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Explosion characteristics of three component hybrid mixtures

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ABSTRACT

Hybrid mixtures of a combustible dust and flammable gas are usually found in many industrial processes that handle combustible dust, vapor or gas. The work of this paper investigates the explosion behavior of mixtures consisting of three flammable components and air. The materials used in this case are corn starch, methane and acetone in vapor state. The experiments took place in the standardized 20 L explosion sphere where modifications were done to allow input of solvent and gas. The test protocol was according to EN 14034 with electrical igniters as ignition source but in the case of pure dust tests both chemical and electrical igniters were used. The experimental results demonstrate the significant enhancements in explosion likelihood and explosion severity when small amounts of solvents or gases below their respective lower explosion limits were mixed with dust. They also confirm that a hybrid mixture explosion is possible even when dust, gas and vapor concentrations are respectively lower than their minimum explosion concentration (MEC) of dust and lower explosion limit (LEL) of gas and vapor. Considering dust as main component the results presented show that the addition of less than 4 vol. % of gaseous fuel significantly lowers the MEC of starch from 250 g/m^3 to 5 g/m^3 and also increase the explosion severity of the dust. In the case of gas/vapor, the addition of starch below the MEC decreases the LELs from 4.9 to 1.0 vol. % and 2.5 to 0.5 vol. % for both methane and acetone respectively.

1. Introduction

Explosion is an exothermic reaction involving a rapid chemical oxidation generating an increase in temperature or pressure or both simultaneously. The typical hazardous areas are in chemical factories, refineries, enameling plants, paint workshops, cleaning equipment, mills and stores for milled products and other combustible dusts, in tank facilities and loading areas for flammable gases, liquids and solids (Baker and Tang, 1991). Dust, gas, vapor and hybrid mixtures explosions can result in catastrophic personal injury and devastating damage.

Hybrid mixture explosions which involve the mixture of flammable dust, gas or solvent continue to occur in industrial processes that handle dust and flammable gases or vapors. Considerable research has therefore been carried out throughout the world with the aim of either preventing the occurrence or mitigating the consequences. Some of these researches are listed below.

Bartknecht (1989) studied the explosibility of cellulose with adding methane, butane and propane. He found that a hybrid mixture constituted by dust and gas concentration which is not explosible can turn into explosible one. In particular, when gas is added to a dust-air mixture, the maximum explosion pressure, p_m was found to have consistent increase, whereas a more dramatic effect was observed on the hybrid deflagration index, K_{St}.

Cashdollar (Cashdollar Kenneth, 1996) studied hybrid mixtures with coal dust and methane in a 20 L sphere using 2500 J

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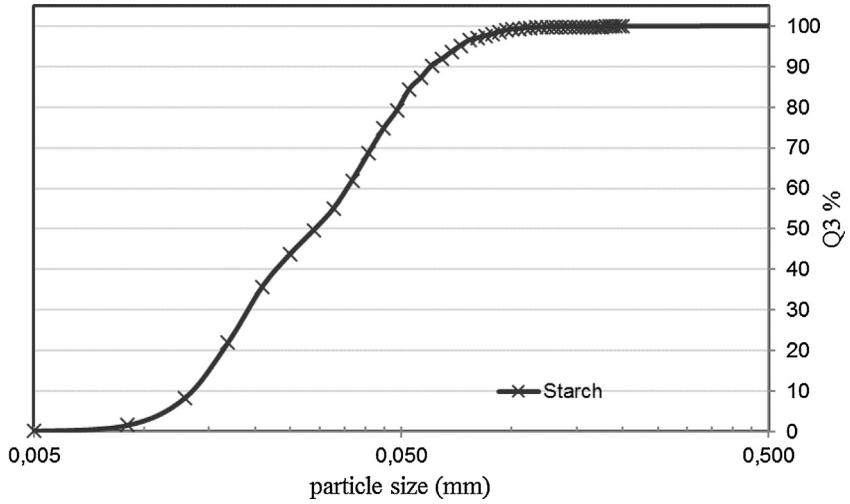

Fig. 1 – Particle size distribution for starch dust.

igniters. Low-volatile Pocahontas coal and high-volatile Pittsburgh coal were tested. He found that both of these substances became more easily ignited as more methane was added even below the LEL of individual substances.

