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EFFECTIVE LOCALIZATION OF COAL DUST EXPLOSIONS USING HYDRO VORTEX COAGULATION**Nikolay P. Kosarev, Vladimir N. Makarov, Nikolay V. Makarov, Aleksandr V. Ugolnikov, Aleksandr V. Lifanov¹**

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¹OilGazMash Research and Production Complex LLC (2d Zheleznodorozhnaya st., Podolsk, 142103, Russian Federation)**ЭФФЕКТИВНАЯ ЛОКАЛИЗАЦИЯ ВЗРЫВОВ УГОЛЬНОЙ ПЫЛИ С ИСПОЛЬЗОВАНИЕМ ГИДРОВИХРЕВОЙ КОАГУЛЯЦИИ****Н.П. Косарев, В.Н. Макаров, Н.В. Макаров, А.В. Угольников, А.В. Лифанов¹**

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ecotechnology, dust suppression, heterocoagulation, hydrophobicity, circulation, wetting angle, adhesion, absorption energy, attached vortex, medial size, orthokinetics, capture coefficient, absorption coefficient, sticking energy barrier, depression force.

The paper is devoted to the development of a mathematical model for high-pressure hydro vortex inertial kinematic dust suppression. The suppression can significantly improve the efficiency of localization of man-made accidents and reduce the level of occupational pulmonary diseases. The dynamics of improving the technology and technical means of dust suppression in the mining and metallurgical complex of Russia shows their lack of effectiveness in ensuring sanitary conditions, especially in localization of dust mixture explosions. A further increase in the efficiency of coal mining and mineral processing is significantly limited by the imperfection of the technology for localizing and eliminating explosions of coal dust. The method of high-pressure hydro vortex dedusting is developed based on the theory of attached vortices. A mathematical model of hydro vortex inertial, kinematic heterocoagulation, which significantly increases the energy efficiency of dust suppression, is proposed. The graphical model of the interaction in the contact zone at the time of the collision in the liquid-solid system is refined. Stokes and Reynolds criteria equations are obtained with hydro vortex inertial orthokinetic heterocoagulation. An equation is obtained which allows to calculate the magnitude of the reduction in the required energy of the total absorption of dust particles as a function of the circulation of liquid droplets. Equations for calculation of effective wetting angle and the minimum diameter of absorbed dust particles are obtained as a function of the angular velocity of rotation of liquid droplets. It is shown that hydro vortex coagulation significantly reduces the size of the dispersed dust composition, water consumption, increasing the efficiency of dust suppression. A significant decrease in the size of the absorbed dust particles increases the efficiency of localization of coal dust explosions, reduces the incidence of silicosis and anthracosis. Certification tests using patent-protected vortex nozzles confirmed that there was a reduction in the minimum size of absorbed dust in four times, increase in dust collection efficiency of up to 99 %, reduce in water consumption by 20 % compared to classic high-pressure spray cleaning. The proposed technology of dust suppression can be used in mining companies when fine explosive dust mixtures are formed.

Ключевые слова:

экологическая технология, пылеподавление, гетерокоагуляция, гидрофобность, циркуляция, угол смачивания, адгезия, энергия поглощения, присоединенный вихрь, медиальный размер, ортокинетика, коэффициент захвата, коэффициент поглощения, энергетический барьер налипания, сила депрессии.

