RESEARCH ARTICLE

Industry specific dust explosion likelihood assessment model with case studies

Dust explosion is a potential threat to the process facilities handling dusts. Dust explosion occurrences are frequently reported in these industries. Industrial professionals and researchers have been trying to develop effective measures to assess and mitigate and/or prevent dust explosion. To develop effective prevention and mitigation strategies, it is important to understand the interaction of dust explosion controlling parameters and also to assess likelihood of occurrence in given conditions. Authors have proposed a conceptual framework to model dust explosion likelihood. In this paper, a detailed implementation of the conceptual model is presented. Three different dust classes (i.e. food feed; plastic, resin and rubber; and metal alloys) are considered for model development. The proposed model considers six key parameters of dust explosion: dust particles diameter, minimum ignition energy, minimum explosible concentration, minimum ignition temperature, limiting oxygen concentration and explosion pressure. These parameters are conditional to the type of dust and chemical composition. A conditional probabilistic approach is used to determine the total probability of dust explosion in a given process facility. Use of this model will help to assess the likelihood of dust explosion in given operating conditions. Moreover, it will help to develop prevention strategies focusing on the parameters that are responsible for dust explosion. Three case studies are presented here to demonstrate the application of the model in real life.

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INTRODUCTION

A dust explosion can take place when the suspended solid particles accumulated in the air receive sufficient energy from the source. The consequence is akin to a typical gas explosion in terms of the impact on the surrounding environment, industrial assets and monetary value. Unfortunately, the dust explosion's causation and severity are less familiar compared to the gas explosion among industrial practitioners.[1] For gas explosion, fuel, oxidant and ignition sources are necessary, while dust explosion requires two more vital criteria: appropriate mixing and confinement. These five elements are denoted with the dust explosion pentagon. The phase of the fuel during gas and dust explosion is different. Gas particles are in a gaseous phase, whereas dust particles are in a solid phase. Therefore, particle size of the dust is a very important fact on which to focus. According to the National Fire Protection Association (NFPA), any finely divided solid, 420 μm (micron) or 0.017 in. or less in diameter (i.e. material capable of passing through a U.S. No. 40 Standard sieve) is defined as dust.[2] The prime concern is combustible dust.

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Abbreviations: PD, particle diameter, μm; MEC, minimum explosible concentration, g/m^3; MIT, minimum ignition temperature, °C; MIE, minimum ignition energy, mJ; LOC, limiting oxygen concentration, %; $P_{\max}$, maximum pressure rise, bar(g); PDF, probability density function; CDF, cumulative density function; μ, mean for normal distribution; σ, standard deviation for normal distribution; ξ, standard deviations for lognormal distribution; λ, mean of lognormal distributions; β, shape parameter for weibull distribution; θ, scale parameter for weibull distribution; $P_x = P/X$, probability of dust explosion given that a particular parameter satisfies necessary condition (where X = PD or MEC or MIT or MIE or LOC); P_{Total}, total probability of dust explosion for a given scenario considering all parameters..

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Any dust capable of creating a violent explosion when it is suspended in air in ignitable concentrations, regardless of size, shape or chemical composition is called combustible dust.[1] The range of explosible particle size may be larger than the defined range for a specific material. Particle sizes distributions are often considered as a measure of the particle diameter in addition to the mean or median diameter.[1] In this paper, the median particle diameter is considered throughout the study.

A number of recent dust explosion phenomena caused severe loss to human lives and associated industries. On January 29, 2003, a massive dust explosion at the West Pharmaceutical Services facility in Kinston, North Carolina, killed six workers and destroyed the facility.[3] On February 20, 2003, a series of dust explosions at the CTA Acoustics facility in Corbin, Kentucky, killed seven workers, injured 37, and destroyed the facility.[3] On October 29, 2003, an aluminum dust fueled explosion killed one worker and injured several others at Hayes Lemmerz International in Huntington, Indiana.[4] On January 9, 2001, at the wool factory "Pettinatura Italiana" in Vigliano Biellese (BI), a massive explosion caused the death of three people, five severely injured personnel and considerable damage to part of the factory.[5] On February 7, 2008, a series of sugar dust explosions at the Imperial sugar manufacturing facility in Port Wentworth, Georgia, resulted in 14 worker fatalities.[6]

With the increasing number of dust explosions in process facilities, the risk has become more alarming. However, substantial progress has been made through extensive research and development for better understanding of dust explosion dynamics. Preventing an ignition source and explosive dust clouds, explosion venting, automatic explosion suppression and good housekeeping are elaborately reported in existing literatures as the means of protective measures of dust explosions.[7]

Industry professionals and researchers are striving for more pragmatic and easily implementable solutions to prevent dust explosion phenomena. However, in the context of quantitative assessment, a predictive tool to assess the explosion probability in a particular industry is absent. In this paper, an effort has been made to establish a probabilistic model to assess dust explosion occurrence. The model is applied for three dust classes: food feed; plastic, resin and rubber; and metal alloys. Five parameters are identified as dust explosion influential parameters: particle diameter, minimum explosible concentration, minimum ignition energy, minimum ignition temperature and limiting oxygen concentration, whereas the maximum explosion pressure represents the severity of a dust explosion. Five essential elements (e.g. fuel, oxidant, ignition source, mixing and confinement) form a dust explosion pentagon.[8] These five elements are represented by five influencing parameters of dust explosion. When these parameters reach the explosible range, dust explosion occurs.[9] Explosion may not occur if all parameters do not reach the explosible range.[10] A conceptual framework has earlier been developed by the authors which describes the method of assessing the dust explosion probability.[11] In this paper, the implementation of the earlier model is discussed elaborately for different dust classes. Three case studies have been studied to demonstrate the applicability of the model. This paper attempts to use the existing information (experimental data) for a particular industry to develop the dust explosion assessment model. To assess the conditional probability, two parameters at a time have been considered to estimate the probability of explosion occurrence for a given industry. Estimating the conditional probability for each parameter and integrating them over a range provides the total probability of dust explosion occurrence. The model renders a nomograph as a quick assessment tool. For a particular industry, the model can assess the probability of explosion in the base condition (normal operating condition). Based on the assessment, the processing facility can implement safety measures (e.g. inherent safety, procedural safety, safety management system, etc.) and can develop effective prevention and mitigation strategies in the working environment.

METHODOLOGY FOR DUST EXPLOSION ASSESSMENT AND MATHEMATICAL MODELING

The proposed methodology to assess dust explosion likelihood is comprised of five steps as outlined in the conceptual model.[11] These steps are subdivided into several sub-steps. Figure 1 represents the framework of the proposed methodology. The main steps are given below; for details see the work on dust explosion likelihood assessment.[11]

1. Hazard identification,
2. Data collection,
3. Data analysis,
4. Probabilistic modeling,
5. Nomograph development.

MATHEMATICAL MODELING OF DUST EXPLOSION ASSESSMENT

The proposed methodology employs the rules of conditional probability. An elaborate description of the methodology is may be seen at Junaid et al.[11] Figure 1 highlight different steps of the methodology.

MODEL TESTING

To use the model, probability distributions of the dust explosion parameters need to be determined for each dust class. The PDFs can be determined from the known distribution. These PDFs are used to formulate the joint probability distribution functions and are integrated over a range to get the CDFs. The integral range is identified according to the available data. Hence, the conditional probability values can be assessed for the particular dust classes. The total probability of dust explosion can be determined from the model and the nomograph is generated as a part of the model. The testing of the model is described in four steps as shown in Figure 1.