THE TECHNOLOGY OF NORMALIZATION OF THE MICROCLIMATE IN THE MINE WORKINGS OF DEEP MINES

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The aim of the study is the solution of urgent scientific and technical problems of increasing the efficiency of normalization of the microclimate in the mine workings of deep mines through the development of new scientifically based methods of effective air-cooling using groundwater.

The subject of research regularities of changes of thermodynamic parameters of mine air when it is cooling, irrigation and cleaning in the underground chambers.

Research methods. Scientific analysis and synthesis of previously executed theoretical and experimental studies on issues of microclimate normalization during underground mining of ore deposits; theoretical researches and mathematical modeling of heat transfer processes in mines.

Results. On the basis of conducted industrial researches it was established that in general thermodynamic processes in ventilation workings are polytropic. The thermal decomposition in polytropic processes at the expense of convective heat exchange in ventilation workings reaches 15 kJ / kg, which leads to an increase in air temperature to 26-30 ° C and deterioration of working conditions. Mathematical modeling is the quantitative and qualitative parameters of the process of normalization of the microclimate in mines, developed technology of irrigation cooling and cleaning the air in underground chambers of mines.

Scientific novelty. Set up the pattern to change the temperature of mine air in deep ore mines, which is formed polytropic processes in mine workings and corresponds to the temperature of the rocks plus 1-3 °C due to the receipt of heat from operating equipment, blasting, process air compression, oxidation, evaporation and hydration tabs.

Practical significance. Developed and implemented in deep ore mines cooler and clean mine air with the use of groundwater. The method involves accumulation of groundwater in the upper horizon of the mine, they are cooled to a temperature of 10-11 °C, for termoisolation supply duct into the chamber irrigation, cleaning and cooling of mine air at 8-10 ºC and feeds it into the area of mining works to normalize the microclimate in the mine workings and hydration stone gobbing.

Key words: microclimate, mine working, chamber, temperature, underground water, cooling, air purification, thermal mode.

The urgency of the problem lies in the fact that exploitation of ores at great depths is accompanied by deterioration of working conditions. At depths of 1500-1700 m, the temperature mine air in mine workings exceeds the permitted value of 26 ºC. Adverse weather conditions in mines lead to overheating of the body running, a malfunction of the respiratory system and reduce immunity to diseases. The problem of normalization of the microclimate in the mine workings of deep mines is dedicated to the research of many scientific-research, design and educational institutions. Among which the works of the National Academy of Sciences of Ukraine, State Makeevka Scientific Research Institute, Donetsk Coal Institute, National Mining University, Polyakov Institute of Geotechnical Mechanics of the National Academy of Sciences of Ukraine, State Research Institute of Labor Safety in the Mining Industry, Kryvy Rih National University.

The solution to this problem will allow to improve working conditions in mines, to reduce the risk of overheating of the body, the violation of the functional respiratory system and occupational diseases working in the region.

Presentation of the basic material. The results of industrial researches of thermal conditions in mining operations of ore mines are given. The studies used a complex method, which involved: conducting airborne temperature measurements in mines of Kryvyi Rih and Zaporizhia iron ore plant; measurement of the temperature of rocks and mine waters in boreholes, wells, working face, the drainage grooves, and mine waters; inspection of ventilation systems of the mines and the work of the main fan. Measurements of air temperature were carried out in the exhaust chambers, in the process of insertion, and in the adjacent mine workings. The measurements used proven standard technique with the use of attorneys and deep electrical mercury thermometers, anemometers APR-2, aspiration psychrometer MV-4M, microbarometer MB-63, microprocessorbased meters barometric pressure type MBTS-5. In fig. 1 shows graphs of change of temperature of rocks t_r and air t_a in working face mines, depending on the depth of the development of *H*.

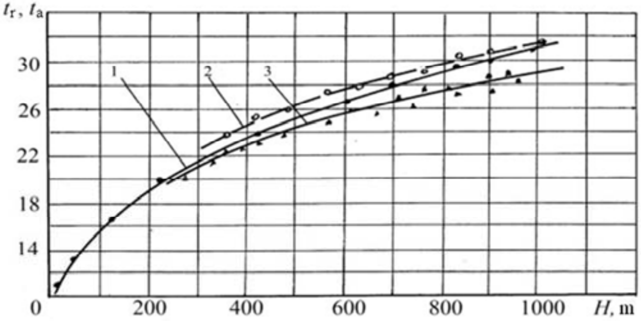


Fig. 1. Graphs of the average temperatures of rocks t_r and air t_a jobs in working from the depths of development H: 1 – the results of thermometry of exploration wells; 2 – the results of measurements t_r in the holes; 3 – the results of t_a measurements in the workplace, in working face and into the mine workings.

These data indicate that the average temperature of the neutral species layer at a depth of 20-30 m is about 10-11 °C. At a depth of 800-1000 *m* the temperature of the rocks is 28-30 °C, and the temperature at these depths reaches 29-31 °C.

Temperature of mine air in mine workings depends on the temperature of rocks; work of machines and mechanisms; processes, compression and oxidation air in the workings, evaporation of moisture; heat of hydration stone gobbing in the chambers; blasting and is expressed as follows.

$$t_a = t_r + \Delta t\ , \qquad (1)$$

where Δt = (1-3)°C– temperature rise due to operation of machinery and other factors.

Factors that determine the condition of a microclimate in mines ore: the efficiency of their ventilation, velocity of air, its temperature and humidity in the workplace. The main method of normalization of the microclimate in mines, where the temperature does not exceed 26 °C is to increase its speed for effective heat factor, which is determined by the formula

$$V_t = k \cdot 0{,}02(t_a - 17)^2, \qquad (2)$$

where k – coefficient taking into account working: k = 1 for treatment working face, k = 0,3 for a blin-drift, development and main workings; t_a is the temperature of the mine air, °C.

The evaluation of these parameters was made by comparing the required value with the actual data. Measurements indicate that the security of air and its velocity is 60-80 %, and the temperature there is around 26-31 °C and relative humidity 85-95 %. In such a climate to improve thermal environment in the workplace is only possible with effective regulation of thermodynamic processes in the ventilation network.

