

PROSPECTS OF THE HYDRAULIC AIR CONDITIONING OF MINE AIR ON THE BASIS OF PULSE WAVE EFFECTS

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The results of analytical and technical substantiation of promising solutions for the development of tools for hydraulic conditioning of mine air in deep mine conditions that combine cooling and purification of air based on pulse-wave effects created by diffuser and confuser elements are presented.

The urgency of the problem of combating dust and high air temperatures in the faces of deep coal mines, especially the north-western Donbass, is due to the need to develop the fuel and energy complex of Ukraine, which requires the introduction of modern mechanized units with effective dust suppression and air cooling systems to ensure labor protection standards. The use of mechanized complexes, on the one hand, ensures the coordination and automation of the cyclic modes of all equipment, but on the other hand, creates difficulties from the intensive formation of process dust and the additional heating of air by the heat of powerful mining machines. However, in the coal and ore mines of Ukraine, modern mechanized complexes are equipped with irrigation and local air coolers, developed half a century ago, with low efficiency indicators, which affects the safety of mining operations.

This problem is aggravated by the fact that, to date, there are no sufficiently substantiated domestic scientific developments to improve the design of modern dust suppression equipment for mechanized complexes, as well as installations for local cooling of mine air in the face, which negatively affects the safe operation of miners in deep mines.

In connection with the stated facts, we consider that **the unsolved part of this problem** of combating dust and local cooling of mine air is the need for a scientific substantiation of prospects for developing new efficient irrigation devices and hydraulic conditioning that meet the requirements of safety rules and occupational safety standards in coal mines.

On this basis, **we investigated out scientific work** on the substantiation of hydraulic conditioning of mine air, general schemes, parametric and design characteristics of elements for hydrodynamic cooling and dedusting of mine air based on pulse-wave effects discovered by us.

Therefore, the purpose of the article is to present the essence of the substantiation of innovative installations – hydrodynamic air conditioners that combine dust suppression and air cooling with only elements and devices that are capable of providing standard indicators of quality mine air with minimal energy and material costs.

The main problem to be solved in the study is to justify the prospects of hydraulic conditioning of mine air, the parameters and functional diagrams of hydrodynamic devices that are capable of providing effective performance indicators in the fight against dust and high air temperature in the faces.

The main research material. A special problem in ensuring regulatory labor protection requirements for the dust factor in the conditions of modern coal mines equipped with mechanized complexes is the fight against aerosol dust generated in the face, as well as during transportation of coal and rock masses. According to our calculations for the average mine in the north-western Donbass, up to 1.5 tons of aerosol dust, which is most dangerous for miners to breathe, enter the mine air during the day. In addition, this problem is aggravated by the high temperature of the mine air (up to 30-35⁰C) from the rocks, which at depths of more than 1000 m are 36-38⁰C. However, to date, domestic coal and ore mines do not yet have sufficiently effective means of combating aerosol dust and cooling mine air, which has caused a series of studies to substantiate new technical solutions and create integrated hydrodynamic air conditioning tools based on pulse-wave effects for conditions deep mines [1].

At the stage of analytical modeling of hydraulic air conditioning, we justified the prospects for

the use of functional elements of devices in the form of diffuser and confused pipes (VCT), which make it possible to create pulse-wave effects with the required frequency. The basic constructive development of a hydraulic conditioner with VCT was made on the basis of work [2].

The necessary experimental studies of hydraulic, or more precisely, by our definition, hydrodynamic air conditioner with VCT functional elements quite reliably confirmed our theoretical propositions that pulse-wave effects created in the process of trapping aerosol solids (dust particles) with water droplets also increase cooling efficiency of air.

