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CALCULATION OF EFFICIENCY OF SEDIMENTATION OF DISPERSION PARTICLES IN A ROTOKLON ON THE BASIS OF MODEL OF HYDRODYNAMIC INTERACTING OF PHASES

Keywords: Rotoclon; shock-inertial; dust clearing efficiency; blade impellers; a particle path; an irrigating liquid.

Stages of process of hydrodynamic interacting of phases in apparatuses with interior circulation of a fluid are studied theoretically and confirmed by data of direct measurements of value of efficiency of shock-inertial sedimentation of dispersion particles in a Rotoklon. The design procedure is developed, allowing to determine sizes of corpuscles which can be precipitated on a fluid surface, and also build critical particle paths. The inertia method of calculation of the dust clearing efficiency is developed, allowing to size up the contribution as performances of a trapped dust (a size and a deneness of corpuscles), and process operating conditions.

Ключевые слова: Rotoklon; шоковый инерционный; эффективность очистки пыли; лезвия рабочих колес; траектория частицы; оросительная жидкость.

Этапы процесса гидродинамического взаимодействия фаз в аппаратах с объемной циркуляцией жидкости изучаются теоретически и подтверждаются данными прямых измерений значений эффективности шокового инерционного осаждения дисперсных частиц в Rotoklon. Разработана конструкция, позволяющая определить размеры частиц, которые могут быть осаждены на поверхности жидкости, а также создать критические траектории частицы. Разработан инерционный метод расчета эффективности очистки пыли, позволяющий определить размер пылевых включений (размер и плотность корпускул), и условия процесса.

INTRODUCTION

Common fault of the known wet-type collectors applied in industrial production, single-valued use of a fluid in dust removal process and, as consequence, its large charges on gas clearing is. For machining of great volumes of an irrigating liquid and slurry salvaging the facility of bulky, capital-intensive, difficult systems of water recycling which considerably process of clearing of gas and do a rise its commensurable with clearing cost at application of the most difficult and cost intensive systems of dry clearing of gases (electrostatic precepitators and bag hoses) is required.

In this connection necessity for creation of such wet-type collectors which would work with the low charge of an irrigating liquid now has matured and combined the basic virtues of modern means of clearing of gases: simplicity and compactness, a high performance, a capability of control of processes of a dust separation and optimization of regimes.

To the greatest degree modern demands to the device and activity of apparatuses of clearing of industrial gases there match wet-type collectors with inner circulation the fluids gaining now more and more a wide circulation in systems of gas cleaning in Russia and abroad.

SURVEY OF KNOWN CONSTRUCTIONS OF SCRUBBERS WITH INNER CIRCULATION OF THE FLUID

An easy way to comply with the journal paper formatting requirements is to use this document as a template and simply type your text into it. The device and maintenance of systems of wet clearing of air are considerably facilitated, if water admission to contact zones implements as a result of its circulation in the apparatus. Slurry accumulating in it thus can continuously be retracted or periodically or by means of mechanical carriers, in this case necessity for water recycling system disappears, or a hydraulic path – a drain of a part of water. In the latter case the device of system of water recycling can appear expedient, but load on it is much less, than at circulation of all volume of water [1, 2].

Dust traps of such aspect are characterized by presence of the capacity filled with water. Cleared air contacts to this water, and contact conditions are determined by interacting of currents of air and waters. The same interacting calls a water circulation through a zone of a contact at the expense of energy of the most cleared air.

The water discharge is determined by its losses on transpiration and with deleted slurry. At slurry removal by mechanical scraper carriers or manually the water discharge minimum also makes only 2-5 g on 1 $м^3$ air. At periodic drain of the condensed slurry the water discharge is determined by consistency of slurry and averages to 10 g on 1 $м^3$ air, and at fixed drain the charge does not exceed 100-200 g on 1 $м^3$ air. Filling of dust traps with water should be controlled automatically. Maintenance of a fixed level of water has primary value as its oscillations involve essential change as efficiency, and productivity of system.

The basic most known constructions of these apparatuses are introduced on fig. 1 [3].

Mechanically each of such apparatuses consists of contact channel fractionally entrained in a fluid and the drip pan merged in one body. The principle of act of apparatuses is grounded on a way of intensive wash down of gases in contact channels of a various configuration with the subsequent separation of a water gas flow in the drip pan. The fluid which has thus reacted and separated from gas is not deleted at once from the apparatus, and circulates in it and is multiply used in dust removal process.

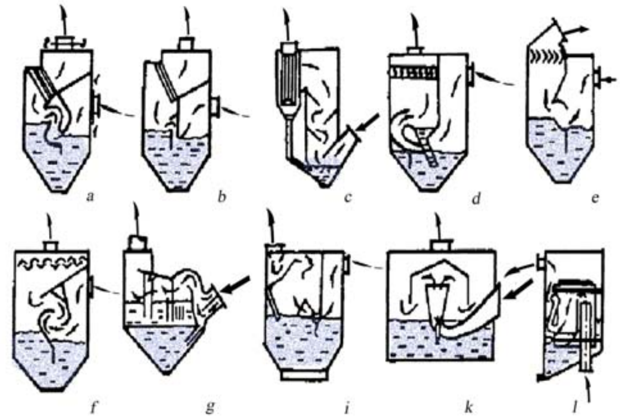

Figure 1 – Constructions of scrubbers with inner circulation of a fluid: a - Rotoklon N (USA); b - PVM CNII (Russia); c - a scrubber a VNIIMT (Russia);d - a dust trap to me (Czechoslovakia); e - dust trap WNA (Germany); f - dust trap "Asco" (Germany); g - dust trap LGP (Russia); i - dust trap "Klayrator" (USA); k - dust trap VDN (Austria); l - Rotoklon RPA a NIIOGAS (Russia)

Circulation of a fluid in the wet-type collector is supplied at the expense of a kinetic energy of a gas flow. Each apparatus is supplied by the device for maintenance of a fixed level of a fluid, and also the device for removal of slurry from the scrubber collecting hopper.

