ECCOMAS Congress 2016
VII European Congress on Computational Methods in Applied Sciences and Engineering
M. Papadrakakis, V. Papadopoulos, G. Stefanou, V. Plevris (eds.)
Crete Island, Greece, 5–10 June 2016

INFLUENCE OF ADJACENT ROOMS ON THE DEVELOPMENT OF GAS EXPLOSION

Polandov Iu.Kh.*[1], Dobrikov S.A.[1]

[1] Orel State University, Scientific - educational center "Fluid Mechanics. Combustion", Naugorskoe shosse 29, Orel, Russia, 302020
E-mail; polandov@yandex.ru

Keywords: room gas explosion, the place of ignition.

Abstract. *The physical experiment conducted at the Moscow State University of Civil Engineering (MSUCE) has revealed that the pressure of a gas explosion in a room with a window and a hole in an adjacent room in the more than two times higher than a similar explosion in a single room. In the experiment, the ignition is located in the center of the room and there was no gas in the adjacent room.*

Our numerical experiments confirm this fact. Calculations were performed using the software "Vulkan-2M", which is based on the method of large particles. Simulated room consisted of two chambers size of 0.5m x 0.5m x 0.5m each with a hole size of 0.15m x 0.15m between them. The first chamber was filled with a stoichiometric mixture of propane-air and had a window size of 0.15m.

Pressure increasing effect reaches a maximum when the ignition is in the area between the window and the center of the first chamber. The pressure is increased more than twice in this case in comparison with a single blast chamber. The effect is minimal when the ignition is closer to a window or a hole between the chambers. These results can be used to assess the risk of explosion.

1 SHORT REWIEV

Researchers from Moscow State University of Civil Engineering (MSUCE) (Mishuev A.V., Kazionnov V.V., Gromov N.V. and others*)* [1] described the effect of increasing the pressure of the explosion in the presence of an adjacent chamber, connected to the vented explosion chamber. They found an increase in overpressure of 2.5 times compared to the same explosion without a hole between the chambers. These results are consistent with earlier studies of Molkov V.V. [2].

The rules of the European Union [3, 4], the USA [5, 6, 7] and Russia [8, 9, 10] does not take into account the effect of the adjacent cameras on the development of explosion. In spite of the different standards, the style and the different calculation formulas, all these documents have a common drawback. Their results based on the quasi-static pressure in the room that is not taken into account the distribution of the parameters of the gas in the chamber volume. The method of quasi-static pressure makes it possible to determine the shape and the flame front area based only on the phenomenological models, in which there is no turbulence. It is not possible to use such a model to account for the maximum pressure in the event of an adjacent room. Only experimental researches or CFD-methods can solve this problem. However, such studies have not been conducted in Europe, even in such research centers as the FM Global (Toronto, USA) [11], known for his experimental work.

Article by software developers FLACS [12] close to the theme of this work. This article describes the development of simulation of a gas flame in the two adjacent chambers filled with gas. However, the authors are more interested in the accuracy of numerical model than in the mechanics of explosion and hazard assessment.

Vodyanik V.I. [13] also considered the development of a flame inside two communicating vessels. In his experiment, the gas fills both of the vessel before the explosion, so that the results are not relevant to the subject.

To this is the closest Molkov's [2] study in which he analyzes pilot burst in the tank from which the volume of 2 m^3 gas out through line into another tank volume 3.5 m^3 which was filled with air. He found that in some experiments the pressure in the receiving vessel during the explosion becomes greater than the pressure in the first tank.

In addition, he established the dependence of explosion from the ignition location of the device in the first tank, which allowed him to explain the reason for this effect. Unfortunately, the studies were not specific for the explosion in the room such as the kitchen where there is a window through which the gases vented to the atmosphere apart holes between rooms.

Thus, the research of scientists from MSUCE are new in this issue.

2 THE HYPOTHESYS

It is known that the place of ignition of gas in the room greatly affect the development of the explosion [3, 5, 11]. These researches show that the farther the place of gas ignition from vent, the greater the maximum explosion pressure. Experimental studies were conducted which confirmed earlier [14, 16] these data, it was found that the impact of this effect (from 0 to 20 times with the difference from maximum pressure) is more complex in dependence on the window size and shape of the room. In this context, and based on the experience Molkov V.V. We can expect that somewhere a source of ignition in explosions in two adjoining rooms, one of which is filled with gas, and the window will also affect the development of the explosion.