In the shaft depending on the season there is a heating or cooling air, increasing its relative humidity, and pressure. In horizontal workings is heat exchange with the wet walls, the increase of humidity, change in air speed, static pressure varies slightly. In mining, which removes exhaust air, there is a decrease in static pressure, which leads to condensation of moisture. Such change of parameters of the air determines the reality of polytropic processes and the ratio polytrope in shafts n=(1,0–1,4), and corresponds to the transition from isothermal to adiabatic and is accompanied by a change in air temperature, and horizontal workings figure polytrope close to n= 0,0 and isobaric process corresponds to the stationary distribution of the temperature. Heat in polytropic processes in the workings reach 15 kJ/kg, which leads to a temperature increase in the area of mining works to 29-31 °C and heavy working conditions in working face.

Below are the results of experimental research thermophysical properties of rocks and gobbing materials. The study was performed by the "regular mode" and "stationary source of heat," an improved method for "instant source of heat", by Professor Kondratyev G. M. Using differential equation the coefficients of thermal conductivity λ, W/m·K, thermal diffusivity a, m^2/s specific heat, J/kg·K. we studied the rock samples (shale, quartzite hematite-martite ore hematite-martite) and stone gobbing from materials of different composition.The test results indicate that the quartzite gematit-martite have a coefficient of thermal conductivity λ = 4,95-5,23 W/m·K and thermal diffusivity $a \cdot 10^{-7}$ = 6,4-8,0 m^2/s, which allowed to recommend this rock as a filler in the amount of 30-40 % in the manufacture of the stone gobbing instead of sand, which has a coefficient of thermal conductivity λ = 0,81 W/m·K.

Thermophysical data of samples of stowing with the addition of 30 % of the rock quartzite hematite-martite instead of sand, the works of Professor V. L.Sakhnovsky, are significantly different. Thus, the thermal conductivity λ increased by an average of 1,7 times, the diffusivity and increased on average 2,2 times, resulting in a rapid transfer of heat into the environment and reducing the temperature of hardening gob.

A pattern to change the temperature of mine air in deep mines has been investigated by means of mathematical modeling of heat transfer processes in mines, which produce the change of microclimate parameters. This approach allows through the use of rapid identification of parameters of mathematical models of heat transfer processes to carry out forecasting of the thermal regime of the mine and its regulation by calculating and implementing the appropriate control action. To build mathematical models of heat transfer processes is composed of the General scheme of ventilation of mine workings (Fig. 2).

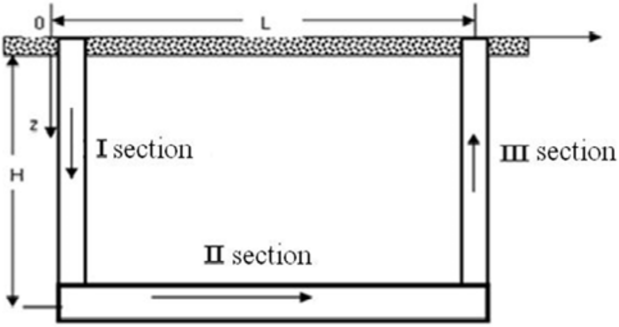


Fig. 2. The scheme of movement of air in mine workings

According to the scheme, the air moves down along the vertical shaft at a depth of H (I section) and then moves the horizontal workings of length L (II section), then rises up a vertical trunk (III section). On the section I allocated to two areas: first, the temperature change takes place without condensation and the second condensation is taken into account. For the two core sections $z = z_1$ and $z = z_2$ the rate of change in time of heat will be

$$\Delta W_c = \int_{z_1}^{z_2} c_1 \cdot \gamma_1 \cdot f_1 \frac{\partial t_1}{\partial \tau} dz \,, \tag{3}$$

where specific heat of air, j/kg °K;

$\gamma_1 = \gamma(z) -$ air density, *kg/m*^{3}; $t_1 = t(z,\tau) -$ air temperature, °C; τ – time, s; f_1- is the cross sectional area of the shaft, *m*^{2}.

In turn, the formula (3) consists of the following parts:

$$k_1 \cdot U_1(t_1 - t_m) + c_1 \cdot \gamma_1 \cdot f_1 \cdot \frac{\partial t_1}{\partial \tau} + \frac{\partial}{\partial z}(c_1 \cdot \gamma_1 \cdot f_1 \cdot w_1 \cdot t_1) = f_1 \cdot W_1, \tag{4}$$

where k_1 – transfer coefficient in the shaft, $W/(m^2 \cdot °C)$; t_m – temperature rock mass around the shaft at a given depth, °C; $W_1 = W(z, \tau)$ is the density of heat sources in W/m^3.

In equation (4) the first component corresponds to the amount of heat per unit time which enters through the lateral surface of the shaft due to heat exchange with the external environment. The second component, referred to the unit of time the amount of heat coming from sources in the section that is considered. The third component is related to the unit of time the amount of heat that enters through the cross section of the bore due to the movement of air.

Condensation of water vapor leads to the allocation of heat, the density of which sources can be determined by the formula:

$$W_c = r \cdot \gamma_1 \cdot d'(t_1) \cdot \left(\frac{\partial t_1}{\partial \tau} + w_1 \frac{\partial t_1}{\partial z} \right), \tag{5}$$

where $d'(t_1) = \frac{d}{dt_1}(d(t_1)) -$ derivative of moisture content, temperature, *kg/kg* °C. To obtain the mathematical model of heat exchange process in the second region of the shaft is necessary in equation (4) to take into account the density of the sources (apparently, heat dissipation when condensing water vapor), is determined by the formula (5). After the developed mathematical model the got results of calculations of temperature of t, and also relative humidity φ and to pressure P, executed as a result of measurings for shaft «Exploited» resulted on fig. 3.

