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# Assessment on the severity of low density polyethylene (LDPE)/Ethylene hybrid explosion

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**Abstract.** The potential explosion for low-density polyethylene (LDPE) dust is greatly increased due to the presence of ethylene gas. Thus, this study was aimed to investigate the explosion severity of polyethylene/ethylene hybrid mixture in a 20-L spherical vessel. The explosion setup is equipped with two chemical ignitors and Kistler piezoelectric pressure sensors to ignite the hybrid mixture and to quantify the propagation of pressure wave during the explosion process respectively. The following hybrid explosion characteristics including the maximum explosion overpressure ( $P_{max}$ ), the maximum rate of pressure rise ( $dP/dT$ ) and deflagration index ( $KST$ ) were evaluated. This study concluded that the explosion severity of polyethylene/ethylene hybrid mixture steeply increases as the gas concentration and particle size increase to 15 g/m<sup>3</sup> and 125  $\mu$ m, beyond which the  $P_{max}$  and  $dP/dT$  steadily decrease. The highest  $P_{max}$  and  $dP/dt$  were recorded at 5.5 bar and, 50.5 bar/s with the  $KST$  value is 50 bar.m/s indicating the LDPE/ethylene hybrid dust explosion possess a weak explosion.

## 1. Introduction

Hybrid mixtures explosions can result in catastrophic personal injury and devastating damage. Hybrid mixture explosion occurs when dust, gas and vapor concentrations are respectively lower than their Minimum Explosion Concentration, (MEC) or Lower Flammability Limit, (LFL). According to Sanchirico et al. [1-2], the severity of hybrid mixture explosions was stronger than dust or gas explosions. For instance, the maximum explosion pressure and rate of pressure rise hybrid explosions (methane/coal) increased because of the presence of methane gas. They also reported that the explosion severity also increased with the increase of the flammable gas concentration. However, hybrid explosions property would be suppressed when the flammable gas was beyond the flammability range [3-4]. This phenomenon can be attributed to the limit of oxygen content.

Polyethylene is combustible dust. The presence of ethylene gas in polyethylene combustion may lead to the series of major fire and explosion. For instance, in 2015, Petronas Chemical LDPE (Low-density polyethylene) experienced a major fire incident. The main factor is due to ethylene gas ignite by the inherent static discharge from the LDPE. Other than that, [5-7] observed that the effect of polyethylene dust size and concentration also contributed to the severity of the hybrid explosion. However, their studies on the hybrid PE/Ethylene explosion were restricted in the flame propagation behavior. No attempt was made to study the explosion characteristic such as explosion pressure, rate of pressure and deflagration index. These characteristics are important to scale the severity of the explosion for prevention and mitigation purpose[8]. Thus, this research is carried to investigate the LDPE/ethylene



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hybrid dust explosion characteristics including maximum explosion overpressure, rate of pressure rise and dust deflagration index at various concentrations of ethylene gas on different polyethylene dust size and concentration.

## 2. Methodology

The flammability and severity data were obtained by employing 20-L spherical vessel as shown in figure 1. The range of LDPE concentrations tested in this vessel were 5, 15, 20, 30, 40 and 50 g/m<sup>3</sup>. The explosion experiments were performed by using two 5 kJ chemical igniters as the standard ignition source that were connected to the ignition leads. The ignition delay time,  $t_v$  was fixed at 60 ms. The pressure inside the spherical vessel was measured by two “Kistler” piezoelectric pressure sensors. The LDPE dust was 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 vessel was interfaced with a computer, which controls the dispersion or firing sequence and data collection by using the control system named KSEP. As part of the experimental program, three repeated tests were performed to ensure a good data reproducibility.

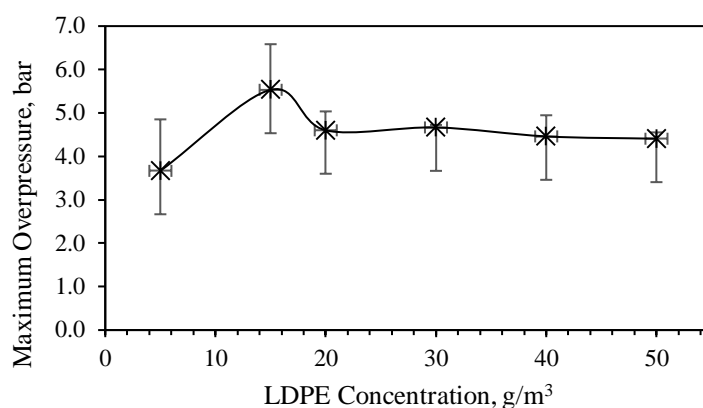


**Figure 1.** The standard 20 L spherical vessel

## 3. Result and Discussion

### 3.1 Effect of LDPE concentration on the maximum overpressure, rate of pressure rise and the deflagration index, $K_{ST}$ .

