Features gas explosion in a cylindrical tube with a hole on the side

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Abstract – We performed numerical modeling of gas explosions in a cylindrical tube with a diameter of 200 mm and a length of 1500 mm, with closed ends and has 5 holes in the side. During explosion was opened only one of them, with passage sections of the openings diameters varied from 20 mm to 70 mm. Ignition is always carried out with the same end. It was found that when you open the 2nd hole (counting from the ignition device) and hole diameter from 50 mm to 61 mm inside the tube develop intense pressure oscillations with an amplitude of up to 15 kPai with a frequency close to the natural frequency of the internal volume (200 Hz).

Modeling technique used of Large Particle Method (LPM) describes these fluctuations, including their excitation, although the system of equations is not explicitly visible in this mechanism.

Keywords – large particles method, gas explosion, tube, hole, vibrations, singing flame Higgins.

I. INTRODUCTION

A method of self-excitation of pressure oscillations in the tube [1] is known as "singing" flame of Higgins, occurring during the combustion of a gaseous fuel in a long tube. In this case, the tube is vertical, the burner is located inside the tube in the bottom quarter, the position of the flame in the tube is steady. It is known a device Rijke, the main element of which is also a vertical tube. This device, named a simple generator of self-oscillation, draws energy not from the flame, but from electric spiral. There is a Helmholtz resonator [3], in which the oscillation frequency can be calculated with confidence. According to studies, described in [4], the cause of excitation of such oscillations is the existence of zones of varying viscous friction along the tube. This statement gives reason to believe that the mechanism of excitation of oscillations has thermoacoustic character.

In this article we consider the process of flame front propagation in a cylindrical tube with a gas explosion. Of course, in this case, there is a lot to do with the processes described, so quite naturally raised the question of the possibility of excitation of vibrations and explosions. However, there are serious differences in the conditions of processes that do not give a clear answer to this question. Firstly, the position of the flame front does not remain in the same place as in the above cases, but quickly moved along the tube. And secondly, the gas flows from the side surface of the hole, but not from the end of it.

Since the processes of gas-dynamic and thermal processes are described in terms of computational fluid dynamics (CFD), then the appropriate formulation of mathematical models can answer the question of the possible existence of oscillations of the gas in the tube when a gas explosion. Furthermore, in order to determine the conditions under which the oscillation can occur.

In this regard, it is unclear why the authors of [5], which used the FLACS in the CFD tool to describe a gas explosion in a cell measuring 4.6 meters x 4.6 meters x 3 meters, it was not possible to simulate the acoustic vibrations, arising in the process, although these fluctuations were mentioned in the article and it was stated on their impact on the explosion pressure. Note that the physical experiments on gas explosion in a referred chamber were conducted by other authors [6].

II. WORKING 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;
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.

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On the domain of integration is superimposed Euler (fixed) grid of rectangular cells with sides \( \Delta x, \Delta y, \Delta z \). Numerical solution of the system is carried out by large particles method, LPM, [10], which is based on the idea of Harlow «particles" in the cell, allowing "splitting" of physical processes. But in the LPM solids replaced by a single liquid, fill the entire volume of the cell. This explains the name of the method. Method of large particles as well as other modern methods such as Godunov method [5], FLACS [6] 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 on the basis of 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 on the basis of 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 pressure in the chamber and atmospheric. For the simulation of flame propagation introduced an additional parameter "mass fraction of combustion products in the cell."

Inside the cell the combustion products and the starting mixture divided by the flame front, which moves relative to the moving direction of the original gas mixture with the velocity of the laminar combustion. Take into account the dependence of the rate of flame propagation on the temperature of the initial mixture.

Ribs cells taken equal \( \Delta x=\Delta y=\Delta z= 0.01 \) m, the time step \( \Delta t=5 \times 10^{-7} \) c with that by a wide margin meets the criterion of stability Courant - Friedrichs - Lewy. Stock of taken in view of the fact that the introduction of the mechanism of flame spread has a negative effect on the stability of the account. The calculated form the boundaries of repeated design a real camera, which is a cylinder \( d = 200 \) mm and \( L = 1500 \) mm, with muffled ends and is equipped with five holes, equally spaced along the length of the cylinder (Fig. 1). Starting positions of hole are closed, except one variable from №1 to №5. During the experiment, one hole is sealed with a piece of paper 0.1 mm thick. The diameter of the open hole varied from 20 to 70 mm. Chamber was filled with a stoichiometric mixture of propane-air gas. Ignition of the gas was produced always at one and the same place at the left end of the tube. Pressure was measured at two points located on both ends of the tube.

