

Inert Substances and Explosion Limits of Hybrid Mixtures

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Problems of formation of hybrid mixtures are a rather neglected hazard to the manufacturing process. With the origin of such mixtures a necessity of minimizing possible risks that may accompany the formation of hybrid mixtures is connected as well. The article focuses especially on problems of possible inerting of hybrid mixtures.

1. Introduction

At present, when new substances are used, the formation of hybrid mixture is not any great problem; that appears at the moment when a possibility of formation of hybrid mixture is neglected and thus a hazard resulting from the formation of hybrid mixture is not handled sufficiently.

One of possibilities of preventing large-scale damage that can be caused by the occurrence of hybrid mixture is efficient inerting of this mixture.

2. Definition of used basic terms

2.1 Lower explosion limit

The lower explosion limit (henceforth referred to as LEL) is the lower limit of explosion range. LEL represents such value when a shortage of flammable substance in the mixture with an oxidizing agent manifests itself. Here it should be stated that LEL does not depend on a ratio of oxygen to nitrogen in the mixture as stated frequently (Damec, 1998).

2.2 Hybrid mixture

The hybrid mixture is a mixture of air and flammable substances of different physical conditions. It should be mentioned here that a small amount of vapours of a flammable liquid or a flammable gas is sufficient for reducing the lower explosion limit of flammable dust-air mixture. The violence of hybrid mixture explosions can be not predicted by simply overlapping the effects of the single (only dust and only gas) explosion. (Russo et al., 2012)

2.3 Inerting

Inerting is included in primary explosion protection. In practice this method is increasingly utilized for its efficiency and maintaining safety. The formation of explosive concentrations is prevented by means of inert substances. As inert substances, substances in gaseous state (e.g. nitrogen, carbon dioxide, noble gases, halohydrocarbons), water vapour and admixtures of solid inert substances in powder state can be used. Disadvantages of this method consist in higher operational costs. In practice, gaseous nitrogen is the most used substance for inerting. In the course of gas inerting, the space in which the inert is to be used is necessary to be enclosed. Nitrogen is capable to ensure a rapid increase in minimum initiation energy and a drop in maximum explosion parameters in the system. If it reaches the limiting oxygen concentration (LOC) value, the mixture cannot be initiated by the initiation source with standard energy of 10 J any more. If the initiation energy is higher (flame, electric arc, etc.), initiation may occur even at LOC value. On the

other hand, nitrogen has in comparison with some other inert gases (e.g. CO₂) the disadvantage of having the specific thermal capacity almost equal to that of oxygen (Eckhoff, 2003). An admixture of inert materials with higher specific thermal capacity will affect more a change in the lower explosion limit as well as upper explosion limit (UEL). This fact is illustrated in Figure 1 where an evident difference between the use of nitrogen and that of carbon dioxide can be seen.

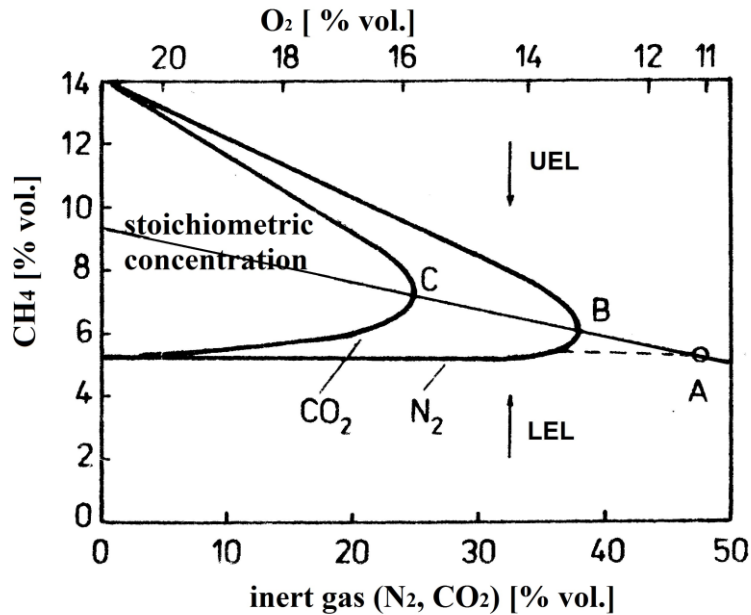


Figure 1: Comparison of influencing of LEL and UEL when inert gases N₂ and CO₂ are used (Novotný, 1988)

3. Experimental determination of LEL of hybrid mixture

Measurement was a part of broader investigation aimed at the determination of lower explosion limit of a hybrid mixture, namely flour-methane mixture. This mixture had been selected to ensure a possibility of easy repeatability of measurement in the future (Serafin et al., 2012).