Theoretical positions for creating a hydraulic conditioner with VCT elements we formed on the basis of comparative modeling with a prototype in the form of a Venturi tube, which is used to clean gases with water. However, the hydraulic resistance of the Venturi pipe increases with increasing water flow and is highly dependent on the method of supplying water to the pipe. Therefore, at the same values of specific consumption of water and gas to be purified, the hydraulic resistance of the Venturi pipe is higher than that of the VCT, and therefore the energy costs increase. In addition, in the Venturi pipe, the fragmentation of water into small droplets deteriorates, which leads to a decrease in its efficiency in dust collection.

We have experimentally established that in the Venturi tube an increase in the relative velocity of air and water to form small (less than 10^{-5} m) droplets, the necessary time for contact between the droplets and solid aerosol particles (dust particles of 10^{-5} m – 10^{-6} m) is not provided to capture them. In addition, the lack of time affects the cooling air drops. Therefore, an increase in the flow rate — a mixture of dusty air and droplets more than 40 meters per second — creates “slippage” of droplets without trapping dust and insufficient contact with air for heat exchange — cooling. This lack of a Venturi tube is eliminated in the VCT.

The consistent connection of diffuser and confused elements creates a hydrodynamic pulsating movement of an airborne dusty flow, which increases the interaction time of components and qualitatively changes the effect of droplets on air and dust in the processes of cooling and dedusting.

The essence of the analytical part of our study is revealed in the process of studying changes in the parameters of an airborne dusty stream as a conditionally homogeneous gas-liquid flow during transitions from the diffuser to confused and, conversely, in the VCT work space. Assuming that the flow is one-dimensional and the flow is adiabatic with respect to the external environment, we obtain the equations of energy and flow homogeneity in the following relations:

$$\frac{1}{U} \frac{du}{dx} = \alpha \frac{1}{S} \frac{dS}{dx}; \quad (1)$$

$$\frac{1}{\rho} \frac{d\rho}{dx} = \beta \frac{1}{S} \frac{dS}{dx}; \quad (2)$$

$$\frac{1}{p} \frac{dp}{dx} = \gamma \frac{1}{S} \frac{dS}{dx}; \quad (3)$$

where α , β , γ – coefficients depending on the nature of the flow;

U , ρ , p – accordingly, velocity, density and pressure for a given section of the pipe;

x – coordinate along the flow axis;

S – cross-sectional area of flow.

Analyzing (1-3), we come to the laws that occur when the flow from the diffuser to confused, namely:

1) in the expanding part of the pipe, i.e. flow deceleration occurs in the diffuser, since its velocity decreases:

$$\frac{dS}{dx} > 0; \quad \frac{dU}{dx} < 0; \quad (4)$$

2) in the confused part, the flow is accelerated, which follows from the relation:

$$\frac{dS}{dx} < 0; \quad \frac{dU}{dx} > 0; \quad (5)$$

3) pressure changes in the flow are inverse to velocity changes, i.e. the pressure in the diffuser increases, and the pressure in the confuser decreases, because

$$\frac{dS}{dx} > 0; \frac{dp}{dx} > 0; \frac{dS}{dx} < 0; \frac{dp}{dx} < 0. \quad (6)$$

Therefore, relations (1-6) provide a basis for concluding that in a hydraulic conditioner consisting of diffuser and confused elements there will be pressure fluctuations along the flow sections, which generates a wave that activates the vortex turbulence of the motion and interaction of the mixture components – droplets and dusty air.

The components of the flow move with an alternating pressure gradient, which follows from (6), and this causes additional inertial collisions of droplets and dust particles, which increases the likelihood of their mergers.

The pulsation of pressures along the length of the flow creates wave motion of the components, which causes intense vortices, in the zones of which active collisions of dust particles and droplets occur. In addition, this nature of the movement increases the time of interaction of the components on each other, which increases both the efficiency of the merging of the droplets that capture the dust and the cooling of the air with these droplets.

Of considerable scientific interest is the distribution of pressures and velocities in the flow of the diffuser – confused tube. First of all, the flow of liquid – water along the walls of the confuser is disrupted by the pulsating effects of gas – air, which returns the liquid to the process of active absorption of dust and cooling of air. This is especially intense in the cross sections for the transition from the confused part of the pipe to the diffuser.

