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ВЛИЯНИЕ ОСНОВНЫХ ФАКТОРОВ НА ЭФФЕКТИВНОСТЬ МОКРЫХ ВИХРЕВЫХ ПЫЛЕУЛОВИТЕЛЕЙ

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Высокая эффективность интенсивной работы мокрых скрубберов является результатом одновременного образования различных коллекторов - пылеуловителей. Под коллекторами можно понимать капли распыленной жидкости, пузырьки, образующиеся в условиях интенсивного барботирования, жидкую поверхность и влажные поверхности. Все коллекторы образуются в процессе работы циркуляционного агрегата, особенности работы которого были рассмотрены в предыдущей статье тех же авторов. В данной статье рассматриваются лабораторные установки для оценки влияния различных факторов на эффективность работы коллекторов. Первое устройство состоит из трех камер, в которых пылеотделение с изменяющейся концентрацией суспензии анализировалось независимо в области капли, в условиях барботирования, а также при ударе о смоченную поверхность. Для оценки дробной эффективности использовались каскадные многоступенчатые ударные механизмы. Значительную часть второго испытательного стенда составляла пылеулавливающая камера, обеспечивающая поперечное течение суспензии по отношению к пылевому газу, воздействующему на поверхность жидкости. На стенде был проведен ряд испытаний общей эффективности в изменяющихся условиях воздействия оттока запыленного воздуха на поверхность жидкости с постоянным дозированием пыли в систему. Эффективность обеспыливания оценивалась путем измерения массы пыли, подаваемой в систему, в сравнении с пылью, удерживаемой фильтром на трубопроводе оттока. Физическая модель явления была разработана на основе гипотезы о том, что эффективность улавливания пылевых частиц влажными скрубберами зависит от впитывающей способности жидкости и, следовательно, связана с концентрацией суспензии. Высокая концентрация суспензии может препятствовать проникновению частиц в коллекторы и не раскрывать их поверхности для дальнейших столкновений пылевых частиц.

Ключевые слова: пылеуловители, эффективность пылеудаления, мокрые скрубберы

INFLUENCE OF THE MAIN FACTORS ON THE EFFICIENCY OF WET VORTEX DUST COLLECTORS

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High efficiency of intensive work of wet scrubbers is the result of simultaneous formation of different collectors - dust collectors. Under the collectors it can understand the drops of the sprayed liquid, the bubbles generated in the conditions of intense bubbling, the liquid surface and the wet surface. All collectors are formed during the operation of the circulation unit, the features of which were considered in a previous article by the same authors. This article discusses the laboratory installation to assess the impact of various factors on the efficiency of collectors. The first device consists of three chambers in which the dust separation with a varying concentration of the suspension was analyzed independently in the drop area, under bubbling conditions, as well as upon impact on the wetted surface. To estimate the fractional effectiveness a multi-stage cascade impact mechanisms was used. A significant part of the second test bench was the dust collecting chamber, which provides a cross-flow of the suspension with respect to the dust gas acting on the surface of the liquid. A number of general efficiency tests were carried out at the stand under varying conditions of the impact of the outflow of dusty air on the surface of the liquid with constant dust dosing into the system. Dust removal efficiency was evaluated by measuring the mass of dust supplied to the system compared to the dust held by the filter on the outflow pipeline. The physical model of the phenomenon was developed on the basis of the hypothesis that the efficiency of dust particles capture by wet scrubbers depends on the absorption capacity of the liquid and, therefore, is associated with the concentration of the suspension. A high concentration of a suspension may prevent the penetration of particles in the reservoirs and not disclose them to the surface for further collisions of the dust particles.

Key words: dust collectors, dust removal efficiency, wet scrubbers

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The purpose of the study was to analyse dust retention efficiency change with altered suspension concentration on droplets, in barbotage condition, on impact against wet surface as well as liquid surface. Tests were carried out on two independent model devices.

The first device consists of three chambers, in which dust separation with changing suspension concentration was analysed independently in droplet area (3), in barbotage conditions (2) as well as on impact against wetted surface (5) (Fig. 1).

The following test velocities of the dusted gas stream on impact against wet surface were assumed: 20, 30, 40 m/s. Such velocity interval had a sufficiently large safety margin of potential velocity variations for prospective industry applications of the results.