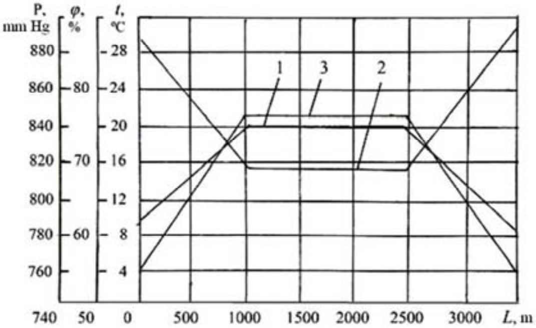


Fig. 3. Dependence of temperature (1), relative humidity (2) and barometric pressure (3) of air on the length of air movement in sections excavations I, II, III

The results of mathematical modeling of cooling processes of the air in the chambers irrigation in the result of heat exchange between air and water droplets (Fig. 4).

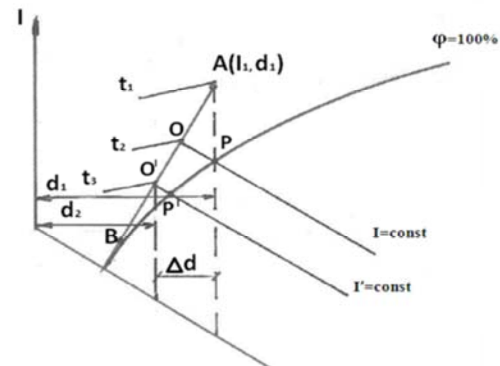


Fig. 4. The change in air parameters for two-stage cooling in the irrigation chamber for the *I-d* diagram; *I, I'* - intermediate heat content; d_1, d_2 - intermediate moisture content

The state of air entering the irrigation chamber is determined by the initial parameters in the position of point A: the heat content of I_1, the moisture content d_1 and the temperature t_1. Ideally, the cooling process should take place in a straight line and I', but in real conditions, as a result of increasing water temperature and partial saturation with moisture of air, the cooling process is direct and occurs to the point A (first stage cooling). Then there is a decrease in temperature to full saturation (point P). Increasing the efficiency of cooling in irrigation chambers is possible by the use of additional means, for example, due to the condenser and water-air mixture.

The efficiency of the cooling chamber irrigation was investigated by mathematical modeling. So, the heat flow is given by the air drops of water will:

$$Q_a = \mathrm{m}c_1(T_1 - T_{1f}) \tag{6}$$

and the amount of heat that is water droplets from the air is determined by the formula:

$$Q_w = Mc_2[T_2(t) - T_{2f} \tag{7}$$

where M and m – the mass expense of air and water respectively through the nozzle, kg/s; T_1, T_{1f} – initial and final temperature, °C; $T_2(t)$ is the temperature drop at time (t), is determined by the formula:

$$T_2(t) = T_1(1 - e^{-\alpha}) + T_2 e^{-\alpha}, \tag{8}$$

where, T_{2f} – final temperature of water, °C; C_1, C_2 –heat capacity air and water, J/kg·K.

On the basis of the law of conservation of energy final temperature air will be:

$$T_{1f} = T_1 - \frac{Mc_2}{m_1 c_1}(1 - e^{-\alpha}) + (T_{2f} - T_2) \tag{9}$$

where α is the relative time setting of the heating water drops ; a $\alpha = \frac{t}{\tau} = \frac{A}{c_2 M}$; A - is the heat transfer coefficient of the air and λ $A = \frac{Nu\lambda}{2R}$, where Nu – Nusselt number and thermal conductivity of water; R- is the radius of the droplet.

To improve the efficiency of cooling at irrigation with water should increase the water consumption, or reduce its temperature. On the basis of calculations by formula (9) plotted temperature T_{1f} to the water temperature T_2 that is used for irrigation (fig. 5 a) and the extent of irrigation $\rho = M/m$, *kg/kg* (fig. 5 b).

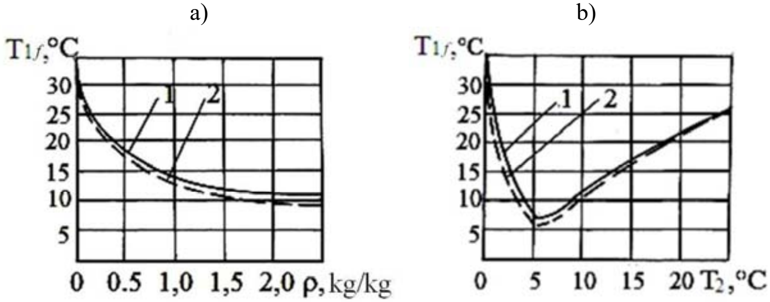


Fig. 5 a, b. Plots of the finite temperature T_{1f}; temperature of water, T_2 (a) and the extent of irrigation ρ (*b*): 1 – incomplete (intermediate) saturation of air by water; 2 – at full saturation of air with water

As evidenced by the results of the calculations (fig. 5 a, b), intense drop in temperature occurs when irrigation water with a temperature of $T_2 \leq 5$ °C (fig. 5 a) and the ratio of the irrigation $\rho \leq$ 1,2 *kg/kg* (fig. 5 b). A further increase of the coefficient of irrigation ρ has little effect on the decrease in air temperature.

Irrigation cooling of the air using water-air of the mixture was carried out using cooling ejector "Dispersed", whose scheme is shown in fig. 6.