Wave movement of the flow reduces the effect of "slipping" of dust particles and droplets, which increases the efficiency of dust capture and heat exchange between the droplets and air.

Analyzing the distribution of pressures and velocities in pipes of different configurations, we conclude that for a diffuser – confused tube as an integral part of the hydrodynamic air conditioner of mine air, a rational relationship between interrelated parameters is created, at which the flow velocity approaches a constant, but not increased, which reduces hydraulic loss of flow

Moving the flow from the diffuser to the confuser of the next stage repeats the process of energy transformation, which causes a longitudinal pulsation of the flow when passing from one part of the pipe to another. Intense vortex formations of the near-wall areas of the diffuser, expanding along the flow axis and in the transverse direction, are replaced by reverse compression processes of the vortex zones in the confused part of the pipe.

This increases the frequency of collisions of droplets and dust particles, and, consequently, the likelihood of dust trapping increases.

In the confused part, the flow is compacted and the wall vortices form, which are compressed along the flow. The compression of confused eddies causes (in accordance with the law of conservation of angular momentum) an increase in the angular velocity of dust particles and droplets, which increases the kinetic energy of the rotation of the eddies, as well as the conditions for collisions during compression pulses.

These processes increase the overall efficiency of air purification from dust and its cooling.

In fig. 1 shows the VCT scheme as a diffuser — a confused element designed for hydrodynamic conditioning of mine air.

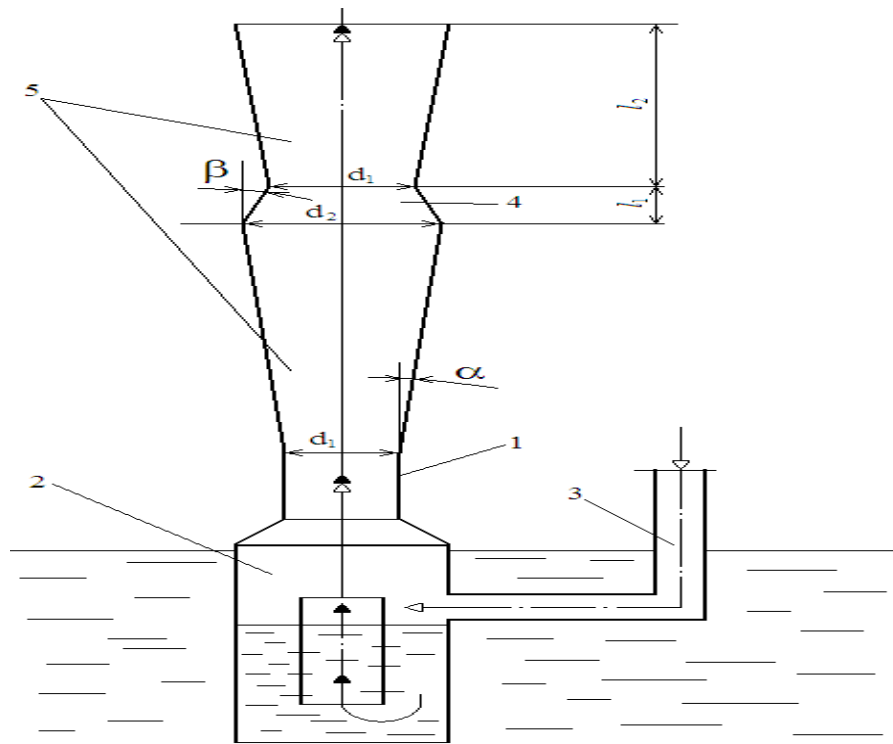


Fig. 1. Scheme VCT of hydrodynamic mine air conditioner

The design of the diffuser – confused tube consists of the VCT steps with an increasing vertical middle section between the steps. The mixing part 2 is immersed in water or a special liquid with a certain temperature, and communicates with part 3 for the supply of dusty air. Each stage VCT is made in the form of a confuser 4 and a diffuser 5.

