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To cite this article: H Badli *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **991** 012119

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The Influence of Ethylene Gas Concentration on LDPE/C₂H₄ Hybrid Explosion Process and its Severity

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Abstract. The influence of ethylene (C₂H₄) gas concentration on the LDPE dust hybrid explosion in a 20-L spherical vessel, equipped with a chemical ignitor was analysed for the determination of maximum explosion overpressure, P_{max} and deflagration index, K_G. The LDPE/C₂H₄ dust hybrid explosibility was evaluated based on the P_{max} development, measured by the Kistler piezoelectric pressure transducer. The adiabatic flame temperature was calculated based on ideal gas law. It is speculated that the LDPE/C₂H₄ explosion undergoes three-phase process, starting with the ignition, followed by flame growth and flame regression. The highest P_{max} (17.9 bar) and flame temperature (5200 K) was obtained at flame growth phase, recorded at C₂H₄ concentration of 3 vol/vol%. It was found that the P_{max} and flame temperature is dependent on C₂H₄ concentration. The calculated K_G values in a range of 14 – 60 bar.m/ms obtained in this study, suggesting that the LDPE/C₂H₄ dust hybrid explosion might subject to an extreme explosion characteristic.

1. Introduction

Explosion which involves a reactive mixture of dust and vapour/gas is defined as hybrid dust explosions [1]. Hybrid dust explosion is characterized based on maximum explosion pressure, P_{max}, maximum rate of pressure rise, (dP/dt)_{max} and deflagration index, K_G. These explosion characteristics have been tested on various hybrid dust mixtures for the hazard prevention and mitigation purposes [2–5]. Most of them agreed that the hybrid dust explosion characteristics are dependent on the particle concentration, size and gas/vapour concentration.

Low-density polyethylene (LDPE) is a thermoplastic, derived from polyethylene (PE), and mainly used in a manufacture of plastic bag. During the production of LDPE, dust clouds and ignition sources (static electric) are formed, potentially contribute to the explosion risk [6]. There was a reported accident where LDPE/C₂H₄ hybrid dust fire and explosion took place on 23rd of June 2005 at Petrochemical Plant in Kerteh, Terengganu due to the interlock system failure to supply and blow the air/nitrogen during the blending process. Even though there was no fatality reported, the plant was called for a temporary shut down for the investigation by the Department of Occupational, Health and Safety (DOSH). According to the internal investigation, there were several potential factors that might have caused this accident,



but it was believed that the presence of ethylene gas is the contributing factor to the LDPE/C₂H₄ fire and explosion which involved one of the silo blenders of that polyethylene plant.

Most of the research work on LDPE dust explosion was explored by Pang research group [6,7]. However, the focus of their investigation was on the effect of LDPE particle size and the effect of inert gas concentration on flame propagation and no attempt has been reported on the repercussion of C₂H₄ concentration to the explosion parameters. The effect of C₂H₄ concentration on HDPE/C₂H₄ hybrid dust explosion has, however been studied by Gan et al. (2018a) and it was reported that the HDPE dust explosion is dependent on C₂H₄ concentration. It was found that the synergistic effect between the HDPE dust particles and C₂H₄ play an important role in the combustion and explosion process. It was reported that the increase in P_{max} is proportional to the concentration of C₂H₄. However, the generated P_{max}-C₂H₄ correlation was subjected to HDPE/C₂H₄ hybrid dust mixture, leaving a room for further investigation on the effect of C₂H₄ concentration and LDPE on the explosion severity.

Badli et al. (2019) reported that C₂H₄ concentration poses a significant effect on the LDPE hybrid explosion characteristic. The P_{max} and dP/dt increase as the C₂H₄ concentration increases up to 3 vol./vol. % beyond which, the P_{max} and dP/dt decrease. Besides gas concentration, flame propagation identification is essential to describe the explosion process [6]. This analysis is instrumental and useful for the prevention and controls of explosion propagation. There are several reports on flame propagation related to the HDPE/C₂H₄ hybrid dust explosion by Gan et al., (2018a, 2018c) and Pang et al. [6]. According to Pang et al. (2019), the explosion process starts with the ignition phase followed by flame growth and flame regression. However, the observation is limited to HDPE/C₂H₄ hybrid dust explosion. In response to the limited information on the explosion parameters of LDPE/C₂H₄ dust hybrid explosion in the fuel database, this study was aimed to evaluate the effect of various C₂H₄ concentrations on the dust explosion characteristics for the LDPE/C₂H₄ dust hybrid system in a closed spherical chamber under a fixed MEC and LDPE concentration.