The gas flow velocity in the drip chamber was 1, 1.5, 2 m/s, and the air outflow rate from the dusted gas inlet piping, at the liquid surface in the barbotage surface, was 9, 12, 15 m/s, respectively.

Talcum dust in the form of fine-grained but poorly wettable dust was selected for the research [1].

Talc used for the research, according to its manufacturer and laboratory measurements, conducted with method analogous to [2], consisted of particles size less than 40 μm.

Multi-chamber wet deduster for assessment of the dedusting efficiency on droplets, in barbotage area and on impact against a wet surface.

On the inlet piping, a pneumatic classifier (1) was installed, separating potential dust agglomerates larger than 20 μm in size. The aerosol was generated by introducing dust into the inlet piping through a dispenser (10). The dusted gas was directed to a wet-type dedusting system (15) for a thorough clean-up, and was subsequently removed from the station through a drop separator (8) and outflow piping.

In vertical segments of inlet and outflow pipes, similar systems were installed to measure dust concentrations (S_w and S_0), fraction composition (I_w and I_0), gas humidity (φ_w and φ_0), temperature, gas volumetric flux and hydraulic flow resistance.

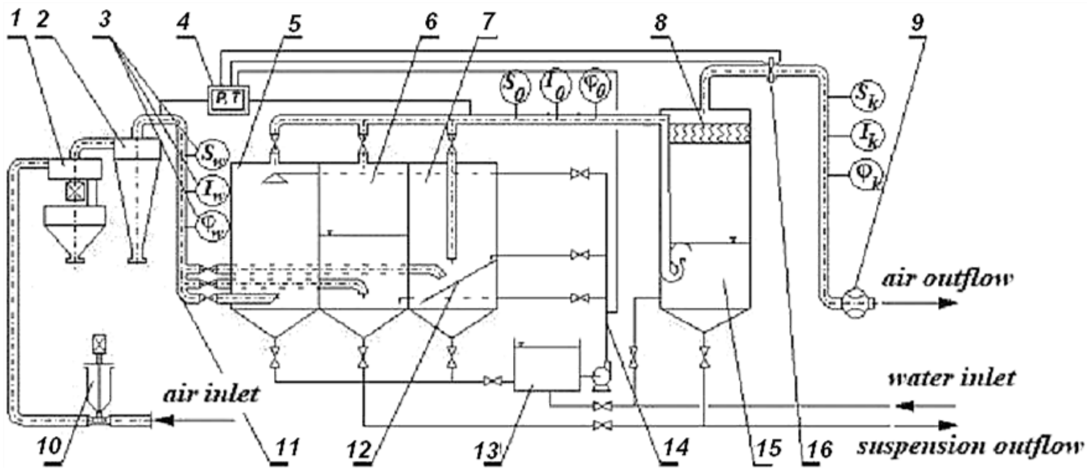


Fig. 1. Experimental set-up diagram: 1 – classifier; 2 – cyclone; 3 – measuring instruments; 4 – pressure and temperature meter; 5 – gas washer; 6 – camera of dust removal; 7 – deposition chamber; 8 – droplet separator; 9 – fan; 10 – dispenser; 11 – power system; 12 – sampler; 13 – collection of washing liquid; 14 – pipeline; 15 – wet dust collection system; 16 – outlet pipeline

Рис. 1. Экспериментальная установка: 1 – классификатор; 2 – циклон; 3 – измерительные приборы; 4 – измеритель давления и температуры; 5 – газопромыватель; 6 – камера обеспыливания; 7 – осадительная камера; 8 – каплеотделитель; 9 – вентилятор; 10 – дозатор; 11 – система питания; 12 – пробоотборник; 13 – сборник промывной жидкости; 14 – трубопровод; 15 – система мокрого пылеулавливания; 16 – выходной трубопровод

To evaluate fractional efficiency, multi-stage cascade impactors were used, presented in Fig. 2 enabling direct in-piping measurement, thus avoiding the necessity to preliminarily separate a specific dust volume designated for measurement purposes.

