UDC 532.57

R. R. Usmanova, G. E. Zaikov

EXPERIMENTAL RESEARCHES AND CALCULATION OF BOUNDARY CONCENTRATION OF AN IRRIGATING LIQUID

Keywords: Boundary concentration; interfacial area; the Rotoklon; the Irrigating liquid; Viscosity; Fractional efficiency; Recirculation.

Experimental researches of work of a rotoklon are executed. It is shown that excess of boundary concentration of slurry, engenders a decline efficiency of a dust separation. The greatest effect is expressed on extent of trapping of small fractions with sizes of corpuscles less than 5 microns. On known boundary concentration $c_г$ the boundary extent of recirculation of the irrigation water, securing stable efficiency of a dust separation is designed.

Ключевые слова: граничная концентрация; межфазная пверхность; ротоклон; орошающая жидкость; вязкость; фракционная эффективность; рециркуляция.

Экспериментальные исследования работы ротоклона проведены. Показано, что превышение граничной концентрации суспензии, вызывает снижение эффективности пылеулавливания. Наибольшее влияние оказывается на степень улавливания мелких фракций с размерами частиц менее 5 мкм. По известной граничной концентрации $c_г$ рассчитана граничная степень рециркуляции орошающей жидкости, обеспечивающая стабильную эффективность пылеулавливания.

Introduction

One of trends of development of wet-type collectors is creation of apparatuses of intensive operation with high carrying capacity on a gas phase that is connected with favourable decrease in gabarits of installations. In these conditions owing to high relative speed of traffic of liquid and gas phases, work upon effect of a dust separation mechanisms: the inertia and direct capture of corpuscles. Such process is realised in impact-sluggish dedusters to which it is possible to refer to the investigated apparatus.

Authors Jarzkbski and Giowiak [9], analysing work of an impact-sluggish deduster have installed that in the course of a dust separation defining role is played by the phenomenon of the inertia collision of a dust with water drops. Efficiency of allocation of corpuscles of a dust decreases together with growth of sizes of the drops oscillated in the settling space. In case of a generating of drops compressed air, their magnitude is defined by equation Nukijama and Tanasawa [10]. From the equation follows that drops that more than above value of viscosity of a liquid phase.

Viscosity growth can call reduction of efficiency of a dust separation. In the literature practically there are no data on effect of viscosity of a trapping liquid on dust separation process. Therefore one of the purposes of our work was revealing of effect of viscosity of a liquid on efficiency of a dust separation.

Current State Of A Problem

It is possible to admit that for certain three-phase systems gas - a liquid - a solid boundary concentration of a dust can appear too big that will directly affect too big extent of circulation which is difficult for realising in the conditions of commercial operation of wet-type collectors.

The problem formulation leans on following rules. In the conditions of full circulation of a liquid, at constant geometrical sizes of a deduster it is possible to secure with a constancy of operational parametres is a relative speed of traffic of a liquid and an aerosol, concentration of a dust in gas, a superficial tension of a liquid or an angle of wetting of a dust. Concentration of a dust growing in a time in a liquid conducts to unique essential change - to increase in its viscosity. After excess of certain concentration suspension loses properties of a Newtonian fluid. Deduster working conditions at full circulation of a liquid are approached to what can be gained in the periodical regime when at maintenance fresh water is not inducted into dust-collecting plant. Collected in the apparatus, the dust detained by a liquid, compensates volume losses of the liquid necessary on moistening of passing gas and its ablation. In the literature there are no works, theoretically both experimentally presenting effect of viscosity and effect of rheological properties of slurry on efficiency of a dust separation. As it seems to us, a motive is that fact that in the capacity of operating fluid water is usually used, and dedusters work, predominantly, at constant temperatures. Simultaneously, at use of partial circulation certain level of concentration of a dust in a liquid is secured. In turn, accessible dependences in the literature specify in insignificant growth of viscosity of slurry even at raise of its concentration for some percent.

