Fire Safety Journal 87 (2017) 1–9

Contents lists available at ScienceDirect

Fire Safety Journal

journal homepage: www.elsevier.com/locate/firesaf

Simplified function of indoor gas explosion in residential buildings

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ARTICLE INFO

Keywords:
Gas
Explosion
Pressure
Buildings
FEM

ABSTRACT

An original function describing the occurrence of indoor gas explosion in residential buildings has been presented in the paper. The function has been developed in order to simplify the description of explosion occurrence with its principal parameters, pressure and dynamics, being retained. It is a self-adaptative function, which means that its time function depends on the condition of construction elements, mainly decompressing areas called vents. The function consists of two parts. One is the phase of explosion pressure increase and the second is the decompression phase described by the $f_{vent.}$ modifier. The multiplication of the explosion pressure increase function and the $f_{vent.}$ modifier provides a final description of a pressure function for a vented explosion. The proposed function dependence enables an efficient dynamic analysis of three-dimensional models of building structures by means of the FEM.

1. Introduction

The use of natural gas as an energy medium in households has many advantages, one of them being the economic issue. Gas fuels are treated as the next stage in the development of usable energy, because of the fact that the global resources of this fuel are sufficient in relation to the current and projected needs. The methods of gas capture are innovated and new gas reservoirs and sources are developed (shale gas, gas hydrates, etc.). In addition, gas fuels currently are treated as more environmentally friendly than other sources of energy, which is especially important according to recent ecological trends.

However, gas fuels have also disadvantages. One of the major drawbacks of gas fuels is its vulnerability to the occurrence of the explosion phenomenon, which can have disastrous consequences for the safety of building constructions and people living in them. Research of gas explosion causes indicates that the important issue is the human factor, e.g. human inattention, ignorance of danger and carelessness. This relates also to the potential hazards connected with other explosion factors, for example very dangerous dusts [1], which are the result of industrial processes, transportation or storage of different materials. Therefore even the most modern electronic warning and security systems are not able to completely eliminate the risk of gas explosion.

Evaluation research of the causes and effects of gas explosion in residential buildings has been conducted by the authors of this paper. The research was carried out under a government grant to a multi-field team of the Building Research Institute in Warsaw, the Central Mining Institute in Katowice and the Oil and Gas Institute in Cracow. The research results can be found in the report made by Krzystolik [15] (in Polish).

One of the tasks was to analyze the three-dimensional computer models of buildings loaded by the pressure of gas explosion. Research has been carried out in terms of the dynamic response of buildings loaded by a pressure function variable in time. To accomplish the task, the development of own model of a pressure time-variable function was required. An elaborated time-variable function has been presented in this article. The purpose for the use of such a function was to increase the accuracy and efficiency of the numerical analysis for three-dimensional models of buildings.

2. Research problem

The loading of a three-dimensional numerical model of a building, in the simplest way can be done by solving the basic equations well-known from literature [18,2,3,20] describing the phenomenon of the indoor gas explosion. The phenomenon is described by two equations: the mass conservation Eq. (1) and the energy balance Eq. (2). For partially open spaces (rooms) equations of combustion products outflowing through the opening should be also indicated, for example in the form of expressions (3)–(5). Further in this article, openings, which in buildings are mostly windows and doors, are called decompression areas or vents. The greatest pressure is called the maximum vented explosion pressure P_{red}.

In order to increase the clarity of the article, Eqs. (1)–(5) have been presented below.

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http://dx.doi.org/10.1016/j.firesaf.2016.10.004
Received 6 November 2015; Received in revised form 19 October 2016; Accepted 24 October 2016
Available online 10 November 2016

1. Equation of mass conservation.

$$\frac{dx_u}{dt} + \frac{dx_b}{dt} + \left(\frac{dx_{vu}}{dt} + \frac{dx_{vb}}{dt}\right) = 0 \tag{1}$$

2. Equation of energy balance.

$$\frac{d}{dt}(x_u U_u) + \frac{d}{dt}(x_b U_b) + (U_{vu}\frac{dx_{vu}}{dt} + U_{vb}\frac{dx_{vb}}{dt}) + \frac{dq}{dt} = 0$$
$$U = u_o + \Delta u$$
$$\Delta u = u(T) - u(T_o) \tag{2}$$

3. Equations of gases outflow through the decompressing area (vent), for example:

– for the subcritical outflow,

$$\frac{dx_v}{dt} = C_d \cdot \frac{A_v}{m_o} \cdot \sqrt{\frac{2\cdot\kappa\cdot P\cdot\rho}{\kappa - 1}\left(\frac{P_{at}}{P}\right)^{\frac{2}{\kappa}}\left[1 - \left(\frac{P_{at}}{P}\right)^{\frac{\kappa-1}{\kappa}}\right]} \tag{3}$$

– for the critical outflow,

$$\frac{dx_v}{dt} = C_d \cdot \frac{A_v}{m_o} \cdot \sqrt{\kappa\cdot P\cdot\rho\cdot\left(\frac{2}{\kappa + 1}\right)^{\frac{\kappa+1}{\kappa-1}}} \tag{4}$$

