϑ and at turn beside the edges of blades loses dust particles, ricochets from blades. Cleared gas lifts off from blades edges, forming in slot channels between them tear-off zones with approximately constant pressure. The boundary of tear-off zones can be considered as the line of breakage of tangents of speeds in ideal (residual) liquid. Definition of speeds of gas at passing through blades enough difficult. Calculation task can be simplified, if at research of process of dust separation to consider an approximate model of gas flow. The model takes into account the main laws of areas of speeds of dust-laden Wednesday installed at more accurate calculation.

In such a manner, if design data of impeller blades are given, it is possible to calculate distribution of speeds of gas at flow with her dust-laden flow. Knowing speeds of gas in various points of efflux, it is possible to define forces of aerodynamic resistance, from which the paths of firm particles in slot channels depend.

Conclusions

1. New design rotoklon is developed, enabling to solve the problem an effective separation of dust from gas flow. In presented apparatus supply of water is carried out as a result of its circulation within the device.
2. It is shown experimentally that grab of liquid with gas flow at sequential passing of impeller blades is one of determining stages of hydrodynamic process in rotoklon.

3. Theoretically obtained and confirmed by the data of direct measurements of the value of efficiency of shock-inertial deposition of dispersed particles in rotoklon. Received calculated correlations allow to evaluate contribution both specifications caught dust (size and density of particles), and control parameters, most important of which gas flow velocity is at passing through impellers blade.

4. A good convergence of results of calculations on received correlations with data present in technical literature and its own experiments confirms acceptability of accepted assumptions.

5. Is installed experimentally that aerodynamic profiling of blades of the impeller to sine wave curve allows to lower considerably a hydraulic resistance of the device. At the same time increase of efficiency of dust separation takes place due to flow of entrance section of the profile of blades with fixed speed and increase of ricochets from profile of blades.

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