Статья посвящена разработке математической модели высоконапорного гидровихревого инерционного кинематического пылеподавления, применение которого позволяет существенно повысить эффективность локализации техногенных аварий и снизить уровень профессиональных легочных заболеваний. Динамика совершенствования техники и технологии пылеподавления в горно-металлургическом комплексе России показывает их недостаточную эффективность в обеспечении санитарно-гигиенических условий, а главное локализации взрывов пылевых смесей. Дальнейшее повышение эффективности угледобычи и переработки минерального сырья существенно ограничено несовершенством технологии локализации и ликвидации взрывов угольной пыли. На базе теории присоединенных вихрей разработан метод гидровихревого высоконапорного обеспыливания. Предложена математическая модель гидровихревой инерционной, кинематической гетерокоагуляции, существенно повышающей энергоэффективность пылеподавления. Уточнена графическая модель взаимодействия в зоне контакта в момент соударения в системе «жидкое – твердое», получены уравнения критериев Стокса и Рейнольдса при гидровихревой инерционной ортокинетической гетерокоагуляции. Получено уравнение для расчета величины снижения потребной энергии полного поглощения частиц пыли в функции от циркуляции капель жидкости. Получены уравнения для расчета эффективного краевого угла смачивания и минимального диаметра поглощаемых частиц пыли в функции от угловой скорости вращения капель жидкости. Показано, что гидровихревая коагуляция существенно снижает размер диспергированного состава пыли, расход воды, повышая эффективность пылеподавления. Существенное снижение размера поглощаемых частиц пыли повышает эффективность локализации взрывов угольной пыли, снижает заболеваемость силикозом и антракозом. Сертификационные испытания с применением защищенных патентом вихревых форсунок подтвердили снижение минимального размера поглощаемой пыли в четыре раза, повышение эффективности пылеулавливания до 99 % при одновременном снижении расхода воды на 20 % по сравнению с классическим высоконапорным гидрообеспыливанием. Предложенная технология пылеподавления может быть использована на горных предприятиях в условиях образования мелкодисперсных взрывоопасных пылевых смесей.

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Introduction

The task of air cleaning at mining enterprises is very important in aspect of better performance, complying with sanitary and hygienic norms limiting permitted concentrations of harmful explosive gases and aerosols. Practice shows that intensification of production, implementation of new technologies providing for effective production and processing raw minerals is restricted by imperfection of coal powder blast localization technologies.

Coal mining in conditions of constant increase of mining works depth is accompanied by increase of negative technogenic and natural processes: gas, dust, endogene fire dangers, gas and coal outbursts. Except that, stable correlation of cause and effect relationships of the above processes leads to that elimination of some dangerous phenomena is accompanied by growth of other, not less catastrophic, processes in coal mines [1-4].

Degassing of coal layers and gas emission control, having purpose to prevent gas hazard in workings, increase endogene fire danger and increase dust-forming ability of coal. Preliminary physical and mechanical action on the layer during degassing increase coal self-ignitability. Gas emission control by drainage levels and suction of methane-air mixture from the mined-out space lead to increase of aeration of mined-out space and intensification of oxidation processes being reason of coal self-ignition [5-9].

Reasons of forming explosive dust-air environment are high hardness and fragility of rocks, leading to intense dust formation during separation of rock from the massive and transportation. Gas and dust explosions are significantly different, but explosive properties of gases and dust have much in common, and so it is possible to develop complex methods to reduce gas and dust hazard in extraction districts of coal mines [3, 10-13].

In the modern conditions fight against dust-air mixture explosions is led in the following main directions: prevention of dust and gas emissions formation; prevention of dangerous concentrations of gas and dust in mine atmosphere; exclusion of

heat impulse occurrence; personnel protection during explosion [14-17].

To eliminate explosive concentrations various means to reduce yield of explosive impurities during massive fracturing, eliminate them from workplaces, neutralization and dust suppression [18-22].

Dust formation in coal mines is determined by technological peculiarities of mining works, application of mining methods supposing intense denudation of coal layer at all area of working. Except that coal dust has high floatability in air, low wettability, and intense aeration causes trapping large amount of dust by turbulent air flow. At the same time increase of energy availability and mechanical separation and crushing of rock and coal directly in actively ventilated workspace of workings lead to constant intense dusting of workings air on their full length.

With regard to the abovementioned, reduction of explosive danger in mines should be performed according to the following interrelated directions:

- change of properties and condition of productive strata, especially layer or deposit being developed with purpose to reduce their negative occurrence, i.e. preparation of the deposit for safe development;
- performing technical actions on dust suppression in the mine.

Experience shows that passive barriers as large stationary constructions are not able to localize explosion in workings with many and relatively mobile potential ignition sources because of difficulty to constantly maintain permitted distances between them under operational conditions [22-25].

Automatic systems contrary to passive barriers have independent from external conditions power supply, serving for forced dispersal and supply of inhibitory substance to fire zone according to sensor signal. Extinguishing of explosion fire is made by substantially lower amount of extinguishing powder comparing to passive barriers. These devices have small size and weight which permits to move them comparatively easy in the working along mining progress, not occupying free space of the working and leaving space for various mining equipment [22].

