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TRANSIENT MOTION OF GAS IN MINE WORKINGS AFTER LARGE EXPLOSIONS

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1. In recent years research on the dynamics of gas pollution of mine workings by explosion products after the simultaneous firing of a large amount of explosives (a massive explosion) has become increasingly urgent in the field of underground aerodynamics. Field experiments are extremely limited owing to the very destructive effect of air shock waves, and the literature gives no results of investigations on models, which are also not without their attendant difficulties.

Lugovskii [1] and Alekseev [2] investigated the ventilation of workings after massive explosions. Our paper is concerned with theoretical investigations of transient motion of gas in mine workings after massive explosions.

2. The distinctive feature of detonations of a large amount of explosives in a so-called "confined medium" is that during adiabatic expansion the gas pressure does not fall to atmospheric pressure but to a somewhat higher value as a result of formation of a large volume of gases which have not had time to fully expand in the medium with a high aerodynamic resistance during the explosion.

Taking account of this characteristic, the equation of retarding vortex motion of gas in mine workings after an explosion is written in the form

$$m_1 \frac{dv}{dt} = \alpha_1 \rho S v^2 + \overline{\Delta P S}, \tag{1}$$

where m_1 is the mass of the gas ejected by the explosion into the working adjoining the side of the latter, v is the gas velocity, ρ is the air density, S is the total cross-sectional area of the working adjoining the explosion site, α_1 is the coefficient of drag of the air and $\overline{\Delta P}$ is the mean excess pressure in the mining-out area after the explosion. The initial condition for Eq. (1) is

$$v(0) = v_0, \tag{2}$$

where v_0 is the maximum gas velocity of the gas (dispersion velocity of the explosion products).

In the case of massive explosions, gas pollution is observed at considerable distance from the explosion site. The workings have junctions and branchings, and it is therefore more convenient to find the gas-contaminated volume, not the corresponding equivalent length. To simplify determination of the gas-contaminated volume we use the identity V = xS, from which the equation for the velocity and acceleration of the gas is written in the form

$$v = \frac{1}{S} \cdot \frac{dV}{dt}, \quad \frac{dv}{dt} = \frac{1}{S} \cdot \frac{d^2V}{dt^2} \tag{3}$$

Substituting (3) into (1), we get

$$\frac{du}{dt} = a - bu^2. \tag{4}$$

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Introduce into Eq. (4) the following notation:

$$u = \frac{dV}{dt}, \quad a = \overline{\Delta P} S^2, \quad b = \frac{\alpha_1 \rho}{m_1},$$

where u is the rate of gas pollution. Integration of Eq. (4) with the initial condition

$$u(0) = u_0 = v_0 S \tag{5}$$

gives

$$\frac{F + u}{F - u} \cdot \frac{F - u_0}{F + u_0} = e^{2bFt}, \tag{6}$$

where the value of F is $F = \sqrt{a/b}$.

Expressing the rate of gas pollution from (6), we get

$$u = F \frac{\varphi_0 e^{2bFt} - 1}{\varphi_0 e^{2bFt} + 1}, \tag{7}$$

where $\varphi_0 = F + u_0/F - u_0$. Integration of Eq. (7) with the initial condition V(0) = 0 gives the equation

$$V = Ft + \frac{1}{b} \ln \frac{\varphi_0 + e^{-2bFt}}{\varphi_0 + 1}, \tag{8}$$

representing the process of gas pollution of the volume of the working in time.

Gas pollution of the space in mine workings is largely completed after a time t_{cr} corresponding to the moment of decrease in the rate of gas pollution to the critical value. The latter corresponds to completion of the process of vortex motion. From Eq. (6) we determine the characteristic time of gas pollution

$$t_{cr} = \frac{1}{2bF} \ln \frac{(F + u_{cr})(F - u_0)}{(F - u_{cr})(F + u_0)}, \tag{9}$$

where $u_{cr} = u(t_{cr})$ is the critical rate of gas pollution. By substituting (9) into (8) we can determine the principal volume of gas pollution of workings after massive explosions

$$V_g = \frac{1}{2b} \ln \frac{\varphi_0 (\varphi_{cr} + 1)^2}{\varphi_{cr} (\varphi_0 + 1)^2} = \frac{m_1}{2\alpha_1 \rho} \ln \frac{\overline{\Delta P} - \alpha_1 \rho v_0^2}{\overline{\Delta P} - \alpha_1 \rho v_{cr}^2}. \tag{10}$$