Distinctive features of apparatuses:

1. Irrigating of gas by a fluid without use of injectors that allows to use for irrigating a fluid with the high contents of suspended matters (to 250 mg/m^3);

2. Landlocked circulation of a fluid in apparatuses which allows to reuse a fluid in contact devices of scrubbers and by that to device out its charge on clearing of gas to 0,5 kg/m^3, i.e. in 10 and more times in comparison with other types of wet-type collectors;

3. Removal of a collected dust from apparatuses in the form of dense шламов with low humidity that allows to simplify dust salvaging to diminish load by water treating systems, and in certain cases in general to refuse their facility;

4. Layout of the drip pan in a body of the apparatus which allows to diminish sizes of dust traps to supply their compactness.

The indicated features and advantages of such scrubbers have led to wide popularity of these apparatuses, active working out of various constructions, research and a heading of wet-type collectors, as in Russia, and abroad.

The scrubbers introduced on fig. 1. Concern to apparatuses with noncontrollable operating conditions as in them there are no gears of regulating. In scrubbers of this type the stable conditions of activity of a high performance is difficultly supplied, especially at varying parameters of cleared gas (pressure, temperature, a volume, a dust content etc.). In this connection wet scrubbers with controlled variables are safer and perspective. Regulating of operating conditions allows to change a hydraulic resistance from which magnitude, according to the power theory of a wet dust separation, efficiency of trapping of a dust depends. Regulating of parameters allows to operate dust traps in an optimum regime at which optimum conditions of interacting of phases are supplied and peak efficiency of trapping of a dust with the least power expenditures is attained. The great value is acquired by dust traps with adjustable resistance also for stabilization of processes of gas cleaning at varying parameters of cleared gas. A row of such scrubbers is introduced in fig. 2.

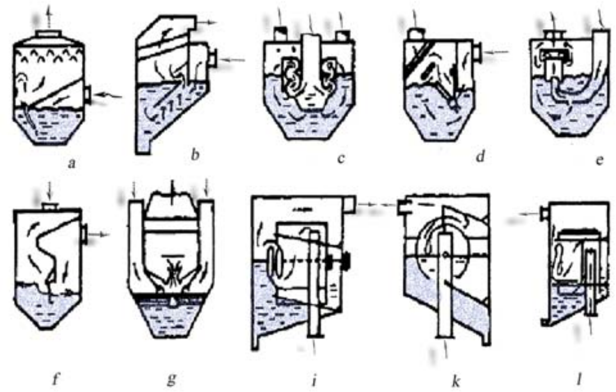

Figure 2 – Apparatuses with controlled variables: a - under the patent №1546651 (Germany), b - the ACE №556824 (USSR), c - the ACE №598625 (USSR), d - the ACE №573175 (USSR), e - under the patent №1903985 (Germany), f - the ACE №13686450 (France), g - the ACE №332845 (USSR), i - the ACE №318402 (USSR), k - the ACE №385598 (USSR), l - type RPA a NIIOGAS (USSR)

In the scrubbers introduced on fig. 2, and, turn of controlling partitions is made either manually, or is distant with the drive from the electric motor, and in a dust trap on fig. 2, in - manually, moving of partitions rather each other on a threaded connection. In dust traps on fig. 2e the lower partitions are executed in the form of a float or linked with floats that allow to stabilize clearing process at varying level of a fluid.

The interesting principle of regulating is applied in the dust traps figured on fig. 2 and fig. 1. In these apparatuses contact devices are had on a wall of the floating chamber entrained in a fluid and hardened in a body by means of joints. Such construction of dust traps allows to support automatically to constants an apparatus hydraulic resistance at varying gas load.

From literary data follows that known constructions of scrubbers with inner circulation of a fluid work in a narrow range of change of speed of gas in contact channels and are used in industrial production in the core for clearing of gases of a size dispersivity dust in systems of an aspiration of auxiliaries [3-5]. Known apparatuses are rather sensitive to change of gas load on the contact channel and to fluid level, negligible aberrations of these parameters from best values lead to a swing of levels of a fluid at contact channels, to unstable operational mode and dust clearing efficiency lowering. Because of low speeds of gas in contact channels known apparatuses have large sizes. These deficiencies, and also a weak level of scrutiny of processes proceeding in apparatuses, absence of safe methods of their calculation hamper working out of new rational constructions of wet-type collectors of the given type and their wide heading in manufacture. In this connection necessity of more detailed theoretical and experimental study of scrubbers with inner circulation of a fluid for the purpose of the prompt use of the most effective and cost-effective constructions in systems of clearing of industrial gases has matured.

ARCHITECTURE OF HYDRODYNAMIC INTERACTING OF PHASES

In scrubbers with inner circulation of a fluid process of interacting of gas, liquid and hard phases in which result the hard phase (dust), finely divided in gas, passes in a fluid implements. Because density of a hard phase in gas has rather low magnitudes (to 50 g/m^3), it does not render essential agency on hydrodynamics of flows. Thus, hydrodynamics study in a scrubber with inner circulation of a fluid is reduced to consideration of interacting of gas and liquid phases.