The above stated proves need of complex approach to safety in coal mines. In advanced coal mines in Russia working faces are equipped with modern extraction equipment providing for up to 25 thousand tons in 24 hours. But high dust content in the workings, abundant methane release from coal layers with high gas content and high dust content reduce intensification of coal production, which significantly decreases economic effectiveness and competitiveness of underground coal producing enterprises [1, 3, 25, 26].

Traumatism with high consequences caused by dust explosions in coal mines is over 10%. This determines special social importance of prevention and localization of dust-air mixture explosions in mines and protection of personnel. Actions on maintaining dust conditions in mines are based on prevention of explosive dust accumulation and prevention of occurrence of high temperature source able to ignite dust aerosols [2, 27].

Except that, dust negatively influences human body, causing lung diseases: silicosis – in case of action of rock dust, anthracosis – in case of action of coal dust. Dust particles with size $(1...6)10^{-6}$ m are especially active on the human lungs.

The most important problem of dust-air mixture explosion is for coal mines with high gas contents, and in the first instance for development faces, where over half of accidents happen.

At mines with high gas contents and gas and rock outbursts successful control of formation of explosive dust-air environment is possibly only on basis of rational combination of dust suppression and degassing.

Studies show that over 60 % of cases of explosive environment formation may be excluded by efficient dust suppression.

Measures on counteraction to coal dust may be grouped in the following main groups: prevention or reduction of dust formation, ventilation, dust catching, dust suppression.

One of the effective means to prevent dust formation is preliminary watering of coal massive. Essence of preliminary watering is that fluid injected onto the layer under pressure

increases coal humidity, causing formation of aggregates from droplets (located in the cracks), which quickly drop out after coming into air [10, 17, 18, 20].

Ventilation provides for extraction of dust from the face and thickening dust aerosol by incoming fresh air with limitation of air speed by dust factor: in preparatory workings – 0.4-0.7 m/s; in production faces – 1-3 m/s [1].

Dust catching is accumulation of dust-air mixture in special bunker due to creation of negative decompression, action of atomized fluid and precipitation in the form of slurry [24].

The most widely spread method of dust sedimentation from air is dust suppression based on watering dust particles by droplets of fluid, forming on collision hetero-coagulation system «droplet – dust particle», which drops down from air and sediments on walls of working [11, 15, 18, 20].

To increase dust suppression efficiency chemical foam is used, which spreads on rock surface, mixes with it, preventing transfer of dust to suspended state. Foam creates large area of interaction of fluid with rock and adds to effective suppression of fine dust fractions and screening dust formation centers [19].

So, complex approach to safety organization in coal mines with regard to interdependence of negative occurrences may provide for increase of economic effectiveness and competitiveness of coal enterprises.

In conditions of increase of coal mining intensity, high specific energy, reduction of dust explosion danger may be provided for only in case of full automation of all complex dust suppression and dust-explosion protection processes:

- system to monitor intensity of dust accumulation and dust-explosion safety of minings, similar to gas control system;
- automatic systems for dust suppression, hydro dedusting, functionally connected to dust accumulation intensity monitoring system.

Improvement of system for localization of possible coal dust explosions – component of mine dust-explosion protection problem, solution of which is one of the most important tasks in field of

safety means and labor protection for the coming years [1, 3, 22].

The methodology of research.

Description of scientific idea

Dust suppression effect substantially is reduced to overcoming energy barrier on process of collision of fluid droplets with dust particles and transfer of «hard – liquid» system to more stable condition, i.e. is determined by degree of coagulation and ability of fluid droplets to capture dust particles.

As shown above, hydro dedusting is one of the most spread means to prevent explosions of dust mixtures, comply with sanitary and hygienic norms in mining technologies [20, 25, 28, 29, 30].

But in high pressure hydro dedusting aeration energy requirements increase significantly, which reduces energy effectiveness of processes providing for sanitary and hygienic conditions, and, as result, leads to reduced competitiveness of environmental technology in mineral resources management [30].

The need in improvement of high pressure hydro dedusting, implementation of environmental mineral resources management require new approach to building mathematical model of inertial orthokinetic hetero-coagulation of water and dust aerosol [31-34].

