# THEORY AND PRACTICE OF FORENSIC EXAMINATION

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## SELECTION OF PARAMETERS FOR ASSESSING THE PROBABILITY OF FIRE AND EXPLOSION OF VAPOR-GAS-AIR MIXTURES AND THEIR CONSEQUENCES

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*Abstract.* The article is devoted to the selection of parameters that allows one to assess the probability and consequences of a fire and explosion of vapor-gas-air mixtures. A review of literature sources devoted to the study of fires and explosions associated with the ignition of vapor-gas-air mixtures is carried out. The study of fires and explosions of vapor-gas-air mixtures in the normative and technical literature is considered in detail. The main calculation parameters are given to assess the probability and consequences of a fire and the explosion of vapor-gas-air mixtures. Characteristics of combustion and explosion of vapor-gas-air mixtures are also considered. It is shown that the timely determination of the causes of fires and explosions of vapor-gas-air mixtures makes it possible to lower the probability of their occurrence.
*Keywords:* vapor-gas-air mixtures, fire, explosion, calculation methods

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### Analysis of existing methods for assessing the probability and consequences of fire and explosion of vapor-gas-air mixtures

Recently, fires and explosions associated with the ignition of vapor-gas-air mixtures have become a frequent phenomenon. Such phenomena can lead to significant destruction, cause serious property damage and threaten civilian lives. In this regard, the study of such fires and explosions is of great importance. Therefore, it is important to assess the probability and consequences of fire and explosion of vapor-gas-air mixtures.

The study of fires and explosions of vapor-gas-air mixtures is considered in the main works devoted to fire-technical expertise. Thus, in the monograph [1, 2], an algorithm for investigating fires is considered when determining the cause by analyzing various expert versions. In this case, the immediate (technical) cause of the fire is considered, that is, the determination of the source, the combustible substance and (if necessary) the oxidizer. And the most important thing is the establishment of a connection between them, which determines the mechanism of interaction, that directly leads to combustion. Since fires associated with the explosion of vapor-gas and dust-air mixtures belong to the competence of fire-technical experts, the authors of the work [2] considered in detail the study of the possibilities of their formation, the features of the study of such fires, expert advice and examples from expert practice.

The work [3] provides information on the occurrence, development and consequences of fire and explosion, their dependence on the properties of substances and materials, sources of ignition and the specifics of the process. The spatial and temporal characteristics of its development, temperature factors are established, and the characteristic signs of the fire source and the center/epicenter of the explosion are evaluated. The experimental and calculated data necessary for the examination are presented. Using specific examples, methodological approaches to the study of fire and explosion from the point of view of establishing the cause, other factors and circumstances, and safety violations are considered. Methodological recommendations for collecting data at the fire site are also offered.

In addition, a large number of educational publications devoted to fire-technical expertise have been studied [4–6]. Thus, it can be argued that information on fire and technical expertise of fires and explosions is covered in a significant number of literary sources: individual issues related to the installation of combustible components are extensively considered.

In addition, there is a large amount of regulatory and technical literature devoted to calculating the parameters of ignition and explosion of vapor-gas-air mixtures. The main interest in carrying out calculations of processes related to the ignition of vapor-gas-air mixtures is:

1. Calculation methods for the spread of gases and vapors:
– concentrations of gases and vapors;
– the size of the zones that limit the areas of certain concentrations;
– parameters of evaporation and vapor spread;
– computer simulation of the vapor-gas-air mixtures movement.

2. Calculation methods for the investigation of fire and explosion of vapor-gas-air mixtures:
– pressure of vapor-gas-air mixtures;
– explosion of the vapor-gas-air mixtures – TNT equivalent and specific impulse of explosion of vapor-gas-air mixtures;
– destruction distances and safe distances in case of fires and explosions of vapor-gas-air mixtures.

3. Calculation methods for the study of critical ignition parameters of vapor-gas-air mixtures and auxiliary calculations:
– concentration limits of flame propagation;
– temperature limits of flame propagation;
– flash and ignition temperatures;
– auxiliary calculations.

GOST 12.1.004–91 «Fire safety. General requirements» [7] contains a method for calculating the size of zones abridged by the concentration limits of flame propagation (CLFP), as well as examples of acetone spills. The definition of a safe depressurization area is considered.

GOST R 12.3.047–2012 «Fire safety of technological processes» [8] contains methods for calculating the overpressure of an explosion of vapor-gas-air mixtures, dust, the size of zones limited by the CLFP, evaporation and outflow of liquids from reservoirs, the intensity of thermal radiation during fires of liquefied petroleum gas spills, the explosion parameters of a vapor-gas-air cloud, overpressure waves, a fireball, as well as methods for determining the safe area of depressurization, calculations of thermal conditions and fire resistance of building structures.