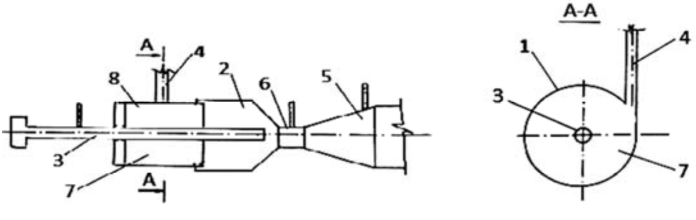


Fig. 6. Schematic diagram of the cooling ejector "Dispersed":
1 – cylindrical body; 2 – confuser; 3 – nozzle; 4 – water nipple;
5 – diffuser-mixer; 6 - cylindrical coupler; 7 – cavity of the housing

The formation of a water-air mixture is as follows. Compressed air with pressure of 0,7 MPa, which is supplied from the nozzle 3 is compressed to a pressure of 0,5 MPa, causes a vacuum in confusing of the housing 2. Due to this water pipe 4 and the cavity of the housing 7, the water enters the cylindrical coupler 6 where it is ejection and spraying with the formation of water-air mixture in diffuser-mixer 5. Air cooling occurs by adiabatic expansion of compressed air during its exit from the nozzle 3 and the diffuser 5. Water-air mixture temperature below ambient air temperature by 3-4 times. Torch water-air mixture is expanded at the exit of the diffuser and eject the surrounding air and cool super by convective heat transfer and evaporation of water droplets.

Based on the analysis of studies of the effectiveness of the cooling air water-air mixture formed by cooling the ejector "Dispersed" the resulting dynamics of its temperature (Fig.7).

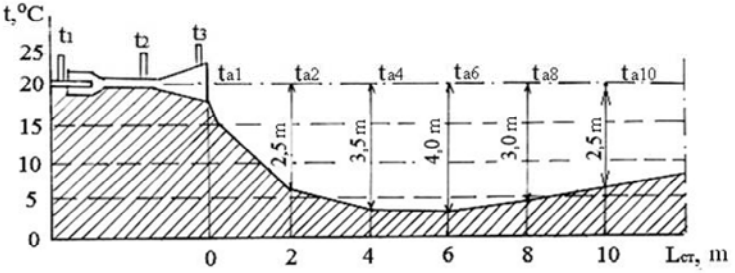


Fig. 7. The dynamics of the temperature along the length of the torch water-air mixture:t_1, t_2, t_3 – temperature inside the "Dispersed"; t_{a1}, t_{a2} – average temperatures along the length of the torch water-air mixture.

As can be seen, in the diffuser, a decrease in temperature from 20 °C to 17 °C, and at a distance of 4-6 *m* from it the temperature drops to 5°C. Is the temperature observed at a distance of 8-10 *m* from the diffuser, and it further increased to 8 °C and at a distance of 25 *m* remains close to ambient temperature. Water-air the effectiveness of cooling was determined by mathematical modeling. It is possible to find such parameters of the device, which provide optimum cooling of mine air. Structure of the mathematical model that describes the excess temperature at an arbitrary point of the cooled compact jet emanating from a circular hole of the diffuser has the form:

$$\Delta T(r,x) = \Delta T_n \cdot a \cdot \left(\frac{r_0}{x}\right)^b \cdot e^{c\cdot\left(\frac{r}{x}\right)^2} ,(2 \le x \le 12) \qquad (10)$$

where $\Delta T(r,x) = T(r,x) - T_0$; $\Delta T_n = T_n - T_0$; $T(r,x) -$ the absolute temperature at the point of the jet *(r,x)*, *K;* t_0 is the absolute ambient temperature; T_n is the average absolute temperature of the jet at the exit of the diffuser, *K*; r_0 – the radius of the outlet of the diffuser, *m; a, b, c* – numeric parameters.

To obtain the numerical values of the parameters *a, b,* use the results of the experiments. In the calculations was taken $t_0 = 298$ *K*, $T_n = 293$ *K*, r_0=0,3 *m*.

The result of the calculations was obtained the following values a = 8,365; b = 2,104; c = -2,197. The coefficient of multiple correlation was equal to R = 0,955, indicating a close correlation.

Taking into account the obtained values, the formula (10) takes the form:

$$r = x\sqrt{0{,}455\ln\left(4294{,}1\frac{\Delta T_n}{\Delta T}\left(\frac{r_0}{x}\right)^{2{,}104}\right)} \qquad (11)$$

The mathematical modeling of heat transfer processes water-air cooling of mine atmosphere allows organizing the computational experiment that gives the opportunity to explore the peculiarities and the efficiency of the process.

The calculation according to the formula shows the practical convergence of the test data and the results of the calculations. It allows investigating the temperature field of the jet. First of all, you can write the equation of the isotherms, i.e. lines of equal temperature jet

The calculations indicate that the cooling range of the jet reaches $x_{\max}$ = 20 *m* and the greatest thickness is $2{\cdot}r_{\max}$ = 17 *m*.

As a result of the computational experiment heat transfer processes water-air cooling of mine atmosphere obtained the necessary parameters of the jet.

Experimental tests cooling ejector "Dispersed" occurred at the site of the mine to them. Lenin Public Joint Stock Company (PJSC) "KRIVOJ ROG'S IRON-ORE COMBINE" (Fig. 8).

The test procedure was provided to determine the dependence of the technical parameters of the installation of the air pressure in the line P_a, *MPa*, and also on geometrical parameters such as the diameter of the outlet of the diffuser d_d and the width of the annular hole for the release of the water-air mixture l_a. The number water-air of the mixture was determined as follows. First measured the speed V_m at the exit of the diffuser anemometer APR-2, then by the obtained speed and the cross-section area of the diffuser S_d found a number water-air mixture Q_m. Thus, we measured the pressure in the supply piping with a pressure gauge. The length of the jet of the water-air mixture was determined by measuring the length L_j. The diameter of the droplets was determined by collecting them on a glass, greased with vaseline, with subsequent determination of their diameter under a microscope.

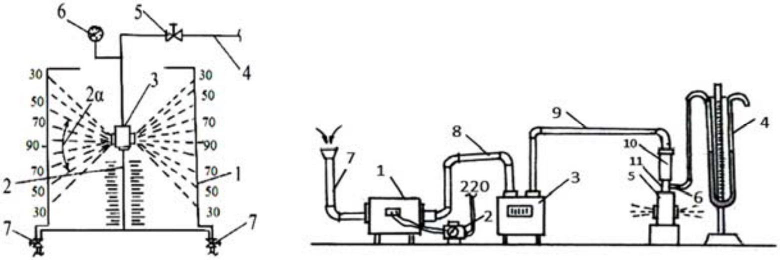
Fig. 8. Test cooling ejector "Dispersed" on the site of the mine to them. Lenin, PJSC “KRIVOJ ROG’S IRON-ORE COMBINE”.