The impactor consists of the inlet head (1) and (2), which through the G1/8 connector is connected by means of a short cable with an inlet probe positioned in the pipeline of the test stand in front of, or behind, the analysed model of dust collector. The enlarged space of the inlet head (2) is applied to mount – next to the walls and bypassing the main aerosol stream – electronic converters of the static pressure P, temperature T and relative humidity φ of the aerosol stream at the impactor inlet. The measured parameters are then used in a calculation programme for determining the stream parameters at particular stages and outlet cross-sections of the impactor nozzles.

Removable collecting plates of the analysed particles (5) are placed under each of the working nozzles. The heights of the outlet surfaces of working nozzles above the surface of the collecting plate H range from, approximately, $3D_i$ to $5D_i$, whereby for the nozzles with larger cross-sections D_i smaller values of the ratio H_i/D_i were accepted, whereas for the nozzles with smaller D_i – higher values H_i/D_i, respectively. The values H_i for particular stages, which are applied in the impactor, are within the values recommended in the literature on the subject.

After the last sixth nozzle stage of the impactor there is a measurement filter paper positioned on the supporting mesh (12), which constitutes an additional seventh stage of the impactor. It consists of a number

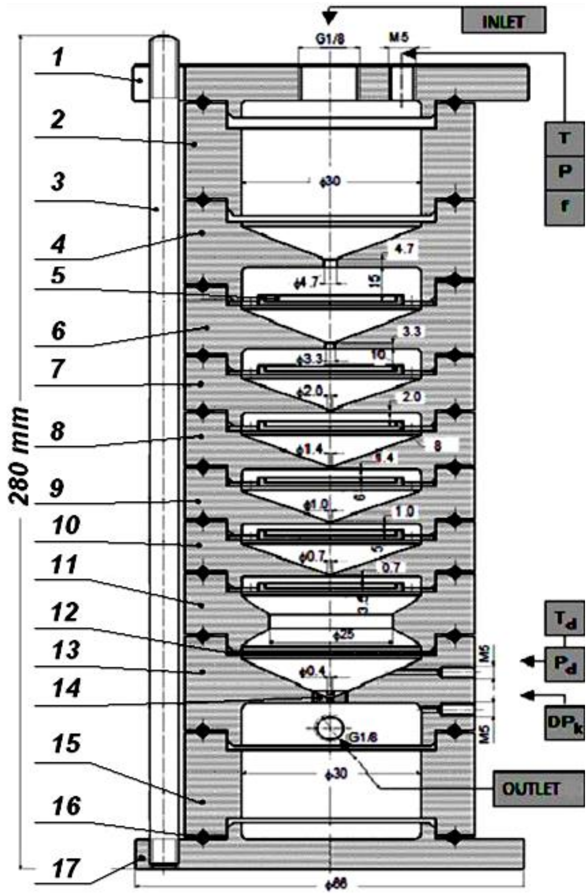


Fig. 2. Multi-stage cascade impactor: 1, 17 – cover; 2 - inlet head; 3 – jack; 4, 6-11, 13, 15 – ring elements; 5 - plate collection of the studied particles; 12 – supporting mesh; 14 – supersonic nozzle; 16 – rubber seal

Рис. 2. Многоступенчатый каскадный импактор: 1, 17 – крышка; 2 - входная головка; 3 – домкрат; 4, 6-11, 13, 15 – кольцевые элементы; 5 пластинчатый сборник исследуемых частиц; 12 – опорная сетка; 14 – сверхзвуковое сопло; 16 – уплотнение of filter paper layers which are stacked one on top of the other; its task is to catch the finest particles from the stream of the analysed aerosol. Moreover, its presence prevents the contamination of the critical nozzle (14) with the finest particles which are not stopped at the last stage of the impactor. The outlet space under the nozzle (14), in the ring (15), is designed to mount measurement sensors "servicing" the critical nozzle. The microsensor of differential pressure, attached to the top surface of the space below the critical nozzle, is connected with the space in front of the nozzle by a hollow channel. All of the elements of the impactor are pressed together between the covers (1) and (17) by three pulling jacks (3). The tightness between particular elements of the impactor is secured by removable rubber seal (16). The connection of the impactor with the vacuum pump is via the bottom outlet pipe of the outlet chamber G1/8 equipped on the outside of the impactor with a quick connector coupling Ø8 hose. The impactor is moreover equipped with additional outlet pipes M5 together with quick connectors (coupling Ø6 pneumatic hoses) for the direct pressure measurement with U-tubes or an external sensor of pressure difference.

