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Explosibility of polyamide and polyester fibers

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ABSTRACT

The current research is aimed at investigating the explosion behavior of hazardous materials in relation to aspects of particulate size. The materials of study are flocculent (fibrous) polyamide 6.6 (nylon) and polyester (polyethylene terephthalate). These materials may be termed nontraditional dusts due to their cylindrical shape which necessitates consideration of both particle diameter and length. The experimental work undertaken is divided into two main parts. The first deals with the determination of deflagration parameters for polyamide 6.6 (dtex 3.3) for different lengths: 0.3 mm, 0.5 mm, 0.75 mm, 0.9 mm and 1 mm; the second involves a study of the deflagration behavior of polyester and polyamide 6.6 samples, each having a length of 0.5 mm and two different values of dtex, namely 1.7 and 3.3. (Dtex or decitex is a unit of measure for the linear density of fibers. It is equivalent to the mass in grams per 10,000 m of a single filament, and can be converted to a particle diameter.) The explosibility parameters investigated for both flocculent materials include maximum explosion pressure (P_{max}), size-normalized maximum rate of pressure rise (K_{St}), minimum explosible concentration (MEC), minimum ignition energy (MIE) and minimum ignition temperature (MIT). ASTM protocols were followed using standard dust explosibility test equipment (Siwek 20-L explosion chamber, MIKE 3 apparatus and BAM oven). Both qualitative and quantitative analyses were undertaken as indicated by the following examples. Qualitative observation of the post-explosion residue for polyamide 6.6 indicated a complex interwoven structure, whereas the polyester residue showed a shiny, melt-type appearance. Quantitatively, the highest values of P_{max} and K_{St} were obtained at the shortest length and finest dtex for a given material. For a given length, polyester displayed a greater difference in P_{max} and K_{St} at different values of dtex than polyamide 6.6. Long ignition delay times were observed in the BAM oven (MIT measurements) for polyester, and video framing of explosions in the MIKE 3 apparatus (MIE measurements) enabled observation of secondary ignitions caused by flame propagation after the initial ignition occurring at the spark electrodes.

1. Introduction

The purpose of the current research is the prevention and mitigation of dust explosions based on the strategic area of safety and security, with a focus on assessing risk and vulnerability. The main motivation for developing this research topic is the protection of personnel, assets, production (business operation) and the environment. By adopting the recommendations arising in this study, industries could reduce and minimize their current dust explosion risk as well as the probability of future occurrences of explosions.

There have been numerous cases of dust explosions over the years, with reported incident data illustrating that dust explosions can occur with a variety of commodities. These include: wood and paper products (dust from sawing, cutting and grinding), grain and foodstuffs (grain dust and flour), metal and metal products (metal powders and dusts), power generation products (pulverized coal, peat and wood), rubber, chemical process industry products (acetate flake, pharmaceuticals, dyes and pesticides), plastic/polymers production and processing products, mining products (coal, sulphide ores and sulfur), and textile manufacturing products (linen

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flax, cotton and wood) (Amyotte & Eckhoff, 2010; Frank, 2004). The first case of a recorded dust explosion was in a wheat flour warehouse in Turin, Italy, as recounted by Count Morozzo in 1785 (Eckhoff, 2003). The report mentioned the destruction of the warehouse due to a primary explosion and successively a secondary explosion.

Dust explosions are a serious hazard in any industry. In the United States alone, the U.S. Chemical Safety and Hazard Investigation Board (CSB) has identified 281 combustible dust incidents between 1980 and 2005 that killed 119 workers and injured 718 more (CSB, 2006). In addition to worker fatalities and injuries, there is also a significant economic impact due to these industrial incidents. The CSB reports damages costing hundreds of millions of dollars for explosions, for instance, at Malden Mills, CTA Acoustics, West Pharmaceutical and Rouse Polymerics (CSB, 2006). One of the key factors for significantly reducing dust explosion hazards is prevention. To accomplish this, it is important to perform adequate housekeeping, as excessive dust accumulation can cause secondary dust explosions (CSB, 2006; Frank, 2004), which can in turn cause significant damage.

Recent incidents have demonstrated the hazards of flocculent (fibrous) materials, which have a cylindrical shape necessitating consideration of both particle diameter and length. The aim of this paper is to provide additional data and knowledge on this nontraditional category of dust. Flocculent materials are not always considered as potential dust explosion hazards; the above-mentioned dust explosion involving nylon flock fibers at the Malden Mills facility in Massachusetts in 1995 (CSB, 2006) demonstrates that they should be viewed in the same light as more traditional dusts composed of spherical or near-spherical particles.