The determining role in increase of effectiveness of coagulation interaction of water droplets and dust particles is exactly in kinetic energy of movement of dispersed water droplets, and not the total water consumption. For low pressure fluid disperse influence of initial part of torch on the total coagulation effectiveness is not so important due to low kinetic energy of the dispersed spray.

In high pressure hydro dedusting, dynamically active initial part with high kinetic energy of fluid droplets is of determining role in total effectiveness of dust particles capture and coagulation by water droplets.

As dust suppression is actually possible only in direct contact of water droplet with dust particle, then the mechanism of this namely process should be studied in order to develop technology and

corresponding technical means providing for most comfortable conditions for its effective implementation.

Technically, coagulation is result of collision of two phases: liquid and hard. Collision happens in contact of fluid droplet and dust particle, while the fact of coagulation, i.e. consumption of dust by liquid, may not happen, as for final capture and transfer to single system «fluid droplet – dust particle» it is necessary that inertia forces of dust particles were larger than adhesion and wetting forces [30, 35].

Degree of mutual penetration of two phases, especially in relation to micro sized particles, corresponding to hydrophobicity, i.e. effectiveness of coagulation, depends on character of surface phenomena behavior in their contact area, determined by influence of relative velocity of water droplet and dust particle, their size, surface tension at boundary surface. It is experimentally proven [30], that dust particles with diameter less than $5 \cdot 10^{-6}$ m are practically hydrophobic. At the same time in coal dust structure prevail particles with size $(1...200)10^{-6}$ m.

So, significant part of the most explosive dust is hydrophobic, which significantly decreases effectiveness of high pressure hydrodynamic dedusting [30].

Goal of modeling parameters of «fluid droplet – dust particle» system in process of proposed vortex inertial orthokinetic hetero-coagulation is study of kinematic coagulation mechanism in conditions of action of attached vortex induced by rotating fluid droplet [30, 36-38].

Fixation of particles coming to the droplet to distance of adhesion forces action depends on value of contact wetting angle θ . To capture hydrophobic dust particles by fluid droplet it is necessary to exert work of external inertial forces, corresponding to kinetic energy W_k of interaction in process of their contact. Dust particle capture by fluid droplet will happen on condition when its kinetic energy W_k will be greater or equal to absorption energy Π_{l-g} , corresponding to sum of adhesion energy W_{ad} (F_{ad} – force of adhesion), determined by

specific separation energy, and wetting energy W_{l-g} (F_{l-g} – force of surface tension), determined by specific spreading energy [30].

Mathematical basis of scientific idea

With regard to stated condition, having expresses mass of dust particle, considering it being sphere, through diameter диаметр $d_{d\min}$, m, expression for minimal diameter of dust particle being absorbed by fluid droplet, will be

$$d_{d\min} = 24 \frac{\delta_{l-g} \cos\theta}{(\rho_d - \rho_g)(V_1 - V_g)^2}, \quad (1)$$

where δ_{l-g} – factor of surface tension at border of two phases «fluid – gas», J/m^2 ; θ – contact wetting angle at border of two phases «fluid – gas», rad; ρ_d , ρ_g – density of dust particle and gas correspondingly, kg/m^3 ; V_1 , $V_g = V_d$ – speed of fluid droplet and speed of gas, equal to speed of dust particle, m/sec.

On basis of known model of kinetic coagulation of dust particle by fluid droplet at $\omega_1 = 0$ [1] Fig. 1 shows graphic model of vortex kinematic coagulation, when fluid droplet rotates with angular velocity ω_1 , inducing attached vortex in contact zone [30, 37, 39].

From analysis of graphic model of interaction in contact zone in moment of collision in system «hard – liquid», shown at Fig. 1, it is clear that

area of contact of fluid droplet with dust particle, determined by diameter of wetting perimeter d_{wet} , directly influences value of contact wetting angle θ . The lower is radius of droplet surface curvature in contact zone, i.e., the lower is its size, then the lower is contact wetting angle θ and, consequently, the larger energy shall be spent for full consumption of dust particle with diameter $d_{d\min}$ by fluid droplet with diameter d_1 , determined by surface energy of separation and spreading.

This work studies mechanism of intended control of contact wetting angle θ and kinetic energy of interaction of fluid droplets and dust particles W_k .