The reasonings proving possibility of effect of viscosity of slurry on efficiency of a dust separation, it is possible to refer to as on the analysis of the basic mechanisms influencing sedimentation of corpuscles on an interphase surface, and on conditions of formation of this developed surface of a liquid. Transition of corpuscles of a dust from gas in a liquid occurs, mainly, as a result of the inertia affecting, effect of "sticking" and diffusion. Depending on type of the wet-type collector of a corpuscle of a dust deposit on a surface of a liquid which can be realised in the form of drops, moving in a stream of an aerosol, the films of a liquid generated in the apparatus, a surface of the gas vials formed in the conditions of a barbotage and moistened surfaces of walls of the apparatus.

In the monography [3] effect of various mechanisms on efficiency of sedimentation of corpuscles of a dust on a liquid surface is widely presented. The description of mechanisms and their effect on efficiency of a dust separation can be found practically in all monographies, for example, [4, 13] concerning a problem wet clearings of gas

emissions of gases. In the literature of less attention it is given questions of formation of surfaces of liquids and their effect on efficiency of a dust separation.

Observing the mechanism of the inertia act irrespective of a surface of the liquid entraining a dust, predominantly it is considered that for hydrophilic types of a dust collision of a part of a solid with a liquid surface to its equivalently immediate sorbtion by a liquid, and then immediate clearing and restoration of the Surface of a liquid for following collisions. In case of a dust badly moistened, the time necessary for sorbtion of a corpuscle by a liquid, can be longer, than a time after which the corpuscle will approach to its surface. Obviously, it is at the bottom of decrease in possibility of a retardation of a dust by a liquid because of a recoil of the corpuscle going to a surface, from a corpuscle which are on it. It is possible to consider this effect real as in the conditions of a wet dust separation with a surface of each fluid element impinges more dust, than it would be enough for monolayer formation. Speed of sorbtion of corpuscles of a dust can be a limiting stage of a dust separation.

Speed of sorbtion of a corpuscle influences not only its energy necessary for overcoming of a surface tension force, but also and its traverse speed in the liquid medium, depending on its viscosity and rheological properties. Efficiency of dust separation Kabsch [5] connects with speed of ablation of a dust a liquid, having presented it as weight m_s, penetrating in unit of time through unit of a surface And in depth of a liquid as a result of a collision of grains of a dust with this surface:

$$r = \frac{m_s}{A \cdot t}$$

Giving to shovels of an impeller sinusoidal a profile allows to eliminate breakaway a stream breakaway on edges. Thus there is a flow of an entrance section of a profile of blades with the big constant speed and increase in ricochets from a shaped part of blades in terms of which it is possible to predict insignificant increase in efficiency of clearing of gas.

Speed of linkage of a dust a liquid depends on physicochemical properties of a dust and its ability to wetting, physical and chemical properties of gas and operating fluid, and also concentration of an aerosol. Wishing to confirm a pushed hypothesis, Kabsch [5] conducted the researches concerning effect of concentration speed of linkage of a dust by a liquid. The increase in concentration of a dust in gas called some increase in speed of linkage, however to a lesser degree, than it follows from linear dependence.

The cores for technics of a wet dust separation of model Semrau, Barth'a and Calvert'a do not consider effect of viscosity of slurry on effect of a dust separation. In-process Pemberton'a [6] it is installed that in case of sedimentation of the corpuscles which are not moistened on drops, their sorbtion in a liquid is obligatory, and their motion in a liquid submits to principle Stokes'a.

The traverse speed can characterise coefficient of resistance to corpuscle motion in a liquid, so, and a dynamic coefficient of viscosity of a liquid. Possibility of effect of viscosity of a liquid on efficiency of capture of corpuscles of a dust a drop by simultaneous Act of three mechanisms: the inertia, "capture" the semiempirical equation Slinna [6] considering the relation of viscosity of a liquid to viscosity of gas also presents.

In general it is considered that there is a certain size of a drop [14] at which optimum conditions of sedimentation of corpuscles of a certain size are attained, and efficiency of subsidence of corpuscles of a dust on a drop sweepingly decreases with decrease of a size of these corpuscles.

Jarzkbski and Giowiak [9], analysing work of an impact-sluggish deduster have installed that in the course of a dust separation defining role is played by the phenomenon of the inertia collision of a dust with water drops. Efficiency of allocation of corpuscles of a dust decreases together with growth of sizes of the drops oscillated in the settling space, in case of a generating of drops compressed air, their magnitude is defined by equation Nukijama and Tanasawa [10] from which follows that drops to those more than above value of viscosity of a liquid phase. Therefore viscosity growth can call reduction of efficiency of a dust separation.