Pilão et al. (2006) investigated the behavior of the hybrid mixture of methane and cork. They observed that the presence of methane at concentrations lower than the lower explosion concentration (LEL) (1.98 and 3.5 vol. %) affects both the explosion severity and the maximum explosion pressure for lower dust concentration (40 g/m^3), whereas both parameters are slightly affected in the case of higher dust concentration (450 g/m^3).

Denkevits (2007) studied the effect of the addition of graphite dust to a flammable mixture of hydrogen–air in the 20 L sphere in the presence of a weak electric spark. At each hydrogen concentration (from 4 up to 1 vol. %) different amounts (25–300 g/m^3) of graphite were added to the mixture and the maximum pressure rise and deflagration index were compared to the pure hydrogen/air mixture. The hydrogen-air mixture explosion tests were performed up to 18 vol.% of H_2 which is much lower than the stoichiometric value and, therefore, a direct comparison with the H_2–air maximum rate of pressure rise at the same turbulent conditions is not straightforward.

Dufaud et al. (2008) studied the influence of mixing pharmaceutical dusts (excipient, vitamins, active ingredients) with solvents (ethanol, di-isopropyl ether, and toluene) on maximum explosion pressure and maximum rate of pressure rise. They measured deflagration index values higher for dust–vapors air mixtures rather than for the pure fuels, thus concluding that there are more than simple additive effects on explosion severity.

Amyotte et al. (2010a,b) studied the explosion features of polyethylene admixed with propane, ethylene and hexane in the standard test conditions for dusts (in 20 L sphere, ignition by 10 kJ chemical igniters and ignition delay time of 60 ms). They performed the experiments adding low gas concentrations (1–5 vol.%) of ethylene, propane and hexane (in vapor state) to polyethylene dust by changing the dust concentration. They observed a significant increase of the deflagration index by adding ethylene at concentrations higher than its flammability limit with respect to the dust alone.

Garcia et al. (2011) studied the hybrid mixtures with niacin dust and methane in the 20 L sphere, using a weak electric spark ignition source instead of standard chemical igniters. They concluded that the additional methane can intensely affect the minimum explosion concentration (MEC) of niacin.

Sanchirico et al. (2009) studied the severity of hybrid mixture explosions with niacin and acetone, using a spark ignition source. They found that the dust and gas or vapor mixtures both at concentration below the explosive range can form an explosive mixture when combined.

Khalili et al. (2012) studied the sensitivity of various gas or vapor/dust mixtures (e.g. starch/methane, starch/hexane) in the 20 L sphere and the Hartmann tube. Their results showed that a concentration of gas/vapors as low as 1.0 vol.% causes a significant decrease of the minimum explosion concentration and induces changes in the rate limiting step of the combustion reaction, from boundary diffusion to homogeneous gas phase reaction.

From the analysis of the available literature, it appears the complexity of the hybrid explosion in fact, the effect of hybrid mixture explosions cannot be predicted by simply overlapping the effects of the single (only dust and only gas or vapor) explosion. Moreover, there is no systematic study able to quantify the role of dust, gas or vapor in driving the explosion.

Also, it can be deduced that the research on hybrid mixture explosions is complicated because of the large number of complex physical processes that occur during the explosion, and the high number of parameters that should be considered together during the explosion. Some parameters related to the hybrid mixture explosion are presented such as parameters related to the ignition source, the enclosure, the initial conditions, response or output flammable parameters, combustion dynamics, available energy, heat transfer and turbulence effects.

The work of this paper aims at studying the explosion features in the case of three combustible components. The components considered in this case are: corn starch, methane and acetone (vapor state). The tests were carried out in the 20 L sphere with electrical spark as ignition source. The safety indicators considered in these work are: p_m, dp/dt, LEL of gas or vapor and MEC of dust.