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Lower explosion limit of hybrid mixtures of burnable gas and dust

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A B S T R A C T

Hybrid mixtures – mixtures of burnable dusts and burnable gases – pose special problems to industries, as their combined Lower Explosion Limit (LEL) can lie below the LEL of the single substances. Different mathematical relations have been proposed by various authors in literature to predict the Lower Explosion Limit of hybrid mixtures (LEL_{hybrid}). The aim of this work is to prove the validity or limitations of these formulas for various combinations of dusts and gases. The experiments were executed in a standard 20 L vessel apparatus used for dust explosion testing. Permanent spark with an ignition energy of 10 J was used as ignition source. The results obtained so far show that, there are some combinations of dust and gas where the proposed mathematical formulas to predict the lower explosible limits of hybrid mixtures are not safe enough.

1. Introduction

Safety related design and safe operation of equipment requires knowledge about the potential of the ignition and explosion behavior of substances. They are based on the safety-related parameters including in particular explosion limits. These values describe the ignition behavior and the possible consequences of explosions.

Usually, these measures refer to a defined material, generally a pure substance or a well characterized dust. However, in industrial production, mixtures of materials either of the same state of matter or different occur during a production process. For these mixtures, the corresponding parameters are not available and their behavior can only be predicted inadequately.

From the perspective of practicality, it is not accomplishable to measure all possible mixing ratios. To obtain at least a partial prediction of the behavior of mixtures is the aim of these research efforts. In particular, the behavior of combustible dusts and gases near the lower explosion limit (LEL) is examined, as it is well known Bartknecht (1989); Amyotte et al. (2010); Cashdollar and Kenneth (1996) that a mixture of flammable dust and gas can be ignitable at concentrations that lie below the LEL of the individual substance. For this reason, the lower explosion limit for mixtures might be derived as a function of the gas (X_{Gas}) and the dust (C_{dust}) concentration, as generally defined in Equation (1):

$$LEL_{hybrid} = f(X_{Gas}, C_{dust}) \tag{1}$$

Research on this problem has been published for example by Bartknecht (1989) and Glassmann and Yetter (2008) and led to different mathematical relationships for the LEL_{hybrid} further described in chapter 2. Based on the investigations on different material combinations, the validity of these formulas are to be questioned.

The starting point for this investigation was the thesis of Zarour (2013) with first series of measurements of mixtures of brown coal and natural gas. Within that, the basic suitability of the existing apparatus for the investigation of the explosion characteristics could be proofed.

The 20 L sphere in the version of “Kuhner Safety” was used to carry out the experiments. It is equipped with the necessary supply connections for gases and with a permanent spark as ignition source.

2. Safety related parameters of hybrid mixtures

The same parameters used to characterize the safety relevant potential of gases and dusts are also applied for hybrid mixtures. These parameters are:

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Table 1
Tested gases and dusts with the applied concentrations.

Gas	Concentration [vol. %]	Dust	Concentration [g/m^3]
Methane	1, 2, 3, 4, 5	Lycopodium	60, 125, 250
Hydrogen	2, 4, 6, 8	Polyethylene (hd)	60, 125, 250
		Starch	60, 125, 250, 500
		Toner	10, 20, 30, 60

- Maximum explosion pressure
- Pressure rise velocity dp/dt
- KSt-value
- Lower explosions limit
- Limiting oxygen concentration
- Minimum ignition energy
- Upper explosion limit
- Minimum ignition temperature

The first five parameters can be derived from the experiments in the 20 L sphere. For hybrid mixtures the last four parameters are seldom measured Khalili et al. (2012) and no standardized procedures are available; thus they are not treated in this work. The main parameter of interest in this work is the lower explosions limit as it is well known that, the maximum explosion pressure, the pressure rise velocity dp/dt and consequently the K_{St}-value are sometimes underestimated if the electrical ignition is used. These values represented in this text are only comparable with each other but not with values measured with standard 10 kJ chemical igniters used for dust explosion testing.

