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Assessment of dust explosion with adipic acid and *p*-terephthalic acid in the powdered resin process

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ABSTRACT

In the powdered resin manufacturing process, methanol and acids are the main raw materials usually added through a hopper into a batch reactor. Under specific manufacturing process conditions, the pressure and temperature are high while the reactants undergo polymerization. Adipic acid (AA) and *p*-terephthalic acid (PTA) were the bulk raw materials used in this reaction to obtain various dust explosion characteristic parameters. Thermogravimetry results showed that AA and PTA experienced mass loss in temperature ranges of 200–220 and 300–330 °C, respectively. According to differential scanning calorimetry tests, the endothermic onset temperatures were 152.0 and 415.2 °C, the reaction heats were 183.4 and 204.3 J/g, and the endothermic peak temperatures were 153.1 and 424.7 °C, respectively. The maximum explosion pressure (P_{max}) and the maximum rate of explosion pressure rise $(dP/dt)_{max}$ of AA and PTA were 6.9 bar and 361 bar/s and 6.4 bar and 218 bar/s, respectively. The K_{st} values of AA and PTA were 98 and 62 m bar/s; both can be assigned to the St-1 explosion class. The results showed that AA and PTA can induce a dust explosion. A proactive loss control strategy is mandatory in the powdered resin process for preventing dust explosion.

1. Introduction

The petrochemical industries have developed rapidly and extensively since the end of World War II. Advanced technologies in various industrial sectors have led to higher living standards with smartphones, tablet computers, laptops, smart TVs, hybrid cars, and other high-tech equipment, all of which have made life much more convenient and comfortable. However, along with improved living conditions, the petrochemical industries also come to the potential risk of accidents.

Most powder materials in the petrochemical process have potential hazards related to dust that can result in an explosion. When leaked raw material accumulates in the workplace, dust explosion accidents may inevitably occur (Chen et al., 2010; Klippel et al., 2015). Dust explosions have occurred in America, Europe, and Asia and have caused casualties and property damage as well as social outcry. Table 1 lists dust explosion-related accidents that have occurred sporadically in the petrochemical industries (CSB, 2015; Myers and Ibarreta, 2013).

Regardless of whether the industry is high-tech or petrochemical, there exists a significant relationship between process safety and dust explosion, with threats emerging from inherent process hazards (Kaelin and Prugh, 2006). In the petrochemical industries, methanol and acids are main raw materials that are normally added through a hopper into a batch reactor. Under specific process conditions, the pressure and temperature are high while the reactants undergo polymerization. Adipic acid (AA) and *p*-terephthalic acid (PTA) are bulk raw materials used in the reaction, as shown in Table 2. When process conditions are under the 200–280 °C and 6–8 bar, organic alcohols and AA/PTA are used to produce an esterification reaction, as illustrated by Eq. (1). Because AA and PTA exist in a powder form, a dust explosion can occur if the conditions are consistent with the theory of the dust explosion

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Table 1
Selected accidents related to explosion/dust explosion in USA, Europe, and Asia since 2001 (CSB, 2015; Myers and Ibarreta, 2013).