Aerosol-to-liquid impact chamber for dedusting efficiency evaluation

A significant part of the second test stand was the dedusting chamber, enabling crossflow of a suspension in relation to the dusted gas impacting against the liquid surface. At the stand, a number of general efficiency tests were carried out in changing conditions of the dusted air outflow impacting against the liquid surface, with constant dust dispensing into the system. Dedusting efficiency was evaluated by measuring the mass of dust delivered to the system versus dust retained by the filter at the outflow piping. A diagram of the test stand was presented in Fig. 3.

In the diagram, the collector (3) is shown, its purpose is to deliver an aerosol into the chamber, and piping collectors (6) and (9), enabling crossflow of the liquid and the supplied aerosol. At the height of 15 mm from the chamber base surface, inlet and outflow channels were milled in the form of 5 mm wide slots. With pipes attached, they served as inlet and outflow collectors. Thus, constant liquid crossflow through the chamber was enabled in relation to the aerosol direction.

A sample collection point (10) was used to control suspension concentration changes with time.

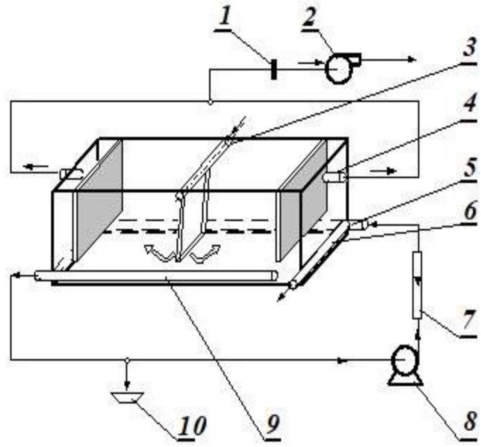


Fig. 3. Schematic diagram of gas-liquid cleaning on a shock stand: 1 – measuring orifice, 2 – fan, 3 – aerosol supply nozzle, 4 – aerosol outlet, 5 – suspension supply piping, 6 – backup suspension outflow piping, 7 – rotameter, 8 – pump, 9 – suspension outflow piping, 10 – suspension sample collection

Рис. 3. Принципиальная схема газожидкостной очистки на ударном стенде: 1 – измерительная диафрагма, 2 – вентилятор, 3 – сопло подачи аэрозоля, 4 – штуцер выхода аэрозоля, 5 –питающий трубопровод, 6 – резервный трубопровод, 7 – ротаметр, 8 – насос, 9 – трубопровод стока жидкости, 10 –сборник

RESULTS AND DISCUSSION

Results obtained from multi-chamber device

Sample results of fractional dedusting efficiency tests are presented in Fig. 4 and 5.

The efficiency of talc dedusting in water was tested for specific liquid collectors, located and dominant in each chamber of the device. The test stand enabled evaluation of influence of the collectors on obtained dedusting efficiency, for different levels of dust suspension concentration in water.

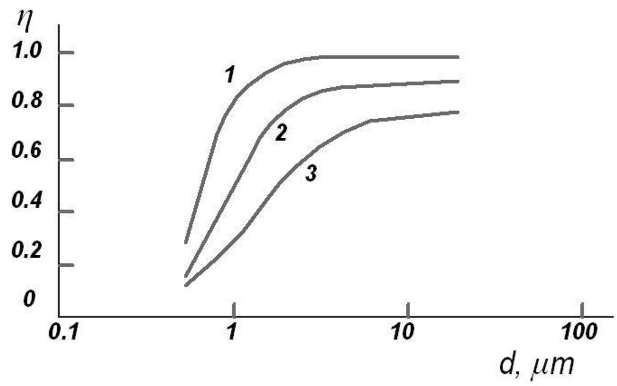


Fig. 4. Fractional efficiency of trapping talc with pure water: 1 -barbotage, 2 – wetted surface, 3 – sprayed liquid

Рис.4. Фракционная эффективность улавливания талька чистой водой: 1-барботаж, 2-смоченная поверхность, 3 – распыленная жидкость

Assuming that in each chamber of the test stand, the dominant role is played by just one collector, tests were carried out for the case of barbotage [3-5], dust retention by the water spray [8], as well as particle retention on the wetted surface [4, 6]. It should be noted, that in the intensive barbotage chamber with high dusted gas velocity a droplet layer emerges, supporting the dedusting effect. It can be assumed that participation contribution of other supporting collectors is minimal, therefore general dedusting efficiency is reached by basic collectors only.

