Scale model operation of formation of pressure at internal explosion

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Abstract. In work the possibility of model operation of internal explosion taking into account fixing of an inertial safety design in an aperture, at some depth is investigated. Explosion process, in this case, kind of breaks into two stages. At the first stage explosion occurs in self-contained volume. When the safety design leaves an aperture and opens space for a venting, it already has the sufficient speed and a venting occurs more efficiently. As a result the effect of prolonged explosion in self-contained volume prevails, and pressure at the first peak because of it is higher in case of the buried safety design. In work equations of motion of a safety design and change of pressure in the dimensionless look are written down and the dimensionless complexes which equality provides similarity opening of an aperture and development of pressure of explosion at the first peak are allocated. In work the way of direct model operation of size of the maximum pressure is offered Examples of determination of parameters of carrying out experience on model $V_0=125$ installation of liters at model operation of explosion in the kitchen room of $V_0=27$ m$^3$ and the experimental $V_0=10$ camera of m$^3$ are given.

1. Introduction

Explosions of gas in rooms of residential and industrial buildings happen to the menacing frequency, lead to the considerable loss of life, the material losses, strongly excite the public. The reasons of explosions are uncontrollable gas escapes with the subsequent inflaming of steam-and-gas mixture. The destroying action of explosion is defined by the level of an overpressure and a carrying capacity of building constructions.

Gas explosion indoors in most cases can be considered as quasistatic, that is pressure is indoors identical in all points of volume and changes in time [1-5].

Change of pressure at explosion is defined by the competition of two processes. Build-up of pressure results from an energy liberation at combustion and expansion of products of explosion by 6 - 8 times of rather original stock. Pressure as a result of the expiration of gases from volume through the opening apertures decreases. Opening of these apertures is provided with the weakened fastening of enclosing structures in these parts. It is accepted to call such designs safety designs or easily thrown off designs.

Industrial buildings and rooms with the address of explosive gases are categorized as explosive [6-8] and for their protection it is necessary to use safety designs or easily thrown off designs [7.8].
The formal transfer of the quantitative criteria of protection against explosion of industrial placements on inhabited, can lead to the considerable mistakes. It is necessary to consider features of explosion in premises, ways of fastening of easily thrown off designs in premises, design features of residential buildings. The typical volume of kitchen rooms, namely in them occurs the overwhelming number of explosions, is 30 - 60 sq.m. Time of development of explosion in such rooms, owing to a volume smallness, is reduced, and time of opening of apertures for the expiration of gases increases because of arrangement of easily thrown off designs in apertures [9.10].

In works [9 - 11] it is shown that during the movement easily thrown off designs in an aperture until opening of space for the expiration of gases pressure can increase to the size exceeding a carrying capacity of designs. In the presented work the question of scale model operation of internal explosions taking into account a location of safety designs in the depth of an aperture is considered.

On an incipient state of explosion in self-contained volume for overpressures \( \Delta P(t) < 20 \) kPa, this body height is described by expression:

\[
\frac{\Delta P(t)}{P_0} = \frac{4}{3} \pi \gamma \left( \frac{\sigma - 1}{\sigma} \right)^{2/3} \frac{U_g^2}{V_0^{2/3}} \left( \frac{t_{op}}{t_v} \right)^3
\]

At the time of opening of an aperture for the expiration of \( t_{op} \) gases pressure accepts value:

\[
\Delta P_{op} = \Delta P_e \left( \frac{t_{op}}{t_v} \right)^3
\]

Where \( \Delta P_e \) and \( t_v \) – pressure and time with which communications of the safety structure with enclosing structures collapse and begins their driving.

Expressions (1) and (2) are written down for a case of development of explosion on an incipient state in tight volume for the spherical center of combustion, and \( U_c = \alpha U_n \) - the speed of explosive combustion, \( U_n \) – laminar burning rate of steam-and-gas mixture, m/s, \( \alpha \) – a factor of an intensification of combustion [12-19], \( \gamma \) – an index of an isentropic line, \( V_0 \) – the free volume of the room, m\(^3\), \( \sigma \) – expansion ratio of gases at combustion.

Interpretation of test data in vitro in application to large-scale (actual) volumes taking into account driving of safety designs in an aperture demands additional studying. In this work the method of scale model operation of internal explosion taking into account movement of a safety design in an aperture is offered.

2. Method of research

Let's consider driving of a safety design at first in an aperture, and then and after escaping it/ After destruction of fastening of a safety design to building walls with a pressure \( \Delta P_e \) it begins to move to \( t_v \) instant in an aperture. At the same time the aperture doesn't open for the expiration of gases and explosion occurs in selfcontained volume. We neglect change of volume of the room because of driving of a safety design in an aperture.