Figure 2 shows the pressure evolution when LDPE concentration varies function of maximum overpressure. The displayed maximum trend indicates that the maximum overpressure is LDPE concentration dependent. The highest value obtained for the maximum overpressure,  $P_{max}$  is 5.5 bar. From the lowest point at  $3.7 \pm 1.1$  bar, the maximum overpressure steeply increases with an increase of LDPE concentration and steadily decreases once passing the maxima at 15 g/m<sup>3</sup> LDPE concentration. This maximum  $P_{max}$  is called optimum dust concentration. We speculated the plausible explanation for the decreasing trend after the concentration at 15g/m<sup>3</sup> is; amount of LDPE dispersed into the vessel overwhelmed the oxidant environment and instead of reacting, the excessive dusts limited the mass transfer of dust-oxidant contact. This result is in sync with the finding by other researcher who also found the inversion trend once the dust concentration is higher than the minimum explosible limit (MEC) [9].

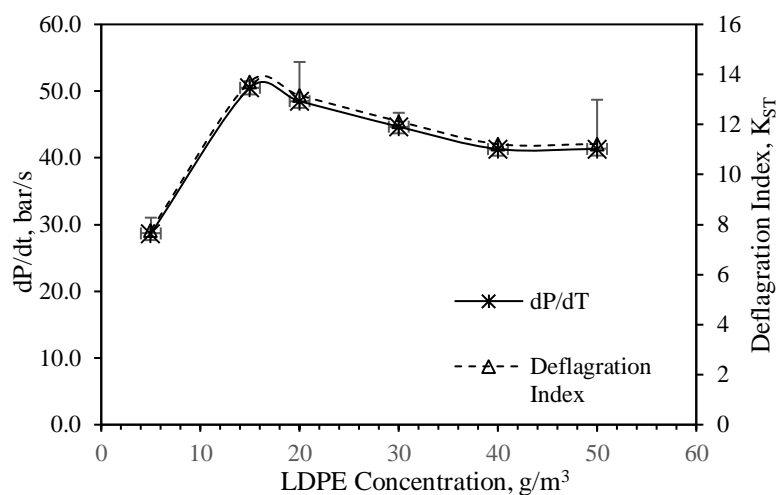


**Figure 2.** Effect of LDPE dust concentration on maximum overpressure. Results are expressed in bar  $\pm$  standard deviations.

The severity of explosion was investigated by the determination of pressure rise rate,  $dP/dt$  and deflagration index,  $K_{ST}$  as a function of LDPE concentration. (refer Figure 3). The maximum value of  $(dP/dt)_{max}$  and  $K_{ST}$  obtained are 50.5 bar and 13.71  $mbar$  respectively, corresponding to 15  $g/m^3$  LDPE concentration. In general, the rate of pressure rise which reflects the explosion violence increases with an increase of LDPE concentration. The rate of pressure rise is also a function of particle size [4]. The  $K_{ST}$  criterium was calculated by the following equation from the cubic root law relationship[10]:

$$K_{ST} = V^{1/3} \left( \frac{dP}{dt} \right)_{max} \quad (1)$$

where  $V$  and  $P$  are the volume ( $m^3$ ) and pressure (bar) in the spherical vessel respectively. From the maximum  $K_{st}$  value obtained from this experiment, the level of severity of LDPE and ethylene explosion can be categorized as moderate, class I (within the tested parameters). However, the  $K_{st}$  of value greater than zero is still a threat and pose the explosion potential. It can be seen that the rate of pressure rise ( $dP/dT$ ) follows the trend of maximum overpressure, but with more declining slope after the peak point.

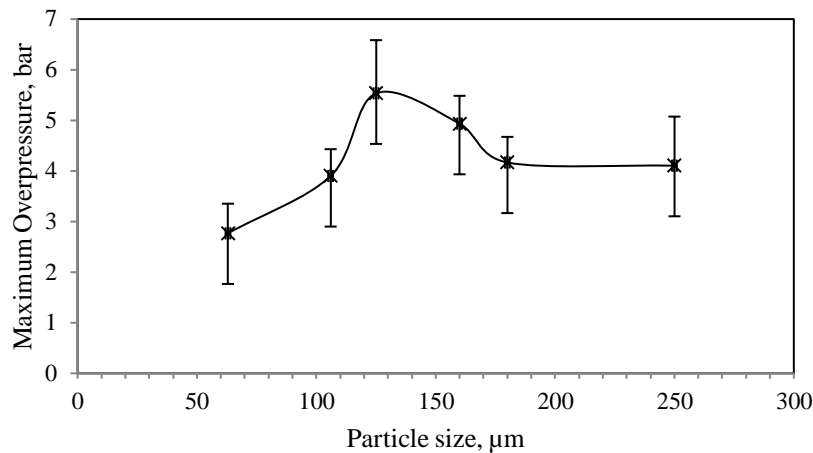


**Figure 3.** Effect of LDPE dust concentration on rate of pressure rise ( $dP/dt$ ) and deflagration index. Results are expressed in bar  $\pm$  standard deviation