2. Methodology

2.1 Material

The effect of C₂H₄ gas concentration on the LDPE/C₂H₄ dust hybrid explosion was performed in a Siwek 20-L spherical vessel as shown in figure 1. Based on the previous study [5], the optimal values of minimum explosible concentration (MEC) and the particle were fixed at 15 g/m³ and 125 μm respectively, in this work. The C₂H₄ gas concentration was varied from 0 – 5 vol/vol%. The C₂H₄ gas with a purity of 99.9% was purchased from a local company. The LDPE dust was supplied by local petrochemical company.

2.2 Experimental

The initial process conditions were fixed at ambient temperature and 1 bar throughout the experiment. The standard chemical ignitor (10 kJ) connected to the ignition electrode was used as an ignition source in this explosion test. The explosion pressure (P_{max}) was measured by two “Kistler” piezoelectric pressure sensors. The designated C₂H₄ concentration was prepared using a partial pressure method with an accuracy of 0.1 mbar (0.01% of the composition) at ambient condition. A vacuum pump was used to depressurize the vessel at the desired pressure (min. of 500 mbarg) to subsequently refill the vessel with C₂H₄ based on the calculated pressure. The LDPE particles are loaded directly to the storage container and were dispersed with the rebound nozzle connected to an outlet valve located at the bottom of the vessel by using compressed air, pressurized at 20 barg. The Siwek 20-L vessel (see figure 1) was interfaced with a computer to control the dispersion or firing sequence and data collection by using the control system, named KSEP. A minimum number of three experiments were performed for each condition to achieve a good reproducibility.



Figure 1. The standard 20 L spherical vessel.

3. Result and Discussion

3.1 LDPE/C₂H₄ dust hybrid explosion development

Figure 2 shows the LDPE/C₂H₄ dust hybrid explosion process, which describes the P_{\max} development in this work. The P_{\max} trend indicates that the dust hybrid explosion is subject to three phases; ignition (a), flame growth (b) and flame regression (c) [7]. The ignition phase (marked as “a”) only starts at $t = 75$ ms, and it takes 170 ms before it is fully developed into a flame growth phase. At the ignition phase, the LDPE particles were pyrolyzed to produce C₂H₄ gas [7]. Simultaneously, some of the LDPE particles participate in the combustion to form a flame. The flame propagates slowly and result in a slight increase of the P_{\max} from 0 to 0.5 bar. At this particular instant, the combustion takes place heterogeneously, indicating that this process is driven by the dust explosion.

Figure 2 also illustrates that when $t > 250$ ms, the P_{\max} increases abruptly from 0.5 to 17.9 bar confirming the transformation from ignition to flame growth phase. The continuous pyrolysis and combustion lead to flame expansion, and establishes the premixed flame at the flame front. Furthermore, the presence of C₂H₄ intensifies the combustion reaction and causes the flames to propagate rapidly. It is understood that the significant increase of P_{\max} is due to the fast flame propagation, steered by the gas explosion. From 452 ms to 500 ms, marked as ‘c’, the P_{\max} , however, reached a plateau. This observation indicates that the flame already extended to the regression phase, where the LDPE/C₂H₄ dust hybrid mixture completely involved in the explosion process.

