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MINIMUM IGNITION ENERGY FOR A FUEL-AIR MIXTURE BY ELECTRICAL SPARK INITIATION

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SUMMARY

From the risks embedded in human activity, the risk of explosion has acquired a important connotation, justified by the statistics results that show the impressive position explosions play across the causes of collective accidents. Minimum ignition energy is a very important parameter in terms of characterization flammable gas mixtures. A brief description of the fundamental aspects of ignition is given as a basis for discussing the initiations of combustion in fuel – air mixtures by local sources (electrical sparks, heated bodies, lasers). The most important aspects of explosion initiations by electrical sparks (capacitive sparks, inductive-capacitive sparks, break sparks, sparks interruption of DC or AC circuits containing inductance) are reviewed in connection with the minimum ignition energy characteristic parameter of the ignition source. Original data are presented and discussed for a fuel-air mixture initiated by electrical spark. Experiments in this work are preliminary tests in order to improve the experimental equipments to achieve the best possible correlation with the literature data and further research on the determination and assessment of explosion initiation characteristic parameters in fuel-air mixture.
Keywords: explosion; explosion initiations; minimum ignition energy.

INTRODUCTION

1. GENERAL CONCEPTS ON FUEL-AIR MIXTURES EXPLOSIVITY

The formation of gas mixtures that can support the explosive oxidation and decomposition reaction is often possible in the chemical and petrochemical industries, in different stages of technological processes, as in other activities involving the use of fuel compounds. Knowing the conditions under which explosions can occur is of great importance both for the design of industrial plants and for operating their business safely. Therefore there is a continuing interest in the research of causes, trends and effects of these phenomena, in order to avoid or minimize their destructive action.

Any chemical reaction followed by the sudden release of a large amount of heat that cannot be transferred quickly enough to the environment by conduction, convection or radiation, is called explosion, and the systems that can support this process are called explosive or flammable systems [1 -3].

In many practical situations which require avoiding an explosion, the composition of a fuel-oxidant mixture can not be changed neither by changing the ratio of the compounds nor by addition of inert ingredients. The behavior of this mixture, of composition placed inside the flammability range, will be characterized by explosive parameters, grouped into three categories:

- parameters characterizing the initiation of the explosion: heated bodies specific initiating parameters (the critical temperature of initiation, induction period, critical initiation energy) and parameters of electric spark initiation characteristics of high or low voltage minimum initiation energy

- parameters characterizing the propagation of the explosion: maximum explosion pressure, the time required to achieve the maximum explosion pressure, maximum pressure increase, the severity factor, flame propagation speed, normal speed of combustion.

- parameters characterizing the explosion extinguishing: extinction distance, maximum security space.

The installation of the explosive system in an explosive fuel-oxidant mixture is named ignition. The ignition is taking the system in the condition in which potentially explosive fuel-oxidant chemical reaction continues after the ending of initiating source. If ignition occurs only on account of self-accelerating growth temperature, the process is called spontaneous ignition (self ignition). If ignition occurs with the help of local sources, with thermal and chemical energy input, it can be said that the ignition is controlled (initiated).

Local sources ignition are: electrical sparks (rapid dissipation sources) capacitive sparks, inductive-capacitive sparks, sparks disruption of DC or AC circuits containing inductance, "corona" discharges; heated objects (slow dissipation sources) heated filaments and other metal objects, flames or hot gases generated by other systems; lasers or other unconventional sources (ionizing radiation, shock waves, etc.).

Ignition stage is followed by the propagation of the explosion throughout the mass of gas, this occurring through a well-defined combustion front, which separates the unconsumed gas from the reacted ones. Electrical sparks are very hot ignition sources and have very short flash time. It is possible for a weak spark to break through an explosive gas without causing an ignition. It was shown that very weak sparks can not cause the ignition of the entire gas, causing local and partial combustion of explosive gas, depending on its composition. It seems that the deflagration is initiated by a spark caused by the burning of quantities of gas. If spark energy increases until a critical threshold where the spark can ignite, the spark will ignite the combustion gas so as to propagate itself throughout the whole volume of gas.