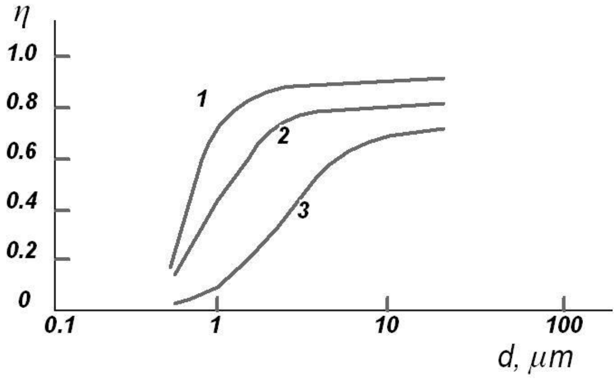
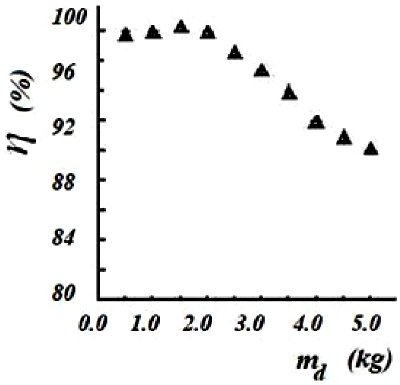


Fig. 5. Fractional efficiency of trapping talc with with suspension: 1 - barbotage, 2 – wetted surface, 3 – sprayed liquid
Рис. 5. Фракционная эффективность улавливания талька суспензией: 1-барботаж, 2-смоченная поверхность, 3 – распыленная жидкость



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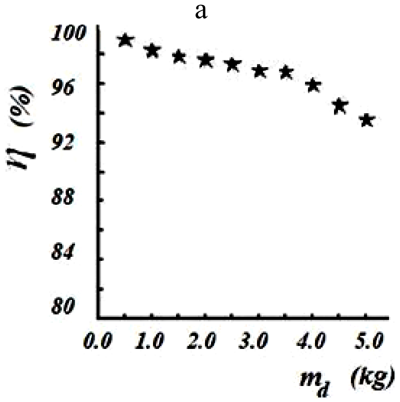


b

Fig. 6. Dependency of cumulative efficiency on deposited mass for talc: a) gas velocity u= 26 m/s; b) gas velocity u= 30 m/s
Рис. 6. Зависимость кумулятивной эффективности от депонированной массы, для талька: а) скорость газа 26 м/с; б) скорость газа 30 м/с

Fig. 5 shows test results of the fractional efficiency of water-assisted talc dedusting for three collectors. According to the graph, peak efficiency was achieved in barbotage. It was to be expected since for gas cavity collectors, due to extended and constantly regenerating interface, a very intensive dust particle retention process occurs.

For the two remaining collectors, significantly lower dedusting efficiency levels were obtained during the test. Compared to approximately 90% efficiency in barbotage, the dedusting efficiency of the sprinkler fell down to 70%.

In Fig. 6 test results are presented, showing the fractional efficiency of talc dedusting with suspension in maximum concentration used for testing.

As shown in the graphs, for all the generated liquid collectors, dedusting fractional efficiency with suspension in maximum concentration used for testing, i.e. 28% of the mass, was lower than that of pure water.

Results of investigations of general efficiency in the impact chamber

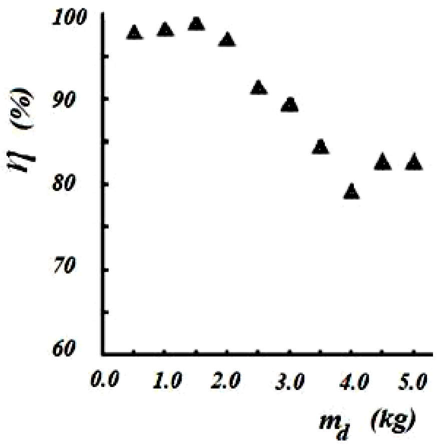
Sample test results for instantaneous and cumulative efficiency calculations for two aerosol flow velocities are presented in Fig. 6 and Fig. 7 [5, 7].