Driving of a safety design at this stage is described by expression [9.10]

\[
X = \frac{B}{4} \left[ \frac{(1 + \theta)^5}{5} - \theta - \frac{1}{5} \right]
\]

Where:

\[
B = \frac{\Delta P_e^{5/3} V_0^{2/3}}{\rho_0 X_0^2 P_0^{2/3} \left[ \frac{4}{3} \pi \gamma (\sigma - 1) \sigma^2 \right]^{2/3}}
\]


\[ t_v = \frac{1}{U_0} \left[ \frac{3\Delta P V_0}{P_0 4 \pi \gamma (\sigma - 1) \sigma^2} \right]^{1/3} \]  

(5)

\[ \bar{X} = \frac{X}{X_0}, \quad \theta = t - t_v \]  

where \( X \) – the shift of a safety design in an aperture, m; \( t \) – time since the beginning of explosion, sec.

At \( \bar{X} = 1, \ \theta = 0 \), the space for the expiration of gases, and an overpressure opens \( \Delta P = \Delta P_{op} \). As during explosion \( t = 0 \) to \( t = t_{op} \) build-up of pressure comes from \( t \) according to (1), and expression (2) can be presented as:

\[ \Delta P_{op} = \Delta P_v (1 + \theta_0)^3 \]  

(6)

The dimensionless time of driving of a safety design in an aperture \( \theta_0 \) is defined provided that \( \bar{X} = 1 \):

\[ 4 \hat{b} = \left( \frac{1 + \theta_0}{5} \right)^5 - (1 + \theta_0) + \frac{4}{5} \]  

(7)

Traveling speed of a safety design at the time of the beginning of opening of an aperture at is \( \bar{X} = 1 \) also \( \theta = \theta_0 \) defined by expression:

\[ \frac{d\bar{x}}{d\theta} |_{\theta = \theta_0} = \frac{\hat{b}}{4}(1 + \theta_0)^4 - 1 \]  

(8)

Driving of a safety design after escaping of an aperture is characterized by length scale \( S_0 \Pi \), and the dimensionless movement is counted from the moment of an exit of a safety design from an aperture \( \bar{X}_1 = \frac{X_1 \Pi}{S_0} \). At the \( \bar{X}_1 = 1 \) area of the expiration through open parts of space it is equal to the area of the aperture therefore at further driving of a safety design the area of the expiration doesn't increase. Time is also counted from the moment of an exit of a safety design from an aperture, and the dimensionless time of driving of a safety design out of an aperture, equally \( \bar{t} = \frac{t - t_{op}}{t_{op}} \).

Initial velocity of a safety design on this site at \( \bar{X}_1 = 0 \) and \( \bar{t} = 0 \) is equal in new variables:

\[ \frac{d\bar{X}_1}{d\bar{t}} |_{\bar{t} = 0} = \frac{\hat{b}X_0}{4}(1 + \theta_0)[(1 + \theta_0)^4 - 1] \]  

(9)

The equation of motion of a safety design and change of pressure in volume of explosion after an exit of a safety design from an aperture has an appearance:

\[ \frac{d^2\bar{X}_1}{d\bar{t}^2} = B(1 + \theta_0)^5(1 + \Delta \bar{P}_1)\bar{X}_0 \]  

\[ \frac{d\Delta \bar{P}_1}{d\bar{t}} = 3(1 + \bar{t})^2 - \left( \frac{P_0}{\delta_c} \right) \left( \frac{\rho_0}{\rho_v} \right)^{1/6} \left( \frac{S_0}{V_0} \right)^{2/3} (1 + \theta_0)^{1/2} \left( \frac{4\pi \gamma \sigma^2 (\sigma - 1)}{\delta_c} \right)^{1/3} \]  

(10)

\[ \frac{d\Delta \bar{P}_1}{d\bar{t}} = 3(1 + \bar{t})^2 - \left( \frac{P_0}{\delta_c} \right) \left( \frac{\rho_0}{\rho_v} \right)^{1/6} \left( \frac{S_0}{V_0} \right)^{2/3} (1 + \theta_0)^{1/2} \left( \frac{4\pi \gamma \sigma^2 (\sigma - 1)}{\delta_c} \right)^{1/3} \]  

(11)

The analysis of a system (10-11) is kept at starting conditions:

\[ \bar{X}_1(0) = 0 \]  

\[ \frac{d\bar{X}_1}{d\bar{t}} |_{\bar{t} = 0} = \frac{\hat{b}}{4}(1 + \theta_0)[(1 + \theta_0)^4 - 1]\bar{X}_0 \]  

\[ \Delta \bar{P}_1(0) = 0 \]  