Process of hydrodynamic interacting of phases it is possible to disjoint sequentially proceeding stages on the following:

• fluid acquisition by a gas flow on an entry in the contact device:

• fluid subdivision by a fast-track gas flow in the contact channel;

• integration of drops of a fluid on an exit from the contact device;

• branch of drops of a fluid from gas in the drip pan.

A. Fluid acquisition by a gas flow on an entry in the contact device

Before an entry in the contact device of the apparatus there is a contraction of a gas flow to increase in its speed, acquisition of high layers of a fluid and its hobby in the contact channel. Function ability of all dust trap depends on efficiency of acquisition of a fluid a gas flow – without fluid acquisition will not be supplied effective interacting of phases in the contact channel and, hence, qualitative clearing of gas of a dust will not be attained. Thus, fluid acquisition by a gas flow on an entry in the contact device is one of defined stages of hydrodynamic process in a scrubber with inner circulation of a fluid. Fluid acquisition by a gas flow can be explained presence of interphase turbulence which is advanced on an interface of gas and liquid phases. Conditions for origination of interphase turbulence are presence of a gradient of speeds of phases on boundaries, difference of viscosity of flows, an interphase surface tension. At gas driving over a surface of a fluid the last will break gas boundary layers therefore in them there are the turbulent shearing stresses promoting cross-section transfer of energy. Originating cross-section turbulent oscillations lead to penetration of turbulent gas curls into boundary layers of a fluid with the subsequent illuviation of these stratums in curls. Mutual penetration of curls of boundary layers leads as though to the clutch of gas with a fluid on a phase boundary and to hobby of high layers of a fluid for moving gas over its surface. Intensity of such hobby depends on a kinetic energy of a gas flow, from its speed over a fluid at an entry in the contact device. At gradual increase in speed of gas there is a change of a surface of a fluid at first from smooth to undular, then ripples are organized and, at last, there is a fluid dispersion in gas. Mutual penetration of curls of boundary layers leads as though to the clutch of gas with a fluid on a phase boundary and to hobby of high layers of a fluid for moving gas over its surface. Intensity of such hobby depends on a kinetic energy of a gas flow, from its speed over a fluid at an entry in the contact device. The quantitative assessment of efficiency of acquisition in wet-type collectors with inner circulation of a fluid is expedient for conducting by means of a parameter $m=V_z/V_g$ m^3/m^3 equal to a ratio of volumes of liquid and gas phases in contact channels and characterizing the specific charge of a fluid on gas irrigating in channels. Obviously that magnitude *m* will be determined, first of all, by speed of a gas flow on an entry in the contact channel. Other diagnostic variable is fluid level on an entry in the contact channel which can change cross-section of the channel and influence speed of gas:

$$\frac{v_r}{s_r} = \frac{V_r}{bh_k - bh_g} - \frac{v_r}{b(h_k - h_g)} \quad (1)$$

where S_r - cross-section of the contact channel; b - a channel width; h_K - channel altitude; h_g - fluid level.

Thus, for the exposition of acquisition of a fluid a gas flow in contact channels it is enough to gain experimental relation of following type:

$$m = f(W_r, h_{ж}) \quad (2)$$

B. Fluid subdivision by a fast-track gas flow in the contact channel

As shown further, efficiency of trapping of corpuscles of a dust in many respects depends on a size of drops of a fluid: with decrease of a size of drops the dust clearing efficiency raises. Thus, the given stage of hydrodynamic interacting of phases is rather important.

Process of subdivision of a fluid by a gas flow in the contact channel of a dust trap occurs at the expense of high relative speeds between a fluid and a gas flow. For calculation of average diameter of the drops gained in contact channels, it is expedient to use the empirical formula of the Japanese engineers Nukiymas and Tanasavas which allows to consider agency of operating conditions along with physical performances of phases:

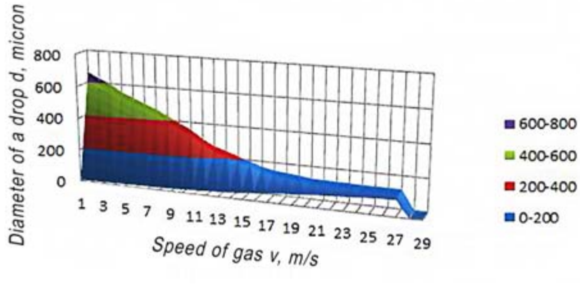

Figure 3 – Relation of an average size of drops of water in blade impellers from speed of gas

$$D_o = \frac{585 \cdot 10^3 \sqrt{\sigma}}{W_r} + 49{,}7 \left(\frac{\mu_l}{\sqrt{\rho_l \sigma_l}} \right)^{0,2} \frac{L_l}{V_r} \qquad (3)$$

where W_r - relative speed of gases in the channel, m/s; σ_i - factor of a surface tension of a fluid, N/m; ρ_i - fluid density, kg/m^3; μ_l - viscosity of a fluid, the Pas/with; L_i - volume-flow of a fluid, m^3/with; V_r - volume-flow of gas, m^3/with.

On fig. 3 computational curves of average diameter of drops of water in contact channels depending on speed of a gas flow are resulted. Calculation is conducted by formula (3) at following values of parameters: $\sigma = 720 \cdot 10^3$ N/m; $\rho_i = 1000$ kg/m^3; $\mu = 1.01 \cdot 10^2$ P/s.

The gained relations testify that the major operating conditions on which the average size of drops in contact channels depends, speed of gas flow W_r and the specific charge of a fluid on gas irrigating m are. These parameters determine hydrodynamic structure of an organized water gas flow.