The complex process of cleaning and cooling the air next. When entering the dusty air through the pipe 3 (vacuum or pressure circuit) in the mixing part 2 a mixture of air and water is formed, which moves into the pipe 1 and then into the diffuser 5 and confuser 4. The increasing flow rate - the mixture in confuser 4 decreases in the diffuser 5, which corresponds to the conversion of the kinetic energy of gas into potential.

Experimentally, we determined that for low-pressure flow of a stream, VCT configurations with the following geometrical parameters are rational from the standpoint of practice: for a diffuser, the diameter of the inlet section d_1 , and the angle of disclosure α is equal $(5...7)^\circ$ with length l_2 is equal:

$$l_2 = 0.5 (d_2 - d_1) (\operatorname{tg} \alpha)^{-1};$$

and for confuser:

$$l_1 = 0.5 (d_2 - d_1) (\operatorname{tg} \beta)^{-1}.$$

Given that the velocity of air entering the dust cleaning in a hydrodynamic installation - air conditioning, does not exceed 20 m/s, we assume that the diameter of the inlet section of the diffuser will be:

$$d_1 = \sqrt{0.7 Q},$$

where Q – gas flow rate, m^3/s .

The layout structure of the diffuser – confused pipe can be composed in the following sequence in the direction of flow: mixing part – confuser 2, cylindrical section 1 for leveling the velocity field of the flow components, diffuser of the first stage, passing into the diffuser and section with centrifugal droplet separator (on fig. 1 is not shown).

Essential for the development of VCT is the assessment of the magnitude of the hydraulic resistance as the pressure drop of the flow "gas – drops – dust particles" in all stages, i.e.

$$\Delta \rho = 0.5 \langle V \rangle^2 \langle \rho \rangle (\xi_1 + \xi_2 + \xi_3),$$

where $\langle V \rangle$ – average flow velocity;

$\langle \rho \rangle$ – average flux density;

ξ_1, ξ_2, ξ_3 – respectively, the hydraulic resistance coefficients of cylindrical, confused and diffuser sections.

For an approximate calculation of the hydraulic resistance of VCT, we will use similar parameters of the prototype – Venture tubes, namely, in average values: $\xi_1 = 0.18, \xi_2 = 0.34, \xi_3 = 0.11$. Using the value of the average flow velocity of 20 m/s, we obtain a hydraulic resistance of 165 Pa, which makes up no more than 10% of the pressure of low-pressure delivery means – fans for moving air.

These parameters of the diffuser – confused pipe for the device of a hydrodynamic air conditioner for mine air are the basis for constructive study of the entire system of protection against dust and cooling of air in specific conditions of a coal mine. We will carry out the substantiation of the parameters and the layout of the stepped cascade pipe (SCP) for cleaning from dust and cooling large volumes of mine air.

The stepped cascade pipe for hydrodynamic conditioning of large volumes of dusty air is shown in fig. 2

