Assessment and analysis of potentially explosive areas in distribution stations, generated by alternative fuels such as LPG, CNG and H_2

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Abstract. Rising prices and the desire to reduce pollution by replacing traditional fuels (benzine and diesel) in the transport system require solutions to make this sector more economically efficient. The use of LPG, CNG and H2 implies, from the point of view of explosion risks, additional features compared to conventional filling stations to increase safety and environmental protection. Thus, this paper presents the effects caused by each fuel analysed (LPG, CNG and H_2), in the worst case, the initiation case. The analysis performed is based on simulation using ANSYS – Computational Fluid Dynamics (CFD) software, and the result is particularly useful for adopting optimal measures to minimise the risk of explosion.

1 Introduction

The increase of energy consumption, for the improvement of conditions and comfort is also correlated with the promotion of the continuous evolution of the development of human society, which implies both the depletion of fossil fuels and the increase of pollution levels.

In the current conditions of the energy crisis, the conflict and the imposed restrictions, the search for solutions for the dependence on traditional fossil fuels is a priority for all industrial fields.

The analysed field is that of transport, a branch of industry significantly affected by the explosion of prices for traditional fuels (gasoline and diesel) but also of the constraint adopted both in Europe and worldwide by the drastic reduction of environmental pollution. In order to remain competitive, in a competitive market with the characteristic restrictions and particularities, they started the steps for the use of alternative fuels [1].

The danger of explosion may occur in all activities involving flammable substances in the form of gases, vapours, flammable mists or combustible dust which, when mixed with air, may form an explosive atmosphere [2–4].

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The assessment of the explosion risk and the establishment of appropriate measures to reduce it to acceptable levels, in accordance with the rules and standards in force, are of particular importance for the safety, health of persons and property. The appearance of the types of protection was determined individually by critical situations, regarding the safety regime for operation of technical equipments in spaces with explosive atmosphere, but also by the forecast of some imminent technical advances [5].

An essential element in the assessment of explosion risk to workplaces where explosive atmospheres may occur is represented by equipment that must be designed, manufactured, installed and maintained so that it cannot generate ignition sources.

Area classification is a method of analysing and classifying the environment in which explosive gaseous atmospheres can occur, so as to facilitate the correct choice and installation of electrical equipment that can be used safely in the given environment. The classification also takes into account the ignition characteristics of gases or vapours, such as the ignition energy and the ignition temperature.

For traditional fuels (petrol and diesel), the zones and extension distances of these zones are well defined and are given in SR EN 60079-10-1, instead for fuels analysed in this standard calculation formulas are indicated according to several parameters resulting the hazardous areas and their extent [6, 7].

An explosion can only occur if the following are met simultaneously: the presence of potentially explosive substance between the lower and upper limits of explosiveness; of oxygen and ignition source.

Explosion protection has the role of preventing the ignition of explosive atmospheres, ie the prevention of potential sources of ignition [8, 9]. Regarding the explosion hazard assumed by the classification of the area, the technical equipment used in these areas must be eligible and in accordance with the legislation in force [2] .

In this paper, the analysis of an explosion for each of the three potentially explosive substances that can be used as fuel (LPG, CNG and H2) are presented.

2 Simulation using the ANSYS - Computational Fluid Dynamics (CFD) software for explosions

The study, presented in the paper, analyses the case of an explosion generated by LPG, CNG and hydrogen inside a production hall, highlighting the effects of hazardous substances and the pressures resulting from the explosion.

The analysed substances, Table 1, are substances that can be used as alternative fuels for car transport.

Table 1. Characteristics of substances used to power cars.

Nr. Crt.	Substance	LEL [%]	Air relative density	Sub-group	Temp. class	Molar mass
1	butane	1.5	2.05	IIA	T2	58
2	hydrogen	4	0.07	IIC	T1	2
3	methane	4.4	0.55	IIA	T1	16
4	propane	2.1	1.56	IIA	T1	44

For exposure and analysis, 3 computer simulations are performed:
- 4% LPG explosion;
- CNG explosion 9.5%;
- 40% hydrogen explosion.