Following denominations are adopted by Fig. 1: ω_1 – angular speed of fluid droplet rotation in respect to speed V_1 ; F_{l-g} , $F_{l-g\omega}$, $\Delta F_{l-g\omega}$ – force of surface tensions at $\omega_1 = 0$, $\omega_1 > 0$ and force of depression in contact zone, determined by rotation of fluid droplet correspondingly; F_{ad} , $F_{ad\omega}$ – force of adhesion at $\omega_1 = 0$, at $\omega_1 > 0$ correspondingly; d_d , d_1 – diameter of dust particle and fluid droplet correspondingly; d_{wet} , $d_{wet\omega}$ – diameter of wetting perimeter at $\omega_1 = 0$, at $\omega_1 > 0$ correspondingly; θ , θ_ω – contact wetting angle at $\omega_1 = 0$, at $\omega_1 > 0$ correspondingly; V_1 , V_g , V_d – speed of fluid droplet, gas and dust particle correspondingly.

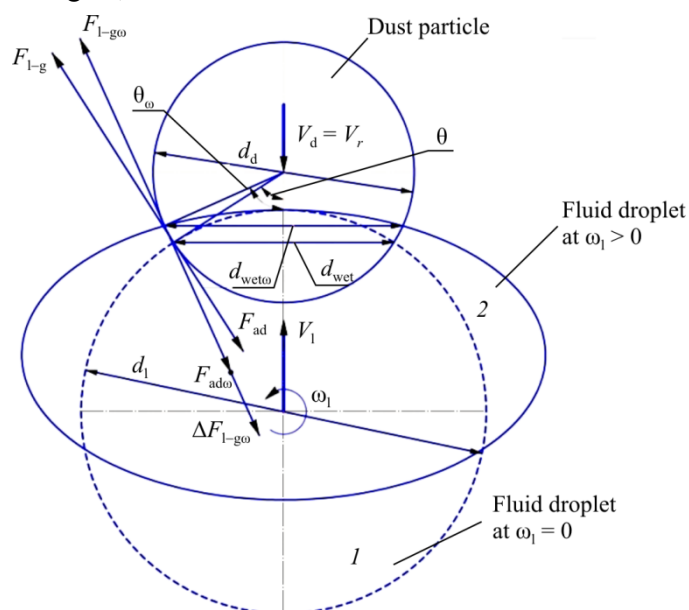


Fig. 1. Graphic model of vortex kinematic coagulation of dust particle and fluid droplet:
 1 – classic inertial orthokinetic hetero-coagulation model, i.e., $\omega_1 = 0$;
 2 – vortex inertial orthokinetic hetero-coagulation, $\omega_1 > 0$

But droplet size by itself is not the determining condition, as at same volumes two droplets may have different forms, determined in particular by rotation speed ω_1 and, correspondingly, by diameter of wetting perimeter d_{wet} at $\omega_1 = 0$ and $d_{\text{wet}\omega}$ at $\omega_1 > 0$.

With increase of contact wetting angle θ value of absorption energy reduces, which makes it possible to provide for given level of dedusting effectiveness at lower energy consumption or increase range of absorption of lower diameter dust particles, i.e. to increase dust suppression efficiency at given energy consumption.

Fig. 1 shows that in collision of dust particle with rotating at speed ω_1 fluid droplet diameter of wetting perimeter increases to value $d_{\text{wet}\omega}$ comparing to its value d_{wet} at $\omega_1 = 0$, i.e. at classic hetero-coagulation.

The bigger is value of contact wetting angle θ , the lower is necessary for absorption fluid droplet kinetic energy, i.e. the bigger is area of contact of fluid droplet with dust particle, the lower speed should be given to fluid droplets to provide for effective dust suppression.

So, to reduce energy consumption of high pressure hydrodynamic dust suppression it is necessary to change kinematics of interaction of fluid droplet and dust particles in vortex zone. With regard to the above it is possible due to influence of vortex energy determined by rotation of fluid droplet with speed ω_1 around its axis, coinciding with speed vector V_1 [30, 36, 37].

Work [30] experimentally determines existence of aerodynamic energy barrier preventing to transfer of «liquid – hard» system to higher energy level of coagulation interaction at lower values of kinetic energy of interaction fluid droplet and dust particle, which corresponds to critical values of Stokes criterion, when capture of dust particles is impossible.

