Ignition source localization in gaseous mixtures explosions expertise

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Abstract. Gas-explosion events in the private or industrial field are usually followed by a technical analysis of the factors that led to their generation. In this respect, INCD INSEMEX Petroșani is accredited for conducting the technical expertise and for the elaboration of the Expertise Report. Starting with on-site findings and sampling, research continues at INCD INSEMEX laboratories, grouped on areas of interest in case management (electrical, ventilation, chemical, pyrotechnics, etc.). Determining the causes of the event implicitly involves establishing the probable source of initiation of the explosive mixture, after discovering the fuel gas source and analyzing how the mixture was formed. Due to the geometric complexity of the space in which the explosion occurred, incident, reflected or compound shock waves generated by explosion can create a footprint of the event that questions the location of the source of initiation. Depending on the possible sources found in the field, the INSEMEX Laboratory of Computational Simulations performs analyzes based on finite elements and finite volumes methods. The elements taken into account in the computational simulations concern both the geometry of the space, the nature of the combustible gas leakage, the dispersion of the gas, and the resulting thermal and mechanical effects.

1 Introduction

The initiation of air- combustible gas mixtures is caused by thermal energy transferred from the ignition source to the flammable / combustible environment [1]. The action of the ignition source on the flammable / combustible environment can be direct or indirect.

Ignition sources may be present continuously / frequently or may occur in rare or very rare situations. By their nature, the ignition sources are classified into the following groups:

- flames (match flame, welding device, etc.);
- sources of ignition of thermal nature (incandescent objects, the heat released by the thermal appliances, the thermal effect of the electric current etc.);
- ignition sources of electrical nature (electric springs and sparks, short circuits, static electricity etc.);
- ignition sources of a mechanical nature (mechanical sparks, friction, etc.);
- natural sources of ignition (solar heat, lightning, etc.);

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- sources of ignition of a chemical, physico-chemical and biological nature, exothermic chemical reactions, explosions and incendiary materials;
- indirect ignition sources (radiation from an existing fire).

No matter the nature of the initiation source, each unique gas explosion event corresponds to a unique footprint recorded on the ground and on the affected buildings. The geometry of the space affected by the explosion (closed or open space, construction, machinery, equipment present), the type of combustible gas, the location of the source of gas, gas concentration in the air, the dispersion mode of the combustible gas in the volume of air, the degree of homogenization of the explosive mixture, the local and the ambient temperatures and pressures, the humidity [2] etc. are factors that each contribute - to a lesser or greater extent - to the creation of the particularity of the explosion footprint. But a totally unique weight in the individuality of the explosion footprint is represented by the location of the source of initiation of the explosive mixture.

2 The necessity to locate the source of initiation

INCD INSEMEX Petroșani is an accredited institution for carrying out the technical expertise and drawing up the Technical Expertise Report in the cases of gas explosion events that take place both in the industrial and in the private environment. Generally, the main objectives covered by these reports refer to the causes of the event's occurrence, the identification of the source of the combustion gas, the identification of the probable source of ignition of the explosive mixture, the establishment of the event production mechanism and the identification of the favoring factors.

By identifying the probable source of ignition of the explosive mixture, the nature of the source and the causes that led to the source occurrence are established. However, for this, first of all, the source of initiation must be located.

Depending on the causes of the ignition source occurrence (electrical or mechanical defects, effects of natural phenomena, fires, chemical reactions, radiation etc.), subsequently measures and plans can be established in order to prevent events of this type which, most of the time, they cause loss of human life and significant material damage.

3 On-site research

The first step in the process of determining the causes that led to a gas explosion event is the on-site research. In this action, a team of specialists makes in-depth findings regarding the thermal and dynamic effects of the explosion on the objects in the affected area. As thermal effects, the burns caused by the flame front are observed on the electrical cables, wood materials, plastic objects, etc. generally on the combustible materials with which the flame front came in contact. The thermal footprint printed on these objects (Figure 1) contains important data regarding the direction of propagation of the flame front (for example, burnt cables only on one side of the casing, PVC joinery with thermal effects on a single technical surface) and the concentration of combustible gas (an excess oxygen concentration produces less colloidal carbon than excess fuel gas concentration, so traces of soot left on walls or other objects are more pronounced in the case of a reaction that occurred at a gas concentration value above that stoichiometric).

Fig. 1. Thermal imprint indicating the direction of propagation of the flame

The dynamic effects observed during the on-site research bring an important contribution in explaining the evolution of the explosion process. In the case of an explosion produced in the center of a simple geometric space (for example a cubic volume), the direct shockwave affects objects near the epicenter of the explosion less, having amplified mechanical effects on objects located at a greater distance. Thus, a glass located near the center of the explosion may remain intact, in the position before the event, and the walls of the room can be destroyed (Figure 2).