Representing stoichiometric concentrations in combination with air.

A hall of random geometry was used, only for the purpose of conducting a comparative study between the 3 cases, Figure 1.

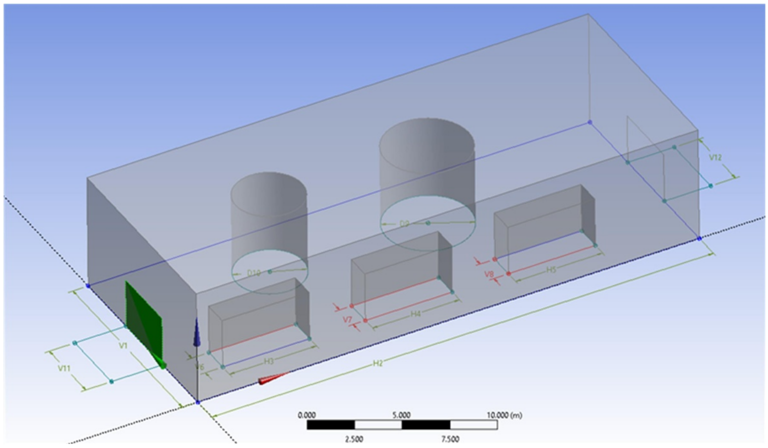

Fig. 1. The geometry of the analysed hall.

The hall has the dimensions 30 x 12x 7 m, inside it being arranged several solid bodies:
- cylinder 1, with a radius of 2.5 m and a height of 5 m;
- cylinder 2, with a radius of 2 m and a height of 5 m;
- 3 parallelepiped objects measuring 5.2 x 1.5 m and 3 m high.

On the short sides of the hall were arranged 2 doors with a width of 4 m and a height of 3 m, to release the explosion overpressures.

The source of initiation of the explosive mixtures was arranged in the space indicated in figure 2, at a height of 1 m from the floor of the hall.

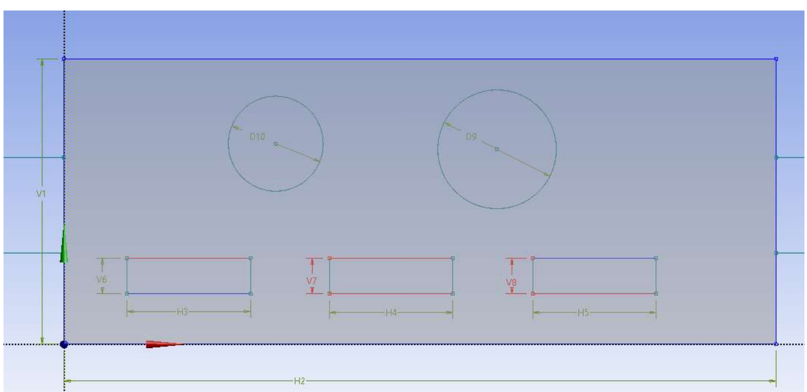

Fig. 2. The position of the ignition source.

Through the discretization process, the fluid volume representing the interior of the hall was divided into 102225 finite volumes, having 20704 nodes.

Mesh at the level of the 3 parallelepiped objects is presented in figure 3 and at the level of the cylinders in figure 4.

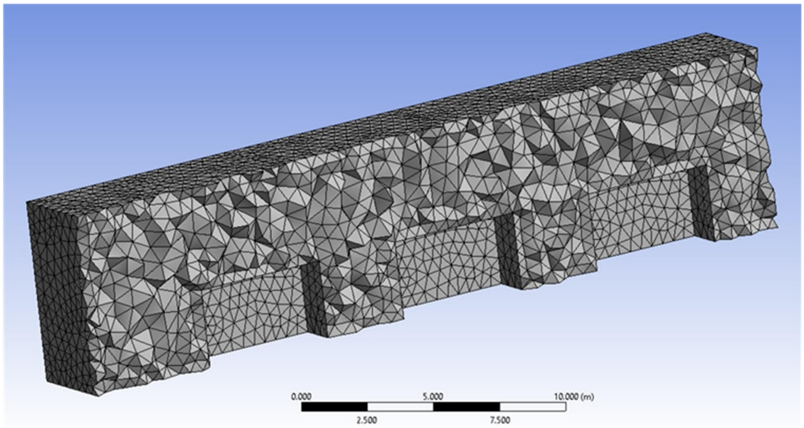

Fig. 3. Discretization network at the level of the 3 parallelepiped objects.