The altitude of a layer of the dynamic foam formed in dust-collecting plant at a certain relative difference of speeds of gas and liquid phases, decreases in process of growth of viscosity of a liquid [15] that calls decrease in efficiency of a dust separation, it is necessary to consider that the similar effect refers to also to a layer of an intensive barbotage and the drop layer partially strained in dust removal systems.

Summarising, it is possible to assert that in the literature practically there are no data on effect of viscosity of a trapping liquid on dust separation process. Therefore one of the purposes of our work was extraction of effect of viscosity of a liquid on efficiency of a dust separation.

The purpose, assumptions and area of researches

The conducted researches had a main objective acknowledging of a hypothesis on existence of such boundary concentration of slurry at which excess the overall performance of the dust removal apparatus decreases.

The concept is devised and the installation which is giving the chance to implementation of planned researches is mounted. Installation had systems of measurement of the general and fractional efficiency and typical systems for measurement of volume flow rates of passing gas and water resistances. The device of an exact proportioning of a dust, and also the air classifier separating coarse fractions of a dust on an entry in installation is mounted. Gauging of measuring systems has secured with respective repeatability of the gained results.

Laboratory Facility And Technique Of Conducting Of Experiment

Laboratory facility basic element is the deduster of impact-sluggish act - a rotoklon c adjustable guide vanes [11] *(fig. 1 see)*. An aerosol gained by dust introduction in the pipeline by means of the batcher. Application of the batcher with changing productivity has given the chance to gain the set concentration of a dust on an entry in the apparatus.

Have been investigated a dust, discriminated with the wettability (a talcum powder the ground, median

diameter is equal δ_{50} =25 microns, white black about δ_{50} =15 microns solubility in water of 10^{-3} % on weight (25°C) and a chalk powder).

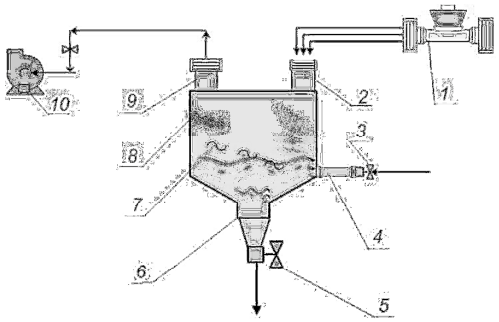

Fig. 1 - The laboratory facility

The gas-dispersed stream passed shovels of an impeller 7 in a working zone of the apparatus, whence through the drip pan 8 cleared, was inferred outside. Gas was carried by means of the vacuum pump 10, and its charge measured by means of a diaphragm 1. A Gas rate, passing through installation, controlled, changing quantity of air sucked in the pipeline before installation. Gas differential heads were measured by a manometer. The composition of each system includes group of three sondes mounted on vertical sections of pipelines, on distance about 10 diameters from the proximal element changing the charge. The taken test of gas went on the measuring fine gauge strainer on which all dust containing in test separated. For this purpose used fine gauge strainer. In the accepted solution have applied system of three measuring sondes which have been had in pipelines so that in the minimum extent to change a regime of passage of gas and to select quantity of a dust necessary for the analysis. The angle between directions of deducing of sondes made 120 °, and their ends placed on such radiuses that surfaces of rings from which through a sonde gas was sucked in, were in one plane. It has allowed to scale down a time of selection of test and gave average concentration of a dust in gas pipeline cross-section.

For definition of structurally-mechanical properties of slurry viscosity RV-8 *(fig. 2 see)* has been used. The viscosity gauge consists of the internal twirled cylinder (rotor) (r = 1.6 centimeter) and the external motionless cylinder (stator) (r = 1.9 centimeter), having among themselves a positive allowance of the ring form with a size 0,3 see the Rotor is resulted in twirl by means of the system consisting of the shaft, a pulley (To = 2.23 centimeter), filaments, blocks and a cargo. To the twirl termination apply a brake. The twirled cylinder has on a division surface on which control depth of its plunging in slurry.