The order of EMERCOM of Russia dated July 10, 2009 № 404 «On approval of the methodology for determining the calculated values of fire risk at production facilities» [9] provides calculations of the excess pressure of the explosion of vapor-gas-air mixtures, dust, a method for calculating the size of zones limited by the CLFP, evaporation and outflow of liquids from tanks, the intensity of thermal radiation during fires of liquefied petroleum gas spills, outflow from the tank, a fire spill of combustible liquids, the effects of explosion of liquefied petroleum gases, evaporation of liquids, thermal radiation and the radius of heat exposure, released during combustion and explosion of vapor-gas-air mixtures, and the damaging effects of pressure.

SP 12.13130.2009 [10] provides methods for calculating zones limited by the CLFP, thermal radiation in case of straits fires, overpressure in case of explosion of vapor-gas-air mixtures. The manual on the application of SP 12.13130.2009 [11] includes various examples of such calculations.

The document «Calculation of the main indicators of fire and explosion hazard of substances and materials» [12] contains methods for calculating the temperature and concentration limits of flame propagation depending on the number of bonds, atoms, according to the Antoine constants, according to the heat of evaporation, calculation of the maximum temperature and explosion pressure, the number of phlegmatizers, critical diameter, etc.

Recommendations for ensuring fire safety of oil product supply facilities located on residential territory [13] contain methods for calculating the spill area and parameters of evaporation of flammable liquids, excess explosion pressure of vapor-gas-air mixtures and the size of zones limited by the CLFP.

The textbook «Theory of combustion and explosion» [14] provides methods for calculating the parameters of evaporation of liquids, the maximum and excess explosion pressure of vapor-gas-air mixtures, the size of zones limited by the CLFP, concentration and temperature limits of flame propagation of TNT equivalent, by the number of atoms and bonds, Antoine constants, by the heat of evaporation, in addition, examples of calculations are offered. Also, the works [15, 12] contain a large number of examples of calculations of critical parameters of combustion and explosion of vapor-gas-air mixtures.

The paper [16] provides methods and examples for calculating the safe distance from the explosion of vapor-gas-air mixtures, TNT equivalent and specific impulse of the explosion.

Due to the great importance of expert research on fires and explosions of vapor-gas-air mixtures, an urgent task is to assess the probability and consequences of vapor-gas-air mixtures, fires and explosions.

## Assessment of the probability of combustion and explosions of vapor-gas-air mixtures

When assessing the probability of combustion and explosion of vapor-gas-air mixtures, the main calculation methods are the following:

1) determination of the concentration of gases and vapors;
2) determination of the size of the zones limiting the area of concentrations exceeding the lower concentration limit of flame propagation;
3) determination of the gas concentration in the room during evaporation;
4) determination of the spreading area of petroleum products;
5) computer simulation of the spreading of vapor-gas-air mixtures.

The calculation of the volume concentration of gas is important when conducting fire and technical examinations. In this case, as a rule, the gas concentration value is compared with the lower and upper concentration limits of flame propagation (LCLP and UCLP). In the event that the gas concentration falls within the interval between the values of the LCLP and the UCLP, the occurrence of a fire and explosion of a vapor-gas-air mixture is possible.

It is necessary to calculate gas concentrations if its quantity and volume of the room are known. Well-known techniques can be used [7, 11]. Such a calculation does not present mathematical difficulties. At the same time, it is necessary to take into account the amount of objects and equipment in the room (for example, this is achieved by introducing a volume change coefficient equal to 0,8) [11]. Attention must be paid to the uneven distribution of gas in the volume. The optimal method of such accounting is the use of computer modeling. As a rough way to account for the uneven distribution of gas in a room, it is allowed to multiply the volume by a factor of 0,5 [17].

When a gas leak occurs, dependencies from the source can be used [9]. The most important parameter in the calculation is the gas pressure [18] and the area of the gas leak, which can be taken from the case materials. The physical-chemical properties of the gas can be taken from the source [19]. It should be borne in mind that natural gas is odorized with strong-smelling substances [20, 21], for example, ethyl mercaptan, while the concentration of odorant at which the smell of gas is felt will differ from concentrations at which ignition of vapor-gas-air mixtures is possible.

Important parameters in calculating the gas concentration in a room are parameters related to ventilation (exhaust and inlet), for example, volume flow. When determining such parameters, it is recommended to use the source [9]. When calculating rooms in which natural is the prevailing one, a source can be used [22], and the parameters of artificial ventilation are often indicated in the documentation attached to the ventilation equipment.

To determine the extent of the spread of vapor-gas-air mixtures, the calculation of the size of zones limiting the concentration range exceeding the LCLP is often carried out.

The determination of the sizes of zones limiting the concentration range above the LCLP can be carried out from sources [7–9, 14, 18]. At the same time, it is necessary to take into account the amount of objects and equipment in the room.

When calculating, it should be taken into account that the zones limiting the concentration area above the LCLP are simply the maximum volume in which the LCLP can be formed. At the same time usually gas-air, heat flows, ventilation and other factors are not taken into account. In this regard, computer modeling is necessary to carry out more accurate calculations. In addition, the calculation results based on widely used formulas for the propagation of gases are more accurate in the case of calculating the parameters of heavier gases than methane and natural gas.

It is also important to calculate the parameters of spillage and evaporation of volatile flammable liquids (VFL). Such calculations are considered in the sources [8, 9, 14, 23].