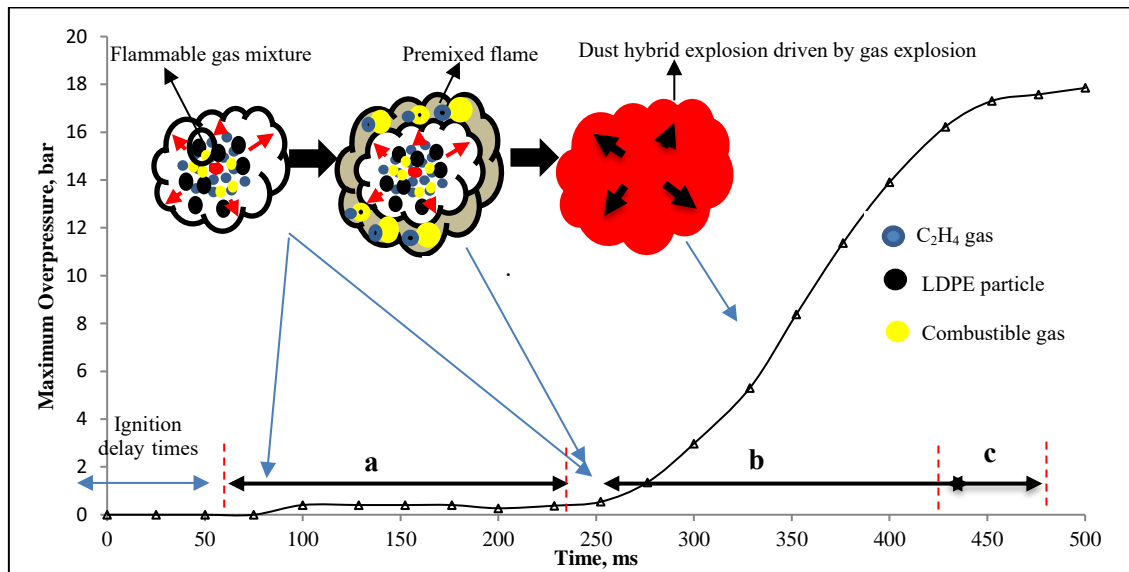


Figure 2. LDPE/C₂H₄ dust hybrid explosion phases.

3.2 The effect of C₂H₄ concentration on P_{max}

Figure 3 shows the trend of explosion pressure, (P_{max}) of LDPE/C₂H₄ dust hybrid mixture for different C₂H₄ concentrations, from 0 to 5 vol./vol. %. The MEC and particle size of LDPE were fixed at 15 g/m³ and 125 μm [5] respectively, it appeared that the P_{max} increases from 5.5 to 17.9 bar as the C₂H₄ concentration increases from 1 vol./vol. % to 3 vol./vol.%, but starts to level off thereafter. The increase of P_{max} may be attributed to the synergistic (interaction) effect [9] between LDPE particles and C₂H₄ gas, leads to a higher explosion intensity.

It is observed that at higher C₂H₄ concentration (4 and 5 vol./vol.%), the difference in P_{max} is contracted by 30 % from 17.9 bar to 12.2 bar. It is speculated that, the synergistic effect was suppressed by the presence of an excess C₂H₄ and deteriorates the explosion development, primarily during the flame growth phase.

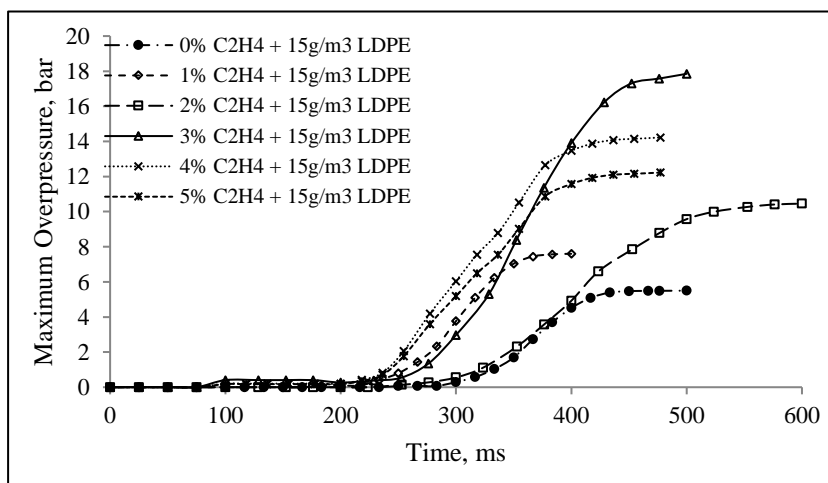


Figure 3. LDPE/C₂H₄ dust hybrid explosion pressure development at different C₂H₄ concentrations.