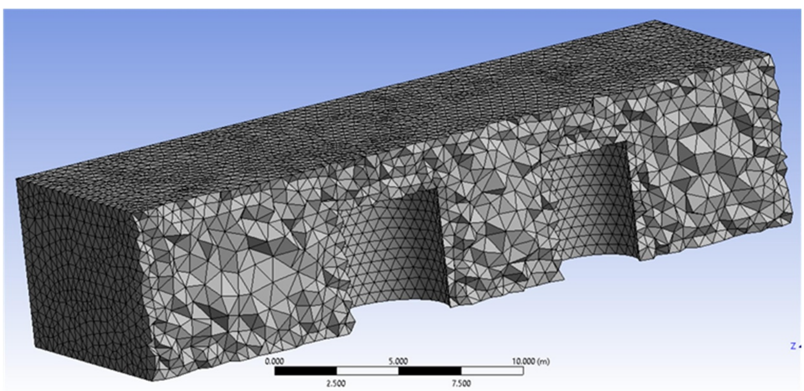

Fig. 4. Discretization network at the level of the 2 cylinders.

The initial settings used for the simulation are as follows:
- indoor temperature: 293 K;
- outdoor temperature on surfaces open (doors): 293 K;
- temperature of walls, including indoor objects: 293 K;
- internal pressure: 101325 Pa;
- external pressure on open surfaces (doors): 101325 Pa.

Propane (C_3H_8) was used for LPG due to its majority presence in the composition of LPG (~ 95%) [10] and due to the fact, that for this gas the Fluent application of the ANSYS Multiphysics, [11] platform has defined the rapid oxidation reaction, mixed with oxygen in the air and in the presence of an efficient source of initiation.

For gases, which generate the potentially explosive atmosphere, the stoichiometric concentrations introduced in values of the mass fraction used are:

- CH_4: 0,055 mass fraction (9,5% vol);
- H_2: 0,045 mass fraction (40% vol);
- C_3H_8: 0.06 mass fraction (4% vol).

3 Results and discussions

Following the running of the program regarding the development of the explosion process in figure 5, 6 and 7 are represented the colour contours of the pressures distributed in the analysed volume, respectively the propagation of the flame front inside the hall.