In Fig. 6, a sample dependency of cumulative efficiency on deposited mass is presented, for talc. In almost all the graphs, for different velocities of the dusted air flowing out of the nozzle, the initial operating range does not exhibit any suspension absorption capacity changes with time. Beyond the range, efficiency tends to drop, albeit not abruptly. Therefore, evaluation of a specific concentration limit, above which the efficiency becomes significantly degraded, becomes problematic.

In Fig. 7, dependency of temporary efficiency on deposited mass for talc is shown. The distribution of test points reflects the rising inaccuracy of measurements, nonetheless it confirms the hypothesis of changes in suspension absorption capacity.

Modelling of changes of the mass of dust caught by wet scrubbers

The physical model of the phenomenon was developed on the basis of a hypothesis that the efficiency of capturing dust particles by wet scrubbers depends on the liquid absorbency and is hence related to the concentration of the suspension. A high concentration of the suspension may impede the penetration of particles into the collectors and not reveal their surfaces for further collisions of dust particles.



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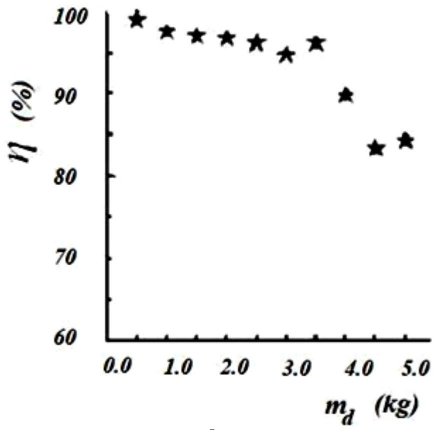
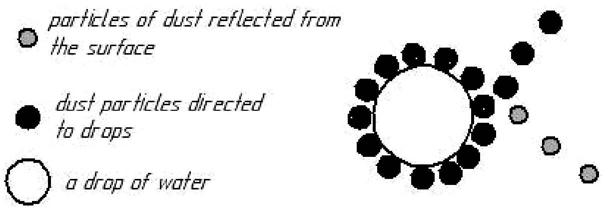


b

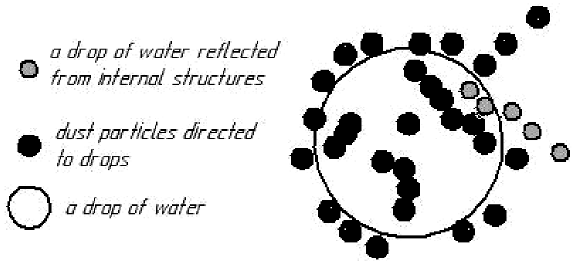
Fig. 7. Dependency of temporary efficiency on deposited mass for talc: a) gas velocity u= 26 m/s; b) gas velocity u= 30 m/s
Рис. 7. Зависимость временной эффективности от депонированной массы для талька: а) скорость газа 26 м/с; б) скорость газа 30 м/с

Scheme 1 illustrates a case when the whole surface of the wet collector (here: a water droplet) is covered with dust particles. The research works have demonstrated that the surface of the particles delivered to the water droplet is larger than the surface of the droplet. More particles head for the surface of the droplet than it is necessary to completely cover its surface. Not wetted particles are not absorbed into the liquid. One may suppose that in such conditions dust particles with small kinetic energy may bounce from the particles which have already settled.



Scheme 1. The entire surface of the wet collector (a drop of water) is covered with dust particles.
Схема 1. Вся поверхность мокрого коллектора (капля воды) покрыта частицами пыли

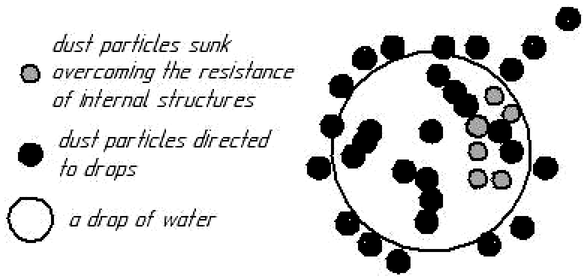
Scheme 2 illustrates a case when in the conditions of a high concentration of the suspension internal structures are formed within in the form of chains of particles which easily bounce off particles with small energy.