3.3 The influence of ignition time delays, t_{eff}

Apart from the C₂H₄ gas concentration, the ignition delay times, t_{eff} (turbulence level) also influence the explosion severity [1,10], as characterized by the deflagration index, K_G. As shown in figure 4, the

K_G value decreases with the ignition time delays (or turbulence level) where, in high turbulence environment, most of the LDPE particles are homogeneously dispersed and participate in the explosion process, and this condition does not occur in the longer ignition time delays (low turbulence level). The shortest ignition delay time is noted at 75 ms with the K_G value of approximately 60 bar.m/ms, while the longest delay time is registered at 230 ms giving K_G of 14 bar.m/ms. Evaluating the obtained range of K_G values, which are greater than 0.3 bar.m/ms, the hybrid explosion within the controlled parameters and conditions in this work can be classified as hazard class ST 3 [11]. This finding suggests that the LDPE/C₂H₄ dust hybrid explosion may potentially generate a severe explosion impact.

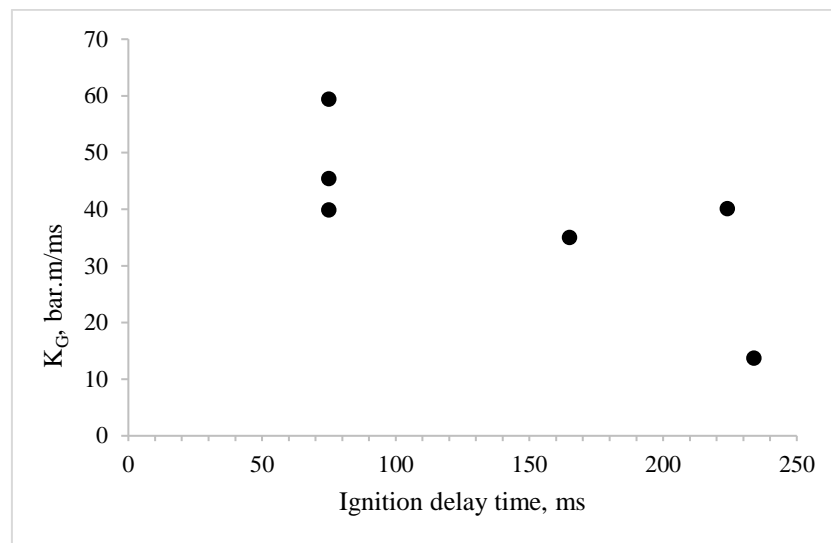


Figure 4. LDPE/C₂H₄ dust hybrid explosion process time.

3.4 The effect of C₂H₄ concentration on flame temperature

The calculated flame temperature of LDPE/C₂H₄ dust hybrid explosion at an identical initial temperature and pressure is presented in Figure 5. The flame temperature is determined according to equation (1):

$$T_2 = \frac{P_{ex2}}{P_{ex1}} \times T_1 \quad (1)$$

Equation (1) was developed based on the ideal gas law [12], employing the assumption that the explosion pressure ratio at different temperature corresponds to the ratio of adiabatic flame temperature to initial temperature. Figure 5 shows that the calculated flame temperature and P_{max} exhibit a similar general trend with a variation of C₂H₄ gas concentration. The highest flame temperature and P_{max} is achieved at C₂H₄ = 3 vol./vol.%, beyond which, the P_{max} and flame temperature decline sharply. The maximum trend of P_{max} and flame temperature to C₂H₄ concentration demonstrate the significant dependency, primarily at 3 vol./vol.% where the optimum combustion is believed to take place. At this optimum C₂H₄ concentration, the highest and lowest flame temperature is 5400 K and 1700 K, respectively, where no additional C₂H₄ was added during the explosion test. Above this concentration, the presence of C₂H₄ exerts less significant effect on the combustion, inducing a flame deceleration and subsequently reduce the flame temperature and P_{max} .

