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Dust explosions: A threat to the process industries

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ABSTRACT

This paper considers more than 2000 dust explosion accidents that occurred worldwide between 1785 and 2012. The statistical features of these cases are first examined spatially and temporally. Accident frequencies at different levels of economic development are further discussed. China and the United States are chosen as examples to represent the differences in distribution features of dust explosions in countries with different economic development levels. Data for combustible dusts leading to dust explosions in both China and the United States are also collected and categorized. The features of ignition sources for dust explosions, the types of enterprises with high risk, and the critical equipment in such enterprises are also analyzed. The results could help identify hazards of dust explosions in various industries, monitor the critical equipment, and further suggest safety improvement procedures to reduce the probability and damage of dust explosions.

1. Introduction

A dust explosion could be triggered when flammable particulates suspended in air encounter ignition sources with sufficient energy (Amyotte and Eckhoff, 2010). According to the Occupational Safety & Health Administration of the US (OSHA), combustible dust can be considered as combustible materials in finely divided forms. Combustible dust can be found in the form of byproduct in various industries such as drilled-charcoal powder in coal mining and wood powder in the wood industry, or in the form of raw materials or intermediate products such as sugar powder in food processing plants. Aside from high temperatures and overpressures caused by dust explosions, toxic gases can also be produced in such violent chemical reactions (Eckhoff, 2003). Thus, dust explosions present significant threats to people, assets, and the environment. Dust explosions have caused numerous losses in industry (CSB, 2006). The dust explosion that occurred in a coal mine in Liaoning province, China, in 1942, causing 1594 deaths and 246 injuries, might be the most serious case in history (Mining-technology, 2014).

According to previous research (Eckhoff, 2003), fuel, oxidant, ignition source, confinement, and suspension are the essential factors for a dust explosion. For example, Callé et al. (2005) discussed the effects of size distribution and concentration on wood dust explosion. Various safety measures have also been proposed to eliminate the foregoing essential factors or reduce damages caused by dust explosions (Eckhoff, 2003). For instance, altering the composition of a dust by admixture of solid *inertants*, recommended by Amyotte et al. (2009) as an inherent safety measure, can be applied to reduce the reactivity of the dust. Similarly, effective housekeeping could also be considered a useful method to lower the probability of dust explosions and their potential damage, because of the elimination of the accumulated amount of combustible dust in high risk areas (Khakzad et al., 2012).

Also, there has been some research to estimate the occurrence probability and risk of dust explosions. In this regard,

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Hassan et al. (2014) proposed a model based on characteristics of combustible dust (e.g., dust particle diameter). van dert Voort et al. (2007) developed a quantitative risk assessment tool for dust explosions consisting of a series of sub-models. More recently, Yuan et al. (2013, 2014) proposed a dust explosion risk analysis model based on the Bow-tie method and Bayesian network. In the aforementioned methodologies, the common step is the identification of hazards, which requires wide knowledge of both dust explosion mechanisms and examination of where the dust explosion takes place. However, in real industrial plants, a large number of potential hazardous factors contributing to dust explosions cannot usually be enumerated. Learning from past accidents could help identify frequent hazardous factors as well as vulnerable units in various industries, and thus enforce monitoring of vulnerable units and prevent dust explosions.

Relevant data for dust explosion accidents can be found in accident reports, literature, reports from professional agencies, and the mass media. For example, the US Chemical Safety Board (CSB) collected data for 197 dust explosions that happened in the US from 1980 to 2005, and these accidents were reported to have caused 109 fatalities and 592 injuries collectively (CSB, 2006). Similarly, data for accidental dust explosions in China from 1980 to 2011 have been collected by Yan and Yu (2012). Zheng et al. (2009) collected 106 dust explosion cases in Chinese coal mines from 1949 to 2007, and analyzed characteristics of Chinese coal dust explosions. Abbasi and Abbasi (2007) gathered some cases in 2004 and made an attempt to investigate the causes, consequences, and prevention methods of dust explosions. Also, according to a report from the National Fire Protection Association (1957), 1123 dust explosions occurred in the US from 1900 to 1956, while 426 dust explosions happened in Germany from 1965 to 1985 (Eckhoff, 2003).

This paper is organized as follows: resources for data collection are introduced in Section 2. Spatial and temporal features of accidents and casualties, types of combustible dust, the type of industries involved, ignition sources, and critical equipment are discussed in Section 3. In Section 4, the contributors to the distributions of accidents, combustible dusts and industries are discussed, while the main conclusions are summarized in Section 5.

2. Information collection of dust explosions

During information collection for the present research, some difficulties were met. First, the number of reported dust explosions is far below their actual occurrence. According to Lees (1996), the gap between the reported and actual numbers decreases as damages increase, implying that accidents with less damage tend to be more easily neglected by related agencies, as opposed to those with severe damages. Second, different information sources may include inconsistent data in terms of casualty and damage even for a similar accident. Further, reporting time could affect the accuracy of the information. For example, in many cases, fatalities and injuries may increase with time after an accident happens. Therefore, seven days following an accident is considered as a term to record losses resulting from the traffic accidents or fire accidents in China (Government of the People's Republic of China, 2007). Also, sometimes factories or governments are suspected to intentionally under-report consequences of accidents to reduce or escape punishment, which also leads to inaccurate information (a very serious problem in China). Related punishment notices for hiding accidents can be found on the website of the China State Administration of Work Safety (CSAWS). Aside from the above-mentioned problems, uncertainty also exists throughout the dust explosion investigation process. For example, assessments of dust explosion origins largely rely on experts' opinions and experience as the accident scenes are usually severely damaged. Moreover, it can be observed that some information (e.g. ignition sources) is absent in accident reports as a result of limited budgets and human resources, or seriously damaged scenes.

The collected dust explosion accident data in this work are mainly from the following sources:

- Reports and accident statistics from professional organizations and national agencies such as NFPA, CSB, CSAWS and OSHA,
- Process safety text books presenting dust explosion cases,
- Academic papers,
- Local newspapers.

A part of the collected cases is shown in Appendix A and categorized according to the following factors:

- Date of accident,
- Country,
- Type of combustible dust,
- Equipment involved,
- Type of industries,
- Number of injuries and deaths,
- Ignition source.

In Appendix A, metal dust mainly includes aluminum, magnesium, iron and associated combustible alloy dusts. Flour, corn, sugar dusts, and other combustible edible dusts are categorized as food dust. The inorganic dust, excluding metal dust and coal dust, includes the other types of inorganic combustible dust such as sulfur powder.

3. The characteristics of hazardous dust explosion accidents

As shown in Appendix A, the collected cases come from a large range of times and industrial types. Features of dust explosions, such as casualties, vary with individual countries and periods. Due to the process characteristics of individual industries, various features can also be observed in ignition source, involved equipment, and so forth.

3.1. *Spatial distribution of dust explosions*

Performing statistical analyses, the distribution of dust explosions in various countries/areas is presented in Fig. 1.

As can be seen from Fig. 1, the dust explosion reports are mainly from the US, Europe, Japan, China and Canada. Among them, the number of dust explosions in the US is 1611—far more than in other countries. The following is Europe, in which the numbers from Germany and the UK account for the majority, holding 426 and 411, respectively. In other European countries, including Norway, Sweden, France, Italy and Spain, the accident reports are also observed.

One contributor to accident distribution might be differing economic development levels in different countries, due to the close relationship between dust explosions and manufacturing activities. The link between economic activities and occupational accidents has been widely discussed