Date	Location	Accident type	Fatalities (F)/Injuries (I)	Material
09/21/2001	Toulouse, France	Explosion	22 F/650 I	Ammonium nitrate
01/29/2003	North Carolina, USA	Dust explosion	6 F/10 I	Powdered plastic
10/29/2003	Indiana, USA	Dust explosion	1 F/1 I	Aluminum dust
04/23/2004	Illinois, USA	Explosion	5 F/0 I	Polyvinyl chloride
05/11/2004	Scotland, Great Britain	Explosion	9 F/10 I	Liquefied petroleum gas
08/19/2004	Ontario, Canada	Explosion	0 F/4 I	Ethylene oxide
05/01/2005	Tao-Yuan, Taiwan	Explosion	0 F/10 I	Boiler
02/07/2008	Georgia, USA	Dust explosion	14 F/38 I	Sugar
11/02/2008	Ning-Xia, China	Dust explosion	0 F/4 I	Powdered fodder
12/06/2008	Shan-Tou, China	Dust explosion	10 F/11 I	Sugar
03/11/2009	Jiang-Su, China	Dust explosion	11 F/20 I	Aluminum dust
02/24/2010	Qinhuangdao, China	Dust explosion	21 F/37 I	Corn starch
11/09/2010	New York, USA	Explosion	1 F/1 I	Flammable vapors
12/09/2010	West Virginia, USA	Dust explosion	3 F/0 I	Powdered titanium
01/20/2011	West Virginia, USA	Explosion	2 F/0 I	Methomyl pesticide
01/31/2011	Tennessee, USA	Dust explosion	2 F/0 I	Powdered iron
05/20/2011	Sih-Chuan, China	Dust explosion	3 F/15 I	Aluminum dust
07/28/2011	Tainan, Taiwan	Explosion	0 F/10 I	Toluene, xylene
10/09/2012	New Jersey, USA	Dust explosion	0 F/7 I	Ink
04/17/2013	Texas, USA	Explosion	70 F/200 I	Ammonium nitrate
08/02/2014	Jiang-Su, China	Dust explosion	146 F/114 I	Aluminum dust
06/27/2015	New Taipei, Taiwan	Dust explosion	15 F/484 I	Corn powder

Table 2
Basic physical properties of adipic acid and *p*-terephthalic acid (Occupational Safety and Health Administration, Ministry of Labor, Taiwan, 2016).

Characteristics	AA	PTA
CAS no.	124-04-9	100-21-0
Chemical formula	$C_6H_{10}O_4$	$C_6H_4(COOH)_2$
Molecular mass (g/mol)	146.1	166.1
Specific gravity (H_2O = 1)	1.36	1.51
Flash point (°C)	196 (closed cup)	260 (opened cup)
Boiling point (°C)	337.5	Not available
Melting point (°C)	151	300
Minimum ignition energy (mJ)	1125	640
Lower explosive limit (g/L)	0.035	0.05
Upper explosive limit (g/L)	–	–

Table 3
Experimental data on dynamic scanning of AA and PTA by DSC tests.

Sample	Mass (mg)	Endothermic onset temperature (°C)	Reaction heat (J/g)	Endothermic peak temperature (°C)
AA	4.1	152.1	−186.5	153.1
	4.1	152.0	−199.3	152.8
	4.3	152.0	−170.2	153.1
PTA	4.5	415.2	−213.0	424.7
	4.3	421.6	−202.1	423.9
	4.0	418.5	−197.9	424.7

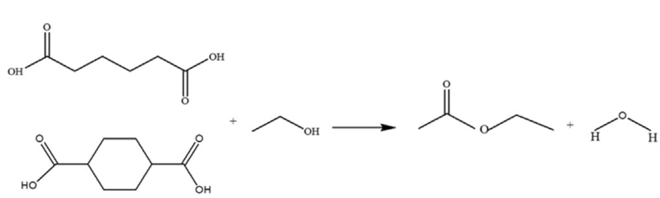
pentagon (fuel, ignition, dispersion, oxygen, and confinement) (Investigation Report–Combustible Dust Hazard Study, 2006; Skjold and Wingerden, 2013).

Before facilities are evaluated for hazards of dust explosion, the process safety parameters of maximum explosion pressure (P_{max}), maximum rate of explosion pressure rise $(dP/dt)_{max}$, explosion limits, and minimum ignition energy (MIE) must be properly established. These key parameters can be determined by using a vibratory sieve shaker (VSS), thermogravimetry (TG), differential scanning calorimetry (DSC), minimum ignition energy tester (MIET), and 20-L apparatus. Finally, consequence modeling can determine the severity of a given hazard once it is realized. Several models have been developed and described for predicting the consequence of a dust explosion. The prediction of laminar burning velocity (S_{lbv}) and $(dP/dt)_{max}$ was established through this model to reduce the testing time in the future (Rahman and Takriff, 2013).

2. Experimental and methods

2.1. Samples

AA and PTA were directly obtained from a petrochemical plant in Taiwan. The dust samples of AA and PTA underwent a pretreatment program in a dry state (at 50 °C in vacuum for 12 h) before testing. The basic properties of AA and PTA are listed in Table 2 (Occupational Safety and Health Administration, Ministry of Labor, Taiwan, 2016).



(1)