Fig. 2 - Measurement of viscosity of slurry

The gained slurry in number of 30 sm^3 (in this case the rotor diving depth in sludge makes 7 sm) fill in in is carefully the washed out and dry external glass which put in into a slot of a cover and strengthen its turn from left to right. After that again remove the loaded cylinder that on a scale of the internal cylinder precisely to define depth of its plunging in sludge. Again fix a glass and on both cups put the minimum equal cargo (on 1), fix the spigot of a pulley by means of a brake and reel up a filament, twirling a pulley clockwise. It is necessary to watch that convolutions laid down whenever possible in parallel each other.

Instal an arrow near to any division into the limb and, having hauled down a brake, result the internal cylinder in twirl, fixing a time during which the cylinder will make 4-6 turns. After the termination of measurements fix a brake and reel up a filament. Measurement at each loading spend not less than three times. Experiences repeat at gradual increase in a cargo on 2 gr. until it is possible to fix a time of an integer of turns precisely enough. After the termination of measurements remove a glass, drain from it sludge, wash out water, from a rotor sludge drain a wet rag then both cylinders are dry wiped and leave the device in the collected aspect.

After averaging of the gained data and calculation of angular speed the schedule of dependence of speed of twirl from the enclosed loading is under construction

Viscosity is defined by formula [15]:

$$\eta = \frac{(R_2^2 - R_1^2)Gt}{8\pi^2 L R_1^2 R_2^2 L} \quad (1)$$

or

$$\eta = \frac{kGt}{L} \quad (2)$$

Discussion Of Results Of Researches

For each dust used in researches dependence of general efficiency of a dust separation on concentration of slurry and the generalising schedule of dependence of fractional efficiency on a corpuscle size is presented. Other schedule grows out of addition fractional efficiency of a dust separation for various, presented on the schedule, concentration of slurry. In each case the first measurement of fractional efficiency is executed in the beginning of the first measuring series, at almost pure water in a deduster.

Analysing the gained results of researches of general efficiency of a dust separation, it is necessary to underline that in a starting phase of work of a rotoklon at insignificant concentration of slurry for all used in dust researches components from 93,2 % for black to 99,8 % for a talc powder are gained high efficiency of a dust separation. Difference of general efficiency of trapping of various types of a dust originates because of their various fractional composition on an entry in the apparatus, and also because of the various form of corpuscles, their dynamic wettability and density. The gained high values of general efficiency of a dust separation testify to correct selection of constructional and operational parametres of the studied apparatus and specify in its suitability for use in technics of a wet dust separation.

The momentous summary of the spent researches was definition of boundary concentration of slurry various a dust after which excess general efficiency of a dust

separation decreases. Value of magnitude of boundary concentration, as it is known, is necessary for definition of the maximum extent of recirculation of an irrigating liquid. As appears from presented in drawings 3 - 6 schedules, dependence of general efficiency of a dust separation on concentration of slurry, accordingly, for a powder of talc, a chalk and white black is available possibility of definition of such concentration.

Boundary concentration for a talcum powder - 36 %, white black - 7 %, a chalk - of 18 % answer, predominantly, to concentration at which slurries lose properties of a Newtonian fluid.

The conducted researches give the grounds to draw deductions that in installations of impact-sluggish type where the inertia mechanism is the core at allocation of corpuscles of a dust from gas, general efficiency of a dust separation essentially drops when concentration of slurry answers such concentration at which it loses properties of a Newtonian fluid. As appears from presented in drawings *(fig. 3 - 6 see)* dependences, together with growth of concentration of slurry above a boundary value, general efficiency of a dust separation decreases, and the basic contribution to this phenomenon small corpuscles with a size less bring in than 5 microns. To comment on the dependences presented in drawings, than 5 microns operated with criterion of decrease in efficiency of a dust separation of corpuscles sizes less at the further increase in concentration of slurry at 10 % above the boundary.

