CALCULATING THE PARAMETERS OF THE WATER–AIR COVERING OF THE FACE AREA IN WORKINGS CUT BY ENTRY DRIFTING MACHINES

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Together with established technical means for improving the efficiency of antidust measures in the operation of entry drifting machines, we need further development of such promising means of dust suppression as water–air ejectors and dust suckers in combination with covers for dust formation foci [1, 2].

Protection of the zone of fracture of the face by machines with cutting arms and the sites of loading of cut rock onto the conveyor of the machine from the action of the active ventilation stream in forced ventilation can be effected with the aid of rectangular water–air ejectors sited on the side walls and roof of the front of the frame of the machine. The exhaust holes of the ejectors are directed toward the side and top dihedral angles formed by the surface of the face and the side walls and the roof of the working, so that the rectangular water–air jets formed by the ejectors cover the broken face and the cutting head of the machine and the suction holes of the dust suction system of the machine.

The water–air jets created from the fresh air forced into the face and projected from the rectangular ejectors, covering the main sources of dust in the machine on three sides, intensively wash over the whole surface of the broken face and, together with the finely dispersed dust and methane, move toward the opening of the air suction duct of the dust suction unit sited in the covered space.

For effective dust suction from the covered face area, at the face surface the velocity of the jets created by the ejectors must be optimal to remove the dust and gas, and to prevent recirculation of air and dust currents in the region of the machine it is necessary that the volume of air carried into the face area by the water–air jets will not exceed the capacity of the dust suction unit.

The aim of this article is to make an analytical investigation of the dependences necessary for calculating the parameters of the water–air jets so as to obtain coverage giving optimal conditions of dust suction from the covered face area. For this purpose we first investigate the laws of development of the enclosing jets, introducing a local i-th system of coordinates for each i-th ejector: The origin Q_i is placed at the center of the rectangular outlet hole of the i-th ejector, and the O_iY_i and O_iZ_i axes are directed parallel to the corresponding larger and smaller sides of the rectangle. The O_iX_i axis is in the direction of flow of the i-th jet. The initial parameters of the i-th jet are the flow parameters of the water-air mixture at the outlet from the i-th ejector.

Assuming that the covering jets develop as free jets until they reach the walls and roof of the face, according to the method of the equivalent problem in the theory of heat conduction [3-5] we write in the chosen system of coordinates the equation of the momentum of the i-th jet:

$$\frac{\partial}{\partial x_i} \left( \rho_i u_{i} \right) = \frac{\partial^2 \left( \rho_i u_{i} \right)}{\partial x_i^2} + \frac{\partial^2 \left( \rho_i u_{i} \right)}{\partial y_i^2},$$

(1)

where \(\rho_i, u_i\) are the density and longitudinal velocity of the i-th jet at the reference point, and \(x_i, y_i, z_i\) are the coordinates of the reference point in the i-th system of coordinates; \(c = 0.082\) is an experimental constant.

Using the solution to Eq. (1) for an axisymmetric elementary jet [4] and the method of infinitely small sources [6, 7], we obtain the velocity field of the rectangular jet induced by the i-th ejector in the form

$$u_i = \frac{u_i^*}{2} \sqrt{\frac{\rho_i^*}{\rho_i} \left( \text{erf} \frac{b_i - 2y_i}{2x_i} + \text{erf} \frac{b_i + 2y_i}{2x_i} \right) \left( \text{erf} \frac{h_i - 2z_i}{2x_i} + \text{erf} \frac{h_i + 2z_i}{2x_i} \right)},$$

(2)

Here \(\rho_i^*\) and \(u_i^*\) are the density and velocity of the water–air current at the outlet from the i-th ejector, \(b_i\) and \(h_i\) are the breadth and height of the duct of the i-th ejector \((b_i > h_i)\), and \(\text{erf} = \frac{2}{\sqrt{\pi}} \int_0^t e^{-y^2} dy\) is the Gaussian probability integral.
For the axial velocity of the i-th jet $u_{,ax}$ from (2) with $y_i = z_i = 0$ we have

$$u_{,ax} = u_i \sqrt{\frac{\rho_i}{\rho}} \frac{\beta_i}{2 \pi_i} \frac{h_i}{2 \pi_i}.$$

(3)