Influence of kinematic and dynamic parameters of fluid droplet rotation to aerodynamic surface adhesion energy barrier and contact wetting angle is shown at graphic model of vortex inertial orthokinetic hetero-coagulation at interaction of dust particle with fluid droplet rotating at speed ω_1 , shown at Fig. 1.

At rotation of fluid droplet with angular speed ω_1 around its surface and in contact zone according to Helmholtz – Bernoulli condition area of depression is created, i.e. lowered static pressure to value of specific energy ΔW_k of attached vortex, which speed according to hydrodynamic analogy is determined by known in theory of electrodynamics Bo-Savar formula. So, attached vortex determined by rotation of fluid droplet, lowering static pressure in area of its contact with dust particle, increases contact wetting angle to value θ_1 , aiding in reduction of aerodynamic energy barrier [30, 36, 37].

In contact zone dust particle will move along spiral line with spiral angle $\alpha = \arctg \frac{d_d \sin \theta \omega_1}{(V_1 - V_g)}$ inside of fluid droplet with travel speed $(V_1 - V_g)$, while rotating at the same time with angular speed ω_1 [37].

Change of kinematic parameters characterizing interaction of dust particle and fluid droplet on contact zone during collision leads to significant change of actual values of Stokes and Reynolds criteria, which in conditions of vortex kinematic coagulation are determined by formulas [30]

$$\text{Re}_{\omega} = \frac{d_1 \rho_1 \sqrt{(V_1 - V_g)^2 + 0,25\omega_1^2 d_d^2 \sin^2 \theta}}{\mu_g};$$

$$\text{Stk}_{\omega} = \frac{d_d^2 (\rho_d - \rho_g) \sqrt{(V_1 - V_d)^2 + 0,25\omega_1^2 d_d^2 \sin^2 \theta}}{18\mu_g d_1}, \quad (2)$$

where d_1 – diameter of fluid droplet, m; ρ_1 – density of fluid droplet, kg/m³; μ_g – factor of gas dynamic viscosity, kg/ms.

So, rotational movement of fluid droplet increases actual effective value of Stokes criterion Stk_{ω} and Reynolds Re_{ω} in contact zone, aiding in reduction of value of surface adhesion energy barrier and critical level of aerodynamic energy barrier [30].

Force of suction pressure in zone of contact of dust particle and fluid droplet determined by influence of attached vortex and equal to reduction of surface tension force may be expressed by equation

$$\Delta F_{l-g\omega} = \frac{1}{2} \rho_l \Gamma_\omega \omega_l S_k S_d^{-1}, \quad (3)$$

where Γ_ω – circulation in zone of contact of dust particle and fluid droplet, m^2/s ; S_k – area of contact corresponding to wetting area, m^2 ; S_n – area of dust particle surface, m^2 .

Equation for additional kinetic energy equal to energy of vortex attached to rotating fluid droplet, with regard to (3) and Fig. 1, Bernoulli and Ostrogradsky-Gauss equations [36, 37] will be

$$\Delta W_{k\omega} = \frac{\pi}{8} \rho_l d_d^3 \sin^4 \theta \omega_l^2. \quad (4)$$

Equation for depression force in zone of contact of dust particle and fluid droplet, determined by influence of attached vortex, with regard to (3), (4) will be

$$\Delta F_{l-g\omega} = \frac{\pi^2}{32} \rho_l d_d^4 \sin^4 \theta \omega_l^2. \quad (5)$$

For vortex inertial orthokinetic hetero-coagulation minimal value of energy for full consumption, with regard to equations (4) on analogy with hetero-coagulation at $\omega_l = 0$ will be

$$\Pi_{l-g\omega} = \Pi_{l-g} - \Delta W_{k\omega} = 2\delta_{l-g} \cos \theta. \quad (6)$$

With regard to equations (4), (6) equation for contact wetting angle in zone of contact of liquid and hard phases at rotation of fluid droplet at angular speed ω_l will be:

$$\theta_\omega = \arccos \left(\cos \theta - \frac{\pi \rho_l d_d^3 \sin^4 \theta \omega_l^2}{8 \delta_{l-g} \cos \theta} \right). \quad (7)$$