The overall scope of this experimental work includes:

- Studying explosibility characteristics of flocculent materials for different shapes of fibers and types of material.
- Generating experimental data for different sizes of flocculent dusts.
- Exploring empirical relationships between the explosibility data and aspect ratio features of length and diameter.
- Carrying out phenomenological analysis.

2. Samples

The samples investigated were flocculent (fibrous) polyamide 6.6 (polyhexamethylene adipinamide, CAS Nr. 32131-17-2) and polyester (polyethylene terephthalate, CAS Nr. 25038-59-9). Experiments were conducted using the most common dtex (3.3) of polyamide 6.6 with changing length, and successively experiments with changing dtex. (Dtex or decitex is a unit of measure for the linear density of fibers. It is equivalent to the mass in grams per 10,000 m of a single filament, and can be converted to a particle diameter.) Further experiments were conducted on polyester fibers – the most commonly used material in the textile industry due to its unique properties and low material cost. The decision to analyze these fibers with changing length or diameter (keeping the other parameter constant) was made to better understand the role of specific surface area with respect to deflagration parameters and explosibility characterization of the materials.

The experimental work undertaken can be divided into two main parts. The first deals with the determination of deflagration parameters for polyamide 6.6 (dtex 3.3) for different lengths: 0.3 mm, 0.5 mm, 0.75 mm, 0.9 mm and 1 mm; the second involves a study of the deflagration behavior of polyester and polyamide 6.6 samples, each having a length of 0.5 mm and two different values of dtex, namely 1.7 and 3.3.

3. Determination of explosion parameters

Explosibility parameters investigated were the maximum explosion pressure (P_{max}), maximum rate of pressure rise ($(dP/dt)_{max}$), size-normalized maximum rate of pressure rise (K_{St}), minimum explosible concentration (MEC), minimum ignition energy (MIE) and minimum ignition temperature (MIT). ASTM (American Society for Testing and Materials) protocols were followed using standard dust explosibility test equipment (Siwek 20-L explosion chamber, MIKE 3 apparatus and BAM oven). Apparatus and procedural descriptions can be found on the equipment manufacturer's (Kuhner's) web site (http://www.kuhner.com/).

3.1. Siwek 20-L chamber

A Siwek 20-L explosion chamber was used to determine P_{max}, $(dP/dt)_{max}$, K_{St} and MEC for the various polyamide 6.6 and polyester samples. Testing protocols followed were according to ASTM E1226-10 (ASTM, 2010) for the first three parameters, and ASTM E1515-07 (ASTM, 2007) for MEC. Because of the low bulk density of the flocculent samples, a test procedure was developed for the 20-L chamber in which a maximum of 15 g of dust were placed in the external dust storage container. This corresponds to a dust concentration of 750 g/m^3; for higher concentrations, the remainder of the sample amount was placed directly in the 20-L chamber around the rebound nozzle used for dust dispersion.

Most of the tests carried out here resulted in weak explosions in terms of the rate of pressure rise. If $(dP/dt)_m$ (maximum rate of pressure rise for a given test) is less than 150 bar/s, it is possible that the rate of pressure rise of the chemical ignitors used as the ignition source will be higher than that of the actual dust explosion. Fig. 1 shows two inflection points where the first is caused by the pressure rise of the ignitors and the second by the flock explosion. In cases such as this, it is necessary to perform a manual evaluation to identify the rate of pressure rise due to the flock explosion rather than relying on the Kuhner-provided software.

3.2. Modified Hartmann tube (MIKE 3)

A modified Hartmann tube (MIKE 3 apparatus) was used to determine the minimum ignition energy (MIE) of the samples. Procedures according to ASTM E2019-03 (ASTM, 2003) were followed. MIE values measured with the MIKE 3 apparatus can be reported as either falling within a specified range, or with sufficient tests at ignition and non-ignition boundaries, as a single value

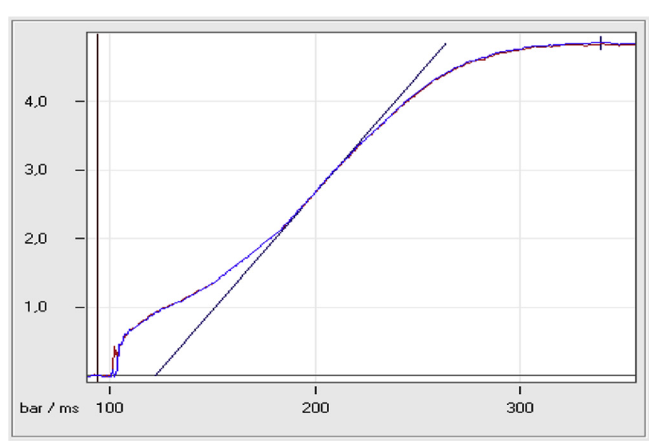

Fig. 1. Example pressure/time trace for flock explosion.