12th Annual Symposium, Mary Kay O'Connor Process Safety Center
"Beyond Regulatory Compliance: Making Safety Second Nature"
Texas A&M University, College Station, Texas
October 27-28, 2009

Review of an Adequate Chemical Dust Suppressant Used for Prevention of Dust Explosions in Food Industry

Diana Castellanos, Dedy Ng, Victor H. Carreto-Vazquez, Hans J. Pasman, and M. Sam Mannan[1]
Mary Kay O'Connor Process Safety Center, Artie McFerrin Department of Chemical Engineering, Texas A&M University System, College Station, TX 77843-3122
[1]Corresponding author: mannan@tamu.edu

Abstract

Recent dust explosion and subsequent fire at the Imperial Sugar refinery in Port Wentworth, Georgia and numerous other industrial dust explosion incidents over the past 25 years have raised serious concerns about combustible dust hazards in the workplace. Suppression of explosion in its early stages is a common approach used to reduce explosion consequences. Currently, there are two types of supressants used to combat dust fires: solid supressants such as mono-ammonium phosphate (MAP), $NaHCO_3$ and gaseous supresants such as nitrogen and CO_2. The present paper reviews the advantages and disadvantages of these two types of supressants in order to identify characteristics that influence each of the efectiveness measures that could be integrated into a new binary solid-gas suppresant. In addition, some experimental studies to explore the suppressant effectivess are proposed for future in-house tests.

1. Introduction

Explosions and fires associated with combustible dust hazards have raised safety concerns in the food industries (Maness). According to U.S. Chemical Safety and Hazard Investigation Board (CSB), dust explosion incidents in the food industry account to almost 23% of the total number of dust incidents in the U.S. (Blair 2007). Although food products are considered innocuous materials, these materials have claimed the lives of 119 people and injured 718 others over the last decades (CSB 2002).

In overall, two possible explanations can be deduced from this high occurrence. The first one is that employers and workers are not aware of or underestimated the dust-related hazards, thus there is no effective safety measure to prevent the accident. Such measures may include improved interlocking systems to prevent grinding without dust extraction, location of fans in dust-free areas, prevention of mechanical and electric sparks and hot surfaces, and good housekeeping in the workrooms (Bartknecht 1989). Secondly, there are no adequate suppressant agents for powder explosions in the food industry. Many investigations have focused in identifying conditions for producing dust explosion (Bartknecht 1989; Abbasi and Abbasi 2007), but little work has been done in suppressing dust explosions. It is known that that the five elements, so-called the explosion-pentagon are necessary to initiate an explosion:

fuel (dust in small particular size), oxygen (which is present in the air), ignition source, confinement and turbulence (Eckhoff 1997). A dust explosion cannot occur with the absence of one of these five elements (Eckhoff 1997). Therefore, methods for prevention and mitigation of dust explosions are based on the elimination of at least one of these five constituents. For instance venting systems are used to alleviate overpressures, which in turn *eliminate the confinement* effect in the initial stages of explosion. Similarly various grounding methods aim to *eliminate ignition sources* thus prevents electrostatic charge formation.

Recent investigations have focused on developing suppression agents that remove the fuel and oxygen elements of the explosion-pentagon(Eckhoff 1997).However, some of this these suppressants are considered toxic in the food industry. Some solid suppressants such as $NaCO_3$ are effective in reducing combustible air-fuel mixture, but they may contaminate the food product; some gas suppressants, e.g., halons are very effective to impede an explosive reaction however they are not environmental friendly (Moore 1996); some dry chemical powders e.g., mono-ammonium phosphate (MAP) has been proven to be more effective than halon to suppress dust explosion from St2 dust powders (Moore 1987) and even more severe explosion caused by ST3 organic dust powders (Moore 1996). However food industries are still cautious to use this suppressant due to the probable food contamination (Moore 1996); and other gaseous suppressants, e.g., nitrogen are very effective in reducing oxygen required for explosion reaction. However, when large amouts of nitrogen are required is not cost-effective. These limitations promote the needs to explore a suitable suppressant for the food industries.

In this paper, a review of solid and gas suppressants are presented. The motivation behind this work is to understand the characteristics, properties, advantages and disadvantages of each type of dust suppressant and how this study can be applied to develop dust explosion suppression experiments. This understanding of dust explosion phenomena and suppressant effectiveness will not only benefit the food industry but also the process industries.