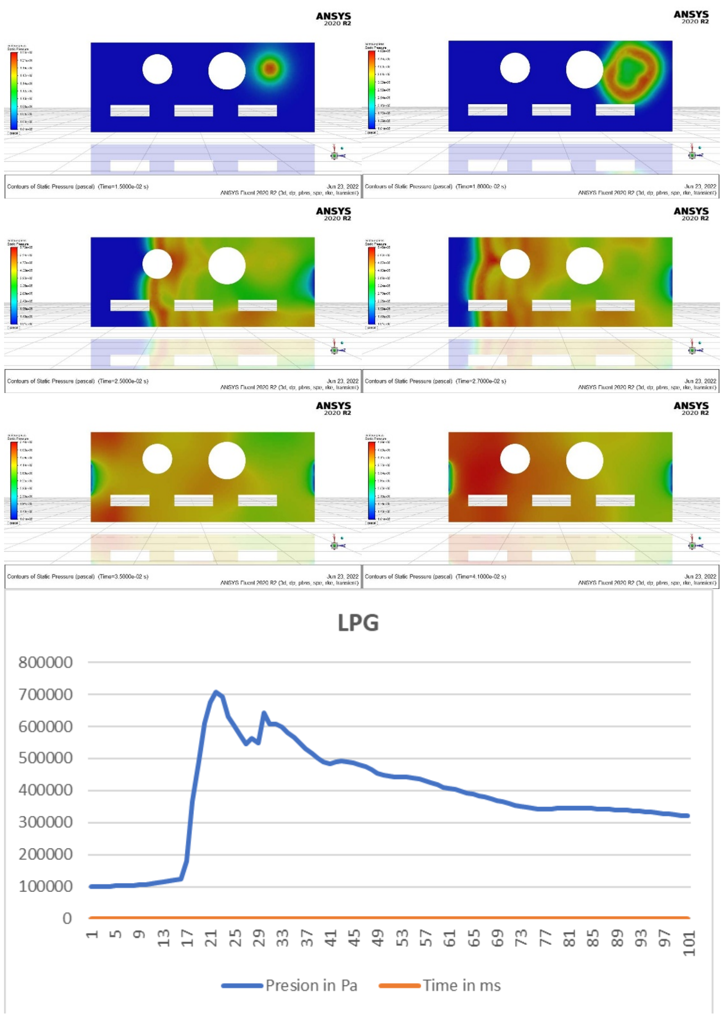

Fig. 5. Variation and propagation of pressures inside the hall, for LPG.

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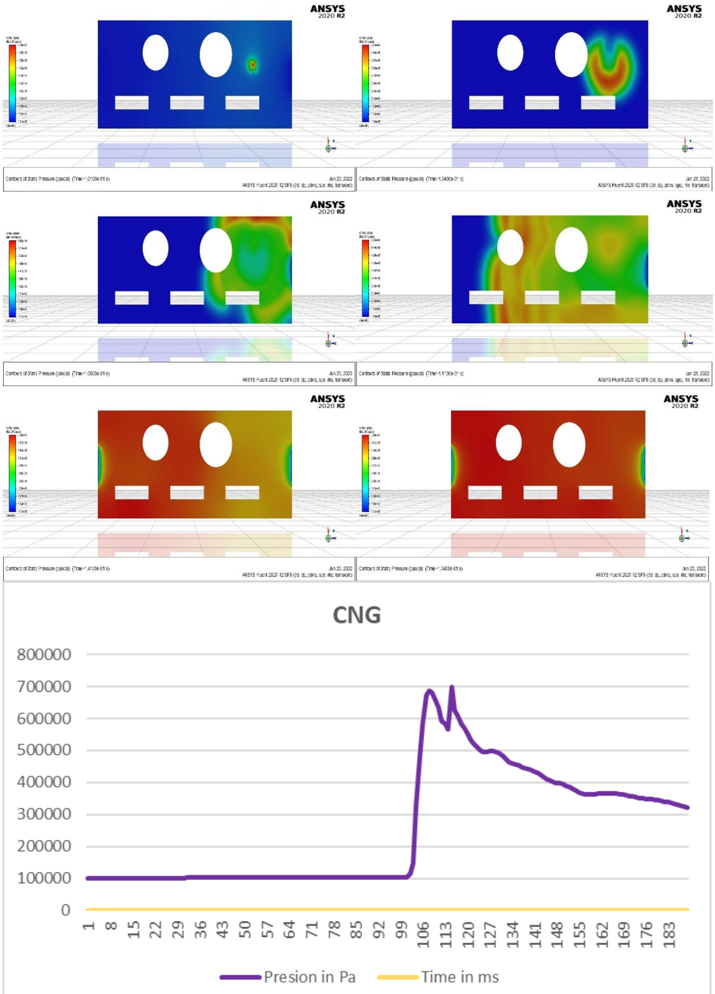

Fig. 6. Variation and propagation of pressures inside the hall, for CNG.