With growth of speed of gas process of subdivision of a fluid by a gas flow gains in strength, and drops of smaller diameter are organized. The most intensive agency on a size of drops renders change of speed of gas in the range from 7 to 20 m/s, at the further increase in speed of gas (> 20 m/s) intensity of subdivision of drops is reduced. It is necessary to note that in the most widespread constructions of shock-inertial apparatuses (Rotoklons N) which work at speed of gas in contact devices of 15 m/s, the size of drops in the channel is significant and makes 325-425 microns. At these operating conditions and sizes of drops qualitative clearing of gas of a mesh dispersivity dust is not attained. For decrease of a size of drops and raise of an overall performance of these apparatuses the increase in speed of gas to 30, 40, 50 m/s and more depending on type of a trapped dust is necessary.

The increase in the specific charge of a fluid at gas irrigating leads to growth of diameter of organized drops. So, at increase m with $0.1 \cdot 10^3$ to $3 \cdot 10^3$ m^3/m^3 the average size of drops is increased approximately at 150 microns. For security of minimum diameter of drops in contact channels of shock-inertial apparatuses the specific charge of a fluid on gas irrigating should be optimized over the range (0.1-1.5·10) m^3/m^3. It is necessary to note that in the given range of specific charges with a high performance the majority of fast-track wet-type collectors work.

C. Integration of drops of a fluid on an exit from the contact device

On an exit from the contact device there is an expansion of a water gas stream and integration of drops of a fluid at the expense of their concretion. The maximum size of the drops weighed in a gas flow, is determined by stability conditions: the size of drops will be that more than less speed of a gas flow. Thus, on an exit from the contact device together with fall of speed of a gas flow the increase in a size of drops will be observed. Turbulence in an extending part of a flow more than in the channel with fixed cross-section, and it grows with increase in an angle of jet divergence, and it means that speed of turbulent concretion will grow in an extending part of a flow also with increase in an angle of jet divergence. The more full there will be a concretion of corpuscles of a fluid, the drop on an exit from the contact device will be larger and the more effectively they will be trapped in the drip pan.

Practice shows that the size a coagulation of drops on an exit makes of the contact device, as a rule, more than 150 microns. Corpuscles of such size are easily trapped in the elementary devices (the inertia, gravitational, centrifugal, etc.).

D. Branch of drops of a fluid from a gas flow

The inertia and centrifugal drip pans are applied to branch of drops of a fluid from gas in shock-inertial apparatuses in the core. In the inertia drip pans the branch implements at the expense of veering of a water gas flow. Liquid drops, moving in a gas flow, possess definitely a kinetic energy thanks to which at veering of a gas stream they by inertia move rectilinearly and are inferred from a flow. If to accept that the drop is in the form of a sphere and speed of its driving is equal in a gas flow to speed of this flow the kinetic energy of a drop, moving in a flow, can be determined by formula

$$E_\kappa = \frac{\pi D_0^{\ 3}}{6} \rho_l \frac{W^2{}_r}{2} \qquad (4)$$

with decrease of diameter of a drop and speed of a gas flow the drop kinetic energy is sharply diminished. At gas-flow deflection the inertial force forces to move a drop in a former direction. The more the drop kinetic energy, the is more and an inertial force:

$$E_\kappa = \frac{\pi D_0^{\ 3}}{6} \rho_l \frac{dW_r}{d\tau} \qquad (5)$$

Thus, with flow velocity decrease in the inertia drip pan and diameter of a drop the drop kinetic energy is diminished, and efficiency drop spreads is reduced. However the increase in speed of a gas flow cannot be boundless as in a certain velocity band of gases there is a sharp lowering of efficiency drop spreads owing to origination of secondary ablation the fluids trapped drops. For calculation of a breakdown speed of gases in the inertia drip pans it is possible to use the formula, m/s:

$$W_c = K \sqrt{\frac{\rho_l - \rho_\kappa}{\rho_r}} \qquad (6)$$

where W_c - optimum speed of gases in free cross-section of the drip pan, m/s; K - the factor defined experimentally for each aspect of the drip pan.

Values of factor normally fluctuate over the range 0.1-0.3. Optimum speed makes from 3 to 5 m/s.

PURPOSE AND RESEARCH PROBLEMS

The following was the primal problems which were put by working out of a new construction of the wet-type collector with inner circulation of a fluid:

• creation of a dust trap with a broad band of change of operating conditions and a wide area of application, including for clearing of gases of the basic industrial assemblies of a mesh dispersivity dust;

• creation of the apparatus with the operated hydrodynamics, allowing to optimize process of clearing of gases taking into account performances of trapped ingredients;

• to make the analysis of hydraulic losses in blade impellers and to state a comparative estimation of various constructions of contact channels of an impeller by efficiency of security by them of hydrodynamic interacting of phases;

• to determine relation of efficiency of trapping of corpuscles of a dust in a Rotoklon from performance of a trapped dust and operating conditions major of which is speed of a gas flow in blade impellers. To develop a method of calculation of a dust clearing efficiency in scrubbers with inner circulation of a fluid;

• definition of boundary densities of suspension various a dust after which excess general efficiency of a dust separation is reduced;

• definition of the maximum extent of circulation of an irrigating liquid;

• to gain the differential equation of driving of corpuscles with which help was possibly to determine paths of their driving in the field of a leak-in of a gas flow on a fluid surface, and also to count limiting sizes of corpuscles which can be precipitated on a fluid surface.

EXPERIMENTAL RESEARCHES

A. *The exposition of experimental installation and the technique of realization of experiment*

The Rotoklon represents the basin with water on which surface on a connecting pipe of feeding into of dusty gas the dust-laden gas mix arrives. Over a water surface gas deploys, and a dust contained in gas by inertia penetrate into a fluid. Turn of blades of an impeller is made manually, rather each other on a threaded connection by means of handwheels. The slope of blades was installed in the interval 25°– 45° to an axis.