3. The mass of gas m_1 ejected into the workings by the explosion, manifested in the solution of (10), is part of the overall mass of gas M formed by detonation of the explosives, i.e.,

$$m_1 = k_1 M,$$

where $k_1 < 1$ is a coefficient depending on the specific conditions under which the explosive is detonated. The other part of the gas with a mass m_2 penetrates intensely into the broken ore and caved rock during the explosion; in this connection

$$M = m_1 + m_2.$$

Putting

$$k_1 = \frac{1}{1 + \frac{m_2}{m_1}},$$

we write

$$\frac{m_2}{m_1} = \frac{\rho_2}{\rho_1} \cdot \frac{V_2}{V_1}.$$

Since at any time during the expansion of the gas during an explosion $\rho_2 = \rho_1$, the masses of the gases ejected into the working and penetrating the broken ore are proportional to their volumes.

The gas volumes can be found from the equations of S. I. Lugovskii [1], extended to the case in question:

$$V_1 = \frac{S_{e1}}{S_{e2} + S_{e1}} V_x, \quad V_2 = \frac{S_{e2}}{S_{e2} + S_{e1}} V_x,$$

where S_{e1} and S_{e2} are respectively the areas of the equivalent orifices of the system of workings and broken ore, and V_x is the total volume of gases after the explosion (at the end of adiabatic expansion). Expressing the areas of the equivalent orifices in terms of the corresponding resistances by means of the known equation $S_{ei} = 0.38/\sqrt{R_i}$, we get the ratio $V_2/V_1 = \sqrt{R_1/R_2}$, which enables us to write the coefficient k_1 in the form

$$k_1 = \frac{1}{1 + \sqrt{R_1/R_2}}.$$

Here R_1 is the resistance of the system of workings from the explosion site to emergence onto the surface, inclusively; R_2 is the resistance of the broken ore and caved rock up to the surface inclusively, which can be calculated from the equation [3]

$$R_2 = 15 \frac{\alpha_2 (1 - \varepsilon)}{\varepsilon^3 d_{me}} \cdot \frac{l}{S_2^2},$$

where ε is the voids ratio, d_{me} is the mean fragment diameter, l is the height of the caved layer, S_2 is the cross-sectional area of the caved layer, and α_2 is the aerodynamic coefficient of resistance of the filtration channel.

Expressing the total mass of the gases formed by the explosion in terms of their weight, equal to the weight of solid explosive, we get the final expression for m_1

$$m_1 = \frac{1}{1 + \sqrt{R_1/R_2}} \cdot \frac{A}{g},$$

where A is the weight of explosive being detonated, and g is the acceleration of gravity.

4. To find the mean excess pressure in the mining-out area after a massive explosion, the following considerations pertain.

The adiabatic expansion of gases during an explosion, which experiences a jump in Poisson's ratio from $\varkappa = 3$ to $\gamma = 7/5$ for diatomic gases at the point with a pressure $P_k = 2000$ kg/cm^2 [4], ceases in the free space when atmospheric pressure is attained and at a certain excess pressure with respect to the latter during an explosion in a confined medium. Further expansion of the gas — polytropic and accompanied by heat exchange with the ambient medium — takes place fairly slowly with a polytropic index n = 1.25 [1].

Let us write the mean excess pressure after the explosion by the equality

$$\Delta \bar{P} = \bar{P} - P_a,$$

where $\bar{P}$ is the mean gas pressure in the mining-out area, and P_a is the atmospheric pressure in the mine. The mean gas pressure in polytropic expansion is written in the form

$$\bar{P} = \frac{1}{V_a - V_x} \int_{V_x}^{V_a} P dV = \frac{P_a V_a^n (V_x^{1-n} - V_x^{1-n})}{(1-n)(V_a - V_x)},$$

where $P = P_a(V_a/V)^n$ is the gas pressure during polytropic expansion and V_a is the volume of the gas at atmospheric pressure. Like its pressure P_x, the volume of the gas V_x can be found from simultaneous solution of the adiabatic with index 5 and the polytrope. In fact, the origin of the polytrope corresponds to the end of adiabatic expansion, the transition point is found from the system of equations

$$P_k V_k^{\gamma} = P_x V_x^{\gamma},$$
$$P_x V_x^n = P_a V_a^n,$$

the solutions of which are

$$V_x = \left(\frac{P_k}{P_a} \cdot \frac{V_k^{\gamma}}{V_a^n}\right)^{\frac{1}{\gamma - n}}, \quad P_x = \left[\frac{P_a^{\gamma}}{P_k^n}\left(\frac{V_a}{V_k}\right)^{n\gamma}\right]^{\frac{1}{\gamma - n}}.$$

