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THEORETICAL AND EXPERIMENTAL RESEARCHES FOR DEFINING THE LOADS DURING EXPLOSIVE BURNING OF AIR-GAS-DUSTY MIXTURES

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The article primary results theoretical and experimental researches for defining the loads during explosive burning of air-gas-dusty mixtures. The rated equations for definition of the maximal load arising at explosion of a coal dust in industrial facility are resulted. The possibility of carrying out of analogy is marked by explosions of a coal dust and air-gas mixtures. Influence of various factors on speed propagation of a flame is analyzed at explosion. The rightness of the choosen theoretical premises was confirmed by the experimental researches.

Keywords: explosion, explosive burning, air-gas-dusty mixtures, coal dust, air-gas mixtures.

Explosions of a dust (air-dust mixtures – aerosols) represent one of the basic dangers of manufacture. Explosions of a dust occur in the limited space – in facilities of buildings, inside of the various equipments, in mines adit. Explosions of a dust on installations of crushing and of a fuel transportation, flour-grinding manufacture, on grain elevators, at the reference with dyes, sulfur, sugar, other powdery foodstuff, manufacture of plastic, medical products, in textile manufacture are possible.

Statistical data testify, that the damage from explosions in industrial facilities all over the world remains enough great and tends an annual increase. It is assisted with an intensification and concentration of manufactures, increase of their installed power per employee, introduction of new substances which explosive properties are sometimes insufficiently studied.

According to foreign sources, 540 from 1120 explosions of air-dust mixtures PVOH (IIBC) on manufactures has occurred at works with grain, a flour, sugar and other foodstuff, 80 – with metals, 63 – with a coal dust on installations of crushing and transportation of fuel, 33 – with sulfur, 61 – in the chemical and petrochemical industry [1].

Explosions of a dust, basically, occur by the deflagration mechanism (explosive burning). Transition to a detonation is possible in long adits mines, on conveyor lines of granaries and concentrating factories of the big extent due to turbulization of a dust. Occurrence of an aerosol clouds from the settled before a dust (aerogel), their ignition and explosion are raised by weak explosion of any air-gas mixture, for example, in mines by explosion of methane.

At explosion of a dust superfluous pressure P in volume V increases up to maximal value P_M step by step for some time interval. It could be explained that burning (at deflagration explosion) extends with subsonic speed. Pressure P_M depends on wide range of factors: concentration and the sizes of a dust particles of the certain type, chemical activity of substance, humidity, initial pressure, volume and availability of apertures or safety (waste) designs.

Generally key parameters defining destructive action of deflagration explosions of aerosols is pressure ΔP_M and the maximal speed of pressure increase ΔP_M .

Conditions of ignition of separate particles of the dust weighed in air, have much in common with the usual theory of thermal explosion for homogeneous reactions. Works of many authors are devoted to ignition of separate particles. The specific character of heterogeneous reactions forces to refuse from some cases in habitual for homogeneous reactions of concepts about normal speed of propagation of a flame, the period of an induction, etc. At the same time the concept of the thermal theory of burning in many ways units these various in essence chemical reactions.

In this case the next physical model is examined: in initial moment of time there is a combustion of the smallest particles of dust-suspension in a volume (run of flame on a small

particles), at that the heat fully expended on gasification of hard un-fire-damaged fuel, after this there are a process of spontaneous combustion of a gaseous product and distribution of flame on productions of gasification(2nd front of flame). It is accepted that the smallest particles of hard fuel are evenly divided on all volume. In that way, we deal with the combustion of hard and small particle of substance on the first stage, and on the second stage - with the process of spontaneous combustion of air-gas mixture. Exactly with this the significant thickness of a flames front and volumes of burning is related.

Being based on the expounded mechanism of air-dust mixture combustion in accordance with the accepted assumptions, we will show out the calculated equalizations for determination the maximal loading arising up at the explosion of a coal dust in industry lodgments. Estimation of loading from the explosion of dust of different substances by analogy with air-gas mixtures is possible to make on normal speed of S_H of a flame distribution in air-dust mixture. Normal speed for a coal dust accounts 0,2-0,7 m/s. The founding for the use of S_H parameter, which is typical for air-gas mixtures, the analogy of explosions of dust and gas serves in the further reasoning's. In addition, the use of concept about normal speed of a flame distribution for air-dust mixtures is also needed for comparison of danger of dustborne and gas explosions. S_H receipt by the indicator-diagrams "pressure - time" is to be less labour intensive than determination of kinetic parameters.