(12)
In expressions (10-12) the following designations are used:

\[ \overline{X}_1 = \frac{X_0 \Pi}{S_0} ; \Delta \bar{P}_1 = \frac{\Delta P - \Delta P_{\text{op}}}{\Delta P_{\text{op}}} ; \bar{t} = \frac{t - t_{\text{op}}}{t_{\text{op}}} ; U_c = \frac{u \rho_0^{1/2}}{P_0^{1/2}} \]

\( S_0 \) is the area of an aperture, sq.m; \( \Pi \) – perimeter of an aperture, m.

\[ \bar{X}_0 = \frac{X_0 \Pi}{S_0} \]

\( K_u \) – the coefficient of discharge, reflects narrowing of a stream at pass of gas through an aperture [20.21].

At scale model operation of internal explosions will be arranged for ensuring equality of efflux coefficients at natural and laboratory explosions

The term considering the gas expiration in the equation (11) is written down in an assumption of a smallness of an overpressure in volume \( \Delta P \leq 0.3 \), that isn’t keyest in further reasonings. This approximation meets the requirement for loss of a carrying capacity of building constructions [22.23].

Outlet velocity of gases – \( v \), is equal in this assumption:

\[ \bar{\theta} = \sqrt{2 \Delta P / \rho_0} \]

Here: \( \Delta P = P_{\text{op}} + \Delta P_1 = \Delta P_{\text{op}}(1 + \Delta \bar{P}_1) \) also it is supposed that at this stage cold original gas mixture density \( \rho_0 \) expires.

As expressions (10-12) are written down in the dimensionless form, driving of a safety design and change of pressure in volume will be similar in various systems if equality of the following dimensionless quantities is carried out:

- Parameter \( B = \frac{\Delta P_0^{4/3} V_0^{2/3}}{\rho_0 X_0 U_c^2 \sigma^2 (\pi \gamma (\sigma - 1) \sigma^2)^{2/3}} \)

- Parameter \( \bar{K}_q = \frac{S_0 d P_0^{1/2}}{V_0^{1/3} \sigma \gamma \rho_0^{1/2}} \)

Dimensionless pressure of opening \( \Delta \bar{P}_a = \frac{\Delta P_a}{P_0} \)

The dimensionless depth of seal of a safety design in an aperture \( \bar{X}_0 = \frac{X_0 \Pi}{S_0} \).

Equality of size for model and nature automatically follows from equality of parameter “B”, look (7).

Discussion of results of a research.

The most important is parameter "B" as it influences formation of pressure prior to pressure release, that is at an opening pressure size: \( \Delta P_{\text{op}} = \Delta P_a (1 + \bar{\theta}_0) \)

As a matter of convenience the experimental model operation, it is necessary to select pressure of opening both upon models and on a natural object identical, identical it is necessary to select also a gas original stock. In this case equality of expansion ratio of combustion gases – \( \sigma \), sizes \( \gamma \) is provided, to density \( \rho_0 \) and it is easier to achieve equality of burning rate of \( U_c \). When performing of the listed conditions equality of parameters «B» on a natural object of «B_{ns}» and a model object comes down to equality:
\[
\frac{V_0^2}{\rho \pi V_0} = \frac{V_0^2}{\rho \pi V_0}
\]

Equality of the dimensionless depth of seal to equality:

\[
\frac{X_0 \Pi_0}{S_0} = \frac{X_0 \Pi_0}{S_0}
\]

The easiest and useful way to satisfy the last condition is use geometrically of squared similar apertures.

In this case it is possible to hope for equality of a coefficient of discharge at the expiration of gases \( K_{0n} = K_{0m} \). In case of apertures, similar in a form, equality of the dimensionless depth of seal comes down to:

\[
\frac{X_0}{S_0} \frac{1}{2} = \frac{X_0}{S_0} \frac{1}{2} = \frac{X_0}{S_0} \frac{1}{2}
\]

Equality of parameter comes down to a condition: \( S_0 = S_0 \left( \frac{V_0}{V_0} \right)^{2/3} \).

As in the last expression all sizes in a right member are set, the area of an aperture is defined on the \( S_{0m} \) models.

Then depth of seal of a model safety design in an aperture is defined:

\[
X_{0m} = X_{0n} \left( \frac{S_0}{S_0} \right)^{1/2} = X_{0n} \left( \frac{V_0}{V_0} \right)^{1/3}
\]

From equality of parameter B the condition turns out:

\[
\rho_{0m} = \rho_{0n} \left( \frac{V_0}{V_0} \right)^{1/3}
\]

At the same time the mass of a model safety design of \( M_m \) will be equal:

\[
M_m = M_n \left( \frac{V_0}{V_0} \right)
\]

Example 1.