The energy q dissipated by a spark depends on the characteristics of the electrical circuit:

to a spark that appears at the break of the inductive circuit, it is expressed by:

$$q = \frac{L \cdot i^2}{2}$$

for a spark produced by a capacitor discharge the energy is:

$$q = \frac{C \cdot \Delta V^2}{2}$$

where L is the coil inductance, and i - the amperage, C is the condenser capacity, and the ΔV is the difference between the energy stored in the capacitor before and after discharge, or rather the amount of energy transferred by the spark to the gaseous mixture.

The time in which energy is dissipated is much shorter in the second case than in the first case [4]. In terms of initiating the explosion in flammable gas mixtures by electric sparks, research has been directed to determine the safe use of electrical appliances in the presence of potentially explosive mixtures. At first, mining and other industries later users of electrical equipment called intrinsic safety certificates [5] for use in environments where flammable gases may occur (methane - coal mining and other combustible gas - other industries). The term may refer to the inherent safety circuit or electrical equipment. If they relate to a circuit, this means that any spark that could occur in normal operation, according to the prospectus, it is unable to lead to an explosion in an atmosphere where gas may occur for which certification was made. In other words, the power consumption of the circuit is always less than the minimum ignition current, I min. If refers to a device, it means that it is built in such a manner that when is connected and operated according to the prospectus, any spark that would occur in normal operation, both within the apparatus and the external circuit, is unable to lead to an explosion in an atmosphere where gas may occur for which certification was made. When making measurements for determination of minimum ignition energy the capacitive spark is normally used because of the efficiency and to determine the amount of energy released in a short time as possible. The method consists in determining the capacity and the voltage corresponding to a spark that is capable of producing the ignition the mixture studied. There has been made more electrical fixtures, one of the simplest is to measure the potential V for different values of capacity until the last value is obtained for small enough energy to become less dispersed minimum flash time energy.

The results have triggered a lot of controversy over the explosion Initiation mechanism, for the spark energy, that is if the value is actually a mixture of each feature value and whether or not it is automatically influenced by temperature. If the spherical combustion wave diameter is less than or equal with a critical value called the critical diameter of the minimum flame, the ignition of the mixture no longer occurs, for example, for a stoichiometric proportion for a mixture of methane and air must have a range of combustion wave at least 0.23 cm. If the spark energy is enough, the spherical wave propagates very quickly - after a few hundred microseconds – with a stable and well-defined spatial speed.

2. MINIMUM IGNITION ENERGY

The critical energy threshold at where source of ignition (spark heated surfaces) can ignite a gaseous mixture, the minimum ignition energy, is a parameter that is extremely useful and much studied in the literature. It heavily depends on experimental variables such as gas mixture parameters (composition, temperature, volume, pressure), initiation configuration source - electric spark initiation, form and time of discharge electrodes and the initiation of heated surfaces (filaments), the rate of energy dissipation from the source ignition the explosive gas.

The ignition mechanism problems with has stirred a lot of debate about energy dependence factor for the spark discharge. It was shown that [6] to obtain a form of pulse for the released spark energy versus time, is required the introduction of a 250-ohm resistors in the discharge circuit, which involves a decrease in the transferred energy and a decrease in the discharge time. Decrease the amount of resistance results in a damped oscillating evolution of the discharge current. Following an aperiodic discharge, Rose and Priede achieved a critical energy value for hydrogen-air mixture lower than that obtained by Lewis and von Elbe [3]. The lowest minimum ignition energy value is reached at the composition of a gaseous mixture which is at the maximum reactivity. Depending by the capacitor power, electric circuit inductance, the material the electrodes are made of by their configuration (hemispherical glass) and the distance between the electrodes, the minimum ignition energy is a measure of easiness of gas mixtures ignition by electric sparks - considered fast ignition sources: sources that transfers its energy to the gas mixture in a time of the order of 10^{-9} to 10^{-8}, thus obtaining values of local temperature on the order of 10^4 K. Systematic research on the minimum ignition energy have revealed an interesting dependence on gas composition and pressure (Fig. 1).