4. Equation of velocity of the combustion products formation.

$$\frac{dx_b}{dt} = \frac{1}{m_o}\cdot\rho_u\cdot S_u\cdot A_f - \frac{dx_v}{dt} \tag{5}$$

where:

– x – mass fraction of gas mixture in a given phase, $x_{phase}=m_{phase}/m_o$,
– o, u, b, v – indexes denoting the initial state, unburnt mixture, burnt mixture and ventilated mixture respectively,
– u_o – internal energy of formation corresponding to T_o and P_o,
– $u(T)$– internal specific energy at T temperature,
– q – heat per mass unit exchanged with vessel walls,
– A_v – vent area,
– P_{at} – ambient (outflow) pressure,
– C_d – outflow coefficient,
– A_f – flame area,
– S_u – combustion velocity.

The numerical analysis of the explosion phenomenon using the above (1–5) formulas is quite time-consuming. Especially in case of a three-dimensional analysis for the explosion phenomenon and for the building construction model. In addition, some researchers state directly that the results obtained from the analytical solutions are not always satisfying, for example Lunn [16]. This is caused by the complexity of the explosion process and its sensitivity to the conditions in which it takes place.

In the engineering practice it is often sufficient to know the value of the maximum vented explosion pressure P_{red}. Then the analysis of a building structure is limited only to a static analysis. That is why the empirical and semi-empirical methods used to determine the pressure value P_{red}, for example Rasbash et al. [21], Rasbash and Rogowski [22], Dragosavic [13], Burgoyne and Wilson [7] or Cubbage and Simmonds [11], etc. are very popular. Examples of comparative analyses has been given by Razus and Krause [23].

In a dynamic analysis of building construction response, the simplification in the form of triangular approximation of the explosion pressure time function is applied [3,25], Fig. 1.

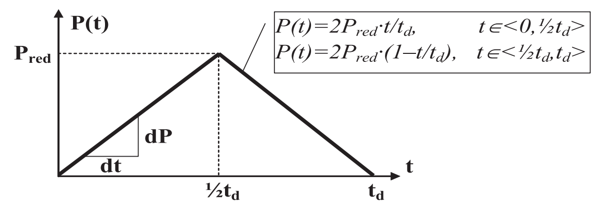

Fig. 1. Triangular approximation of explosion pressure.

The triangular function is useful when its parameters are known: P_{red} and time duration t_d. The authors' aim, however, was to develop such a function whose parameters adapt themselves automatically to the conditions of a structure and its decompressing areas (vents). The opening of the vents has a significant influence on the time-characteristics of the explosion process. This function has been called as a self-adaptative, which means that the algorithm can change the time values of pressure according to the changes of system load – construction and in particular to the changes of the vent parameters. The algorithm has been denoted as the *SVEF – the Simplified Vented Explosion Function*. The idea of the *SVEF* is the maximum simplification of the algorithm and the elimination of the necessity of solving the set of differential equations describing an explosion in a three-dimensional space. The function has been implemented into the author's FEM system ORCAN, which is available on the website: http://kmb.pb.edu.pl/dydaktyka/tchyzy/orcan.html.

3. Definition and assumptions of the simplified explosion function

3.1. The phase of the explosion pressure increase

It has been assumed that the function increases in the same way as in the case of a constant volume explosion (a closed vessel – unvented explosion) and reaches the maximum possible value of the pressure for a given gas or mixture P_{max}. The trigonometric function shown in Fig. 2 has been used to describe this phase.

The fundamental assumptions of the *SVEF* function in the unvented phase are:

1. The gas explosion takes place in rooms of a cuboid shape which are the most typical for residential buildings. It has been assumed that $L_{max}/L_{min} \leq 3$, where L_{max} and L_{min} denote the maximum and the minimum dimension of a cuboid room respectively.
2. The explosion is a deflagration by nature, i.e. the burning zone propagation is slower than the sound speed in the not burning mixture.
3. The ignition initiator is located close to the centre of the gas-filled area.

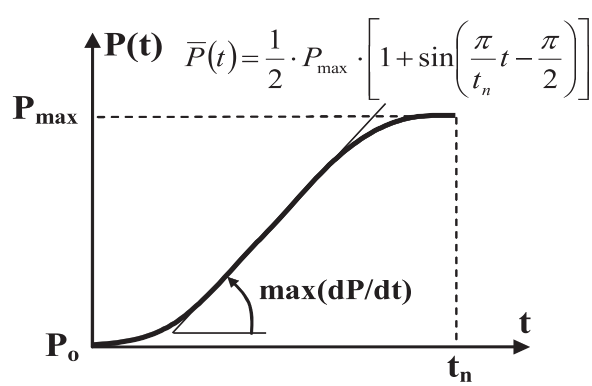

Fig. 2. Trigonometric function idealization.