3.1 Measuring procedure

The mixture that was used in the experiment was a mixture of smooth flour (Figure 2), methane and air under conditions of laboratory test.

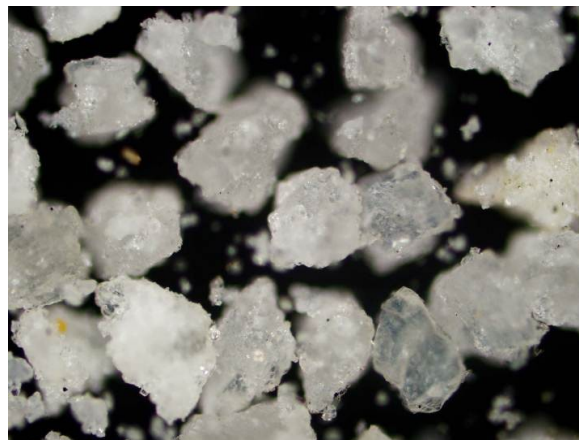


Figure 2: Grain flour dust

For measurement, wheat fair smooth flour according to Product specification (Přihoda, 2012) was used. Table 1, Table 2 and Figure 3 show results of executed sieve analysis.

Table 1: Physical and chemical properties of flour

Physical	Chemical
Moisture	Max 15.0 %
Ash in dry matter	Max 0.68 %
Wet gluten in dry matter	Min 28.0 %
Granulation: undersize 257 μm	Min 96.0 μm
Granulation: undersize 162 μm	Min 75.0 μm
Number of decrease	Min 200 s

Table 2: Sieve analysis of flour

Granulometric state	P
Sieve [mm]	Oversize [mass %]
0.063	98.3
0.075	89.6
0.106	61.6
0.125	34.8
0.150	9.5
0.212	2.2
Middle size of a grain [mm]	0.116

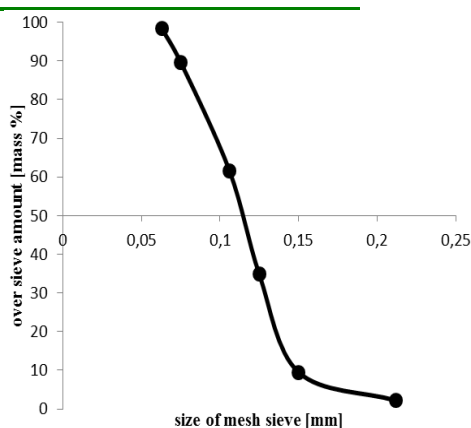


Figure 3: Sieve analysis of flour

Granulometric state, P consists of original delivered sample. Apparent heterogeneous particles are removed from the sample. If needed, weight of the sample could be decreased using quartering. Table 3 introduces the values of poured density of flour for single measurements.

As already outlined above, the experiment was based on the measurement that had aimed at the determination of lower explosion limit of the given hybrid mixture. Results of previous measurement, it means the basis for the determination of influence of inert admixtures on the lower explosion limit of hybrid mixture being studied, are presented on Figure 4.

Table 3: Poured density

Measurement No.	Weight of dust [g]	Volume of a cylinder V [cm ³]	Poured density [g/cm ³]	Poured density [kg/m ³]	Average poured density [kg/m ³]
1.	279.09	500	0.55818	558.18	556.8
2.	277.48	500	0.55496	554.96	
3.	278.58	500	0.55716	557.16	