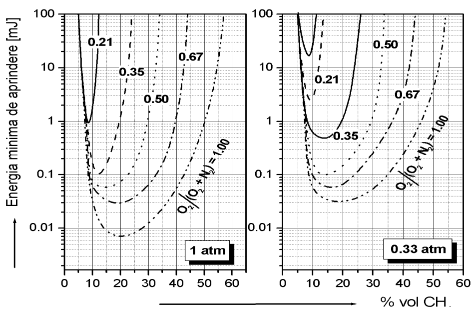

Figure 1. Variation of minimum ignition energy with pressure and gas composition for an oxygen-methane mixture.

MATERIALS AND METHODS

Experiments conducted in this paper focuses on the behavior of the propane - air explosion, to measure the minimum ignition current in order to determine the minimum ignition energy by sparks disruption of Direct Current circuit containing inductance initiation. It is noted that the experiments are preliminary tests to improve the system, to achieve the best possible correlation with literature data for further research and to evaluate and to determine the ignition characteristic parameters for the fuel-air explosion. Experiments to determine the minimum ignition current were conducted by using a cell specifically designed for experimental explosion at normal pressure and the under pressure. Diagram of such an installation is shown in fig. 2 and the electric circuit in fig. 3.

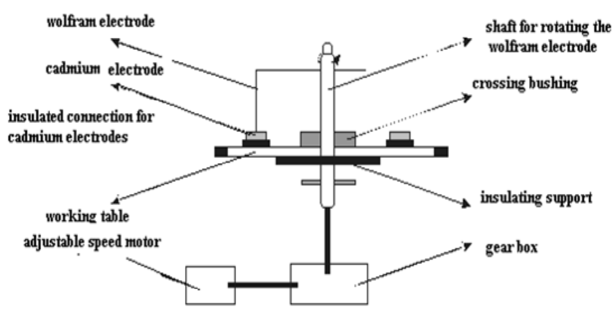

Figure 2. Explosion cell for the determination of the minimum ignition current

By interruption of electric circuit the energy accumulated in the inductance of the circuit discharges as a spark and is released partially to the explosive gas. Most times, the minimum ignition current is determined for the composition of a reactive mixture composition close to stoechiometric, ambiental temperature and pressure.

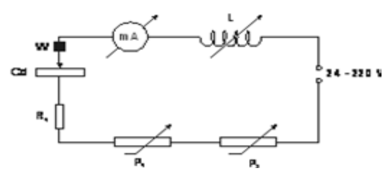

Figure 3. Electrical circuit
W – wolfram electrode; Cd – cadmium electrode R1 – current limit ressistence; P1, P2 – potentiometers for current reglation; L – inductance; mA – miliampermeter.

Current value is adjusted using variable resistors P1 (coarse adjustment) and P2 (fine adjustment). Since these settings changes the circuit inductance, this is measured in terms of current and it is used a calibration curve. Minimum ignition energy determined by this method is calculated from the stored energy by the inductance L for current Imin according to the equation:

$$q = \frac{L \cdot i^2}{2}$$

For the experiments it has been used propane, because this seems to be one of the most studied hydrocarbon, for wich there can be found experimental data in order to compare the experimental results.