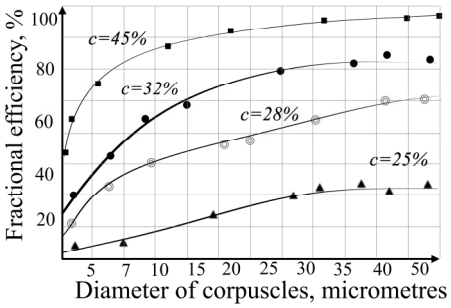

Fig. 3 - Dependence of fractional efficiency on diameter of corpuscles of a talcum powder and their concentration in a liquid

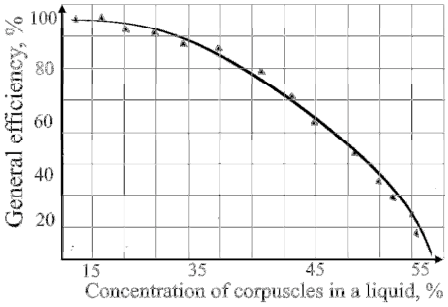

Fig. 4 - Dependence of general efficiency of concentration in a liquid of corpuscles of a talcum powder

Taking it in attention, it is possible to notice that in case of allocation of a dust of talc growth of concentration of slurry from 36 % to 45 % calls reduction of general efficiency of a dust separation from 98 % to 90 % at simultaneous decrease in fractional efficiency of allocation of corpuscles, smaller 5 microns from η = 93 % to η = 65 %.Analogously for white black: growth of concentration from 7 % to 20 % calls falling of fractional efficiency from η = 65 % to η = 20 %, for a chalk: growth of concentration from 18 % to 30 % calls its decrease from η = 80 % to η = 50 %. Most considerably decrease in fractional efficiency of a dust separation can be noted for difficultly moistened dust - white black (about 50 %).

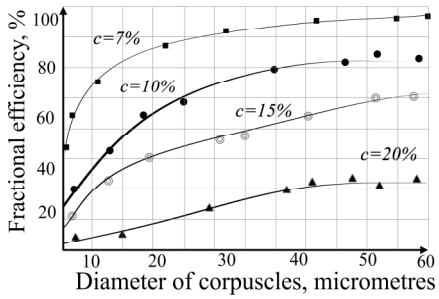

Fig. 5- Dependence of fractional efficiency on diameter of corpuscles of white black and their concentration in a liquid

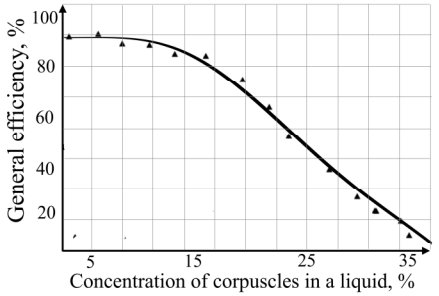

Fig. 6 - Dependence of general efficiency on concentration in a liquid of corpuscles of white black

Thus, on the basis of the analysis set forth above it is possible to assert that decrease in general efficiency of a dust separation at excess of boundary concentration of slurry is connected about all by decreasing ability of system to detain small corpuscles. Especially it touches badly moistened corpuscles. It coincides with a hypothesis about updating of an interphase surface. Updating of an interphase surface can be connected also with difficulties of motion of the settled corpuscles of a dust deep into liquids, i.e. with viscosity of medium.

The analysis of general efficiency of a dust separation, and, especially, a talcum powder and white black powder specifies that till the moment of achievement of boundary concentration efficiency is kept on a fixed level. In these boundary lines, simultaneously with growth of concentration of slurry dynamic viscosity of a liquid, only this growth grows is insignificant - for talc, for example, to $2{,}7 \cdot 10^{-3}$ Pascal·second. At such small increase in viscosity of slurry the estimation of its effect on efficiency of a dust separation is impossible. Thus, it is possible to confirm, what not growth of viscosity of slurry (from 1 to $2{,}7 \cdot 10^{-3}$ Pascal·second), and change of its rheological properties influences decrease in efficiency of a dust separation.

The method of definition of boundary extent of circulation of a liquid in impact-sluggish apparatuses is based on laboratory definition of concentration of slurry above which it loses properties of a Newtonian fluid. This concentration will answer concentration of operating fluid which cannot be exceeded if it is required to secure with a constant of efficiency of a dust separation.

In the conditions of spent researches, i.e. constant concentration of an aerosol on an entry in the apparatus, and at the assumption that water losses in the apparatus because of moistening of passing air and, accordingly, ablation in the form of drops, is compensated by volume of the trapped dust, the water discharge parametre is defined directly from the recommended time of duration of a cycle and differs for various types of a dust. Counted its maximum magnitude is in the interval 0,02 - 0,05 l/m^3, i.e. is close to the magnitudes quoted in the literature.