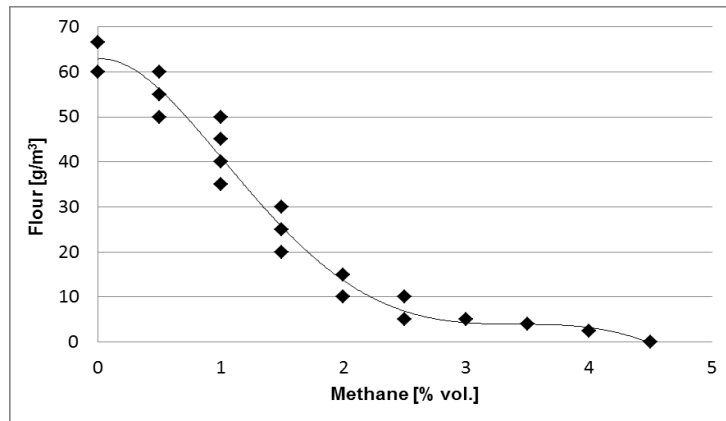


Figure 4: Measured values of dependence of LEL_{FLOUR} on methane amount

4. Hybrid mixtures and inerts

4.1 Ground limestone inerting

The charge, i.e. the required amount of flour, was mixed with the determined amount of limestone in a beaker. This mixture of ground limestone and flour was evenly poured in four spreading devices in the explosion chamber VK-100 (Figure 5).

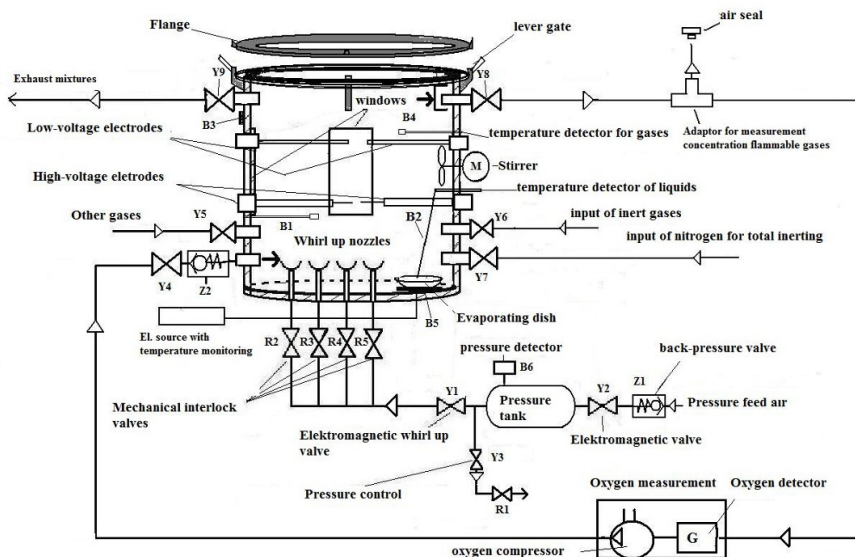


Figure 5: Scheme of the explosion chamber VK-100.

The chamber was covered with paper foil, and the required amount of methane was added through the inlet valve, when simultaneously with gas supply the homogenization of methane-air mixture was

performed by means of a stirrer. After completing the homogenization, the mixture of flour and ground limestone was raised in the explosion area. The formed hybrid mixture containing the given amount of inert powder was subsequently initiated. After each measurement, impurities had to be carefully removed from the internal space of the chamber to avoid affecting the next experiments (Mynarz et al., 2013). At first, the influence of limestone inerting of flour itself without any admixture of methane was examined. Then this was gradually performed for 1 % by volume, for 2 % and for 3 % by volume of methane. The overall result is given in Figure 6, where curves for all methane concentrations being determined are plotted. The raising pressure was 3 bars in all three experiments. Values of densities of the whole mixture, limestone and flour are already multiplied by 10 (thus they are converted to the volume of 1 m³).