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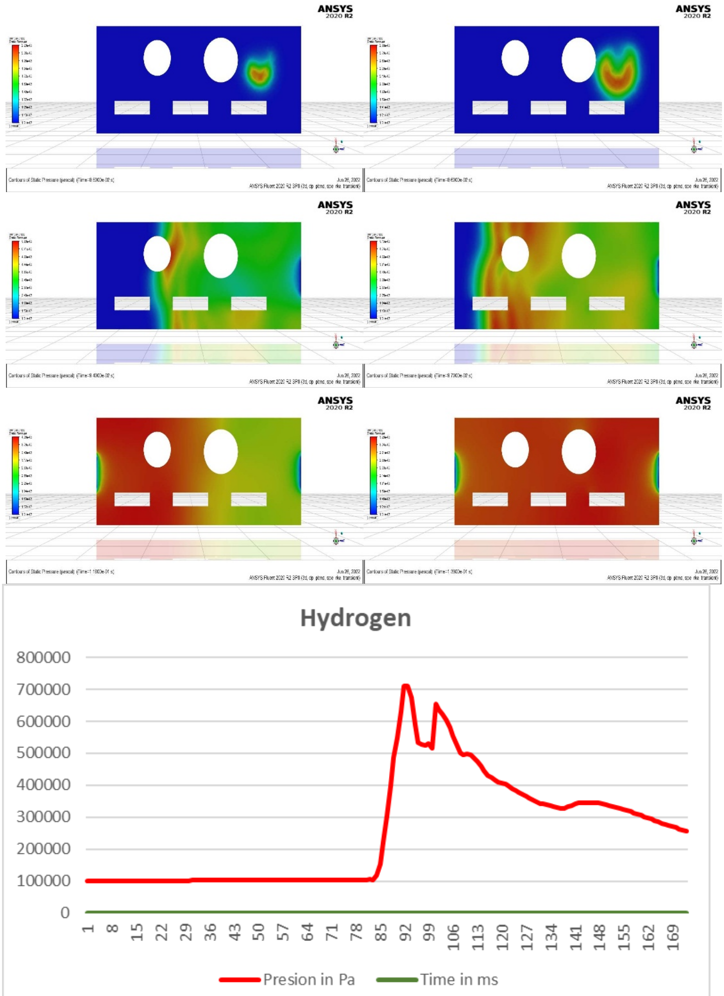

Fig. 7. Variation and propagation of pressures inside the hall, for H_2.

Following the analysis of the simulation, the following conclusions can be drawn:

• The possibility of a reaction taking place over a period of time is studied in chemical kinetics, a field that provides relationships about the rate of reaction, the number of molecules actually involved in the reaction and the intermediate stages of chemical transformation.

• Reaction rate is the number of molecules that react in a unit of time.

• To describe the reaction rate, it is necessary to determine the concentration of a reactant or product at successive intervals during the reaction.

• The reaction rate is directly proportional to the concentration of the reactant and its reaction order.

• The reaction rate can be represented by the derivative of the decrease of the concentration of one of the reactants, or by the derivative of the increase of the concentration of one of the reaction products.

• Activation energy is the excess energy, relative to the average energy of the gas molecules, that the reactant molecules must have to react. Molecules do not react unless they together have an energy greater than or equal to the activation energy.

• An increase in pressure corresponds to an increase in the reaction rate for the same values of the activation energy and the concentrations of the chemical species involved in the reaction.

• Chained reactions that characterize an explosion phenomenon can be defined by three stages: initiation, propagation and interruption. They define a reaction mechanism.

4 Conclusions

The use of computer simulations is particularly important to avoid catastrophic events caused by the explosion, the adoption of optimal solutions to avoid them and last but not least in case of initiation, the implementation of scenarios to limit the resulting damage. Moreover, the presented simulation addresses a possible scenario of an explosion inside a hall for the storage of the three substances and dispersion analysis of (toxic or explosive substances) generated to highlight the possible consequences but also for expertise to elucidate the causes of initiation and propagation.

The data obtained can be used to determine the structure and geometry of storage spaces containing the substances analysed on the one hand but also to continue research to determine the resulting temperatures under the simulated conditions. The simulation can be used on particular cases of geometry and the size of the units for production, storage and sale of products that generate potentially explosive atmospheres.

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