2. Types of Chemical Dust Suppressant

Two types of chemical suppressants, i.e., solid and gas compounds have been introduced to prevent dust explosion. Recent efforts have also focused on combining the solid and gas compounds as another types of suppressant. Detailed explanation of these suppressants and the characteristics that affect their efficiency are as follows.

2.1. Suppression with solid compounds

Suppression with solid compounds is useful to keep the combustible dust concentration below the dust flammability range. However, some solid suppressants required large quantities usage in order to be effective in the suppression process thus introducing contamination to the food products, such as sugar, corn, and powdered milk.

One of the main characteristic of solid suppressant is its composition (Amyotte 2006). The suppressant composition is crucial because it may affect the decomposition temperature and specific heat. As the specific heat varies, the heat capacity of the dust cloud will be affected (Amyotte 2006). At high heat capacity, solid suppressant enables the dust to be decomposed by an endothermic reaction, in which it absorbs high quantities of heat released from the explosive reaction of the combustible dust (Eckhoff 1997). This phenomenon reduces the temperature of explosive mixture and also acts as a barrier for explosion wave (Amyotte, Mintz et al. 1991). However, it is important to note the rate at which the tranfer of heat occurs, the decomposition rate for the inert particle should be high enough as compared to the fuel decomposition rate in order to extinct the flame (Chatrathi and Going 2000).

Other characteristics that influence the solid suppressant effectiveness are particle size, surface area and inhibitors. .Smaller particles are generally used for greater absorption (Amyotte, Mintz et al. 1992). In order to be effective, the optimum particle size should be less than 30-50 μm (Krasnyansky 2006). Smaller particle is generally preferable since it rapidly dissipates the heat radiation and heat convection resulted from the explosion reaction (Chatrathi and Going 2000), which in turn reduces explosion consequences. This reduction in the suppressant's particle size leads to an increase in surface area, which enhances the suppressant decomposition and heat absorption needed to reduce the flame propagation. Additionally, the use of inhibitor will help in achieving a targeted threshold value in order to produce an effective suppression (Krasnyansky 2006). Although many researchers have postulated the relationship between the inhibitor amount and suspended fuel concentration (Amyotte, Mintz et al. 1991; Dastidar, Amyotte et al. 1999), this correlation has not been proved for suppression and solid compounds. For this reason the flammability limits and explosivity characteristics should be determined for safety consideration (Bartknecht, 1989).

On the other hand, the conditions under which the explosion occurs have also a considerable effect in the suppressant effectiveness (Amyotte 2006). Explosion conditions may be aggregated by the presence of flammable gas, ignition source and affected equipment. Moore observed that MAP suppressant is effective to combat maize dust explosions, however this chemical will only effective as a post-explosion inerting agent rather than being an explosion prevention agent (Moore 1996). Thus, the presence of gases could restrain suppression mechanism. Moreover, ignition sources can have indirect effect on the suppression performance. Different ignition sources will supply different amounts of energy , it is known that high energy will facilitate particles oxidation. The minimum explosive concentration (MEC) decreases when increasing the ignition energy (Nifuku and Katoh 2001), therefore one must consider the potential ignition sources in the food industry in order to select an adequate suppressant.

2.2. Suppression with gaseous compounds

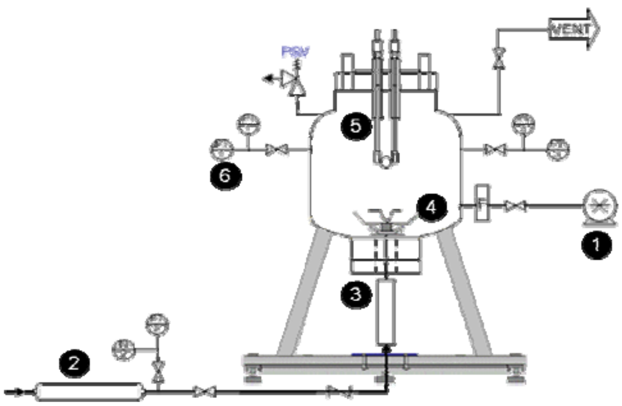
Suppression with gaseous compounds aims to reduce oxygen content in the atmosphere rather than decrease the combustible concentration. This method is also called inerting because an inert gas is used to substitute or reduce oxygen concentrations in the atmosphere. The most commonly used gas for inerting is nitrogen. Once the oxygen has been substituted by the gas suppressant, the flame cannot propagate in the dust cloud due to low oxygen content thus cannot maintain a combustion reaction. The main disadvantage of this method is that it could require large amounts of inert gas, therefore it is not cost-effective. Another disadvantage is that while explosion risk is substantially reduced by the suppressant, a new hazard would be introduced to the system: asphyxiation hazard (Daniel A. Crow1 2002; Eckhoff 2005). High nitrogen contents in the human body can produce fatal effects (OSHA 2009). For this reason this method is usually used when the combustible dust is extremely flammable (Eckhoff 1997).