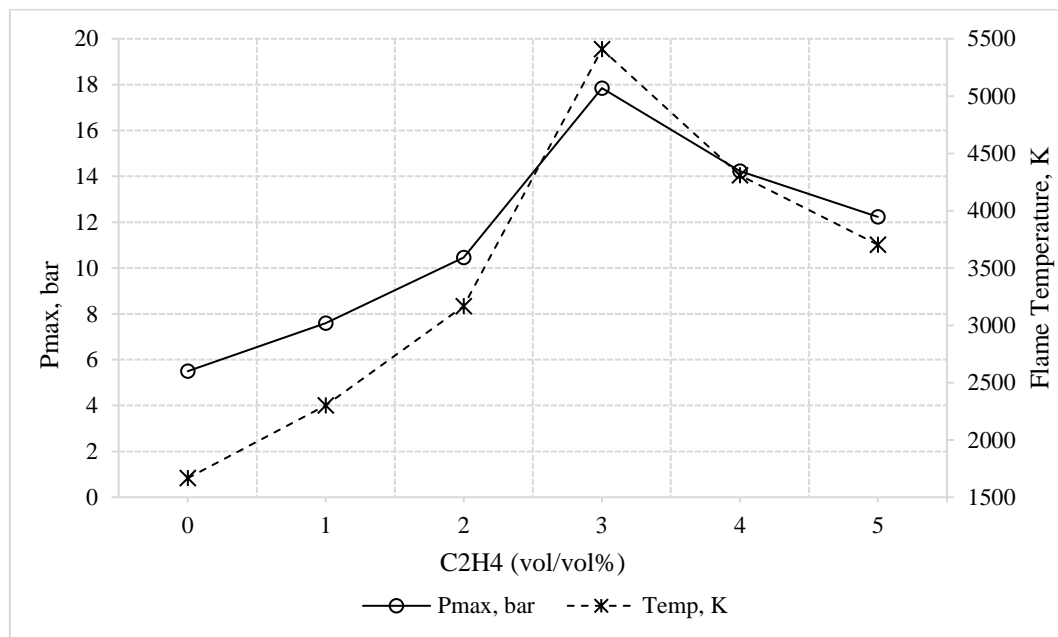


Figure 5. Adiabatic flame temperature and P_{\max} at various C_2H_4 concentrations

4. Conclusions

Hybrid explosions of LDPE/ C_2H_4 mixture were investigated to evaluate the influence of C_2H_4 gas concentration on the severity of dust explosion. The conclusions are drawn as follows:

1. The LDPE/ C_2H_4 explosion process can be broken down into three phases, starting with ignition, flame growth and flame regression. At the ignition and flame growth phase, the hybrid explosion is driven by the dust and gas explosion respectively.
2. The P_{\max} and calculated flame temperature increase as the C_2H_4 concentration decreases. The synergistic effect between LDPE particle and C_2H_4 gas play a major role in the explosion intensity leading to the increase of P_{\max} and flame temperature. The highest P_{\max} and flame temperature are 17.9 bar and 5200 K respectively, recorded at $C_2H_4 = 3$ vol./vol. %
3. The ignition delay time, $t_{v_{eff}}$ (turbulence level) influences the LDPE/ C_2H_4 hybrid explosion severity. At high turbulence level (or short ignition delay time) most of the LDPE particles disperse and participate in the explosion process result in a surge of explosion severity.
4. The shortest and longest ignition delay times were recorded at 75 ms and 230 ms, corresponds to the K_{GT} of 60 bar.m/ms and $K_{GT} = 14$ bar.m/ms respectively.
5. The K_G values ranging from 14 - 60 bar m/ms indicate that the LDPE/ C_2H_4 dust hybrid explosion demonstrates an explosion impact.

Acknowledgments

The authors would like to thank Universiti Malaysia Pahang for supporting this study financially under UMP grant (PGRS180325) and Petronas Refinery and Petrochemical Corporation Sdn Bhd, Malaysia for providing the raw material (LDPE).

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