We offer three versions of the explosion in this case.

The first case. The source is located near the hole in the next room. The products of combustion will flow into the next room, not gas-air mixture. In this case, the adjacent room will act as a damper.

The second case. Upon ignition of the mixture near the center of the room, it can be expected that the gas mixture will fall into the next room, where it will burn. However, hole will turbulence mixture, it should dramatically increase the area of the flame front and explosion pressure.

The third case. The gas is ignited near the window. In this case, the maximum amount of mixture enters the next room. But it enters into force known pressure lowering effect of an explosion if ignited near a window. The explosion pressure will depend on the ratio of these two factors.

Therefore, we decided to investigate the relationship between the maximum pressure of gas explosion and ignition of the gas mixture space.

3 RESEARCH TOOLS

In drawing up the mathematical model of the process, we have made the following assumptions concerning the simulated environment:

1. The initial mixture of propane-air is a homogeneous and stoichiometric;
2. The difference between the thermodynamic characteristics of the original mixture and the combustion products is negligible;
3. The gases in the physical process is inviscid and are ideal fluid;
4. The combustion reaction occurs at the boundary of the original mixture and the combustion products.

Given the assumptions, the problem is reduced to modeling the dynamics of the gas with uniform properties by using one of the methods for the unsteady multidimensional problems of fluid mechanics (CFD). The choice of a particular method is limited by arbitrary geometry of the computational domain, as well as the possibility of taking into account the availability of features in the simulated currents. As a basic system of equations to describe the dynamics of the medium was used known system of Euler equations in divergence form, closable equation of state.

On the domain of integration is superimposed Euler (fixed) grid of rectangular cells with sides Δx, Δy и Δz. Numerical solution of the system is carried out by large particles method, LPM [16], which is based on the idea of Harlow n particles in the cell, allowing splitting of physical processes. However, in the LPM instead small solids particles replaced by a single a drop of liquid, fill the entire volume of the cell. Method of large particles as well as other modern methods such as Godunov method [17], FLACS [12] et al., allow us to study the gasdynamic flow without a priori information about the structure of the solution. The calculation consists of repetitive time steps. In turn, each such step includes three steps:

1. "Euler" stage, when neglected all effects associated with the movement of the fluid (mass flow through the faces of the cells is not);
2. "Lagrangian" stage, where the calculated mass flow through the cell boundaries;
3. The final stage, which determines the final flow parameters based on conservation laws for each cell and the entire system as a whole.

The system includes equations that describe the process of heat and mass transfer with the environment and the process of propagation the flame. Cooling processes on the chamber walls are estimated based on physical experiments carried out according to pressure drop in the explosion in a closed chamber. To calculate the flow through the open border to border pressure cell is assumed equal to the average between the pressures in the chamber and atmospheric.

Two additional parameters, "the mass fraction of combustion products in the chamber," and "the mass fraction of the formation of the products of combustion", introduced for the simulation of flame propagation. The first parameter in the cell determined by the position of the flame front, which moves toward the initial mixture at a rate equal to the sum of the gas flow velocity and the normal combustion rate. The second parameter, the mass fraction of newly formed products of combustion is determined by taking into account only the normal burn rate, and takes into account only if the flame front is located within the cell.

In the system of equations in the equation of conservation of momentum, we have taken into account the effect of buoyancy.

The computer model uses 7 types of cells:

– calculated cells - which are carried out of the equation;
– border cells provide impermeability condition;
– flow cells - which connect the cells of calculated area with the atmosphere;
– flame front - cells in which combustion occurs;
– cells with the products of combustion;
– air cells - which are filled with air;
– non-calculated cells - which are located behind the border and fix their properties.