In a Rotoklon three pairs lobes sinusoidal a profile, the regulating of their rule executed with a capability are installed. Depending on cleanliness level of an airborne dust flow the lower lobes by means of handwheels are installed on an angle defined by operational mode of the device. The Rotoklon is characterized by presence of three slotted channels, a formation the overhead and lower lobes, and in everyone the subsequent on a course of gas the channel the lower lobe is installed above the previous. Such arrangement promotes a gradual entry of a water gas flow in slotted channels and reduces thereby a device hydraulic resistance. The arrangement of an input part of lobes on an axis with a capability of their turn allows to create a diffusion reacting region. Sequentially had slotted channels create in a diffusion zone organized by a turn angle of lobes, a hydrodynamic zone of intensive wetting of corpuscles of a dust. In process of flow moving through the fluid-flow curtain, the capability of multiple stay of corpuscles of a dust in hydrodinamically reacting region is supplied that considerably raises a dust clearing efficiency and ensures functioning of the device in broad bands of cleanliness level of a gas flow.

The construction of a Rotoklon with adjustable sinusoidal lobes is developed and protected by the patent of the Russian Federation, capable to solve a problem of effective separation of a dust from a gas flow [6]. Thus water admission to contact zones implements as a result of its circulation in the apparatus.

The Rotoklon with the adjustable sinusoidal lobes, introduced on fig. 4 contains a body 3 with connecting pipes for an entry 7 and an exit 5 gases in which steams of lobes sinusoidal a profile are installed. Moving of the overhead lobes 2 implements by means of screw jacks 6, the lower lobes 1 are fixed on an axis 8 with a capability of their turn. The turn angle of the lower lobes is chosen from a condition of a persistence of speeds of an airborne dust flow. For regulating of a turn angle output parts of the lower lobes 1 are envisioned handwheels. Quantity of pairs lobes is determined by productivity of the device and cleanliness level of an airborne dust flow, that is a regime of a stable running of the device. In the lower part of a body there is a connecting pipe for a drain of slime water 9. Before a connecting pipe for a gas make 5 the labyrinth drip pan 4 is installed. The Rotoklon works as follows. Depending on cleanliness level of an airborne dust flow the overhead lobes 5 by means of screw jacks 6, and the lower lobes 1 by means of handwheels are installed on an angle defined by operational mode of the device. Dusty gas arrives in the upstream end 7 in a top of a body 3 apparatuses. Hitting about a fluid surface, it changes the direction and passes in the slotted channel organised overhead 2 and lower 1 lobes. Thanks to the driving high speed, cleared gas captures a high layer of a fluid and atomises it in the smallest drops and foam with an advanced surface. After consecutive transiting of all slotted channels gas passes through the labyrinth drip pan 4 and through the discharge connection 5 is deleted in an aerosphere. The collected dust settles out in the loading pocket of a rotoklon and through a connecting pipe for a drain of slime water 9, together with a fluid, is periodically inferred from the apparatus.

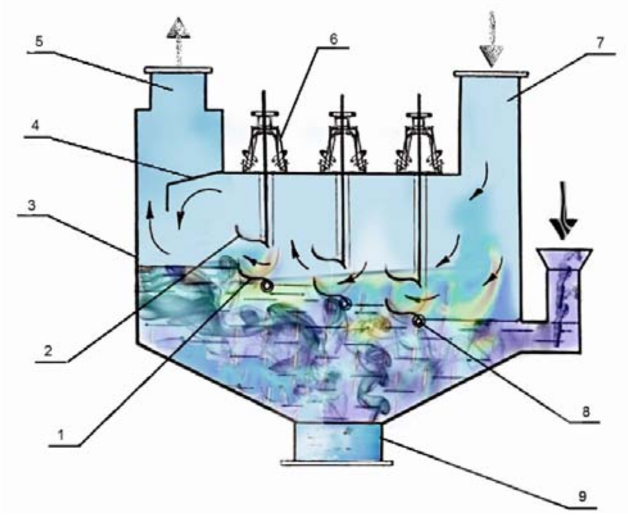

Figure 4 – A Rotoklon General view: Lower 1 and the overhead 2 lobes; a body 3; the labyrinth drip pan 4; connecting pipes for an entry 7 and an exit 5 gases; screw jacks 6; an axis 8; a connecting pipe for a drain of slurry 9

Noted structural features does not allow to use correctly available solutions on hydrodynamics of dust-laden gas flows for a designed construction. In this connection, for the well-founded exposition of the processes occurring in the apparatus, there was a necessity of realization of experimental researches.

Experiments were conducted on the laboratory-scale plant "Rotoklon" introduced on fig. 5.

The examined Rotoklon had 3 slotted channels speed of gas in which made to 15 km/s. At this speed the Rotoklon had a hydraulic resistance 800 Pases. Working in such regime, it supplied efficiency of trapping of a dust with input density 0,5 g/nm^3 and density 1200 kg/m^3 at level of 96,3 % [7].

In the capacity of modelling system air and a dust of talc with a size of corpuscles d = 2÷30 a micron, white black and a chalk have been used. The apparatus body was filled with water on level h_g = 0.175m.