![Fig. 1 - Estimated area](image)

### III. THE ADEQUACY OF THE MODEL

The adequacy of the numerical model is confirmed by comparing the results of calculations and data of physical experiments.

For this purpose, given the published data [7] for the physical gas explosion in the chamber of Fig. 1 at the position of the hole in the position 3 and 40 mm in diameter, and they are compared with calculations which are obtained for the same physical conditions of the experiment (Fig. 2). It can be seen that the physical and numerical experiments on approximately the same pressure stroke, despite the rather complicated dynamics of the process (Fig. 2a). Moreover, in both cases (Fig. 2B and 2C) were observed the pressure oscillations with amplitude about 1 kPa and a frequency of about 200 Hz, which coincides in time with the flame hit the hole. We can also note that the testimony of the first and second pressure sensors are out of phase, that is, we are dealing with a standing sound wave.

We see the adequacy of the model.

### IV. 2. THE RESULTS OF THE EXPERIMENT

The results of the experiment are shown in Fig. 3. Data are shown in their absolute values. In the graph on the
ordinate postponed the value of excess pressure in the explosion, and on the horizontal axis - the number of position the open hole.

It is seen that these numerical experiments confirmed the known strong influence on the size of the hole of the explosion pressure: in this case, by increasing the hole size from 20 mm to 70 mm the pressure decreases from 5 to 30 times. They also indicate that the hole effectiveness as means the protection with explosions depends from the distance between the opening and the source of ignition. Fig. 4 shows the result of translation to experimental data where the ordinate postponed the ratio of the pressure of the explosion at each position of the hole to the pressure of the explosion at the near position (№1). The graph shows the anomaly that occurs when the diameters of the hole over at least 55 mm and 61 mm, and only in the position №2.

![Graph](image1)

Fig. 3 - Dependence of the pressure of the explosion on the size and position of the hole

We have noticed that in these cases the camera develop intense pressure fluctuations (Fig. 5), the frequency of which varies from 150 to 210 Hz. The oscillation amplitude in this case reaches a value of 15 kPa. The maximum amplitude was at a frequency of 200 Hz.

![Graph](image2)

Fig. 4 - Dependence of pressure of the explosion on the size and position of the hole relative units

We draw attention to two points:
- Firstly, the vibrations begin when the flame enters the hole;
- Secondly, the area of the flame front varies synchronously with the pressure variations, moreover the value of amplitude of the flame in relative units is not less than the pressure.

This suggests that the pressure fluctuations is associated with fluctuations of the area of the flame front. Or is vice versa.

In addition, we also note that the hole № 2 located at a distance from sources of ignition for about a quarter of the

The initial section of the flame front takes a certain shape of a tulip. Due to expansion of the area of the combustion front at this stage (up to 0.05) dramatically increases the pressure in the chamber. Then, reaching the edge of the side wall of the chamber forms the shape of an octopus. After entering the combustion products through the open hole (0.05) and shortening the "tentacles" pressure begins to fall sharply. At this time, begin to develop pressure fluctuations, reaching a maximum when the cross-section of the hole is fully occupied flame. After 0.1 seconds the front area increases again, which explains the increase in pressure. At the time of 0.15 with flames completely detached from the hole and vibrations begin to fade. At 0.35 with burning practically stops.

![Graph](image3)

Fig. 6 shows the pattern of the flame front in the experiment.
length of the chamber (a little more) "singing" flame Higgins. In this case the tube becomes similar to a device that produces an effect Higgins. However, in our case, according to the scale of oscillations, we are talking about the "very loud" flame.

It was found that the range of parameters for which there are vibrations in the flame spread along the length of the tube, has clear boundaries. For example, if we consider the effect of the diameter of the holes, as shown in Fig. 7, with values less than the diameter of the hole 61 mm there are fluctuations, and with a diameter of 62 mm and more - there are no fluctuations.

Fig. 5 - Dynamic pressure chamber. (Hole 2, d = 60 mm); 1 - the pressure in the chamber; 2 - the area of the combustion front

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Fluctuations occur at the coincidence of three factors:
- Flame front is in the first half of the length of the chamber;
- Tube is located near the quarter length of the chamber;
- Tube have a certain size.

The fact that we are dealing with the effect of close to "singing" flame Higgins agrees fact that in other cases, such intense vibrations no.

Of course, this approval should be checked using a physical experiment.

V. CONCLUSION

- Tube with closed ends and an opening on the side in the case of the explosion of gas can be "tuned" to vibrating combustion.
- Vibration combustion increases the explosion pressure in the tube.
- Approval needs to be tested on a physical experiment.
REFERENCES


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