Scheme 2. Under conditions of high concentration of the suspension, internal structures in the form of chains of particles are formed inside the droplet.
Схема 2. В условиях высокой концентрации суспензии внутри капли образуются внутренние структуры в виде цепочек частиц

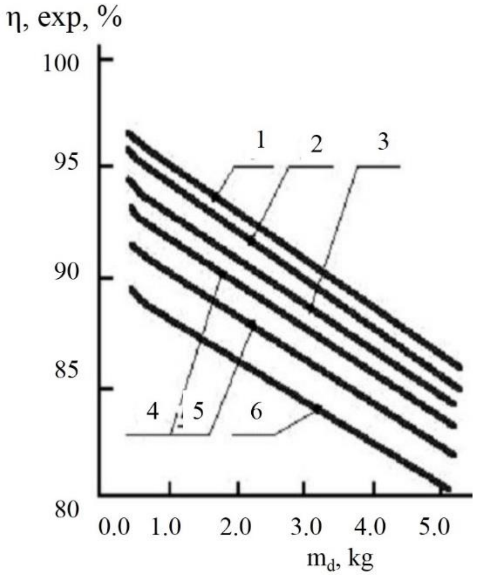
Scheme 3 illustrates a case when a dust particle with sufficient energy overcomes the forces of surface tension, the resistance of the resistance of the liquid medium and breaks the internal structures (particle chains) penetrating deep into the liquid.

The models of interaction of dust particles with wet scrubbers, which have been illustrated in the successive schemes, may explain the possibility of changing the efficiency of dust removal with an increase in the concentration of the suspension and kinetic energy of dust particles, which is related to the scale of the volume concentration of the aerosol flow.



Scheme 3. A particle of dust with sufficient energy overcomes the forces of surface tension and resistance of a liquid medium
Схема 3. Частица пыли с достаточной энергией преодолевает силы поверхностного натяжения и сопротивления жидкой среды

The models of interaction of dust particles with wet scrubbers, which have been illustrated in the successive schemes, may explain the possibility of changing the efficiency of dust removal with an increase in the concentration of the suspension and kinetic energy of dust particles, which is related to the scale of the volume concentration of the aerosol flow.



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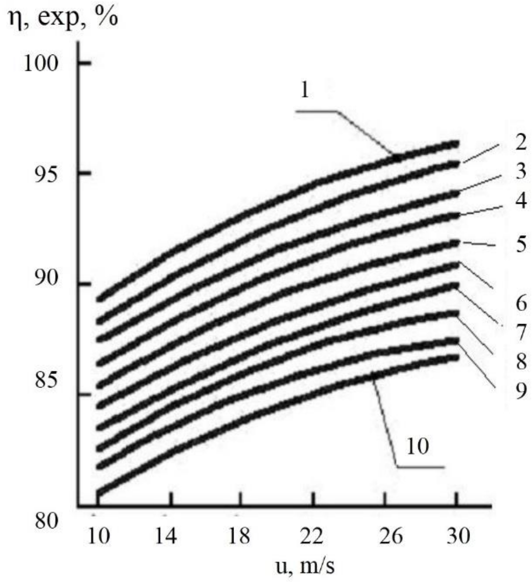

b

Fig. 8. Graphs based on obtained correlation for talc: a) 1 - u = 30 m/s; 2 - u = 28 m/s; 3 - u = 22 m/s; 4 - u = 18 m/s; 5 - u = 14 m/s; 6 - u = 10 m/s; б) 1 – m_d = 0.5 kg; 2 – m_d = 1.0 kg; 3 – m_d = 1.5 kg; 4 – m_d = 2.0 kg; 5 – m_d = 2.5 kg; 6 – m_d = 3.0 kg; 7 – m_d = 3.5 kg; 8 – m_d = 4.0 kg; 9 – m_d = 4.5 kg; 10 – m_d = 5.0 kg