Fig. 1 shows a diagram of the calculated volume that is represented by two cameras, one of which (left) filled with gas, and the second - the air. Overall dimensions make 0.5x0.5x1.0 m. Designated ignition of the gas mixture are in the left chamber. Ribs cells taken equal $\Delta x=\Delta y=\Delta z=0.01$ m, so that only received about 100,000 cell, the time step $\Delta t=5\cdot10$-7 s with that by a wide margin meets the criterion of stability Courant - Friedrichs - Lewy. This margin is accepted, because the equations describing the propagation of flame, adversely affect the stability of the account.

On fig. 2 shows a typical picture of the explosion. In this case, the vector lines are shown as lines Bezier, flame front - red cells, and other gases are painted on a scale that the higher the temperature, the lighter background.

4 THE SIMULATION RESULTS

a) An explosion in solitary chamber

In the first stage, experiences were conducted with a gas explosion in a solitary chamber with disconnecting adjacent chamber. The simulation results shown in figure 2.

It is seen that with the appearance of the flame front starts expiration of the initial mixture to the atmosphere. The flame front initially increases as a sphere, and then starts to be pulled towards the vent. As soon as the flame front will come to the vent, begin to expire the flame cell. In the last step, expire only products of combustion. Released source mixture of gas burns outside the chamber in the atmosphere.

According to the data, is shown in figure 3, it is evident that the time of fire is not exceed 0.6 seconds at any position of the igniter in chamber. In addition, it traced unique relation between the parameters of the explosion and the place of ignition of gas.