For periodical regime dedusters this concentration defines directly a cycle of their work. In case of dedusters of continuous act with liquid circulation, the maximum extent of recirculation securing maintenance of a fixed level of efficiency of a dust separation, it is possible to count as the relation:

$$r = \frac{Q_{cir}}{Q_{ir}} \qquad (3)$$

where Q_{cir} - the charge of a recycling liquid, m^3/h; Q_{ir} - the charge of an inducted liquid on an irrigation, m^3/h.

Assuming that all dust is almost completely trapped on a liquid surface, it is possible to write down a balance equation of weight of a dust as:

$$G \cdot (c_{on} - c_{in}) = L \cdot c_{on} \qquad (4)$$

where $(c_{on} - c_{in}) = c_r$ - limiting concentration of a dust, g/m^3

Then in terms of for calculation of extent of recirculation it is possible to present (4) formula as:

$$r = \frac{G \cdot c_{on}}{L \cdot c_r} \qquad (5)$$

Conclusion

1. Excess of boundary concentration of slurry at which it loses properties of a Newtonian fluid, calls decrease in efficiency of a dust separation.

2. At known boundary concentration c_r it is possible to define boundary extent of recirculation of the irrigating liquid, securing stable efficiency of a dust separation

3. Magnitude of boundary concentration depends on physical and chemical properties of system a liquid - a solid and changes over a wide range, from null to several tens percent. This magnitude can be defined now only laboratory methods.

4. Decrease in an overall performance of the apparatus at excess of boundary concentration is connected, first of all, with reduction of fractional efficiency of trapping of small corpuscles with sizes less than 5 microns.

5. On the basis of observations of work of an investigated deduster it is possible to assert that change of viscosity of an irrigated liquid influences conditions of a generating of an interphase surface and, especially, on intensity of formation of a drop layer.

6. Selection constructional and the operating conditions, securing high efficiency of a dust separation at small factor of a water consumption, allows to recommend such dedusters for implementation in the industry.

References

1. Valdberg, A. j. *Wet-type collectors impact-sluggish, centrifugal and injector acts.* M.: Petrochemistry. (1981).
2. GOST 21235-75 *Talc and a talcum powder the ground. Specifications*
3. . Egorov, N.N. *Gas cooling in scrubbers*. - M : Chemistry publishing house. (1954).
4. Kutateladze, S.S., Styrikovich, M.A. Hydrodynamics of gas-liquid systems . M: Energy, 1976.
5. Kabsch-Korbutowicz M. and Majewska-Nowak K., *Removal of atrazine from water by coagulation and adsorption*. Environ Protect Eng. **29**(3). 15-24. (2003).
6. Kitano. T., and Slinna T. *An empirical equation of the relative viscosity of polymer melts filled with various inorganic fillers*. Rheologica Acta **20** (2), (1981).
7. Margopin, E. V, Prihodko, V.P. *Perfection of production engineering of wet clearing of gas emissions at aluminium factories.* M. : Colour. Metal the information. (1977).
9. Jarzkbski, L. and Giowiak., A.. *Ochrvmy Ibrod*. itr, II (1977).
10. Nukijama S., Tanasawa Y//Trans. Soc. Mech. Eng. Japan. V.**5**. (1939).
11. The patent 2317845 RF. *The Rotoklon with adjustable sinusoidal guide vanes* 27 February, (2008).
12. Ramm, V.M. *Absorption of gases*. M: Chemistry. (1976).
13. Rist, R . *Aerosols: introduction in the theory*. M: the World, (1987).
14. Stepans, G. J., Zitser, I.M. *The Inertia air cleaners*. M: "Engineering industry", (1986).
15. Shwidkiy V.S. *Purification of gases.* Handbook. M: Thermal power. (2002).

© **R. R. Usmanova** - Ufa State technical university of aviation; 12 Karl Marks str., Ufa 450000, Bashkortostan, Russia, regina.uu2012@yandex.ru; **G. E. Zaikov** - professor, Kazan national research technological university, chembio@sky.chph.ras.ru.