All were tested 4 types of units that differ in the length and the diameter of the mixing chambers. The test results show that with increasing air pressure increases the length of the jet of installation. So, if you increase the pressure P_a from 0,1 to 0,8 *MPa* length of the jet, L_rj increases from 6,5 to 36 *m*.

Analysis of test results shows that with the air pressure in the line P_a= 0,8 *MPa* length of the jet is L_r = 34-36 *m*.

During the test, the average droplet diameter d_{dr} ranged from 25 to 140 *microns*. The diameters of such droplets, mist, promote efficient evaporation and cooling air flow.

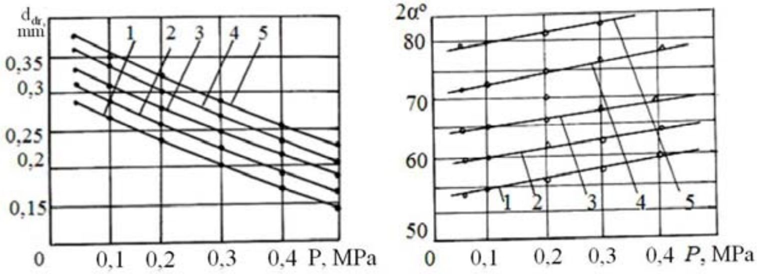
Research bidirectional nozzle and ejector "Dispersed" carried out with the help of stands (Fig. 9). During the test was determined: the opening angle of the torch nozzle 2α, dispersion of water droplets d_{dr}, the local resistance coefficient ξ depending on the pressures of water and air in the lines (P_w and P_a) and the diameter of the injector nozzle d_i. During testing, the injector nozzle diameters were taken from 1 to 5 *mm*, and pressure of air and water before the nozzle was changed in the range from 1 to 5 *kgf/cm*^{2}.



a) b)

Fig. 9. Schemes of experimental setups for the study of the technical and aerodynamic parameters of a bidirectional tangential nozzle: a) scheme of stand to determine the technical parameters of the injectors: 1 – capacity for water collection; 2– dividing wall; 3 – dual-sided nozzle; 4 – water pipeline; 5 – valve; 6 – manometer; 7 – drain cranes; b) scheme of stand to determine the hydraulic parameters of the nozzles: 1 – traction exciter; 2 – voltage regulator; 3 - gas meter; 4 – manometer; 5 – nozzle; 6 – a tube static pressure; 7, 8, 9 – flexible connection hoses; 10,11 – water nipples.

The results of experimental studies of nozzle parameters are shown in Fig. 10.



a) b)

Fig. 10. Based on the average dispersion of droplets and spray angle of water pressure before the nozzle: a) the dependence of the dispersion drops from water pressure: 1, 2, 3, 4, 5 – nozzle diameter respectively 1.5; 2; 3; 4; 5 *mm*; b) dependence of the angle of spray droplets from the water pressure in the supply piping before the injector with a nozzle diameter of respectively 1.5; 2; 3; 4; 5 *mm*

As you can see, the diameter of drops decreases with increasing pressure of water in front of the nozzle. Thus, with a diameter of a nozzle of 1.5 mm, the diameter of the droplets decreases from 0,3 to 0,15 mm, and at the diameter of the nozzle 5 mm - decreases from 0,4 to 0,25 mm.

The spray nozzle, on the contrary, increases the pressure of water in front of the nozzle from 1 to 5 kgf/cm^2 with a nozzle diameter of 1,5 mm, increasing from 55 to 60°, and with a diameter of the nozzle of 5 mm, the torch of sawing increases from 80 to 90°.

The results of experimental tests on the stand (Fig. 9a) showed that for reduce humidity of air after cooling it in the chamber irrigation (after the first stage of cooling) is apply cameras of irrigation, it is advisable to apply a tangential nozzle bilateral water spray with a nozzle diameter of $d_n = 3\ mm$.

Determinations of aerodynamic parameters of the nozzle were carried out on the stand (Fig. 9b). The test procedure provided for the determination of local resistance coefficient for both single and double nozzles. For each experiment, during t_e with fixed initial N_{in} (m^3) and destination N_f (m^3) of gas meter readings. Air flow that passed through the injector was calculated by the formula $Q_{inj}=(N_{\mathrm{f}}-N_{\mathrm{in}})/t_e$, where t_e is the time of the experiment, (s). In the inlet nipple with a diameter of 5/8" (with metric diameter $d = 1{,}59\cdot 10^{-}2\ m$) and a section S = $1{,}99\cdot 10^{-4}\ m^2$ first, determine the air velocity by the formula $V = Q/S$, and then calculated the Reynolds number $Re=d\cdot V/15\cdot 10^{-6} = 10{,}60\cdot V$.

For the experimental conditions (t = 26 °C and $P_{atm.}$ = 754 $mm\ Hg$) density of air amounted $\rho = 1{,}17\ kg/m^3$. On the basis of the difference between the heights of the liquid column in the water h U-shaped manometer calculated static pressure in the inlet nipple $P_{st.} = \rho gh$ and the local resistance coefficient $\xi = 2P_{st.}/(\rho V)^{2\cdot}$ Studies were carried out: bilateral nozzle exit openings $d \approx 3{,}5 \pm 0{,}1\ mm$ with a swirler in the form of cones (type 1); two-sided nozzle with $d \approx 3{,}5 \pm 0{,}1\ mm$ without the swirler (type 2); nozzle unilateral action $d \approx 3{,}5 \pm 0{,}1\ mm$ with guide cone (type 3).