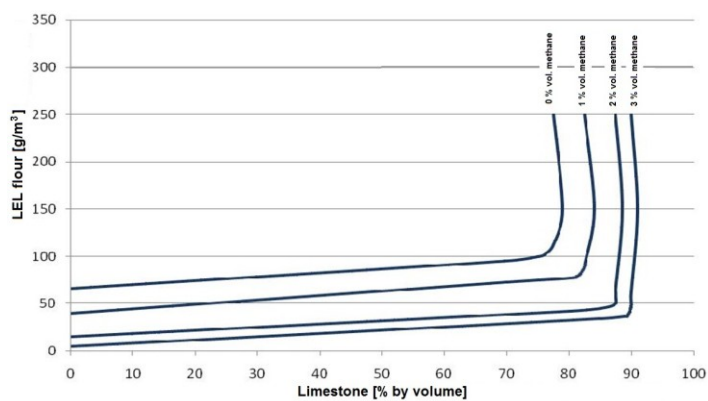


Figure 6: Influence of limestone on LEL of flour-methane hybrid mixture

4.2 Nitrogen inerting

Another part of experiment was to measure the influence of gaseous inert substance on the explosion range of flour-methane-air hybrid mixture in the explosion chamber. In this case, nitrogen was selected as the inert substance. In practice, nitrogen is the gas that is used for inerting most frequently. The determined amount of flour was poured in the spreading dishes in the chamber. On electrodes, nitrocellulose blasting caps was mounted, and the upper part of explosion area was covered, likewise in the course of previous measurements, with paper foil. At first, nitrogen stored in a pressure bottle was supplied to the chamber. In the paper foil, a hole was produced to enable the determination of concentration of oxygen by an oximeter in the explosion area. After that nitrogen was put to the space and the chamber fan was switched on from the control panel to homogenize the mixture.

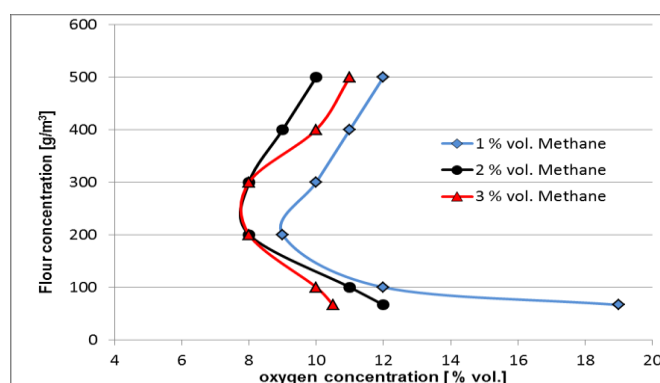


Figure 7: Influence of nitrogen on concentration of flour-methane hybrid mixture

On the oximeter display, the value of volume percentage of oxygen in the chamber was read. As soon as the required value of oxygen was achieved, the oximeter mouthpiece was taken from the paper foil and the hole was sealed with an adhesive strip. The inlet of nitrogen was closed and the same procedure as with previous measurements followed. The determined amount of methane was supplied, flour was raised and

the mixture produced was initiated. Again, the flame, foil rupture and temperature on the thermometer was observed.

Measurement was carried out for three different volume amounts of methane in the hybrid mixture (1 % vol., 2 % vol., 3 % vol.). It is necessary to emphasise that inerting of the hybrid mixture with an inert gas had not been measured in the explosion chamber yet and measured results are thus of experimental character. All outputs of this measurement are in Figure 7.

5. Conclusions

Problems of hybrid mixtures are an ever topical subject. Thus it is clear that if hybrid mixtures will be formed, it will also be necessary to be concerned with them, to study their properties and possibilities how to minimize potential consequences brought with such a mixture as efficiently as possible.

The part of measurement was to determine the effect of inert gas hybrid mixture. The result is a general graph, from which it is apparent that the closure explosive areas for these hybrid mixtures is between 8 -10 % by volume of oxygen in the mixture.

In the course of measuring the hybrid mixture with 3 % by volume of methane, around a value of the concentration 8 % by volume of oxygen in the mixture, a problem appeared; the initiation of the nitrocellulose blasting cap failed and thus the sufficient initiation energy as in all previous cases of measurement was not generated.

The amount of oxygen too small to cause the ignition of nitrocellulose could be the cause. For this reason, these values of the mass concentration of flour ranging from $200 \text{ g}\cdot\text{m}^{-3}$ to $300 \text{ g}\cdot\text{m}^{-3}$ cannot be taken as experimentally correct.

Figure 7 also shows that increasing of the percentage of methane influences resulting values of the substance. This fact is evident from the curves for 2 and 3 % vol., when the values of 300 to $500 \text{ g}\cdot\text{m}^{-3}$ leads to crossing of the resulting curves.

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