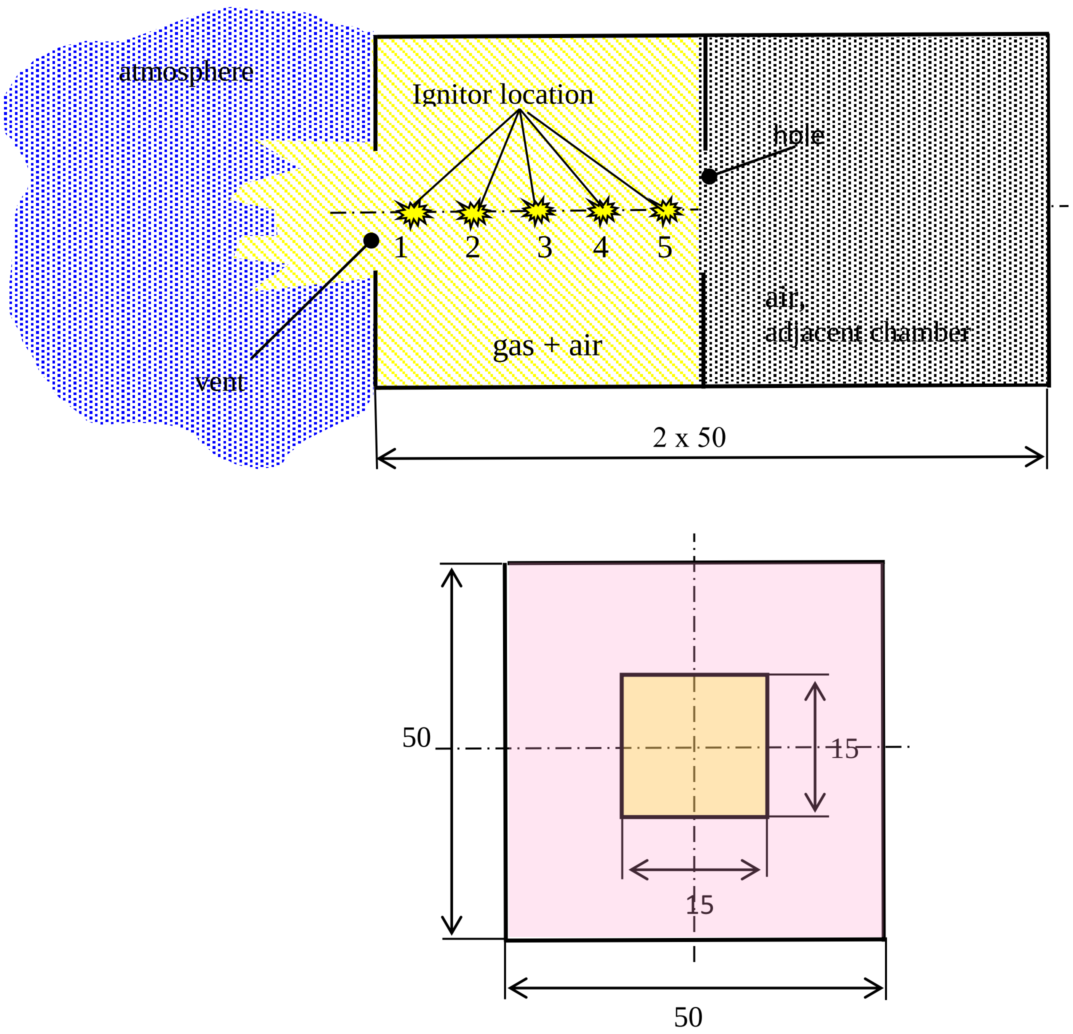

Figure 1: Calculated scheme 2-chamber unit (dimensions in cm)

Firstly, the farther from the window is igniter, the shorter the time of the explosion, the more the primary mixture is ejected in atmosphere out and flame particles. Second, the farther from the window ignition occurs, the greater the pressure of an explosion (fig. 4), in this case a factor of 2, which confirms the above results known. In a graph, this result is shown in fig. 7 (curve 1).

b) explosion in chamber in the presence of adjacent chamber

At first glance, the presence of the adjacent chamber with the explosion (fig. 4) should lead to a simple damping process in its dynamic development. It is certainly true, but not entirely so. At first, with increasing pressure in the first chamber starts flowing gas mixture it into the next. Due to the leak, mixture begins to increase the pressure in the adjacent cell. Therefore, the amount of the mixture received into an adjacent chamber can be estimated by the pressure, which is reached in an explosion. In this case, the excess pressure is from 6 to 20 barg. Therefore, in the adjacent volume chamber gases arrive from 6 to 20% of the chamber volume. This, of course, raises the question, what kind of gas is supplied to an adjacent camera? The answer is quite simple. Composition of gas entering in the adjacent chamber it depends on whether approached to the hole of the flame front or not. If you have not yet approached the combustion front, only the initial mixture is fed into an adjacent chamber when approached, they begin to enter the combustion products.