V_k, the volume of gas corresponding to the pressure P_k, is found from the equation of state during adiabatic expansion of gas with a Posson's ratio $\varkappa = 3$

$$V_k = V_i\left(\frac{P_i}{P_k}\right)^{\frac{1}{\varkappa}}.$$

Here V_i is the initial volume of gas equal to the volume of explosive in the solid state, P_i is the initial gas pressure corresponding to the volume V_i.

5. The critical velocity corresponding to a decrease in the Reynolds number to the critical value is determined from the expression

$$v_{cr} = \frac{Re_{cr} \nu}{d},$$

where $d = \sqrt{S}$ is the equivalent diameter of the system of workings in which the glas flows, ν is the critical viscosity of the air, and $Re_{cr} = 2300$ is the critical Reynolds number.

Since the mouths of the charge holes have junctions with the workings, and dispersion of the gases produced by the explosion takes place directly into the space of the workings, there is no point in examining separately the problem of the rate of dispersion of the explosion products into the working, owing to the fact that the analogous problem of the rate of dispersion of the explosion products into a tube has been solved in principle and examined, for example, in [4].

It can be readily shown that $\alpha_1 = k/2$, where k is the coefficient of kinetic energy taking account of the nonuniformity of the velocity over the cross sections of the workings. The value of k for roadway-like workings is found from the equation [5] $k = 1 + 213\alpha$, where α is the aerodynamic resistance coefficient of the system of workings.

6. For convenience the theoretical expression for the gas-polluted volume of the workings after massive explosions, Eq. (10), is rewritten in the form

$$V_g = \frac{2.3A}{(1 + \sqrt{R_1/R_2})\, k\gamma_1} \lg \frac{2\overline{\Delta P} g - k\gamma_1 v_0^2}{2\overline{\Delta P} g - k\gamma_1 v_{cr}^2}. \tag{11}$$

where γ_1 is the specific gravity of air.

The complete gas-polluted volume $V_{g \cdot p} = V_1 + V_g$, but $V_1 \ll V_g$; there is therefore no practical necessity to take account of the volume V_1 filled with gas directly during the explosion. The process of laminar gas pollution, which begins after the velocity of turbulent gas pollution has fallen to the critical value, is also ineffective, because the velocity of laminar gas pollution is low and comparable in value with the velocity of steady diffusion, which has no practical significance for ventilation calculation. Thus Eq. (11) contains all the practically necessary volume of gas pollution of mines after massive explosions. Estimates of the volume of gas pollution by means of Eq. (11) for the topological scheme of the Sheregesh iron ore mine when a massive explosion was performed in an experimental block with end-face ore discharge agree satisfactorily with those based on information obtained from mine-rescue personnel at this mine.

LITERATURE CITED

1. S. I. Lugovskii, Ventilation of Mines after Massive Explosions [in Russian], Metallurgizdat, Moscow (1958).

2. A. G. Alekseev, "Ventilation of workings after massive explosions with use of the system of induced level caving with vertical blastholes," Izv. Vuzov, Gornyi Zhurnal, No. 4 (1962).
3. V. G. Kozlov, G. F. Musokhranov, V. A. Zelenetskii, and A. V. Obrosov, "Aerodynamic resistance of broken ore in mining-out rooms," Trudy VostNIGRI, No. 13, Kemerovo (1973).
4. F. A. Baum, K. P. Stanyukovich, and B. I. Shekhter, Physics of an Explosion [in Russian], Fizmatizdat, Moscow (1959).
5. A. S. Burchakov, P. I. Mustel', and K. Z. Ushakov, Mine Aerology [in Russian], Nedra, Moscow (1971).