### 3.2 Effect of LDPE particle size on the maximum overpressure ( $P_{max}$ ) and rate of pressure rise, $dP/dt$

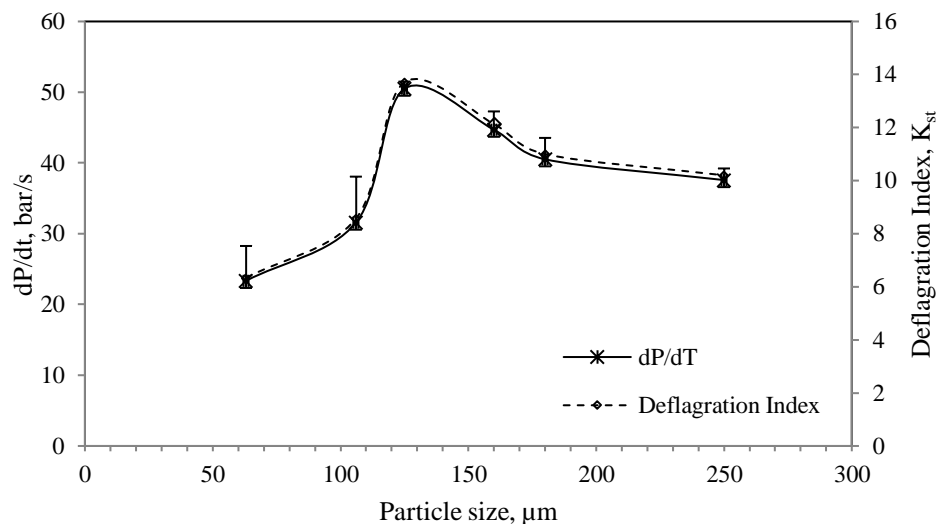
Figure 4 illustrates the effect of LDPE dust particles on the maximum overpressure, with the particles size ranging from 63 to 250  $\mu m$ . The results of this particular test indicate the particle size affecting  $P_{max}$

in the same pattern as the LDPE concentration vs  $P_{\max}$ . From this figure, the  $P_{\max}$  is at the highest when the particles size of 125  $\mu\text{m}$  was tested. The smallest particle gives the lowest  $P_{\max}$  at 2.78 bar, almost 50% lower than the maximum point. In this experiment, the collected data show the effect of gravity sedimentation and dispersibility of LDPE dust particles is negligible to the  $P_{\max}$ . This could be attributed by the drag of air exerted on the dust particles counteracting the gravity effect on the particles.



**Figure 4.** Effect of LDPE dust size on the maximum overpressure. Results are expressed in bar  $\pm$  standard deviations.

The results of the particles size effect on the  $dP/dT$  and  $K_{st}$  are depicted in Figure 5. It can be seen that the rate of pressure rise and  $K_{st}$  depend on the LDPE particle size. The optimal particle size contributed to the  $(dP/dT)_{\max}$  is 125  $\mu\text{m}$ . As the particles size increase, the  $dP/dt$  also increases except after passing the maxima point where the  $dP/dt$  and  $K_{st}$  start to decrease. This finding could be explained by having the most effective suspension in the vessel when the size of the particles is 125  $\mu\text{m}$ . At this size, it is speculated that there were less particles settle at the bottom of the vessel as compared to the larger size dusts. As for the smaller particles, the mass and volume of polyethylene involved in combustion and explosion is less effective leading to the less  $dP/dT$  and  $K_{st}$ .



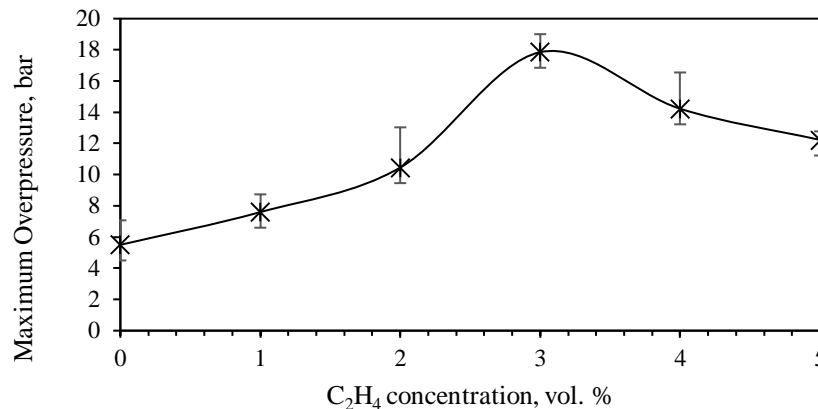
**Figure 5.** Effect of LDPE dust size on the rate of pressure rise ( $dP/dt$ ) and deflagration index. Results are expressed in bar  $\pm$  standard deviations.