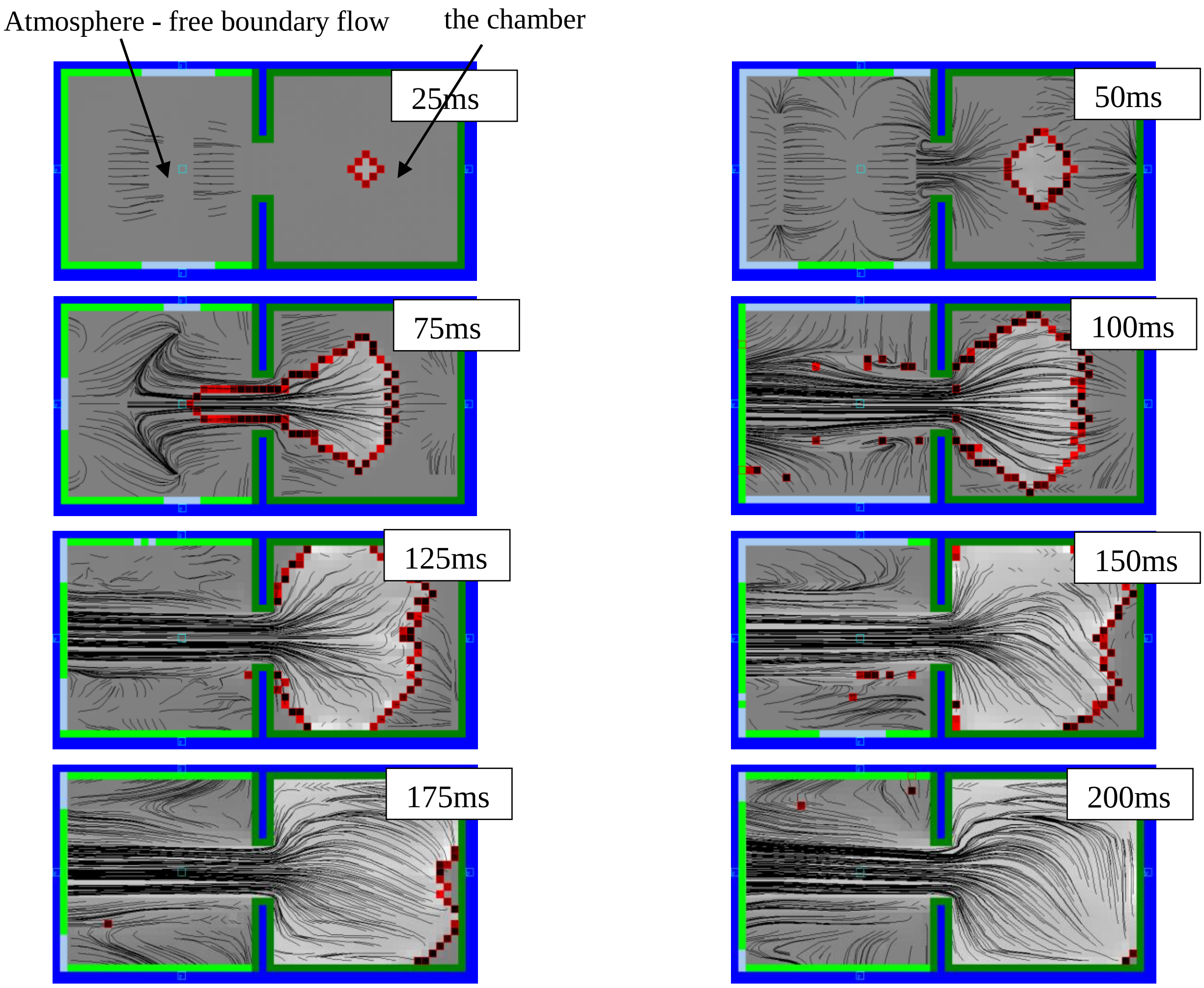

Figure 2: The picture of gas explosion in solitary chamber when ignition in position 3

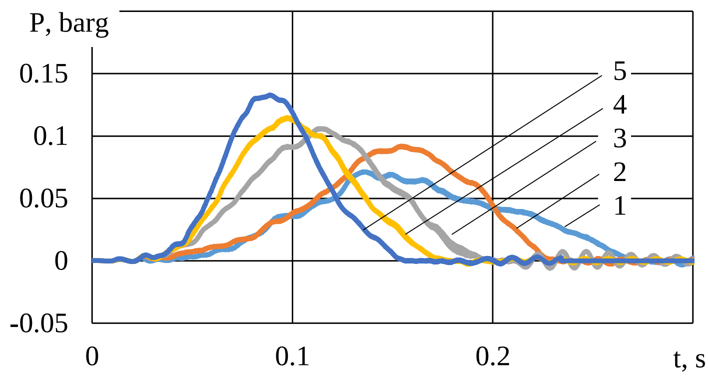

Figure 3: Dynamics of explosion pressure depending on the position igniter in the solitary chamber

The change in time of pressure in the explosion chambers is shown in fig. 5 and 6. The number of each curve corresponds to the number igniter place according to fig. 1. The greatest pressure reaches values in position 2. When you install the ignition at the passage into the adjoining chamber, the pressure of the explosion nearly corresponds to the pressure in solitary confinement. In addition, when installing igniter close to the vent, pressure is lower than the maximum, but higher than in solitary confinement.

It is understood that the earlier the ignition of the mixture in the adjacent cell, the higher pressure will be in the first chamber. This effect is particularly strong if the ignition happens when the pressure in the first chamber increases. However, the closer to the passage of ignition occurs, in the adjacent room is less than the initial mixture. In this case, the "help" the adjacent room to increase the pressure will decrease.

c) Comparing the results of numerical and physical experiments

Comparison of numerical simulation results and the results that have been obtained researchers at the MSUCE shown in figure 7.

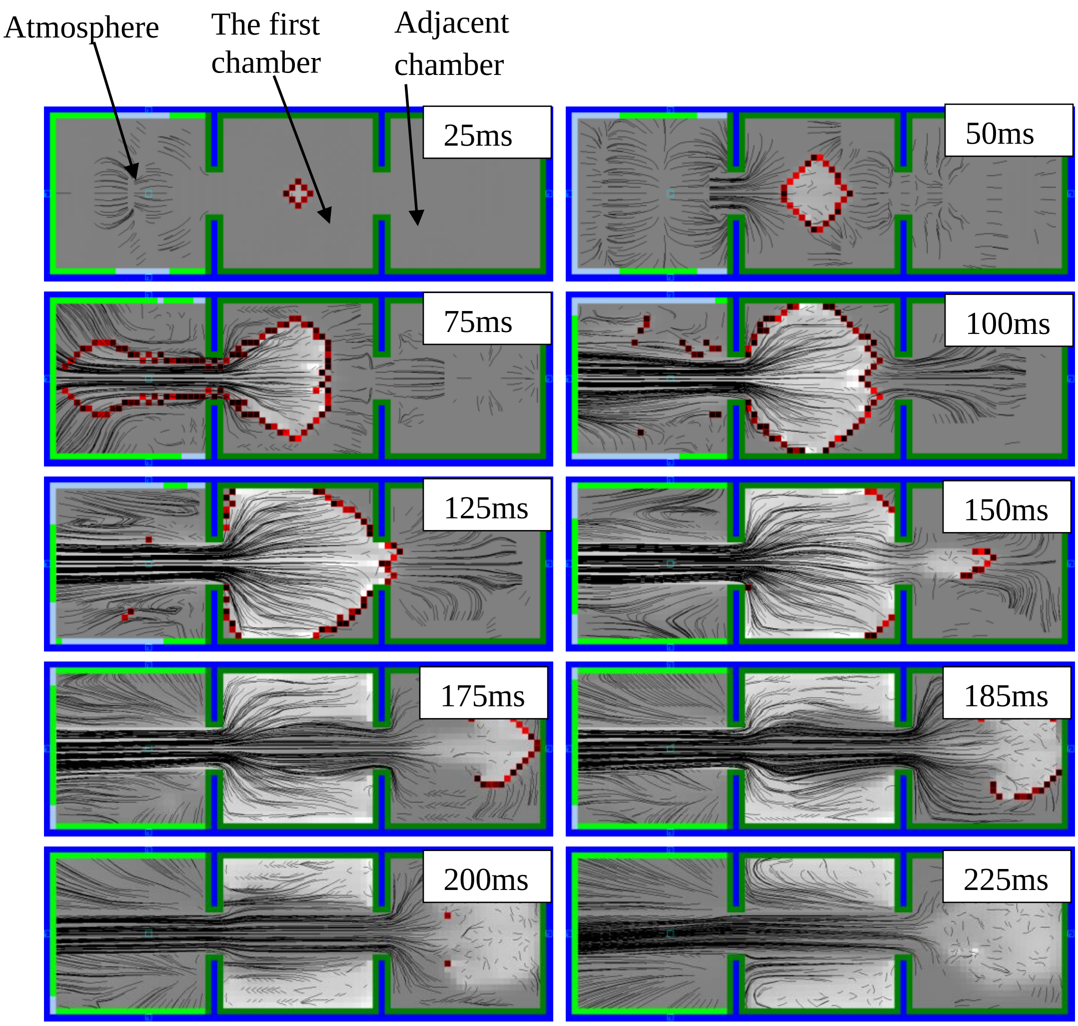

Figure 4: The picture of gas explosion in solitary confinement at position igniter 3

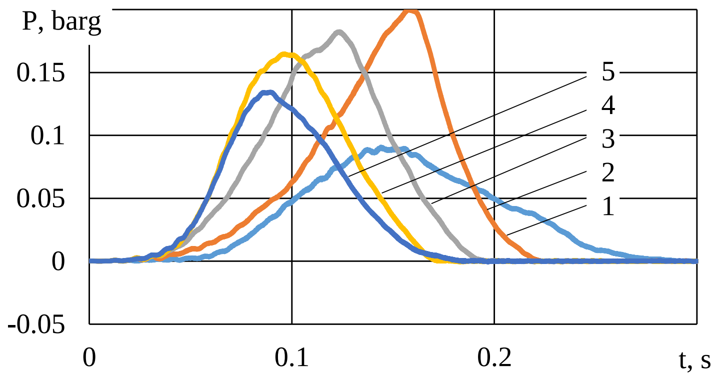

Figure 5: The development of pressure in the explosion in the chamber together with the adjacent chamber at different positions ignition

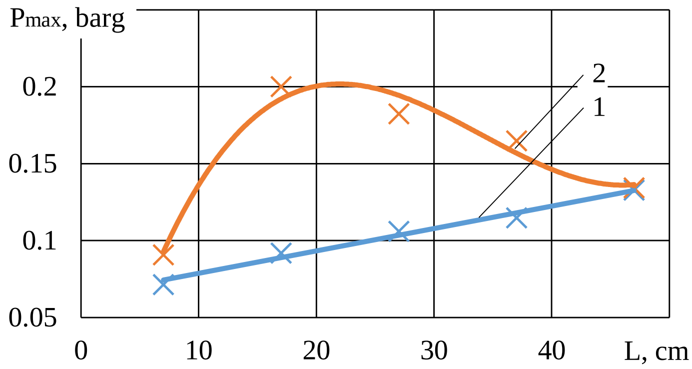

Figure 6: Regression curves $P_{max} = P$ (L),
where P_{max} - maximum pressure in the explosion;
L - the distance from the vent, cm;
1 - single chamber; 2 - together with the adjacent

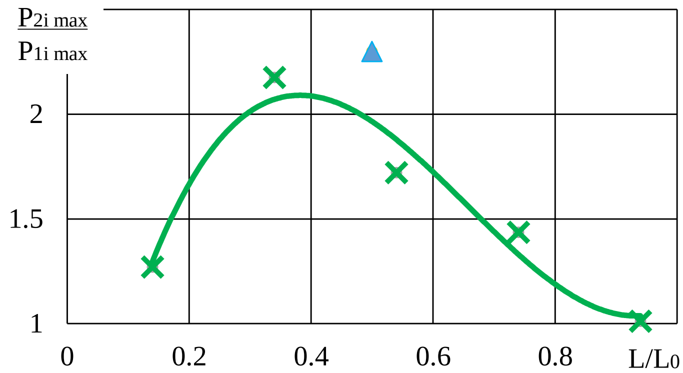

Figure 7: Comparison of the results of computing and physical experiments
Symbol Δ denotes the result of a physical experiment in MSUCE.

It must be borne in mind that the installation had different geometrical dimensions, although the ratio $(V^{2/3} / F)_c = 11.1$, and $(V^{2/3} / F)_e = 12$, where V - volume of the first chamber, m^3 and F - m^2 vent area, both systems have similar values. If in addition to this, use the relative pressure and the distance from the ignition space by entering them in the calculations and the physical experiment, it seems a formal opportunity to make such a comparison. It is best to do this by plotting $P_{2i\ max}$ /$P_{1i\ max}$=f (L/L_{0}), where $P_{2i\ max}$ - maximum explosion pressure with the adjacent chamber in 1th position; $P_{1i\ max}$ - the maximum pressure in the explosion in solitary chamber in the 1 - position; and L/L_0, where L - distance from Vent to the place of installation of igniter and L_0 - distance from vent to pass into the adjoining chamber. We see an acceptable coincidence. It is understood that the proposed dimensionless quantities not fully correspond to the concept of criteria but they allow somehow compare with each other the results obtained under various conditions.

5 CONCLUSION

These results confirms the hypothesis about the influence of gas ignition locations for the development of the explosion in the chamber. It was found that when ignited gas near passage into the adjoining chamber explosion pressure is almost the same as in an explosion in a separate room. Influence of combustion is shown at center of the chamber and, especially, in the space between the center and vent. However, when ignited near the vent begins to affect other effect: release of combustion products with a high temperature of the flame, resulting in the effect of the adjacent rooms on the development of the process is reduced.

REFERENCES

[1] Mishuev A. V., Kazyennov V. V., Komarov A. A., Gromov N. V., Lukyanov A. V., Prozorovskiy D. V. Osobennosti avariynykh vzryvov vnutri zhilykh gazifitsirovannykh zdaniy i promyshlennykh obyektov [Peculiar properties of emergency blasts inside gasified buildings and industrial objects]. Pozharovzryvobezopasnost – Fire and Explosion Safety, 2012, vol. 21, no. 3, pp. 49–56.

[2] Molkov V. V. Dinamika sgoraniya gaza v negermetichnom sosude. Dis. kand fiz.-mat. nauk [The dynamics of the combustion gas in the sealed container. [Cand. phys. and math. sci. diss.]. Moscow, Moscow Engineering Physics Institute Publ., 2006. 211 p.

[3] EN 14994:2007. Gas explosion venting protective systems. BSI, 2007. Available at: http://shop.bsigroup.com/ProductDetail/?pid=000000000030117073 (Accessed 25 October 2015).

[4] EN 14797:2006. Explosion venting devices. BSI, 2007. Available at: http://shop.bsigroup.com/ProductDetail/?pid=000000000030104794 (Accessed 25 October 2015).

[5] NFPA 68:2007, Standard on explosion protection by deflagration venting. USA, Quincy, National Fire Protection Association, 2007.

[6] Ismaila A., Andrews G. E., Abdullahi I., Nasiru R, Abdullahi Y. A. Venting as a means of mitigating explosions: The need to revised European and USA (NFPA68) guidance for explosion venting. *Archives of Applied Science Research*, 2012, vol. 4, no. 1, pp. 155-168.

[7] Bauwens C. R., Chaffee J., Dorofeev S. Experimental and numerical study of methane-air deflagrations in a vented enclosure. *Proceedings of the Ninth International Symposium “Fire Safety Science”*, vol. 9, pp. 1043–1054. DOI: 10.3801/IAFSS.FSS.9-1043.

[8] State standard 12.3.047–2012. Occupational safety standards system. Fire safety of technological processes. General requirements. Methods of control. Moscow, Standartinform Publ., 2014. 65 p. (in Russian).

[9] Set of rules 12.13130.2009. Determination of categories of rooms, buildings and external installations on explosion and fire hazard. Moscow, All-Russian Research Institute for Fire Protection of Emercom of Russia Publ., 2009. 27 p. (in Russian).

[10] Set of rules 89.13330.2012. Combustion boiler systems of heating generation. Moscow, FAU "FCC" Publ., 2013.

[11] Bauwens C. R., Chaffee J., Dorofeev S. Effect of ignition location, vent size, and obstacles on vented explosion overpressures in propane-air mixtures. *Combustion Science and Technology*, 2010, vol. 182, issue 11-12, pp. 1915–1932. DOI: 10.1080/00102202.2010.497415.

[12] Helene Hisken Pedersen, Gary Tomlinc, Prankul Middhab, Herodotos Phylaktouc, Gordon Andrewsc. Comparison of FLACS Simulations against large-scale vented gas explosion experiments in a twin compartment enclosure.

[13] Vodyanik V. I. Vzryvobezopasnost tekhnologicheskogo oborudovaniya [Explosion technological equipment]. Moscow, Khimiya Publ., 1991. 254 p.

[14] Polandov Yu. H., Barg M. A., Vlasenko S. A. Modelirovaniye protsessa goreniya gazovozdushnoy smesi metodom krupnykh chastits [Simulation of combustion gas mixture by large particles]. *Pozharovzryvobezopasnost – Fire and Explosion Safety*, 2007, vol. 16, no. 3, pp. 6–9.

[15] Belocerkovskii O. M., Davidov Yu. M. Method of large particles in the gas dynamics. Moscow, Science, 1982. 370.

[16] Polandov Yu. Kh., Babankov V. A. Vliyaniye mesta raspolozheniya istochnika vosplameneniya v pomeshchenii na razvitiye vzryva gaza Effect of location source of fire in the room on the development of gas explosion]. *Pozharovzryvobezopasnost – Fire and Explosion Safety*, 2014, vol. 23, no. 3, pp. 68–74.

[17] Godunov S. K., A difference method for numerical calculation of discontinuous solutions of the equations of hydrodynamics, *Mat. Sb. (N.S.)*, 47(89):3 (1959), 271–306