Fig. 2. Crockery left intact, in position, following the explosion

The dynamics of the shockwaves is directly proportional to the complexity of the geometry and the modification of the initial positions of the objects / parts is due to the action of the explosion pressure, either as incident, reflected or compound waves. Thus, certain objects in the space affected by the explosion may be dropped in a direction opposite to the propagation of the flame front, leading to confusion in defining the location of the initiation source (Figure 3). Therefore, during the in-site investigations, the probable source of initiation cannot be established, its location being analyzed later, in the laboratories of the institute, by corroborating the results of the computational simulations with those of the physico-chemical experiments carried out for this purpose.

Fig. 3. Different directions of deformation of the wall and carpentry

In order to transfer the research activity from the in-site to the laboratories of the institute, photo-video recordings are made at the event site and material samples are taken. Also, for investigating the event, other documents such as IGSU reports, weather reports, police inspectorate reports, witness statements etc. are considered, regarding the case.

4 Laboratory tests

As stated above, material samples are collected during the in-site research. Regarding the source of ignition, the material samples are collected from the entire affected area, consisting of elements that could constitute an effective source of initiation [3], no matter of its nature. Thus, electric cables with melting effects, devices or their components capable of generating electrical or mechanical sparks, chemical solutions producing exothermic reactions, individual protective equipment etc. are collected. Within the INCD INSEMEX, the material samples are distributed, for analysis, to the laboratories specialized in the respective domains (chemical, electrical, etc.), determining the capacity of each material sample to represent an efficient source of ignition of the explosive mixture similar to the one involved in the event. For example, Figure 4 shows a cable broken by elongation under the effect of temperature (a) and a cable subjected to an electrical short circuit (b).

Fig. 4. Cable broken by elongation (a) and by electrical short circuit (b)

5 Computational simulations

The trajectories induced by the forces generated by the explosion to the objects in the affected area have a vital significance in defining the location of the source of initiation. But these trajectories depend on the dynamics of the shock waves. In the case of a simple geometry, the objects are moved by the direct wave, the trajectories converging approximately in the epicenter of the explosion where we will find the source of initiation. In the case of complex geometries, the trajectories of objects no longer converge at the same point being deflected by the forces staged by the reflected and composed waves. Thus, the footprint of the event presents, at first glance, a strange spread of objects compared to the initial positions. Calculating these trajectories that should be approximately convergent at one point becomes an extremely difficult and time-consuming task. Therefore, to approximate the location of this point of convergence, therefore of the location of the source of initiation, computer simulations are used.

Based on the data collected from the site and on the documents related to the event, the geometry of the space affected by the explosion is reconstructed, on a 1: 1 scale, in the virtual environment. In this stage, the detail is essential because [4] the dynamics of the shock waves depends on the shape of the three-dimensional space and, implicitly, the accuracy to determine the area in which the explosion started. The virtual geometry is then discretized into finite volumes, the resulting mesh being used in computational simulations.

The great advantage of computational simulations is that, once the mesh is obtained, it can be used in any scenario [5, 6] and the presumed location of the source of ignition can be moved in any area of the space under analysis, until a corresponding explosion footprint with the one from the place of the event is obtained. In other words, through repeated computational simulations, by changing the location of the ignition source in relation to the position of the source of the combustible gas and its dispersion mode, the aim is to obtain the initial and final positions of objects similar to the positions in the real case. The position of the virtual initiation source, obtained by this method, offers a valuable clue in locating the real source, greatly narrowing the search area and eliminating other alleged sources that might exist in the affected area, but whose initiation would lead to a different event footprint of the real one.

An example of using this method is shown in Figure 5. The object MG initially positioned according to Figure 5a, is displaced by the forces generated by the explosion in the final position of Figure 5b, according to reality (Figure 5c). The explosion center in Figure 5a locates the source of initiation at a position approximately identical to that of the real event.

Fig. 5. Determining the location of the initiation source by computational method

At the same time, in different scenarios, less known properties of the environment at the time of the event can be tested – properties that could not be determined during on-site research – until the similarity with the real footprint of the explosion is obtained.

6 Conclusions

The analysis of the material samples collected from the event place offers answers regarding the capacity / incapacity of the analyzed elements to constitute an efficient source for initiating the explosive mixture. In some cases, several sources of ignition, of the same or different nature, can be found in the area affected by the explosion. This can create confusion about the location where the explosion was initiated and can lead to wrong conclusions about the causes of the event. The confusion can be amplified by the final "illogical" arrangement of the objects in relation to their initial position, before the explosion.

However, through repeated computational simulations performed on the same virtual space similar to the one in which the event took place, modifying the location of the virtual ignition source until obtaining an explosion footprint similar to the one in reality substantially reduces the real source location area and narrows the list of possible sources discovered at the place of the event, during the on-site investigations.

Also, through the different scenarios tested in the computational simulations, less known properties of the environment at the time of the event can be revealed.

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