RESULTS

Below are presented obtained data in this experiment that took place during propane-air explosion with propane concentrations of 4%, 5.2% and 6%:

Tabel I. Minimum ignition current and minimum ignition current for explosive mixture propane-air

4 % propan-aer				5.2 % propan-air				6 % propan-air			
p_0 (kPa)	i_{min} (mA)	Inductan□ă	H_{min} (mJ)	p_0 (kPa)	i_{min} (mA)	Induct an□ă	H_{min} (mJ)	p_0 (kPa)	i_{min} (mA)	Inducta n□ă	H_{min} (mJ)
101.3	117.5	111.1	0.76	101.3	105	113.08	0.62	101.3	120	112.24	0.808
81.3	135	110.6	1.007	81.3	135	111.14	1.01	81.3	140	111	1.08
61.3	147.5	110.3	1.19	61.3	150	110.4	1.24	61.3	165	109.9	1.49
41.3	200	109.3	2.18	41.3	175	109.6	1.68	41.3	240	108.13	3.14

To determine the inductance was used the calibration curve inductance-current for the generating sparks interruption circuit shown below:

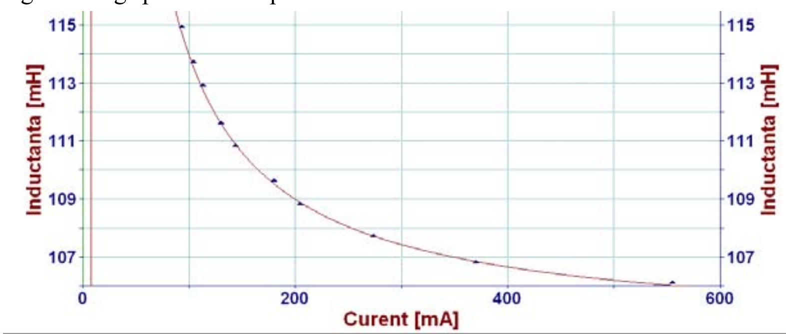

Figure 4. Inductance-current calibration curve

DISCUSSION

Minimum current value obtained experimentally was compared with the minimum ignition current value from IEC 60079-11: EXplosives ATmospheres - Part 11: Equipment protection by intrinsic safety "i", value that is recommended to calibrate the circuit for fitting the equipment operating in explosive atmospheres in explosive groups. The minimum ignition current obtained experimentally, for similar experimental conditions, was very close to that recommended in the standard mentioned, as below: standard MIC value: 100-101 mA, and the MIC was obtained experimentally 102.5 mA.

Also, the minimum ignition energy values obtained using minimum ignition current values were located very close to those reported in the literature, e.g. minimum ignition energy reported in the literature was 0.49 mJ with a probability of 25% and 0.76 mJ at a probability of 100% [11] for propane-air mixture with a propane concentration of 4% and the minimum ignition energy obtained experimentally was 0.76 mJ. This has led to the conclusion that this experimental set up for the determination of minimum ignition energy by measuring the minimum ignition current, does not have too much energy loss, so after a brief reevaluation, it can be used in experiments that will follow, for the study of the explosive characteristics of complex gas mixtures.

CONCLUSION

Explosions are complex phenomena of quick and violent combustion of the explosive atmospheres, with unpredictable developments, including various chemical processes and physical (heat transfer, flame formation, pressure growth, gas exchange with the environment, structural transformations produced building materials and elements of the resistance of targets in the area of influence, etc.).

Concern to avoid accidental explosions and limiting damage caused by them (when explosions cannot be suppressed) is a more consistent research direction, as production development increases the risk of such incidents. Indeed, increased consumption of fuels, solvents and other flammable substances resulted in increasing number of units that can form explosive mixtures, during the manufacturing, storage, handling or transport.

Experiments conducted in this paper focuses on the explosive behavior of propane - air, to determine the minimum ignition energy by measuring the minimum ignition current on a break spark initiation.

Experiments were preliminary tests to improve the system in order to achieve the best possible correlation with literature data for further research on the determination and assessment of explosion initiation characteristic parameters in fuel-air environment.

In the future we want to study the behavior of complex explosive gas mixtures, such as biogas because of the current trend of using it more and more as an energy source.

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