To estimate the LEL_{hybrid} of gas/dust mixtures two main suggestions can be found in literature. The empirical formula below was derived from measurements done by Bartknecht (1989) that was used by the author himself to propose a formula for the LEL_{hybrid} (Equation (2)), the so-called Bartknecht curve:

$$LEL_{hybrid} = MEC_{dust}\left(\frac{X_{gas}}{LEL_{gas}} - 1\right)^2 \quad (2)$$

where

MEC_{dust} = minimum explosion concentration of the dust in air (g/m^3)
X_{gas} = gas concentration in the hybrid mixture (vol. %)
LEL_{gas} = lowest explosion limit of the gas in air (vol. %)

This relation was derived for the hybrid mixture of methane and PVC.

A more general approached was chosen by Glassmann and Yetter (2008) taking Le Chatelier's law as origin. The latter originally describes homogeneous mixtures by considering a constant flame temperature which was adopted by the authors for hybrid mixtures as presented in Equation (3):

$$LEL_{hybrid} = \frac{100}{\frac{X_{gas}}{LEL_{gas}} + \frac{C_{dust}}{MEC_{dust}}} \quad (3)$$

where

X_{gas} = gas concentration in the hybrid mixture (vol. %)
LEL_{gas} = lowest explosion limit of the gas in air (vol. %)
C_{dust} = dust concentration in the hybrid mixture (g/m^3)
MEC_{dust} = minimum explosion concentration of the dust in air g/m^3)

Both relations can be displayed in the diagrams used to represent the measurement results. The first forms a curve and the second a straight line to separate the region of explosion from the non-explosion region. This way of representing the result is used in

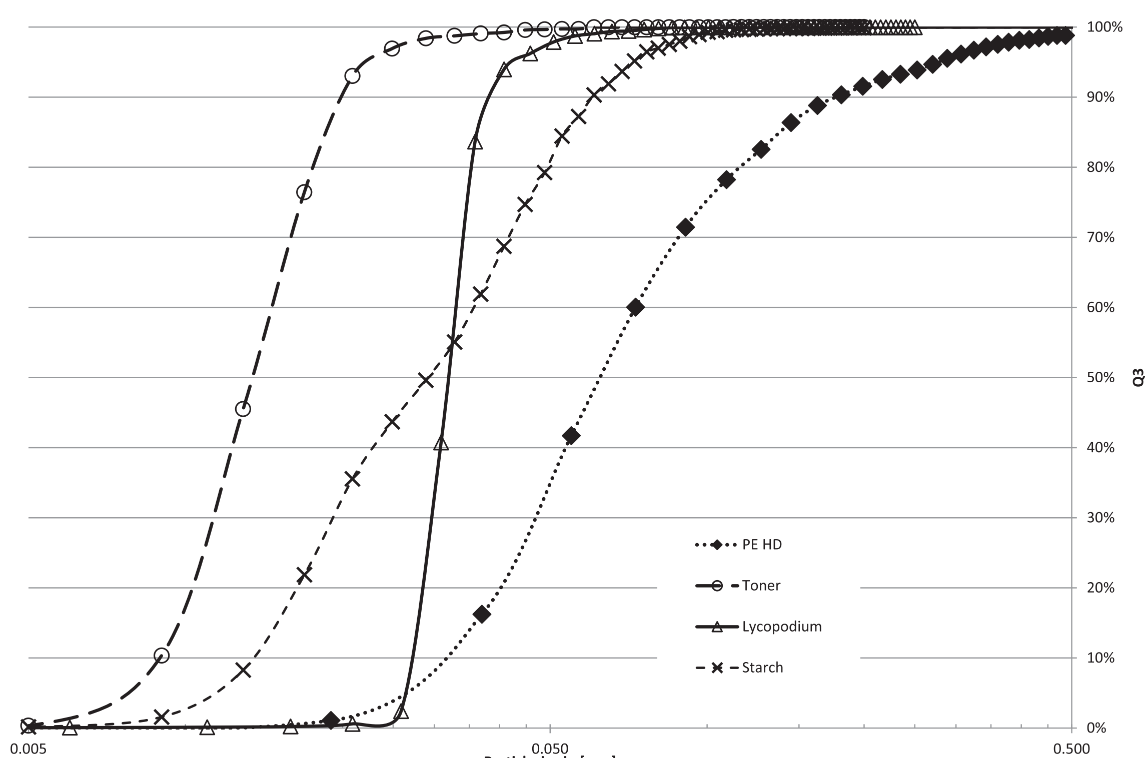

Fig. 1. Particle size distribution for the dusts used.