It is assumed that the heat capacities of initial and fire-damaged gases are identical and permanent by volume and times, which means it does not depend on a temperature. Thus pressure in an apartment linearly depends on the part η of fire-damaged mixture [2]:

$$P = P_0 \cdot [1 + (\varepsilon - 1) \cdot \eta], \quad \varepsilon = P_{\varepsilon} / P_0 = T_{\varepsilon} / T_0, \quad (1)$$

where P_0 - is initial pressure(at $\eta = 0$), Pa; P_{ε} - is eventual pressure(at $\eta = 1$), Pa; ε - is a level of expansion of a explosion products; T_0 - is initial temperature, K; T_{ε} - the average value of temperature by the end of complete burning down, K.

After differentiation (1) by the t time, we will have:

$$dP / dt = P_0 \cdot (\varepsilon - 1) \cdot d\eta / dt, \quad (2)$$

$$\text{As since } d\eta / dt = F_n \cdot S_H \cdot \rho \cdot \varepsilon / (V_0 \cdot \rho_0), \quad (3)$$

$$\text{then } \frac{dP}{dt} = P_0 \cdot (\varepsilon - 1) \cdot \frac{F_n \cdot S_H \cdot \rho \cdot \varepsilon}{V_0 \cdot \rho_0} \quad (4)$$

where, F_n - the surface of a flames front, m^2 ; S_H - the normal speed of a flame expansion, m/c; V_0 - initial volume of air-dust mixtures, m^3 ; ρ_0 и ρ - initial and current density of gases in volume, kg/m^3 .

The current volume of combustion products V_t is equal to:

$$V_t = V_0 \cdot \eta \quad (5)$$

For the spherical surface of a front in accordance with (5) we have:

$$\frac{4}{3}\pi \cdot r^3 = \frac{4}{3}\pi \cdot R_0^3 \cdot \eta \quad (6)$$

где r – the radius of sphere, suitable to V_t , м; R_0 – the radius of sphere, suitable to V_o , м.
The current surface of flame is determined by a formula:

$$F_n = 4 \cdot \pi \cdot r^2 = 4\pi \cdot R_0^2 \cdot \eta^{2/3} \quad (7)$$

For determination of the part of a reacted substance we will use the next formula:

$$\eta = \frac{P - P_0}{P_0(\varepsilon - 1)} \quad (8)$$

The density ratio incoming in (4) equation could be replaced by the following ratios of pressures (by counting the process as polytropic):

$$P / P_0 = (P_0 / P)^{(k-1)/k} \quad (9)$$

If we take into account the equations (5-7), formula (4) might be presented as the following way:

$$\frac{dP}{dt} = 3 \cdot P_0 \cdot \varepsilon \cdot (\varepsilon - 1)^{1/3} \cdot \frac{S_h}{R_0} \cdot (P_0 / P)^{(k-1)/k} \cdot \left(\frac{P - P_0}{P} \right)^{2/3} \quad (10)$$

At the deriving of formula (10) a spherical volume was examined. However it is obvious, that formulas (6) and (10) do not change, by examining the volume of a cube form.

Possibility of drawing analogy between explosions dust- and air-gas mixtures was higher marked. We will apply the same positions for determination of aperture areas. In case of aperture absences (reserved volume) speed of growth of pressure is determined by a formula (10). At presence of aperture by an area A_{np} foods of combustion in air-dust mixtures which are under current pressure of P retire from aperture with speed equal to (P) , depending on P . The mass expense of substance retiring through aperture is determined by expression:

$$m_c = \rho_0 \cdot A_{np} \cdot \varphi \cdot \sqrt{\frac{2k}{k-1}} \cdot \frac{P}{\rho} \left[1 - \left(\frac{P_0}{P} \right)^{(k-1)/k} \right], \text{ kg/s} \quad (11)$$

где φ - coefficient of discharge; $h = 1,2$ index of polytropes .

By using the ratio (9), we will get:

$$m_c = A_{np} \cdot \varphi \cdot \sqrt{\frac{2k}{k-1}} \cdot P \cdot \rho_0 \left[\left(\frac{P}{P_0} \right)^{(k-1)/k} - 1 \right]. \quad (12)$$

Knowing mass expense of substance, as well as initial density, it is possible to define the superseded volume normalized to atmospheric pressure = 105 Pa. For defining the pressure $_{\Delta}P$ at the expense of moving off the volume of combustion products we will use the following equation:

$$P/P_0 = (V_0/V)^k \quad (13)$$

where $V = V_0 +_{\Delta}V$.