### 3.3 Effect of ethylene concentration on the maximum overpressure, rate of pressure rise and the deflagration index, $K_{ST}$ .

The effect of ethylene concentration on the maximum overpressure is uptrend from 0 to 3 vol. % (refer Figure 6). The range of ethylene concentration was selected based on the flammability limit to gauge the hybrid effect of the LDPE. The maximum overpressure,  $P_{max}$  reaches the highest point when 3 vol.% of  $C_2H_4$  injected into the system for hybrid explosion with LDPE. The particles size tested in this experiment is 125  $\mu m$ . In the absence of ethylene, the maximum overpressure shows the lowest, 5.5 bar, but the  $P_{max}$  starts to rise with an introduction of ethylene owing to the synergistic effect[6]. The reduction of  $P_{max}$  when the ethylene was tested at 4 and 5 vol.% is in a good agreement with other researchers[11, 12] who also found the quite similar pattern of  $P_{max}$  with gas concentration. Another way of looking at the increasing trend of  $P_{max}$  can be related to the flammability limit where the  $P_{max}$  only increases when the explosion occurred at the lower flammability limit (LFL), below approximately 3 vol. % at which the explosion possible occurred at the gas-driven region. The equation to represent the overpressure as a function of ethylene concentration from 2 to 4 vol% is as follows:

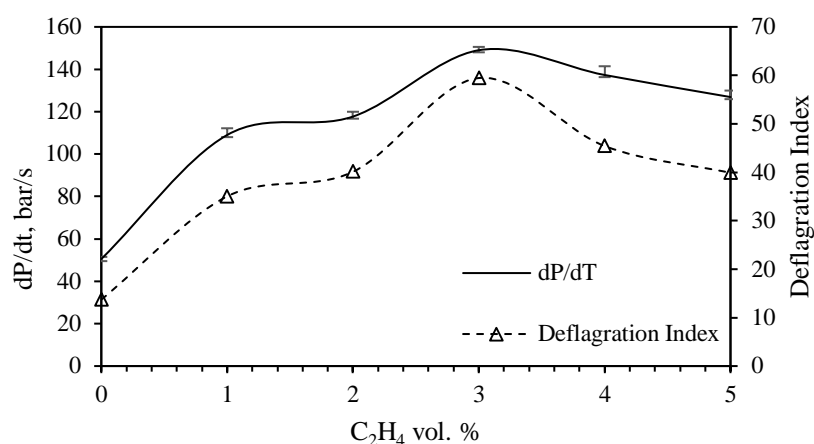
$$P_{max} = -5.5105C^2 + 34.948C - 37.398 \quad (2)$$

where  $P_{max}$  and C is the maximum overpressure and concentration of the ethylene respectively.



**Figure 6.** Effect of ethylene gas on the maximum overpressure. Results are expressed in bar  $\pm$  standard deviations.

Experimental results as shown in Figure 7 demonstrated that  $dP/dt$  and  $K_{st}$  increase as  $C_2H_4$  concentration increases. The optimal point for both parameters are 137.3 bar/s and 45.41 bar. m/s. As compared to the dust concentration and size particle effects on  $dP/dt$ , the rate of pressure rise for ethylene concentration is 137.3 bar/s, greater than double of the other two effects. As a consequence, the severity of explosion,  $K_{st}$  also increases to 45.41, more than three times higher than  $K_{st}$  values when particle size and dust concentrations were measured. These results indicate higher potential violence and severity if the ethylene concentration is present at the high concentration in the confined space.



**Figure 7.** Effect of ethylene gas on the the rate of pressure rise (dP/dT) and deflagration index,  $K_{st}$ . Results are expressed as bar  $\pm$  standard deviations.

#### 4. Conclusion

The highest  $P_{max}$  recorded over the whole range of concentrations (5-50 g/m<sup>3</sup>) and particle sizes (63-250  $\mu$ m) is 5.5 bar at 15 g/m<sup>3</sup> and 125  $\mu$ m respectively. The highest rate of pressure rise (dP/dT) is calculated as 50.5 bar/s, corresponding to the optimal concentration and particle size. This study concluded that the explosion severity of polyethylene/ethylene hybrid mixture steeply increases as the dust and gas concentration and particle size increase to 15 g/m<sup>3</sup>, 3 % vol/vol and 125  $\mu$ m, beyond which the  $P_{max}$  and (dP/dT) steadily decrease.

#### Acknowledgments

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