When calculating liquid spills, it is necessary to calculate the free volume of the room $V_f$, the evaporation area S of the surface, restrictions related to the location of local obstacles, or take into account the presence of VFL and flammable liquids in various containers. Then, according to the reference data, the evaporation intensity W is calculated.

To carry out more accurate calculations and obtain fields of concentrations of combustible substances, computer modeling of the propagation of vapor-gas-air mixtures is carried out. When carrying out such calculations, it is necessary to take into account the characteristics of the formation of vapor-gas-air mixtures and comparisons with the available combustible load. As a result of calculations, information can be obtained about the source of the fire, as well as the center / epicenter of the explosion.

When determining the source of the fire, it is assumed that it may be located in the place where:

1) the ignition source is located;

2) there are significant thermal damages that do not coincide with the corresponding combustible load.

The center/epicenter of the explosion of vapors about the gas-air mixture may be located in the place where:

1) the ignition source is located;

2) significant destruction of objects and enclosing structures took place. However, this is true only when mere presence of vast amounts of vapor-gas-air mixtures could not have the source of this destruction.

The most accurate method for calculating the propagation of gases in a volume is the use of computer modeling. During its implementation, the basic equations of conservation of mass, momentum, energy, etc. are solved. As a result of the numerical solution of such equations, fields of gas concentrations and other factors necessary for calculating the spread of fire hazards are formed.

The resulting gas concentration field can be used to assume whether a fire could have occurred in the room. This assumption is made as a result of the analysis of the zone in which the gas concentration is located between the LCLP and the UCLP.

The most well-known software package for such calculation is Fire Dynamics Simulator (FDS) [24], a graphical interface to which can be provided by the Pyrosim program [25].

The methods of mathematical modeling are described in the sources [9, 24, 26], and as a result of the calculation, it is possible to predict the possibility of fire and explosion.

Fire modeling can be performed as follows. The geometry of the room, initial parameters, gas inflow of the appropriate value and ventilation conditions are set. As a result of the calculation, an estimated concentration field is formed, and in those zones where the gas concentration is between the LCLP and the UCLP, its ignition and explosions are possible. The explosion of such a mixture is most likely in areas with concentrations close to stoichiometric.

## Calculation of combustion and explosion characteristics of vapor-gas-air mixtures

When calculating the characteristics of combustion and explosion of vapor-gas-air mixtures, usually, the following characteristics are determined:

1) excessive pressure;
2) TNT equivalent (thermal effect);
3) specific impulse of the shock wave.

When making calculations, it should be borne in mind that the ignition of vapor-gas mixtures occurs in the deflagration mode. Detonation is possible only in small areas where the gas concentration is close to stoichiometric.

Calculations usually determine the maximum explosion pressure – the highest excess pressure that occurs when a vapor-air mixture burns in a closed container at an initial pressure of 101.3 kPa.

The calculation of the maximum explosion pressure of vapor-gas-air mixtures is described in the sources [11, 14]. During the calculation, the pressure obtained is compared with actual or suspected lesions of people, biological objects, mechanical damage and destruction. In the case when the calculated pressure is above the critical values [14, 27], it can be concluded that a fire or an explosion is very probable.

An important parameter, the calculation of which is often posed as a question to experts is the TNT equivalent. Its value coincides with the thermal effect produced by an explosion in terms of the amount of TNT needed for the same thermal effect. When calculating the TNT equivalent for vapor-gas-air mixtures, it must be taken into account that the TNT equivalent of gases and flammable liquids can significantly exceed the TNT equivalent of the same mass of condensed explosive. Since the explosion of such a vapor-gas-air mixture occurs with the participation of oxygen in the air, which is not part of the combustible gas, the total mass of substances involved in the reaction becomes larger compared with the explosion of the same amount of condensed explosive.

One other parameter in calculating the possible consequences is the determination of the excessive pressure of the explosion. The degree of damage to people and buildings depends on the magnitude of the explosion pressure. Such dependencies are given in the source [10]. For more accurate calculations, the value of the specific impulse of the shock wave is also used.

## Conclusion

Thus, when conducting research on fires and explosions of vapor-gas-air mixtures, it is important to assess the probability and consequences of a fire and explosion of vapor-gas-air mixtures. At the same time, it is necessary to assess the probability of combustion and explosions of vapor-gas-air mixtures.

The main calculation methods are as follows:

1) determination of the concentration of gases and vapors;
2) determination of the size of zones limiting the area of concentrations exceeding the LCLP;
3) determination of the gas concentration in the room during evaporation;
4) determination of the spreading area of petroleum products;
5) computer simulation of vapor-gas-air mixtures' propagation.

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1) excessive pressure;
2) TNT equivalent (thermal effect);
3) specific impulse of the shock wave.

Conducting forensic fire and technical examinations is of great public importance, since timely determination of the causes of fires and explosions allows to reduce and prevent the occurrence of such dangerous phenomena. This is of particular importance in the study of fires and explosions of vapor-gas-air mixtures, which are capable of causing significant damage and pose a great public danger

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