Let's consider model operation of explosions in the kitchen room of \( V_0=27 \ m^3 \), \( X_{0n} =0.3 \ m \), \( S_{0n} = 30 \ kg/sq.m \, S_{0n} =1.7 \times 1.5 \ sq.m \). The area of an aperture is caused by the size of a window cover. The model camera has the volume of 0.125 m³.

1. The area of an aperture in the model camera:

\[
S_{0m} = (1.7 \times 1.5) \left( \frac{0.125}{27} \right)^{2/3} = 0.0708 m^2 = 7.08 dm^2
\]

2. Aperture perimeter on the model camera:

\[
\Pi_m = 2(1.7 + 1.5) \left( \frac{0.125}{27} \right)^{1/3} = 1.067 m
\]
3. Depth of seal of a model safety design in an aperture:
\[ X_{0M} = 0.3 \left( \frac{0.5}{3} \right) = 0.05M = 5\text{cm} \]

4. Density and mass of a model safety design:
\[ \rho_{pm} = 30 \left( \frac{0.125}{27} \right)^{\frac{1}{3}} = 5 \frac{\kappa^2}{M^3}; M_m = 5 \times 0.0708 = 0.354kg \]
\[ M_m = 5 \times 0.0708 = 0.354kg \]

During the model experiment it is possible to vary both pressure of opening and burning rate. At the same time the maximum pressure at the first peak during a model trial will be equal to pressure at explosion on a natural object with the same pressure of opening. At the same time gas mixture same. Except pressure at the first peak there is an opportunity to count and dynamics of development of explosion at natural explosion at it on its dynamics at explosion on model installation.

Example 2.

Natural explosion on the camera 10\text{m}^3, the area of an open aperture \( S_0 = 0.05V_0 = 0.5\text{m}^2 \).[7]

Depth of seal of a safety design \( X_{0i} = 0.15\text{m}, \rho_{im} = 25 \frac{\kappa^2}{M^3} \). Ratio of the parties of a safety design \( a:b = 0.833:0.6 \); Same Model camera.

1. The area of an aperture in the model camera:
\[ S_{0m} = 0.5 \left( \frac{0.125}{100} \right)^{\frac{2}{3}} = 0.02693\text{m}^2 \approx 2.7\text{dm}^2 \]

2. Aperture perimeter on model installation:
\[ \pi_m = 2(0.6 + 0.833) \left( \frac{0.125}{10} \right)^{\frac{1}{3}} = 0.665\text{m} \]

Sizes of the parties respectively:
\[ 0.139:0.193\text{m}^2 \]

3. Depth of seal model the safety design in an aperture:
\[ X_{0m} = 0.15 \left( \frac{0.125}{10} \right)^{\frac{1}{3}} = 0.0348M = 3.48\text{cm}. \]

4. Density and weight model a safety design:
\[ \rho_{im} = 25 \times 0.0232 = 5.8 \frac{\kappa^2}{M^2}; M_m = 5.8 \times 0.02693 = 156.2g \]

3. Conclusion
In the conclusion it should be noted that scale model operation of process of explosion is more reliable way of determination of parameters of natural explosion in comparison with numerical model operation. So it is optional to know some uncertain parameters at an experiment. The made assumptions of a smallness of an overpressure aren't basic and model operation is possible.
Experimentally on small volume it is possible not only to check dynamics of pressure at natural explosion, but also to select corresponding parameters in charge of the nature of explosion for optimization of protection of an object at explosion. At model operation of explosion with a safety design without deepening of parameters $X_0$ disappears, size $\theta_0 = 0$, and parameter B has an appearance:

$$B = \frac{\Delta P B^{5/3} V_0^{2/3}}{\rho_0^{2/3} \rho S_0 U_0^{4/3} \pi [\sigma - 1] \sigma^2}.$$  

Other chain of reasoning remains. It should be noted that determination of the area of the apertures blocked by safety designs on dependence $S_{OH} = 0.05V_0$ gives strongly overestimated area sizes at larger to values of volume of the room, so in this case the dependence is broken $S_0 \sim V_0^{2/3}$. At model operation of the first peak it is important to keep proportionality of perimeters of apertures of model and nature and therefore the perimeter of an aperture of model should be defined through the relation $(V_0^m / V_0^n)^{1/3}$, or through the relations $(S_0^m / S_0^n)^{1/2}$ in spite of what $S_0^m$ is defined incorrectly.

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