Рис. 8. Графики, основанные на полученной корреляции для талька: а) 1 - u = 30 м/с; 2 - u = 28 м/с; 3 - u = 22 м/с; 4 - u = 18 м/с; 5 - u = 14 м/с; 6 - u = 10 м/с; б) 1 – m_d = 0,5 кг; 2 – m_d = 1,0 кг; 3 – m_d = 1,5 кг; 4 – m_d = 2,0 кг; 5 – m_d = 2,5 кг; 6 – m_d = 3,0 кг; 7 – m_d = 3,5 кг; 8 – m_d = 4,0 кг; 9 – m_d = 4,5 кг; 10 – m_d = 5,0 кг

Mathematical model of particles dedusting on the liquid surface

A mathematical model for both discussed cases may be derived from the following relationships [8]:

$$\dot{m}_z = \dot{m}_d - \dot{m}_w \quad (1)$$

$\dot{m}_z$ – change in mass of retained dust in time, change in sediment mass in time, kg·s^{-1}, $\dot{m}_d$ – change in mass of inflowing (supply) dust in time, change in mass of deposited particles, kg·s^{-1}, $\dot{m}_w$ – change in mass of generated dust emission, removed from the sediment, kg·s^{-1}.

The mathematical model of changes in mass of dust retained in the suspension, takes the following from [9]

$$m_z = A \cdot u^D \left[1 - \exp\left(-B \cdot u^{2-C} \cdot m_d\right)\right] \quad (2)$$

m_d – cumulative mass of supplied dust, directly proportional to the time of operation, kg.

Values of regression coefficients for model [9] Regression coefficients were calculated using estimation method described and used, e.g. in [10-13].

A = 91.780; B = 0.010; C = 2.000; D = 0.020.

The average correlation match relative error is 2.55%.

CONCLUSIONS

Having compared the test results of fractional dedusting efficiency of talc for all the liquid collectors used in the tests, a conclusion can be drawn that suspension concentration significantly affected the resulting dedusting efficiency.

The cumulative curve of fractional dedusting efficiency for the maximum suspension concentration used in the tests falls below the pure water curve.

The effect of degraded fractional dedusting efficiency pertains to both small dust particles, several microns in diameter, and to those resulting from fraction decomposition of dust used for testing. This shows that some dust was not retained by the suspension.

The use of a physical model taking into account changes of the absorption capacity of a suspension with its concentration may partially explain test results. Impacting dust particles are not absorbed by the suspension, as they bounce off dust particles previously retained in it, and are therefore not absorbed into the liquid. It can be assumed, that in such conditions dust particles of small kinetic energy may bounce off particles already retained on the liquid collector surfaces. At high concentrations, particle chaining occurs in suspension, enabling easy deflection of low energy particles. The particle features sufficient energy to enter the suspension, destroy the emerging structures and overcome the resistance of the medium.

The above may partially explain altering dedusting efficiency with a rising concentration of the suspension, as well as the dependency of efficiency on the growth of kinetic energy of dust particles, relative to increasing aerosol flow velocity.

It should be emphasised that increase of dedusting suspension concentration incurs generation of collectors, which may affect dust particle retention.

It is specifically evident in intensive barbotage, when aerosol cavities penetrating the high concentration suspension layer are irregular both in shape and outflow frequency.

With a rising suspension concentration, mist uniformity and the shape of emerging droplets dispersed by the sprinkler is also altered.

Higher kinetic energy of the high concentration fluid flow allows for more efficient dispersion of the layer wetting the surface, exposing it entirely for subsequent impacts and disabling dust particle retention.

As the above effects superimpose, the final result is degradation of both general and fractional dedusting efficiency levels. This pertains to cases of dust particle retention by the water spray generated by the sprinkler, in the barbotage chamber, as well as on impact of the dusted gas against the wetted surface and liquid surface.

The analysis of general dedusting efficiency of talc for the collectors considered in the current paper demonstrates that the highest efficiency was achieved in intensive barbotage conditions.

The analysis of efficiency changes in barbotage conditions shows that the effect of dedusting efficiency degradation grows with increasing gas flux, which is consistent with the physical model used in the study.

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