Analysis of the results indicates that for each type of nozzle (single-sided, double-sided with the swirler, double-sided without the swirler) there is a correlation between the local resistance coefficient ξ and the number of Re. This connection is established by using the regression equation of the form $\xi = aRe + b$, where a and b are coefficients, determined by solving the system of equations obtained by the method of least squares.

$$\begin{cases} a\sum_{i=1}^{10}\xi_i^2 + b\sum_{i=1}^{10}\xi_i = \sum_{i=1}^{10}\xi_i \mathrm{Re}_i \\ a\sum_{i=1}^{10}\xi_i + 10b = \sum_{i=1}^{10}\mathrm{Re}_i \end{cases}.$$

The test results of three types of tangential nozzles indicate that the smallest coefficient of the local resistance, on average, ξ_1=237, has the nozzle bidirectional action with an orifice diameter of d ≈ 3,5 ± 0,1 mm with a swirler in the torsion chamber (type 1).

To reduce humidity of air after cooling it in the chamber irrigation (after the first stage of cooling) is applied to the contact condenser, the study which was carried out on models made of hollow corrugated elements, which circulate water (Fig. 11)

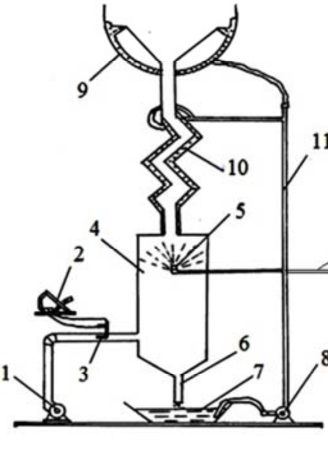


Fig. 11. Diagram of model for investigating the efficiency of the contact condenser: 1 – fan; 2 – micro-manometer MMN; 3 – air tube; 4- the chamber of irrigation; 5 – nozzle; 6 – outlet nipple; 7 – under-pan; 8 – pump; 9 – device for the formation of film water; 10 – elements of the condenser; 11 – pipeline; 12 – main pipeline.

The results of studies on the efficiency of the contact capacitor show that the greatest decrease in temperature Δt is observed at air velocity up to *2 m/s* and the distance between the elements *b*=15-25 *mm*. Under these conditions, in the contact condenser the temperature drops by Δt = 2,5 to 3,0 °C, and the amount of moisture in the air decreases t_o the level of d_m = 0,45–0,22 *kg/kg.*

The cooling efficiency in the chamber irrigation was studied using the laboratory setup shown in Fig. 12.

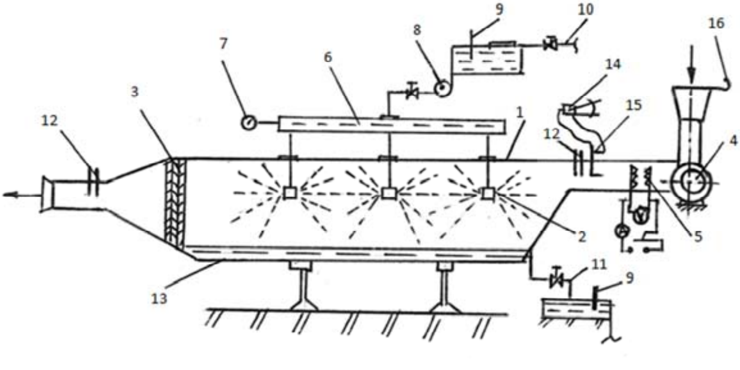


Fig. 12. Principal scheme of a laboratory installation for studying the effectiveness of irrigation cooling air: 1 – irrigation chamber; 2 – nozzles; 3 – condenser; 4 – fan; 5 – electric heater; 6 – collector; 7 – manometer; 8 – pump; 9 – mercury thermometer; 10 – inlet pipe; 11 – outlet pipe; 12 – dry and wet thermometers; 13 – under-pan; 14 – micro-manometer MMN; 15 – pneumometric tube; 16 – latch

In the irrigation chamber 1, there are three rows of nozzles 2 unilateral and bilateral actions. At the outlet of the chamber is the condenser 3. The air supplied by the fan 4 and heated by electric heater 5. Water supply for nozzles 2 was carried out through the collector 6 with the inlet pipe 10, and the temperature and humidity of the air was measured by thermometers and psychrometers 12, the temperature of the water coming from the collector 6 and is drained from the sump 13 into the container and measured using mercury thermometers 9. Airflows, and therefore the speed of his in the chamber irrigation 1 were varied with the help of the latch 16.

The experimental data were calculated the degree and the irrigation density according to the formulas respectively, $\rho = G_w/G_a$, *kg/kg* and $\mu = G_w/F_c$, kg/m^2, where G_w, G_a– consumption of water and air, respectively, *kg*; $F_c = 0{,}3 \times 0{,}35\ m^2$ – section plane of the chamber irrigation. Temperature and relative humidity of the air entering the chamber was varied within t_a = 25-35 °C and relative humidity φ in the range of 62-65 %. The temperature of the water entering the chamber irrigation was maintained within t_w= 4-7 °C by the use of ice, and the degree of irrigation ρ = 0,1-1,24 *kg/kg*. Water pressure before the nozzle was 0,3–0,4 *MPa*, and the pressure drop of the laboratory setup ΔP was changed in the range of 13,7-117,6 *Pa*.

For fig. 13 shows the results of the experiments with the value of the cooling efficiency of air in the chamber irrigation obtained using the laboratory setup (fig. 12).