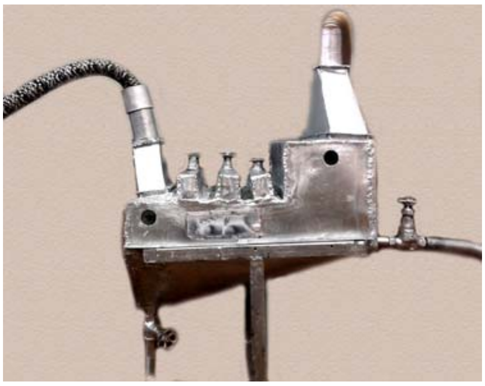

Figure 5 – Experimental installation "Rotoklon"

Cleanliness level of an airborne dust mix was determined by a direct method [8]. On direct sections of the pipeline before and after the apparatus the mechanical sampling of an airborne dust mix was made. After determination of matching operational mode of the apparatus, gas test were taken by means of intaking handsets. Mechanical sampling isocinetycs on intaking handsets were applied to observance replaceable tips of various diameters. Full trapping of the dust contained in taken test of an airborne dust mix, was made by an external filtering draws through mixes with the help calibrates electro aspirator EA-55 through special analytical filters AFA-10 which were put in into filtrating cartridges. The selection time was fixed on a stop watch, and speed – the rotameter of electro aspirator EA-55.

Dust gas mix gained by dust injection in the flue by means of the metering screw conveyer batcher introduced on fig. 6. Application of the batcher with varying productivity has given the chance to gain the set dust load on an entry in the apparatus.

Figure 6 – The metering screw conveyer batcher of a dust

The water discharge is determined by its losses on transpiration and with deleted slurry. The water drain is made in the small portions from the loading pocket supplied with a pressure lock. Gate closing implements sweeping recompression of air in the gate chamber, opening – a depressurization. Small level recession is sweepingly compensated by a top up through a connecting pipe of feeding into of a fluid. At periodic drain of the condensed slurry the water discharge is determined by consistency of slurry and averages to 10 г on 1 $м^3$ air, and at fixed drain the charge does not exceed 100-200 g on 1 $м^3$ air. Filling of a Rotoklon with water was controlled by means of the level detector. Maintenance of a fixed level of water has essential value as its oscillations involve appreciable change as efficiency, and productivity of the device.

B. *Discussion of results of experiment*

In a Rotoklon process of interacting of gas, liquid and hard phases in which result the hard phase (dust), finely divided in gas, passes in a fluid is realized. Process of hydrodynamic interacting of phases in the apparatus it is possible to disjoint sequentially proceeding stages on the following: fluid acquisition by a gas flow on an entry in the contact device; fluid subdivision by a fast-track gas flow in the contact channel; concretion of dispersion particles by liquid drops; branch of drops of a fluid from gas in the labyrinth drip pan.

At observation through an observation port the impression is made that all channel is filled by foam and water splashes. Actually this effect caused by a retardation of a flow at an end wall, is characteristic only for a stratum which directly is bordering on to glass. Slow-motion shot consideration allows to install a true flow pattern. It is visible that the air jet as though itself chooses the path, being aimed to be punched in the shortest way through water. Blades standing sequentially under existing conditions restrict air jet extending, forcing it to make sharper turn that, undoubtedly, favours to separation. Function ability of all dust trap depends on efficiency of acquisition of a fluid a gas flow – without fluid acquisition will not be supplied effective interacting of phases in contact channels and, hence, qualitative clearing of gas of a dust will not be attained. Thus, fluid acquisition by a gas flow at consecutive transiting of blades of an impeller is one of defined stages of hydrodynamic process in a Rotoklon.

Fluid acquisition by a gas flow can be explained presence of interphase turbulence which is advanced on an interface of gas and liquid phases. Conditions for origination of interphase turbulence is presence of a gradient of speeds of phases on boundaries, difference of viscosity of flows, an interphase surface tension.

C. *The estimation of efficiency of gas cleaning*

The quantitative assessment of efficiency of acquisition in apparatuses of shock-inertial type with inner circulation of a fluid is expedient for conducting by means of a parameter $n = L_z/L_g$, m^3/m^3 equal to a ratio of volumes of liquid and gas phases in contact channels and characterizing the specific charge of a fluid on gas irrigating in channels. Obviously that magnitude n will be determined, first of all, by speed of a gas flow on an entry in the contact channel. The following important parameter is fluid level on an entry in the contact channel which can change cross-section of the channel and influence speed of gas:

$$\frac{\vartheta_g}{S_g} = \frac{\vartheta_g}{bh_k - bh_l} - \frac{\vartheta_g}{b(h_k - h_l)} \quad (7)$$

where S_g - cross-section of the contact channel; b - a channel width; h_K - channel altitude; h_l - fluid level.

Thus, for the exposition of acquisition of a fluid a gas flow in contact channels of a rotoklon it is enough to gain the following relation experimentally:

$$n = f(\vartheta_g \cdot h_l) \quad (8)$$

As it has been installed experimentally, efficiency of trapping of corpuscles of a dust in many respects depends on a size of drops of a fluid: with decrease of a size of drops the dust clearing efficiency raises. Thus, the given stage of hydrodynamic interacting of phases is rather important. For calculation of average diameter of the drops organized at transiting of blades of an impeller, the empirical relation is gained:

$$d = \frac{467 \cdot 10^3 \sqrt{\sigma}}{\vartheta_o} + 17{,}869 \cdot \left(\frac{\mu_l}{\sqrt{\rho_l \sigma}} \right)^{0{,}68} \frac{L_l}{L_r} \quad (9)$$

where ϑ_o - relative speed of gases in the channel, m/s; σ- factor of a surface tension of a fluid, N/m; ρ_l - fluid density, kg/m^3; μ_l - viscosity of a fluid, the Pas/with; L_l - volume-flow of a fluid, m^3/with; L_g - volume-flow of gas, m^3/with.