So, with regard to (1), (7), proposed model of inertial orthokinetic hetero-coagulation system «dust particle – fluid droplet» at rotation of fluid particle at angular speed ω_l minimal diameter $d_{d\omega \min}$ of dust particle being fully absorbed during process of capture and wetting by fluid droplets at action of surface tension forces, inertial forces of travel and rotational movement, will be

$$d_{d\omega \min} = \frac{\delta_{l-g} \cos \arccos \left(\cos \theta - \frac{\pi \rho_l d_d^3 \sin^4 \theta \omega_l^2}{8 \delta_{l-g} \cos \theta} \right)}{(\rho_d - \rho_g)(V_l - V_g)^2}. \quad (8)$$

Fig. 2, 3 Show results of calculation per proposed mathematical model of vortex kinematic coagulation of change of critical values of Stokes criterion Stk_{crit} depending on angular speed of rotation of fluid droplets ω_l with diameter $d_l = 4 \cdot 10^{-6}$ m and dependence of minimal diameter $d_{d\omega \min}$ of dust particle, fully absorbed during process of capture and wetting by fluid droplets, and change of Stokes criterion Stk at fixed effective critical value of Stokes criterion $Stk_{\omega crit} = 4.1 \cdot 10^{-2}$ for absolutely hydrophobic coal dust particles.

Shown at Fig. 2, isolines of angular speed of fluid droplets rotation in function from critical values of Stokes and Reynolds criteria confirm significant reduction both of forbidding level of surface adhesion energy particles adhesion barrier, and critical level of aerodynamic energy barrier.

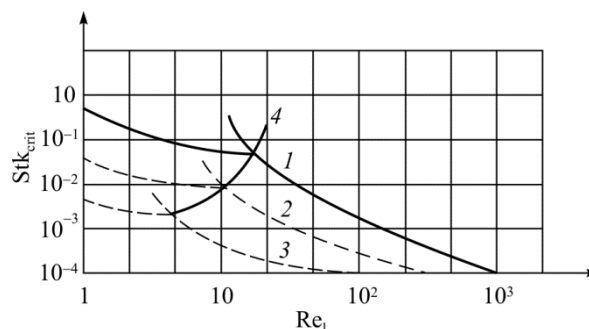


Fig. 2. Isolines of angular speed of fluid droplet rotation in function of critical values of Stokes and Reynolds criteria: 1 – $\omega_l = 0$, $Stk_{crit} = 4.1 \cdot 10^{-2}$, $Re_l = 20$, $d_{d \min} = 4 \cdot 10^{-6}$ m; 2 – $\omega_l = 1.5 \cdot 10^2$ s^{-1} , $Stk_{crit} = 8 \cdot 10^{-3}$, $Re_l = 15$, $d_{d \min} = 3 \cdot 10^{-6}$ m; 3 – $\omega_l = 2.5 \cdot 10^2$ s^{-1} , $Stk_{crit} = 4.5 \cdot 10^{-3}$, $Re_l = 6$, $d_{d \min} = 1.2 \cdot 10^{-6}$ m; 4 – dependence of critical value of Stokes criterion on angular speed of droplet rotation

At angular speed of rotation of fluid droplets $\omega_l = 2.5 \cdot 10^2$ s^{-1} critical value of Stokes criterion reduces more than four times, and critical value of Reynolds criterion – more than three times, comparing their values in conditions of travel movement of fluid droplets, i.e. at $\omega_l = 0$. At the same time effective values of Reynolds and Stokes criterion, calculated per formula (2) at line 4 (see Fig. 2), correspond to their full absorption critical values at $\omega_l = 0$, i.e. per known criteria equations.