Having divided numerator on a denominator in the right part of the equation (13) and having limited the small of the second order, we will receive:

$$(P/P_0) = 1 - k \cdot_{\Delta}V/V_0, \quad (14)$$

$$\text{or }_{\Delta}P = -k \cdot_{\Delta}V \cdot P_0/V_0. \quad (15)$$

In that way the differential equation taking into account (12) and (15) will have the following appearance:

$$\begin{aligned} \frac{dP}{dt} = & 3 \cdot P_0 \cdot \varepsilon \cdot (\varepsilon - 1)^{1/3} \cdot \frac{S_H}{R_0} \cdot \left(\frac{P_0}{P}\right)^{1/k} \cdot \left(\frac{P - P_0}{P_0}\right)^{2/3} - K_{c\bar{o}p} \cdot \varphi \cdot k \times \\ & \times \left[1 - \left(\frac{P_0}{P}\right)^{1/k} \right] \sqrt{\frac{2k}{k-1}} \cdot \frac{P}{P_0} \cdot \left[\left(\frac{P}{P_0}\right)^{(k-1)/k} - 1 \right], \end{aligned} \quad (16)$$

where $K_{c\bar{o}p} = A_{np}/V_0$, m^2/m^3 .

The equation (16) with the permanent condition $P(0) = 1$ has a solution, which depends on $K_{c\bar{o}p}$ parameter. Now it is necessary to find dependence of the required value $K_{c\bar{o}p}$ from P_{max} . In other words, parameter of the solution of differential equation is selecting to reach the maximum in formula (16).

But in this case the right side of equation must be equal to zero, this means that it is not necessary to solve all differential equation; it is enough to equate the right side to zero to find the dependence P_{max} ($K_{c\bar{o}p}$).

Equation (16) has extra advantages that its right part doesn't depend on time. This circumstance in the present case gives opportunity to get from (16) required result:

$$K_{c\bar{o}p} = a \cdot P_0 \frac{\left(\frac{P_0}{P}\right)^{1/k} \cdot \left[\left(\frac{P - P_0}{P_0}\right)^{2/3}\right]}{\sqrt{P \left[\left(\frac{P}{P_0}\right)^{(k-1)/k} \right]} \cdot \left[1 - \left(\frac{P_0}{P}\right)^{1/k} \right]}, \quad (17)$$

where

$$a = \frac{3 \cdot \varepsilon (\varepsilon - 1)^{1/3} \cdot S_H}{k \sqrt{\frac{2k}{k-1}} \cdot \frac{1}{\rho_0} \cdot R_0 \cdot \varphi}$$

It is necessary to define a degree of expansion of combustion products ε . For this purpose it is necessary to define the maximal temperature of combustion products in the closed volume, proceeding from the general power content of system on the whole. The procedure of such calculation is stated in work [3] and consequently we will result only final settlements. The degree

of expansion of combustion products is equal to 4,8. If we accept speed of propagation of a flame equal to $S_{fl} = 0,2$ m/s then parameter α in equation (17) will be equal to the 3,4. Results of calculation under the formula (17) are comparable to experimental dependences, received by us as a result of carrying out of researches on explosivity of a coal dust with the additive equation of prosir in the chamber in 1 m^3 volume.

CONCLUSIONS:

1. The conducted experimental researches have proved the accuracy of the chosen theoretical preconditions at a conclusion of the rated equations for defining the loads from explosive burning of PVOH (ПВС).
2. Character of pressure increase from the time at explosion of a coal dust is similar to air-gas mixtures.
3. It is necessary to note the essential influence of the prosir additive on an increase of superfluous pressure at explosion of a coal dust.
4. Various factors influence on character of an explosion course and, accordingly, on speed of a flame propagation such as concentration of a dust, humidity, dispersiveness, availability of apertures and pressure of their opening, volume and extent of installation, turbulazation of a flame which should be considered for specific substances.
5. Results of research can be used as initial materials for recommendations by defining the loads in facilities, dangerous on explosion of a dust and, in particular, for pathes of transportation of organic substances (a fuel, flour dust, etc.).

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