The offered formula allows to consider also together with physical performances of phases and agency of operating conditions.

On fig. 7 design values of average diameter of the drops organized at transiting of blades of an impeller, from speed of gas in contact channels and a gas specific irrigation are introduced. At calculation 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·C/m^2, ς =72.86·10^{-3} N/m.

The gained relations testify that the major operating conditions on which the average size of drops in contact channels of a Rotoklon depends, speed of gas flow ϑ_o and the specific charge of a fluid on gas irrigating n are. These parameters determine hydrodynamic structure of an organized water gas flow.

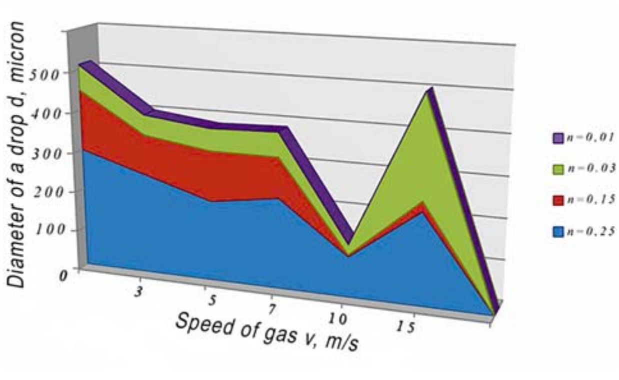

Figure 7 – Computational relation of a size of drops to flow velocity and a specific irrigation

Separation efficiency of gas bursts in apparatuses of shock-inertial act can be discovered only on the basis of empirical data on particular constructions of apparatuses. Methods of the calculations, found application in projection practice, are grounded on an assumption about a capability of linear approximation of relation of separation efficiency from diameter of corpuscles in is likelihood-logarithmic axes. Calculations on a likelihood method are executed under the same circuit design, as for apparatuses of dry clearing of gases [9].

Shock-inertial sedimentation of corpuscles of a dust occurs at flow of drops of a fluid by a dusty flow therefore the corpuscles possessing inertia, continue to move across the curved stream-lines of gases, the surface of drops attain and are precipitated on them.

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

$$\eta_u = f\left(\frac{m_p}{\xi_c} \cdot \frac{\vartheta_p}{d_0} \right) \quad (10)$$

where m_p - mass of a precipitated corpuscle; ϑ_p - speed of a corpuscle; ξ - factor of resistance of driving of a corpuscle; d_0 - diameter a midelev of cross-section of a drop.

For the spherical corpuscles which driving obeys the law the Stokes, this criterion looks like the following:

$$\frac{m_p \vartheta_p}{\xi_c d_0} = \frac{1}{18} \cdot \frac{d_r^2 \vartheta_p \rho_p C_c}{\mu_g d_0} \quad (11)$$

Complex $d_p^2 \vartheta_p \rho_p C_c / (18 \mu_g d_0)$ is parameter (number) of the Stokes

$$\eta_u = f(Stk) = f\left(\frac{d_p^2 \vartheta_p \rho_p C_c}{18 \mu_g d_0} \right) \quad (12)$$

Thus, efficiency of trapping of corpuscles of a dust in a Rotoklon on the inertia model depends primarily on performance of a trapped dust (a size and density of trapped corpuscles) and operating conditions major of which is speed of a gas flow at transiting through blades of impellers.

On the basis of the observed inertia of model the method of calculation of a dust clearing efficiency in scrubbers with inner circulation of a fluid is developed.

The basis for calculation on this model is the formula (12). For calculation realization it is necessary to know disperse composition of a dust, density of corpuscles of a dust, viscosity of gas, speed of gas in the contact channel and the specific charge of a fluid on gas irrigating.

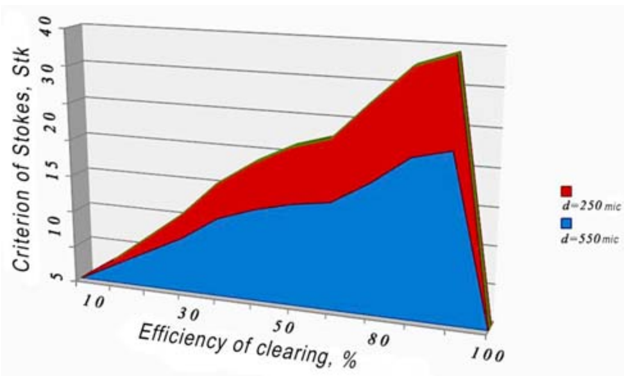

Figure 8 – Relation of efficiency of clearing of gas to criterion StK

Calculation is conducted in the following sequence:

• by formula (9) determine an average size of drops D_0 in the contact channel at various operating conditions;

• by formula (10) count the inertia parametre of the Stokes for each fraction of a dust;

• by formula (11) fractional values of efficiency η for each fraction of a dust;

• general efficiency of a dust separation determine by formula (12), %.

The observed inertia model full enough characterizes physics of the process proceeding in contact channels of a Rotoklon.

D. *Comparison of experimental and computational results*

Analyzing the gained results of researches of general efficiency of a dust separation, it is necessary to underscore that in a starting phase of activity of a dust trap for all used in researches a dust dust separation high performances, components from 93.2% for carbon black to 99.8% for a talc dust are gained. Difference of general efficiency of trapping of various types of a dust originates because of their various particle size distributions on an entry in the apparatus, and also because of the various form of corpuscles, their dynamic wet ability and density. The gained high values of general efficiency of a dust separation testify to correct selection of constructional and operation parameters of the studied apparatus and indicate its suitability for use in engineering of a wet dust separation.