To determine the initial parameters $\rho_i$ and $u_i$ of the covering streams let us consider the process of formation of the water–air current in the ejector. Since the ejector operates in an atmospheric–atmospheric regime, i.e., it creates no appreciable pressure difference, we assume that the kinetic energy of the water jet emerging from the atomizer at velocity $u_0$ is partly expended on its atomization, while the rest is converted to kinetic energy of formation of the water–air flow, which at the outlet from the ejector has some mean density $\rho_i$ and velocity $u_i$. The loss of part of the energy of the water jet on its atomization can be regarded as expenditure of energy on increasing the forces of surface tension, since atomization of volumes into small particles with mean diameter $d_p$ is accompanied by an increase in their total free surface, and the forces of surface tension are proportional to the area of the free surface. Hence it follows that the fraction of the energy lost on atomizing the jet, $W^{-}$, is proportional to the relative increment of the free surface of the outflowing liquid:

$$W^{-} = k W_0 \frac{S^* - S_0}{S_0} = \frac{k}{2} \rho_0 u_0^2 F_0 \left( \frac{3 \sqrt{F_0}}{d \sqrt{\pi}} - 1 \right),$$

(4)

where $W_0$ is the kinetic energy of the water jet; $S_0$, $S^*$, initial and final areas of the free surface of the outflowing liquid; $\rho_0$, density of water; $F_0$, area of the opening of the atomizer; and $k$, a proportionality coefficient to be determined experimentally.

Let us write down the equation of conservation of energy,

$$W_{el} = W_i^* + W_i^-,$$

(5)

together with the equation of conservation of mass per second in the duct of the i-th ejector,

$$m_{el} = m_i^*.$$

(6)

Here, $W_{i}^*$ is the kinetic energy of the water–air flow at the exit from the i-th ejector, and $m_{el}$, $m_i$, and $m_i^*$ are, respectively, the masses per second of water, air, and the water–air mixture in the i-th ejector. From Eqs. (5) and (4), together with the fact that $0 < W_i^* < W_0$, we can derive an estimate of $k$:

$$0 < k < \frac{d \sqrt{\pi}}{3 \sqrt{F_0} - d \sqrt{\pi}}.$$

Hence it follows that $k$ depends on the dimensions of the atomizer opening and the degree of atomization of the liquid.

Experimentally it was established that for a flat-jet atomizer with an expansion angle of $\gamma_1 = \pi/2$, $\gamma_2 = \pi/6$, with $F_0 = 3 \cdot 10^{-2}$ $m^2$, $d \sqrt{\pi} = (5-7) \cdot 10^{-4}$ $m$, $k = 0.016$.

Substituting values in (5) and (6) and adding the relation between the rate of flow of the liquid out of the i-th atomizer $u_{el}$ and the pressure difference in the atomizer $\Delta \rho_i$ [8] and the condition that $u_{,ax} |_{X_i} = u_{cr}$, which must be satisfied by the maximum velocity of the water–air jet at the face surface with respect to the dust factor in ventilation [9], we get the following system of equations:

$$\rho_i F_0 u_{el}^2 = \rho_i F_i^2 (u_i^*)^2 + k \rho_0 F_0 u_{el}^2 \left( \frac{3 \sqrt{F_0}}{d \sqrt{\pi}} - 1 \right);$$

(7)

$$\rho_i F_0 u_{el}^2 + \rho_0 (F_i - F_0) u_{el} = \rho_i F_i u_i;$$

(8)

$$u_{el} = \mu \frac{2 \Delta \rho_i}{\rho_i};$$

(9)

$$u_{,ax} |_{X_i} = u_{cr}.$$  

(10)

where $F_i = b d_i$; $\rho_i$, density of the air; $u_{el}$, velocity of the air in the duct of the i-th ejector; $\mu$, coefficient of discharge of the liquid (for atomizers with cylindrical nozzles in the region of turbulent flow, $\mu = 0.80-0.95$ [8]); $u_{cr}$, critical value of the air current velocity according to the dust factor; and $X_i$, distance from the nozzle of the i-th jet to the surface of the face in the direction of flow of the jet.

In order to isolate the zone of dust separation by the rectangular jets with minimum energy loss due to friction on the wall and roof of the face, the jets must be directed so that they meet the walls only at the surface of the face. Then the flow directions of the horizontal and vertical ejectors make the following angles with the axis of the working, respectively: