On conditions for reducing the hazard of a gas explosion in the kitchen

Iurii H. Polandov, Vitalii A. Babankov and Sergei A. Dobrikov

Abstract. Often gas explosions occur in amenity rooms and, especially, in the kitchen. During the research, as a rule, pressure is studied as the development of such process, under the influence of which rooms can be destroyed. While doing this, one can miss not less dangerous factor - high temperature of combustion products, under the influence of which fire can occur. Meanwhile, it seems that its more preferable to assess not only the possibility of destruction of a building, but also the risk of fire.

At the same time, of course, to assess the danger of destruction of the rooms during the explosion, it is reasonable to use a well - known process indicator - pressure. But for assessing the fire hazard of explosion it is proposed to use a measure called the index of fire danger in the gas explosion (briefly If), defined as the integral over time of the difference between the temperature of the gases in the room and the ignition temperature of the interior of the kitchen: the increase in the index corresponds to an increase of fire hazard.

Based on the results of the physical experiment it is shown that when $k=S/V^{2/3}>0,03$ where S is the area of the window, m^2; V is the volume of the room, m^3, that is, for most ordinary kitchens, the idea that the approximation of the gas stove to the window contributes to the reduced explosion pressure, remains in force. In addition, analysis using a numerical model based on the method of large particles showed that the traditional arrangement of furniture along the walls is the most preferable from the point of view of reducing the pressure of a possible explosion, and from the point of view of reducing fire hazard.

Key Words**:** simulation and physical experiment, the gas in the room, explosion, pressure, index of fire hazard in an explosion. [1]

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I. Introduction

Is known that after the growth of the number of explosions and fires associated with increasing gasification of countries, there was a decrease in the number of explosions, but recently the time of relative stabilization has taken place.

This obviously is due to the fact that the applied measures to reduce the number of explosions have exhausted its potentialities. To shift the current "parity" between the level of gasification and the frequency of the explosions occurrence and fires in the right direction, new ideas and technical solutions are needed, which, on the one hand, will reduce the risk of explosion and, on the other hand, have a low dependence on the human factor.

This can be adequately implemented, in particular through a new look at the physics of the process, its modeling, which allows to take into account the distribution of gas due to the volume, in which the explosion occurs. But, as it is known that the simulation of such processes, in recent years, especially numerical, faced with the complexity of the calculation, but the rapid development of computer technology every year better meets the needs of researchers.

II. Research Objectives In The Explosions In The Premises

The hazard of gas explosions in buildings lies in destructive properties of the resulting excess pressure and the ability of the combustion products to cause fire. Due to the significant difference between the mechanisms of these processes, research tasks are divided into two groups: we assign tasks related to the pressure dynamics to the former, and the task of heat transfer between the combustion products and the kitchen interior to the latter.

A. Research Objectives in the Dynamics of Explosion Pressure

Known results of studies of gas explosions on models and approximating the natural size of the room [10]–[13], [18]–[21], [26]–[28], [32], which prove two points: the first one, the approximation to the window (safety window) ignition source gas reduces the pressure of the explosion. And the second, the installation of barriers between the ignition source and the window leads to increases of the explosion pressure.

Of course, the results achieved are of considerable interest for the recommendations development on the arrangement of furniture and equipment to reduce the risk of gas explosion. Surely, the question may arise, how these results are related to the placement of furniture in the kitchen. The fact that the center of the open fire in the kitchen is often a gas stove and the area close to it, so in this case it is about the place of installation of the gas stove. The second result has a direct and natural attitude to furniture arrangement.

However, generally speaking, approvals, based on the results of physical or numerical experiments, are true only in those conditions in which the experiments have been conducted. In this case, only certain aspects of the gas explosion mechanics were reflected, which do not allow to use these results directly. The purpose of this study is to increase knowledge about the impact of furniture on the explosion hazard and the conditions under which this risk can be reduced.

Due to the first result it was decided to define the boundary of the claim justice according to the place of ignition on the character of the explosion development, in particular, due to the different sizes of windows. This is necessary for rooms, in order to use the first result, which have windows due to their geometry differ from those which were under the experiments.

And due to the second result to supplement it with study of the installation location influence of obstacles in the room on the explosion pressure.

B. The Index of the Potential Danger of fire when the Gas Explosion

Almost all known results of the gas explosions researches concerned, first of all, the dynamics of pressure, but temperature gases were taken into account only as a parameter affecting the pressure. In regard to the flammability risk, gas explosion is considered to be a powerful thermal pulse, at which inflammation of any combustible items and materials is possible.

Meanwhile, if we consider gas explosion to be a time-limited process and the heating of the materials from which the interior of the kitchen is made, up to the ignition temperature is also time-limited, so it is appropriate to take this factor into account. This approach allows us to introduce the notion of a flammability risk index for each point of room - $P_o(x, y, z)$ - gas explosion in the room, based on estimation of time of combustion products impact on combustible material.

It seems that the index Ipo value can be calculated on the basis of a simplified representation of heat transfer process from the gases to the combustible material. It is assumed that the transfer takes place by convection, which is described by Newton's equation:

$$Q(x,y,z) = \alpha F \int_0^{\infty} \left[T_g(x,y,z,t) - T_v(t) \right] dt, \qquad (1)$$

where α –is the heat transfer coefficient, $J/(m^2 s)$;

$T_g\ (x, y, z, t)$ – the temperature of the gases at the point with coordinates (x, y, z);

$T_v\ (t)$ – the surface temperature of the interior of the kitchen, K;

F – the area of the heating element surface, m^2;

t – time, s.

Let us note some features of this integral, the purpose of which is to characterize the parameters of gas at a specific point of physical fields, limited location:

• the value of the coefficient of heat transfer is determined by the shape and position of inflammable subject, but also the circumfluence conditions;

• the size of the square, through which heating of inflammable subject takes place, doesn't refer to the field characteristic;

• upper limit of integration is limited to the value of the time when gases cool down after the explosion, and the temperature difference becomes equal to zero;

• the temperature of the gases flowing a inflammable subject, is determined by calculation, and in every time and in every point of space;

• change interval values of T_i is in the range from normal temperature to the ignition temperature of the flammable object - T_v;

• taking into account the fact that in comparison with $T_g(x, y, z, t)$ changes $T(t)$ is negligible, then $T(t)$ can be given a constant value. It's more preferable to do this using the value of the ignition temperature of inflammable subject of T_v, because the danger of fire exists only at temperatures greater than T_v, and the difference $(T_g(x, y, z, t) - T_v)$ is related to the flammability risk.

Now, considering all the features of the integral (1), it can be replaced by more concrete and simple integral, emphasizing its value as an index of flammability risk during the gas explosion at each point of the estimated volume.

$$I_{fd}(x,y,z) = \int_0^{\infty} \left[T_g(x,y,z,t) - T_v \right] dt \qquad (2)$$

One should note, however, that during the process of integration the condition of nonnegativity of the integrand must be kept, that is, if $(T_g(x, y, z, t) - T_v)<0$, take the value of $(T_g(x, y, z, t) - T_v)=0$.

C. The Task of the Distribution of Flammability Risk in the Gas Explosion due to the Room Volume

Using the flammability risk index of gas explosion, it is possible to assess the level of risk of fire in each of its points when calculating the parameters of the explosion in the room, and to compare risk levels among each other. Thus the distribution of the fire risk level in the kitchen during the gas explosion will be defined.

III. The Influence Of The Window Size On The Pressure Dependence Of The Gas Explosion In The Premises From The Place Of Ignition

The problem is solved by conducting a physical experiment, which examined the development of gas explosion in a cylindrical chamber (d=200 mm, L=1500 mm). The chamber (Fig. 1) was filled with a stoichiometric mixture of propane and air, which was ignited by means of an electrical impulse and always in the same place at the end of the chamber, adopted at its beginning. During the explosion combustion products were released into the atmosphere through one of the three valves located on the cylindrical part of the chamber at the beginning of the chamber, in the middle of its length and at the end. The initial position of all valves is closed. During the initialization of one of the valve was opened and the hole sealed up the sheet of paper. The experiment was modified by two factors: the change in the place of the open valve and the valve size (from 20 mm to 70 mm). The experimental setup is equipped with a purging system of chamber and computerized systems of automatic control and measurement of pressure in the explosion.

It is found that with increasing distance between the open valve and a source of ignition increases the pressure of the explosion, and this dependence becomes On each of the graphs the results of 10 repeated experiments are combined, this is done to demonstrate the results reproducibility of and non - randomness of the conclusions. weaker with decreasing diameter of the holes (Fig. 2 and Fig. 3).

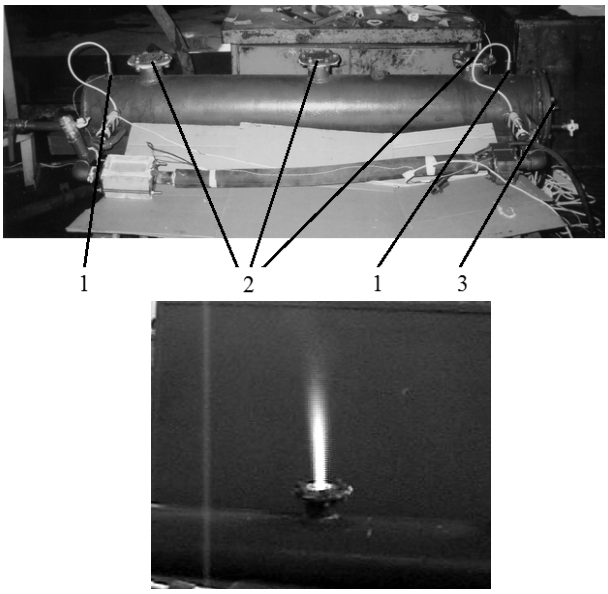

Fig. 1 general view of "Sergeant" and experienced an explosion: 1 - pressure sensors, 2 - place of the explosion-relief valve, 3 - ignition device fitting position

It may be noted that when the small valve size (d=20 mm) distance change has virtually no effect on the explosion pressure. In contrast to the large diameter (d=70 mm) changes in the location of the open valve pressure of the explosion varied more than an order of magnitude.

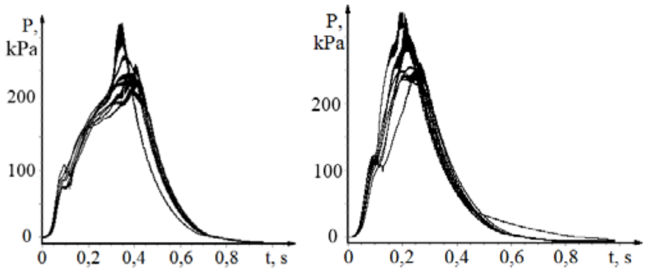

Fig. 2 stroke of pressure at explosions with a diameter of 20 mm valve: graph on the left – a source of ignition and the window are close; graph on the right – far from the source window

Using these data and the known (rough) measure of the degree of protection of the premises $k=F/V^{2/3}$ (F - cross-sectional area of the valve, m^2; V - value of the protected volume, m^3), it can be noted that according to the experiment, at values greater than k=0.03, there is a strong dependence of the pressure of the explosion from the location of the ignition source.

Projecting this result to the kitchen area, it can be noted that all known standards [15]–[18] make such demands to the size of the window in a hazardous location that is always k>0,03, it can be argued that for kitchen areas characterized by a strong dependence of the pressure of the explosion from the point ignition.

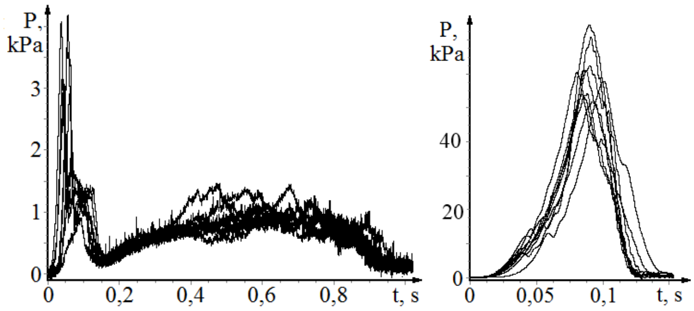

Fig. 3 stroke of pressure at explosions with a diameter of 70 mm valve: graph on the left – a source of ignition and the window are close; graph on the right – far from the source window

IV. The Numerical Model Of Gas Explosion In The Kitchen

The study was conducted by the method of numerical simulation. The mathematical model consists of three blocks: the original system of equations with initial and boundary conditions, models of flame spread and the method of numerical solution of the system.

A. The original system of equations.

In the original system of equations included known in gas dynamics differential equations in the form of Euler, expressing the basic laws of conservation (continuity equation, momentum and energy) relative to the ideal compressible discrepancy environment. The equation of conservation of momentum, in turn, is given in the form of three scalar equations.

B. The initial and boundary conditions

It is assumed that all space is filled with a stoichiometric composition of methane-air mixtures, the initial pressure and temperature of the mixture has a normal value. Boundaries of the room impermeable, in explosions gas is ejected through the window. The gas composition is not changed in the process is the same combustion and air. Window is a weightless and collapsing at the initial moment of the explosion.

C. The system of equations.

The system is solved by a numerical method developed by Belotserkovskii O.M. and Davydov Y.M. [30], called the method of large particles (LPM), which develops Harlow particle method [33]. LPM [30], along with the methods of Harlow [33], Godunov [29] and FLACS do not require prior knowledge of the structure of the flow. Under this method, the volume of kitchen was divided into cells of size 1 cm x 1 cm x 1 cm number of about 30,000 pieces, which are called calculated ones. On the borders of all the cells performed the laws of conservation of mass, momentum and energy. Distinguish boundary cells and cell expiration.

$$\begin{cases} \frac{\partial \rho}{\partial t} + div\left(\rho \overline{U}\right) = 0 \\ \frac{\partial \rho U_x}{\partial t} + div\left(U_x \rho \overline{U}\right) + \frac{\partial p}{\partial x} = 0 \\ \frac{\partial \rho U_y}{\partial t} + div\left(U_y \rho \overline{U}\right) + \frac{\partial p}{\partial y} = 0 \\ \frac{\partial \rho U_z}{\partial t} + div\left(U_z \rho \overline{U}\right) + \frac{\partial p}{\partial z} = 0 \\ \frac{\partial \rho B}{\partial t} + div\left(\mathrm{E} \rho \overline{U}\right) + div\left(p \overline{U}\right) = 0. \end{cases} \quad (3)$$

Encloses the system of equations of gas in the form of state

$$p = \rho I\left(\gamma - 1\right). \quad (4)$$

where

ρ – gas density, kg/m^3;

$\overline{U}$ – velocity vector, m/s;

E – specific total energy, J/kg;

p – pressure, Pa;

γ – adiabatic index of the medium;

I – specific internal energy, J/kg;

U_x, U_y, U_z – velocity components respectively along the axes x, y, z, m/s.

In calculated cells are conserved, approximated difference equations. In the border cells of the condition of impermeability by introducing them fictitious speed, direction normal to the interface inside volume and equal modulo speed computational cell, is also normal and oppositely directed to the border. On the outside of cells through which the outflow of medium pressure from the equivalent pressure values calculated in the short cell and the atmosphere. The magnitude of the time step is chosen based on the size of cells, and in accordance with the criterion of stability of computing, CFL condition, in our case $\Delta t = 5 \cdot 10^{-7}$s. As is known, the solution is sought in three stages, called Euler's stage, Lagrange and final. Despite the fact that the system of linear equations can be solved explicitly, the solution is stable.

D. Model of flame propagation

For simulation of flame propagation introduced a new variable – the mass fraction of combustion products in a cell that is equivalent to applying a fourth type of cells in which the line moves separating the products of combustion and the initial mixture. This technique has allowed not only to monitor the combustion process for the line section, but using the difference in the calculation of heat in the general algorithm. Movement is carried out inside the cell lines at a rate equal to the normal combustion rate, which depends on the temperature and pressure in the starting mixture. We consider separately the issue of transition line section through the cell border. More detail the movement of the line described in the software product "Voulcan – M" [14].

Using additional cell type affects the stability of the solution, it degrades, so as experience has shown [31], it became necessary to carry out calculations with increased reserves by sustainability.

E. Taking into account the losses on the borders volume

Studies conducted previously by us revealed a fairly noticeable effect of heat loss on the borders of the volume on the parameters of explosion. Are taken into account, according to [14] amended to incorporate these heat losses.

F. Visualization of the calculations.

A data base is being calculated allowed to visualize the process of the explosion, to follow the condition of parameters at each step of the account. To facilitate the monitoring of the development of the explosion, the cells are painted in different colors. Since the velocity vectors are known in each cell, it has been possible to see the vector lines (trajectories), on which moves the gas medium.

According to the calculation the dynamics graphs of the individual parameters are plotted.

G. Demonstration of adequacy of model

For assessing the adequacy of the model, a series of numerical experiments with regard to conditions of physical experiments. Fig. 4 shows how the computational domain, the shape and dimensions of which are repeated construction of a physical model. Ignition of the mixture produced at the tip of the left as well as on the physical experiment.

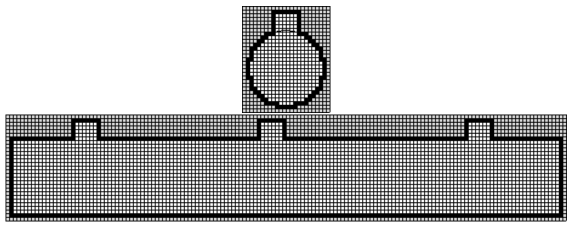

Fig. 4 the computational domain of the experimental setup "Sergeant" (white cells - calculated, blue - the border (the boundary of the computational domain))

In fig. 5 compares the dynamics of explosions obtained from numerical and physical experience. See the closeness of the results.

Additional confirmation the adequacy of the numerical model is the registration for these experiments (physical and its corresponding numerical) unplanned secondary effect - of periodic oscillations of pressure - with the same frequency and amplitude. In the fig. 6 by the center and on the right shows callouts entries that increase in scale of pressure values for the each of the sensors. Committed in the opposite phase periodic pressure fluctuations can be explained by the presence of an acoustic wave, of moving from one face end of the chamber to the other and back as in physical experience, and in the settlement. It can be seen that the frequency of the acoustic oscillations and their amplitude are identical during both types of experiments (frequency - about 160 Hz, amplitude - a little less than 1 kPa, which correspond to the sound level of 110…120 dB *spl*). It seems to us that the existence of these oscillations can be explained by the dynamics of the share of the products of combustion in the total mass of gas flowing out of the chamber.

H. Object of the research.

The numerical experiment was carried out with respect to the volume, which is typical for a small kitchen space size of 4x3 m and a height of 2.2 m, which has a window of 1x1.2 m. Considered three variants of the premises: the first is empty, the second has a barrier in the middle of the room, and a third furniture, placed on the side walls (Fig. 6).

V. Results Of Experiment

A. Gas explosion in an empty kitchen

It seems that it would be methodically correct at first to look at the explosion in an empty room. Fig. 7 shows the visualized picture of the progress of the flame front in the empty kitchen, while the dimensions in terms of 3x4 meters Gray color represents the initial no flammable mixture, the color lightened with increasing temperature. The products of combustion are presented in white. Red stained cells in which burning occurs, and a series circuit such cells is the flame front. The figure presents a horizontal cross section of the front at a height of 1 m. Fig. 8 shows the evolution of the pressure during the ignition of the gas in different parts of the kitchen. It is clear that by the third second combustion ends and the implosion of the premises from outside enters the cold air (fig. 7 the last frame) that does not contradict the well-known notions of deflagration explosion. It is seen that during ignition against the far wall, and near it pressure has the highest value, the lowest – in window, and the process, on the contrary – the longest in the ignition at the window.

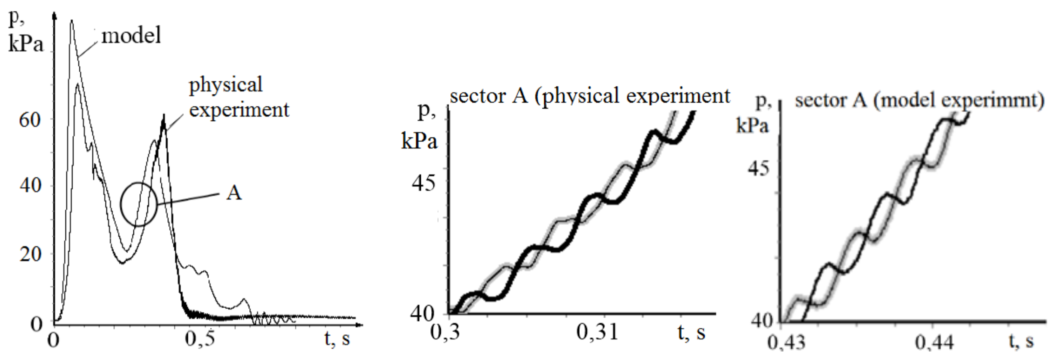

Fig. 5 general picture of the process

Furniture presented in the form of parallelepipeds. There are 5 points along the axis of the room at a height of 1 meter, at these points produced ignition of the gas and the measurement parameters using sensors of pressure, temperature and index of fire danger. Estimated volume was divided into cells of size 0.1x0.1x0.1m number about 30,000 pieces. The furniture pushed against the walls and the floor tightly, its surface is impermeable to gases.

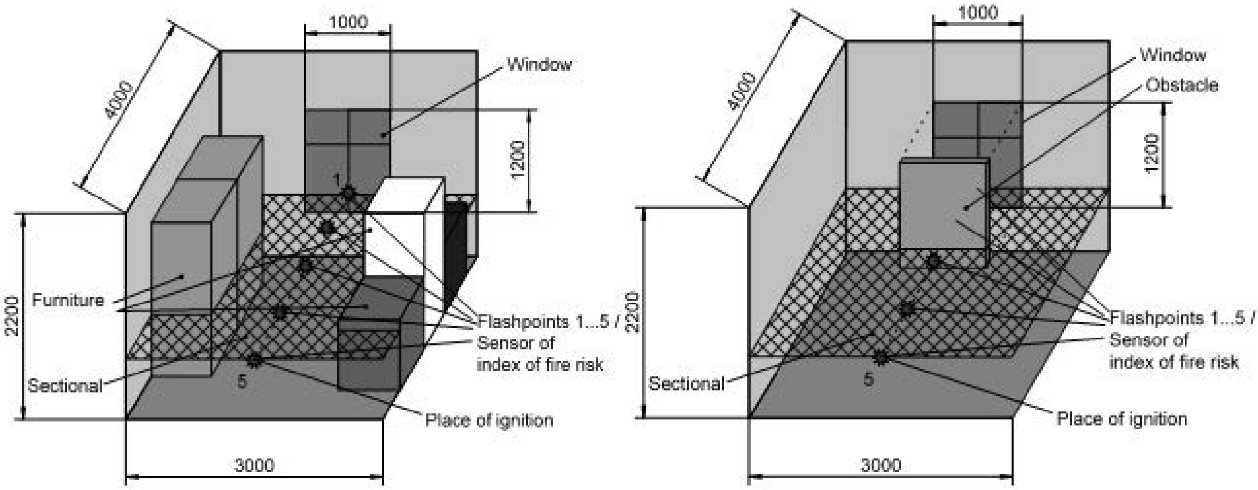

Fig. 6 the scheme of the kitchen facilities (dimensions in mm)
left - with furniture, the right - with the obstacle of 100 mm

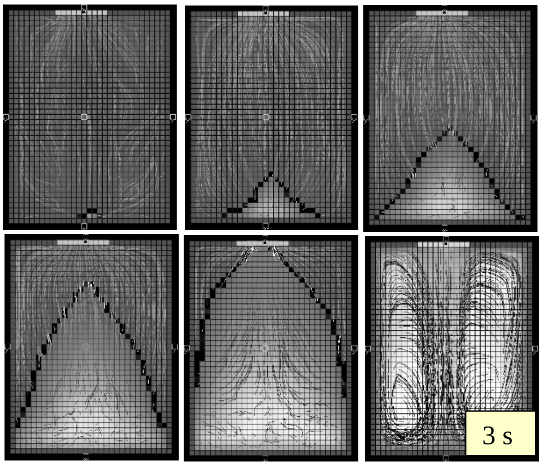

Fig. 7 development of the flame front in an empty room when ignited at the far wall (step 0.125 s)

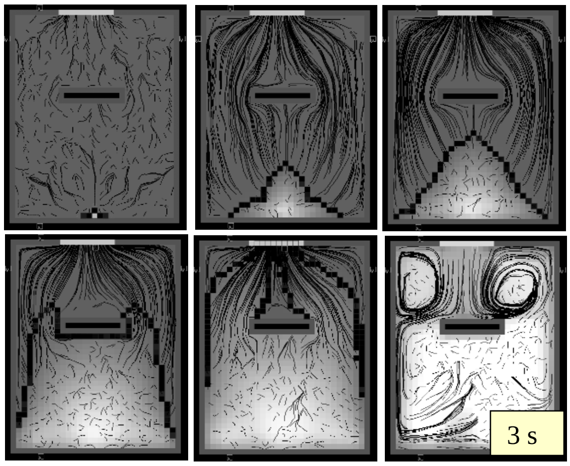

Fig. 9 development of the flame front in a room with a barrier when ignited by the far wall (step 0.125 s)

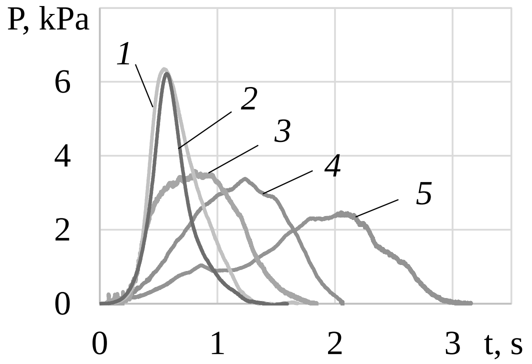

Fig. 8 pressure variation in the empty kitchen 3x4 m at various locations of ignition (as shown in Fig. 6)

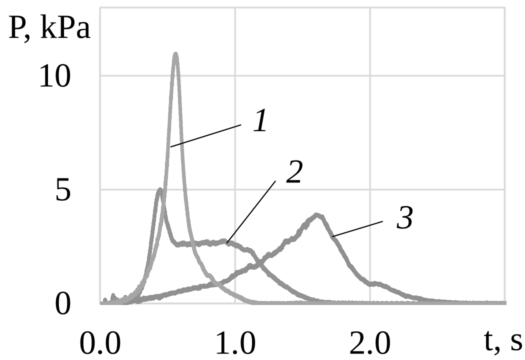

Fig. 10 dynamics of explosion pressure at the barrier in the center of the room and ignited the far wall (1); middle of the kitchen (2) and the window (3)

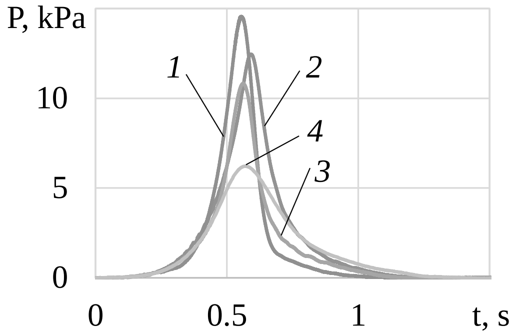

Fig. 11 combined charts ignition pressure dynamics on the fa wall with the obstacle (on the far wall from window (1), in the middle of the room (2) and at the window (3)) and cutting obstacle (4)

B. The explosion in the room with an obstacle.

On the influence of obstacles arranged in the room, on the development of the explosion is known, this is reflected in many papers, for example [13], [32], [33]. It is considered that turbulence-flow obstacle, increasing the area of the flame front and, at the same time, increasing the flow of combustion products into the room, resulting in increased pressure deflagration. Fig. 9 shows the rendered picture of the development of the flame front in a room with a obstacle. The ignition source is located at the far wall. It should be noted that the obstacle hardly reduces the volume of space, but reduces the cross-sectional space in the plane of the obstacle itself. It can be seen as evolving, the flame front bends around an obstacle, while its size is greatly extended.

Fig. 10 shows the dynamic pressure in the various embodiments of the location of obstacle, the pressure decreases with the approach of the obstacles to the window. Fig. 11 shows graphs combined pressure gas explosions in three versions location obstacles at a distance of 1.4 m; 2 m and 3.4 m from the window. For comparison the result of the explosion in the empty kitchen (all 4 variants ignition of the gas produced by the far wall) is given.

It is seen that in the case of an obstacle explosion pressure is higher by more than half compared with the explosion in the empty kitchen, although at an early stage, all the graphics are close to each other, the difference takes place when the flame reaches the obstacle.

Moving obstacles along the axis of the room has little effect on the value of the peak pressure, although there is some decrease at the location of obstacles in the center of the kitchen. But cutting the obstacle into two equal parts and pushing each of them to different walls, we find that an obstacle has almost no influence on the process, which becomes similar to the process of the explosion in an empty room (Fig. 8).

C. The explosion in the kitchen with furniture

Visualized picture of the propagation of a flame front by the volume of kitchen furniture (Fig. 12) is shown by the example of fire against the far wall. It may be noted that the explosion pressure in the kitchen furniture along the walls depends greatly on the site of inflammation. On this example, the explosion pressure in the ignition of the wall 6 times higher than in the ignition window (Fig. 13). Analyzing the results presented in Fig. 8, Fig. 10 and Fig. 13, we can say that the presence of obstacles in the room makes the pressure of the explosion more "sensitive" to the coordinate of the source of gas ignition.

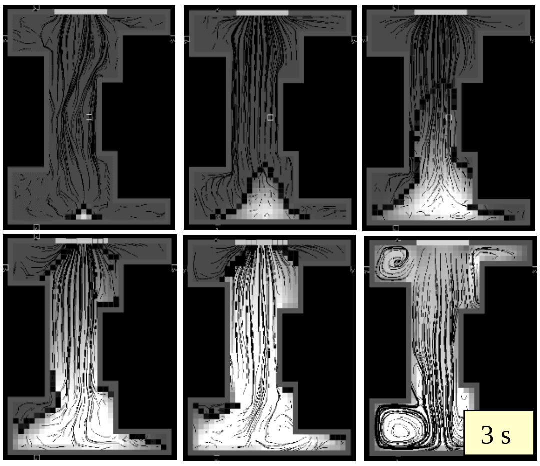

Fig. 12 development of the flame front in the room with furniture in the ignition on the far wall (step 0.125 s)

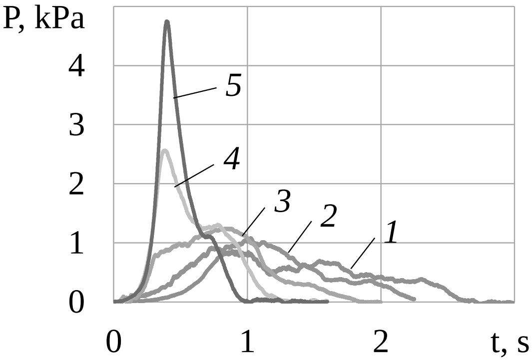

Fig. 13 graphs of pressure at different positions of the source of ignition in the kitchen with furniture (numbers correspond to Fig. 6)

On the last frame picture of implosion is rendered, that is the entry of outdoor air into the kitchen.

D. Comparison of the explosion in different versions premises

Fig. 14 and 15 compares the development of gas explosions in various embodiments' kitchen facilities obstacles when the ignition source is located at the far side (Fig. 14) and upon the gas ignition at the window (Fig. 15). It is seen that the maximum pressure is reached in the version with the obstacle located in the middle of the room, significantly (twice) than the pressure of the explosion in an empty room. Explosion pressure in the room with furniture, even less than in the explosion in an empty room.

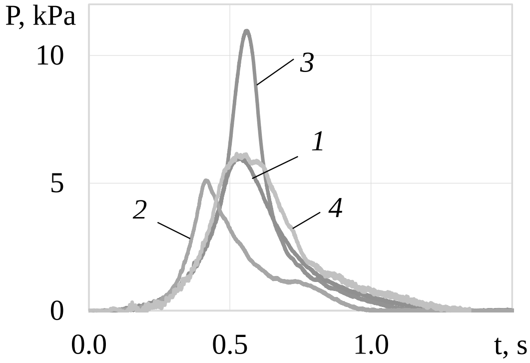

Fig. 14 dynamics in the ignition of the mixture pressure at the far wall: 1 - in an empty room; 2 - in the kitchen with furniture; 3 - with a barrier along the axis of the kitchen; 4 - with a barrier along the walls

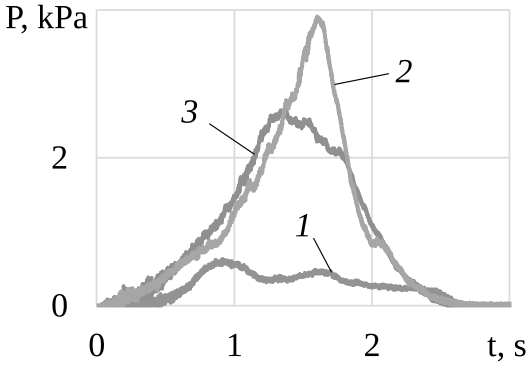

Fig. 15 dynamics in the ignition of the mixture pressure at the window: 1 - in the kitchen with furniture; 2 - in the kitchen with an obstacle; 3 - in an empty room

This result seems to be inconsistent with the common opinion about the impact of obstacle to development. But the explanation of this effect is quite simple. Fig. 14 shows that the rate of pressure rise in the kitchen with furniture the largest compared with other options, and speed to the window as the greatest. As a result, in the plane of the window before the combustion products enter (by 0.4 seconds) than in other cases, and therefore the pressure in the kitchen has lagged far behind the other embodiments.

VI. Evaluation Of Gas Explosion Fire Hazard

Possessing a database relating to the development of the explosion in the volume of food, including temperatures in each of the 30,000 cells, and provided with a fire danger index, we can estimate the potential fire hazard posed by the hot gases at each point of the volume of the kitchen. Fig. 8, Fig. 10 and Fig. 13, in color range from dark to light colors, shows a qualitative picture of the dynamics of the fire hazard in the volume of the kitchen in the propagation of the flame front. It is seen that immediately after the flame front positioned cells with elevated index. And while the implosion it is seen that the axis of the room along the flow of incoming air index growth is low, because this prevents fresh air.

Fig. 16 shows a picture of index of flammability hazard values axis placed at the points denoted in Fig. 6 with numbers from 1 to 5: line 1 corresponds to an explosion in an empty room, line 2 - in the kitchen with furniture, and line 3 - in a room with a obstacle in the middle of the kitchen. In the graph L - distance from the window to the measuring point, L_0 - length of the room along the measurement axis.

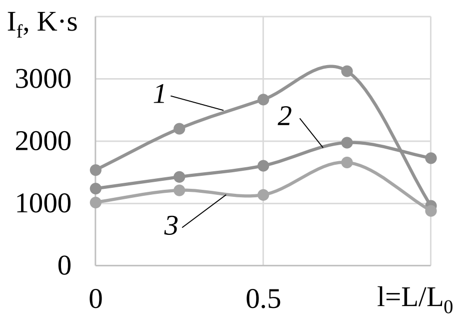

Fig. 16 dependence of the maximum index of fire risk on the relative distance from the window
1 - in the empty room, 2 - with furniture, 3 - with obstacle

It turns out that the explosion in an empty room is the most dangerous in terms of flammability risk in comparison with which the value of its index in the room with the presence of obstacles or furniture - less than 1.5 times. The safest place in terms of the fire in the kitchen is a space near the far wall and a window. Fire hazard increases with distance from the window, reaches a maximum in the middle and then decreases sharply as the proximity effect of cold wall.

For ignition of the sheet of writing paper thickness of 0.1 mm, a streamlined with only one hand, according to approximate estimates, the index value must be a power of about 1,500 or more units. Then, in accordance with the schedule in Fig. 16 sheet does ignite not at all locations under consideration cuisine. However, if the sheet flows about combustion products from two sides, then ignited in any way.

VII. Conclusion

For more efficient use of known results of studies for reducing the risk of gas explosions in such specialized and common areas like kitchens, the knowledge on this topic should be expanded.

- Firstly, it was found that for modern kitchens thesis about the dependence of the explosion pressure in the room is just the place of ignition thanks the large size of the windows;

- Secondly, it is found that obstacle located indoors, the explosion pressure valid on two ways: if they are in the middle of the room, the pressure increases, and if the walls, then decreases.

- Third, thanks to the introduced the concept of the flammability risk index it was found that the greatest risk of fire occurs in an explosion in an empty kitchen, and in the presence of obstacles (or furniture) - less.

On this basis, it was noted that the traditional placement of furniture along the walls of the kitchen is appropriate not only for ergonomic positions, but also in terms of reducing fire and explosion during gas explosion.

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