As appears from introduced in Fig. 9-10 graphs, the relation of general efficiency of a dust separation to speed of a mixed gas and fluid level in the apparatus will well be agreed to design data that confirms an acceptability of the accepted assumptions.

On fig. 11 results of researches on trapping various a dust in a Rotoklon with adjustable sinusoidal are shown. The given researches testify to a high performance of trapping of corpuscles of thin a dust with their various moistening ability. From these drawings by fractional efficiency of trapping it is obviously visible, what even for corpuscles a size less than 1 microns (which are most difficultly trapped in any types of dust traps). Installations considerably above 90%. Even for the unwettable sewed type of white black general efficiency of trapping more than 96%. Naturally, as for the given dust trap lowering of fractional efficiency of trapping at decrease of sizes of corpuscles less than 5 microns, however not such sharp, as for other types of dust traps is characteristic.

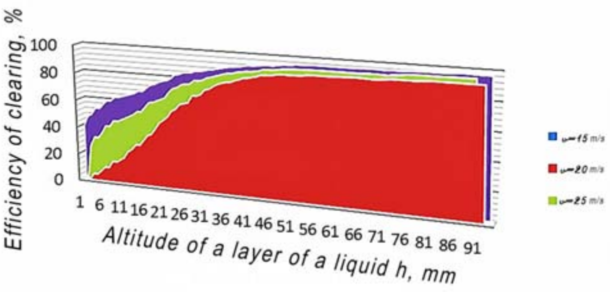

Figure 9 – Relation of efficiency of clearing of gas to irrigating liquid level

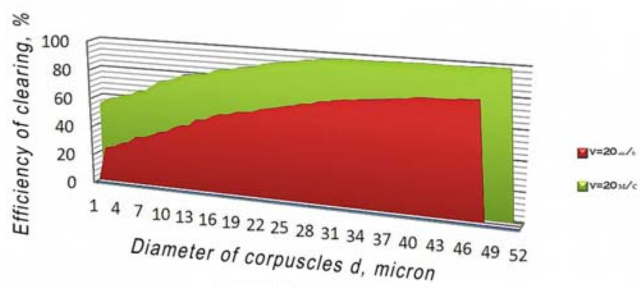

Figure 10 – Dependence of efficiency of clearing of gas on a size of corpuscles and speed of gas

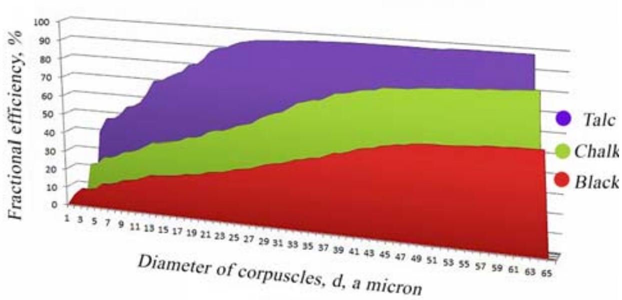

Figure 11 – Fractional efficiency of clearing of corpuscles of a various dust

CONCLUSIONS

1. The new construction of the Rotoklon is developed, allowing to solve a problem of effective separation of a dust from a gas flow. In the introduced apparatus water admission to contact zones implements as a result of its circulation in the device.

2. Experimentally it is shown that fluid acquisition by a gas flow at consecutive transiting of blades of an impeller is one of defined stages of hydrodynamic process in a Rotoklon.

3. Are theoretically gained and confirmed by data of immediate measurements of value of efficiency of shock-inertial sedimentation of dispersion particles in a Rotoklon. The gained computational relationships, allow to size up the contribution as performances of a trapped dust (a size and density of trapped corpuscles), and operating conditions major of which is speed of a gas flow at transiting through blades of impellers.

4. Good convergence of results of scaling on the gained relationships with the data which are available in the technical literature and own experiments confirms an acceptability of the accepted assumptions.

The formulated leading-outs are actual for intensive operation wet-type collectors in which the basic gear of selection of corpuscles is the gear of the inertia dust separation.

REFERENCES

1. V.N. Uzhov, A.J. Valdberg, and B.I. Myagkov *Clearing of industrial gases of a dust,* Moscow: Chemistry, 1981.
2. A.I. Pirumov *air Dust removal,* Moscow: Engineering industry, 1974.
3. V.S. Shvydky, M.G. Ladygichev *Clearing of gases. The*

directory, Moscow: Heat power engineering, 2002.
4. V. Straus. *Industrial clearing of gases* Moscow: Chemistry, 1981.
5. P.A. Kouzov, A.D. Malgin and G.M. Skryabin *Clearing of gases and air of a dust in the chemical industry*. - St.-Petersburg: Chemistry, 1993.
6. Patent 2317845 RF, IPC, cl. B01 D47/06 *Rotoklon a controlled sinusoidal blades* // R.R. Usmanova, Zhernakov V.S. and Panov A.K. - Publ. 27.02.2008. Bull. № 6.
7. R.R. Usmanova, G.E. Zaikov, O.V. Stoyanov, and E. Klodziuska *Research of the mechanism of shock-inertial deposition of dispersed particles from gas flow the* bulletin of the Kazan technological university №9, pp. 203-207, 2013.
8. P.A. Kouzov. *Bases of the analysis of disperse composition industrial a dust.* Leningrad: Chemistry, 1987. pp.183-195.
9. N.I. Vatin, K.I. Strelets. *Air purification by means of apparatuses of type the cyclone separator.* St.-Petersburg, 2003.

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