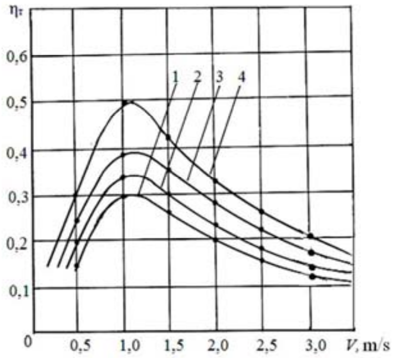


Fig. 13. The dependence of the magnitude of thermal coefficient η_T from the air speed in the chamber: 1 – one row of the unilateral nozzles; 2 – one a number of bilateral nozzles; 3 – two rows of unilateral nozzles; 4 – two rows bilateral nozzles

Processing of the results of laboratory tests using the methods of mathematical statistics dependence for determining thermal efficiency ratio of η_T cooling air in the chamber irrigation

$$\eta_T = \frac{kV^{-0,5}\rho^{0,9}\Delta t_a m_a c_a}{\Delta t_w m_w c_w}, \qquad (12)$$

where k – coefficient characterizing the design of the chamber irrigation, the value of which is determined depending on the number of rows of nozzles, diameter of nozzles and heat losses through the walls; V – velocity of air in the chamber, *m/s;* ρ is the degree of irrigation, *kg/kg*; Δt_a – temperature difference between the air inlet (t_{in}) and the output (t_{out}) from the chamber, °C; Δt_w – temperature difference of water entering the injector (t_{win}) and after irrigation (t_{wout}), °C; m_a – the mass of air, *kg*; m_w – mass of water, *kg;* c_a , c_w - heat capacity air and water, J/kg·K.

For fig. 14 shows a technological scheme of the cooling of mine air in the chamber irrigation using groundwater that accumulated in the main reservoir 11 formed in the mine working 10 on the upper horizon of the mine. In the main reservoir 11 is pumped mine water from the auxiliary reservoirs 13. In the main reservoir 11 mine water cooled to 1-13 °C after mechanical treatment in a sand filter 12 through a thermally insulated pipeline 9 is laid along the shaft 14, are fed into the irrigation chamber 1 due to the static pressure of the water column. If the temperature of the mine air does not exceed 30 ° C, it is cooled by water coming from the nozzle 6, and when the air temperature is higher 30 °C cooling is carried out water-air mixture formed by "Dispersed" 5, which is directed into the irrigation chamber 1 through the nozzles 6.

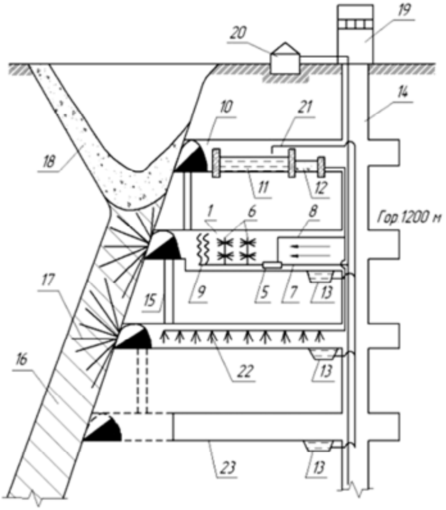


Fig. 14. Technological scheme of the cooling of mine air in the chamber irrigation using groundwater

The results show that when the velocity of air in the chamber irrigation within the V=1-2,5 m/s and the degree of irrigation ρ=0,7 to 1,2 kg/kg, cooling efficiency, specific heat ratio, is η_T=0,31 and 0,52, and the value of reducing air temperature is in the range Δt=5-20°C. Increasing the cooling efficiency, which is expressed by the thermal coefficient, achieved through the use of groundwater, cooled to a temperature close to the neutral layer of the earth 10-11° C. In addition, used water-air mixture formed by setting "Dispersed" and has a temperature of up to 5°C.

It is known that in the presence of large amounts of water, irrigation, air cooling is the most economical. In the extraction of iron ore underground mining in Kryvyi Rih basin is pumped annually about 18 million m^3 mine water in the calorimetry Results indicate that the specific heat capacity mine water (of 3.81 kJ/kgK) below the drinking water (3,92 kJ/kgK), but it is sufficient for the irrigation cooling of mine air.

When using water-air mixture using a cooling nozzle for the normalization of the microclimate in the ore mines developed the installation "the Oasis", which consists of trunk water and air pipeline, from two to four rows of nozzles, which are mounted hydraulic injector bidirectional action.

For air cooling is used, both horizontal and vertical chambers irrigation length $L_{cham} = 10d_{cham}$, where d_{cham} is the equivalent diameter of the chamber, which is determined by the formula

$$d_{\text{cham}} = 2\sqrt{\frac{Q_a}{\pi V_{dr}}}\,, \tag{13}$$

where Q_a – the amount of air that enters the chamber irrigation, m^3/s; V_{dr} – speed of free fall of drops of water, m/s.

Installation testing "Oasis" was carried out in 2 stages. The first phase of testing was carried out with cooling air, the spray water which is all collected from nozzles. The second stage is the cooling of the formed unit "Dispersed" water-air mixture coming from the nozzles. Application water-air mixture is recommended for cooling of mine air, whose temperature is above 30°C. The results of industrial tests show that the cooling of mine air by irrigation of mine water, a decrease in its temperature by 5-6°C, and using water-air mixture cooling temperature decreases to 9-11°C.

In order to control the process of cooling the air in the irrigation chamber, a program for a personal computer has been developed that allows you to calculate the final temperature of the cooling of the mine air in the irrigation chambers and the required amount of air entering the mining zone.

The program implies the application of formula (9) and constants: the initial specific heat of air and water, respectively, $C_a = 1$ kJ / kg·K; $C_w = 3{,}81$ kJ/kg·K; coefficient of thermal conductivity of water $\lambda_w = 0{,}6$ W/m·K; coefficient of heat transfer per unit time $\alpha = A/C_w m_w$, where parameter $A = Nu\lambda/2R$; m_w - mass flow of water, kg/s; Nu – Nusselt number; R - radius of the drop, mm.

The values of the variables are taken within: mass air flow m_a = 0,4-0,8 kg/s; Reynolds number $1<Re<10^4$; Prandtl number $1<Pr<400$; radius of drops R = 0,1-3,0 mm; mass flow of water m_w = 0,1-0,2 kg/s; air temperature T_a = 25-35°C; the temperature of the water going to the nozzles, T_w = 11-13°C. After entering all the parameters the program automatically determines the temperature of the air depending on its massive costs. Application of this program makes it possible, by adjusting the parameters of water or water-air mixture to maintain the temperature in the irrigation chamber at the level of 20-22°C. After entering the specified parameters, the program automatically builds the diagram.