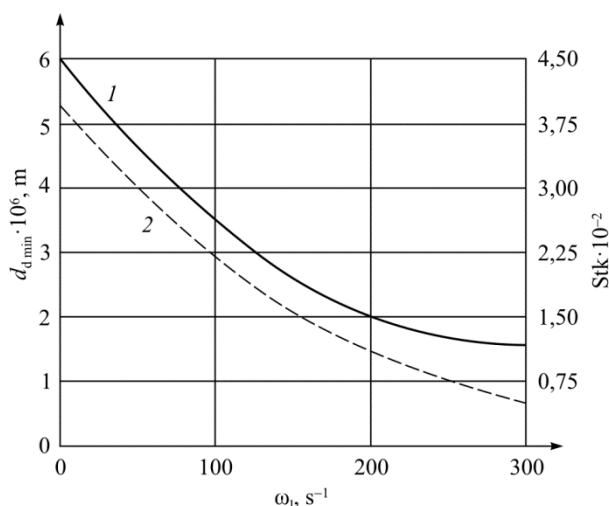


Fig. 3. Dependency $d_{d, \omega_{min}}$ (1) and Stk (2) on change of angular speed of fluid droplet rotation ω_1 at $Stk_{\omega_{crit}} = 4,1 \cdot 10^{-2}$

Reduction of energy barriers in conditions of vortex coagulation is determined, as shown above (3), by increase of values of Stokes criterion Stk_{ω} and Reynolds criterion $Re_{l\omega}$, at rotation of fluid droplet comparing to their values Stk , Re_l , calculated without regard of fluid droplet rotation, i.e., $\omega_1 = 0$.

From analysis of Fig. 3 it is clear that along with decrease of diameter of particles of dispersed dust consistency of critical effective value of Stokes criterion $Stk_{\omega_{crit}} = 4,1 \cdot 10^{-2}$ is achieved kinematically due to rotational movement of fluid droplet according to equation (1), providing by it full consumption of dust particles of lower diameter comparing to classic hetero-coagulation.

At angular speed of fluid droplets rotation $\omega_1 = 3 \cdot 10^2 \text{ s}^{-1}$ values of Stk reduces more than four times comparing to their critical values providing for full consumption of dust particles in conditions of travel movement of fluid droplets, i.e. at $\omega_1 = 0$. At the same time effective values of Stokes criterion calculated per formula (1) correspond to their critical values of full consumption at $\omega_1 = 0$, i.e., received per known criterial equations [6].

Reduction of Reynolds criterion value for fluid droplets at hydro vortex high pressure hydro dedusting corresponds to reduction of travel speed of fluid droplet V_l , i.e. reduction of water consumption, with improvement of dust

suppression system resource efficiency. Given data show that at vortex inertial orthokinetic hetero-coagulation interaction of rotating fluid droplets and non-wettable dust particles capture factor η_{Stk} will be equal to coagulation factor η_k at significantly lower values of Reynolds criterion, i.e. at lower fluid droplet travel speeds or lower dust particle sizes. Fig. 3 shows results of calculation per proposed mathematic model of hydro vortex kinematic hetero-coagulation, calculated per formula (1) depending on angular speed of fluid droplet rotation ω_1 .

Experimental studies performed confirm results of calculations per proposed mathematic model with accuracy enough for engineering calculation, showed high effectiveness of vortex inertial orthokinetic hetero-coagulation, permitting to reduce water consumption by 20 %, reduce minimal absorption size of absolutely hydrophobic coal dust particles to $1,2 \cdot 10^{-6}$ m, increase dust suppression effectiveness up to 99 % comparing to classic high pressure hydro dedusting.

Conclusions

1. Rotation of fluid droplet reduces wedging action of gas environment at border «hard – liquid», i.e., reduces value of necessary full absorption energy A_{l-g} , increases wetting surface and actual effective value of Stokes Stk_{ω} and Reynolds $Re_{l\omega}$ criteria.

2. Vortex high pressure hydro dedusting aids in increase of wetting angle, reduction of forbidding level of surface adhesion energy barrier of particles adhesion and critical level of aerodynamic energy barrier.

3. Vortex kinematic coagulation permits to reduce water consumption by 20 %, increasing dust suppression effectiveness up to 99 % due to reduction of median size of dust particles comparing to classic high pressure hydro dedusting.

4. Vortex high pressure hydro dedusting permits to reduce minimal size of hydrophobic coal dust absorbed to $1,2 \cdot 10^{-6}$ m, and so significantly reduce probability of explosions of aerosol dust mixtures, provide for compliance with

normative requirements on maximal permitted concentrations of dust in the air.

5. Gas and dust explosions are significantly different, but their explosive features have much in common (ignition temperature value is close,

lower and upper explosive limits are present etc.), which makes it possible to develop complex methods of reduction of gas and dust danger in extraction areas of coal mines.

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