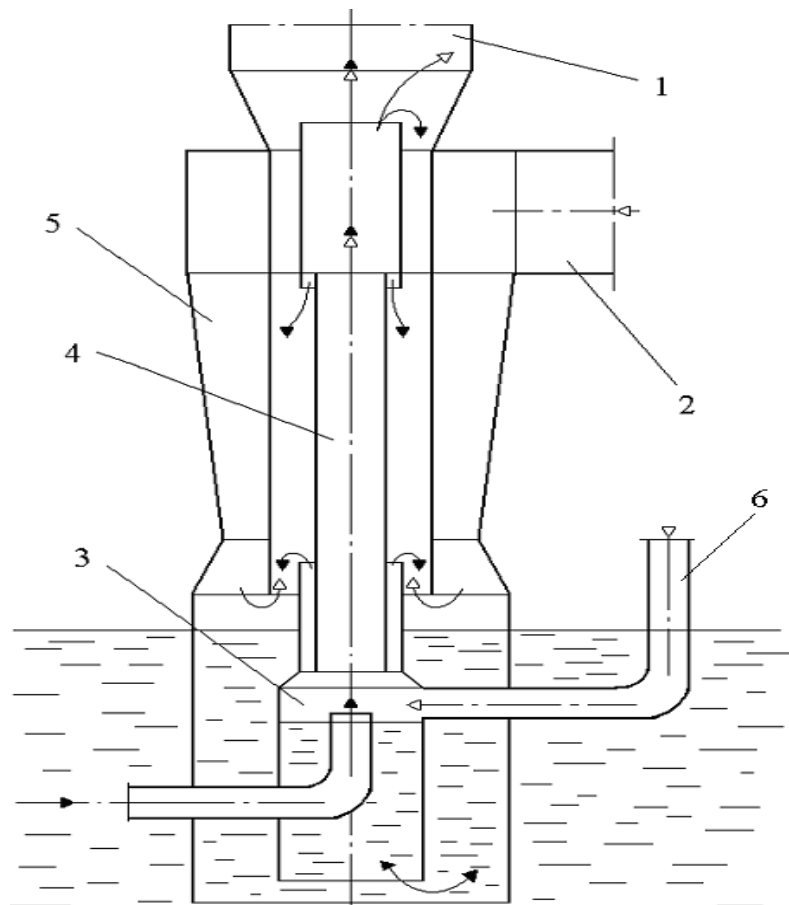


Fig. 2. SCP scheme for hydrodynamic air conditioning

The design of a stepped cascade tube allows cleaning and cooling large volumetric costs of dusty thermal-potential air with minimal energy costs by creating ejection in successive tube steps [3].

The lifting pipe 1 (see Fig. 2), which can be made of diffuser – confused construction, is mounted concentric with the mixer of the preceding stage 3 with the lifting pipe 4, which is also located concentrically inside the lifting pipe 1. The end of the output section of the lifting pipe 4 is located above the level of placement pipe 2 supply of dusty air.

This allows to achieve linear homogeneity of the trajectories of the movements of the components at the entrance to the mixing part of the lifting pipe 1. Water for the integrated process of cooling and cleaning the air is supplied to the mixing part of the pipe 1 together with the air supplied through the pipe 6.

The stepped cascade pipe, as the main element of the hydraulic conditioner for large volumes of mine air, operates as follows.

Compressed air through the pipe 6 enters the mixer 3 of the first stage and, capturing water, lifts it into the pipe 4. Part of the water pours out of the mixer 3 into the lifting pipe 1, into which dusty air enters through pipe 2, which creates a gas-liquid emulsion, which is from the pipe 4 is poured into the mixing part of the riser pipe 1, exposing the dusty air to the treatment with water droplets.

In the space between the riser tubes 1 and 4, a counter-pulse-wave motion of two streams occurs – the fluid flow and the dusty mine air flow. Dust particles and water droplets have different relative velocities, which depend on the volumetric flow rates of the components.

This allows you to increase the time of interaction of dust particles and liquid droplets. With a minimum relative velocity of droplets moving both down and up, the frequency of their collisions with dust particles will be proportional to the number of stages, which increases the efficiency of the overall process of dust collection, as well as air cooling. The height of the mixing part of the riser can be determined from the condition of the required time of exposure to the dust and gas flow for its conditioning.

The specific parameters and design relationships of the stepped cascade pipe as part of the hydrodynamic air conditioner for mine air are calculated on the basis of the specified conditions characterizing the dusty air entering the cleaning and cooling.

Conclusions and prospects of application. Thus, the development of hydrodynamic air conditioners with functional elements in the form of a diffuser – confused and cascade pipes – is a promising direction in the fight against dust and the high temperature of mine air in the deep mines. A series of necessary laboratory studies are planned for the release of experimental industrial designs.

References

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