The block diagram of the air conditioning program is implemented as follows:

1. Determine the amount of air Q_g, its temperature t_g, and humidity φ, in the mining area.
2. Identify the normative parameters of air in the mining area: the amount of air Q_a, which would ensure the removal of excess heat, the normative temperature t_n and humidity φ_n.
3. Match the output (actual) data of mine air in the area of mining operations with its normative values in the workplace.
4. Determine the required amount of air for the mining area, which should not be less than the normative value $Q_g \geq Q_n$.
5. Determine the required air temperature for the mining area, which should not be greater than the normative value $t_g \leq t_n$.
6. Determine the required air humidity, which should not be greater than the normative value $\varphi_g \leq \varphi_n$.
7. Create the air of the required condition.
8. Provide cooled and drained air to the mining area and carry it out to reduce the temperature and humidity of the air in the mining area to the standard value: Q_n, t_n, φ_n.

The experience of using mine water for irrigation of mine air proves that the main accumulating reservoirs is expediently located on the upper horizon in an array of rocks adjacent to a neutral layer of land and have a temperature of 11-13°C. The vertical or horizontal irrigation chamber is located closer to the mining area to prevent the heating of cooled air.

Taking into account heat exchange processes in mining operations, the amount of air necessary for the normalization of microclimate in deep mines is determined by the effective rate of air movement adopted by the thermal factor:

$$Q_a = (\Sigma Q_{ma} + \Sigma Q_{sh} + \Sigma Q_{ch} + Q_{ca})K_m, \qquad (14)$$

where $Q_{ma,}$ Q_{sh}, Q_{ch}, respectively, the largest, calculated by the thermal factor of the air flow for ventilation of mining activity, shafts and chambers working equipment, m^3/s; Q_{ca} - consumption of compressed air, m^3/s; K_{gr} = 1,5-1,7- general factor of air reserve.

The general depression of the ventilation network of the mine is determined by the formula:

$$h_n = R_n Q_a^2, \text{ Pa} \qquad (15)$$

where R_n - is the value of the general aerodynamic resistance of the mine network, $N \cdot s^2/m^8$.

The microclimate of deep mines has the value of natural draft, which is determined by the formula:

$$h_{nd} = H \cdot g(\rho_{av1} - \rho_{av2}), Pa \qquad (16)$$

where g - is the acceleration of free fall, m / s, ρ_{av1}, ρ_{av2} - the average density of air pillars in downcast shaft joint ventilation shaft, kg/m^3; H - depth of location of the main working horizon, m.

The analysis of technical and economic indicators of the method of microclimate normalization with the use of refrigeration machines and the use of the recommended cooling technology of mine air with the help of mine waters allows obtaining the following results.

Calculation of the cost of cooling the mine air supplied to the mining activity, in the amount of 55 m^3/s, by the method of irrigation cooling in comparison with the cooling of air by refrigerating machines of the type air conditioner mobile shaft CMS-300 evidence of its obvious efficiency. Thus, the material costs of purchasing equipment for cooling a given air quantity (55 m^3/s) by refrigeration machines type CMS-300 in the amount of 7 pieces make up 2.8 million $ C, which significantly exceeds the total amount of material costs for the implementation of the proposed method, which is estimated: the axial fan type AFE - 1000 $; equipment for the installation of the "Oasis" installation - 63500 $. The total material cost of acquisition, taking into account the additional costs, is 167 000 $, which is 17 times less than the cost of cooling the mine air with the help of refrigerating machines.

The energy consumption when cooling the air by refrigeration machines is (75 kW/h multiplied by 7 machines = 525 kW / h) by 30 \$/h, and the cooling of the miner air in the proposed method involves compressed air consumption in the amount of 0,1-0,3 m^3/s, cost 0,02 \$/m^3, thus the cost of energy consumption is 6,1-17,7 \$/h. On this basis, the energy costs for the implementation of the recommended method are 1,7 times smaller than the refrigeration machines.

Irrigation chambers in mines workings in close proximity to the mining activity, and they are performed as a horizontal or vertical through-working. The air velocity in the irrigation chambers for its efficient cooling should be maintained within the range of H = 1-2,5 m/s. At the temperature of the mine air in the mining activity up to 30° C it is expedient to use a system of irrigation cooling in the chambers, and at air temperature more than 30°C - use irrigation cooling using a water-air mixture, formed using the ejector "Dispersed". The cost of compressed air per one ejector is 0,1-0,3 m^3/s, and the pressure in the compressed air line is 0,4-0,6 MPa. Number of row of nozzles in the irrigation chamber is accepted ≥ 2. The uses of an accumulation reservoir allows the accumulation of mine water in the amount of 1200-1500 m^3 with a temperature of 11-13°C, and then use them to cool the mine air and irrigate the technological processes. The rest of the mine water is pumped off at night at a reduced tariff for electricity costs. This allows to improve the working conditions and reduce the annual cost of pumping out mine water within the limits of 45000-92000 \$ per mine.

Given the large amount of mine water that is pumped out from underground water bodies, the developed method of microclimate normalization also has significant economic expediency.

Summary

1. The results show that when the velocity of air in the chamber irrigation within the V = 1-2,5 *m/s* and the degree of irrigation ρ = 0,7 to 1,2 *kg/kg,* cooling efficiency, specific heat ratio, is η = 0,31 and 0,52, and the value of reducing air temperature is in the range Δt= 5-20 °C. Increasing the cooling efficiency, this is expressed by the thermal coefficient, achieved through the use of underground coolled water.

2. Industrial tests of the irrigation cooling of mine air with the use of underground waters in conditions of mines of (PJSC) "KRIVOJ ROG’S IRON-ORE COMBINE" showed the possibility of reducing air temperature by an average of 8 – 10 º C and humidity of 60 – 70 %.

3. The accumulation of underground water waste in the mine workings adjacent to the neutral layer of the earth, allows cooling it to 10 – 11 ° C with subsequent use for conditioning mine air.

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