2.3. Suppression with solid-gaseous suppressant compounds

The new solid-gaseous suppressant alternative will comprise inherent advantages and disadvantages derived from each property. The characteristics of this binary suppressant will depend on the suppressant's amount (large amounts of solid suppressant will lead to larger contamination), and properties of initial suppressants (e.i chemical properties, heat capacity, reactivity). Dust explosions caused by food products should be reproduced and simulated under the new solid-gaseous suppressant system at different ratios in order to measure suppressant effectiveness. Thus, experimental work is needed to identify the effectiveness of binary gas-solids suppressants.

3. Overview of Dust Explosion Research at the Mary Kay O'Connor Process Safety Center (MKOPSC)

The 26-L dust explosion chamber was donated by Dow Chemical Inc. The 26-L chamber is a semi-spherical vessel made of stainless steel and has a Maximum Allowable Working Pressure (MAWP) of 1000 psi. All fittings and accessories were integrated to the vessel. Additionally, a control box with a built-in remote control capability has been added to the system. The LabView software was used to control hardware and create a user interface. Figure 1 shows a schematic drawing of 26-L chamber and its main components.



Legend:
1. Vacuum pump
2. Air reservoir
3. Dust container
4. Nozzle
5. Igniters
6. Pressure Transducers

Figure 1. Schematic drawing of 26-L chamber.

ASTM standard test method (ASTM E-1226-05) will be used to guide laboratory-scale tests. The working principles of the 26-L is as follows:

- Nominal dust are loaded in the test chamber
- The test chamber is partially evacuated to allow the tests to be conducted at atmospheric pressure
- Dust are dispersed by a blast of air from the bottom of the test chamber
- The ignition source is initiated after the pressure has returned to 1 atm and dust has been uniformly dispersed.

Results from the test will be tabulated in a pressure-time profile. Other parameters that will be used to determine the explosive characteristics of combustible dusts include maximum explosion pressure (Pmax), maximum rate of pressure rise ([dP/dt]max), deflagration index (Kst), Minimum Explosible Concentration (MEC) and Limiting Oxygen Concentration (LOC). The reduction of Pmax will be used to indicate the suppressant efficiency and the value of Kst will be used to measure the relative explosion severity.

4. Future Work

This paper identifies the advantages and disadvantages of solid and gases suppressants used in food industry. Further studies indicate that some characteristics of these suppressants can be combined in order to produce an effective suppression action. Future work will focus in verifying suppressant effectiveness by determining the minimum concentration of binary solid-gas suppressants in reducing the explosion violence. Experimental data will be used to reveal the optimum concentration ratio needed to produce a weak explosion. Research will also focused on dust products in food industry in order to design a systematic approach that can be used to prevent dust explosions in food industry.

Acknowledgement

This research is funded by the Mary Kay O'Connor Process Safety Center of the Department of Chemical Engineering at Texas A&M University

References

Abbasi, T. and S. A. Abbasi (2007). "Dust explosions - Cases, causes, consequences, and control." Journal of Hazardous Materials **140**(1-2): 7-44.

Amyotte, P. R. (2006). Solid inertants and their use in dust explosion prevention and mitigation, Elsevier Sci Ltd.

Amyotte, P. R., K. J. Mintz, et al. (1992). "EFFECTIVENESS OF VARIOUS ROCK DUSTS AS AGENTS OF COAL-DUST INERTING." Journal of Loss Prevention in the Process Industries **5**(3): 196-199.

Amyotte, P. R., K. J. Mintz, et al. (1991). "EFFECTS OF METHANE ADMIXTURE, PARTICLE-SIZE AND VOLATILE CONTENT ON THE DOLOMITE INERTING REQUIREMENTS OF COAL-DUST." Journal of Hazardous Materials **27**(2): 187-203.

Bartknecht, W. (1989). Dust Explosions. Course, Prevention, Protection. Germany, Springer Verlag Berlin Heidelberg.

Blair, A. S. (2007). Dust explosion incidents and regulations in the United States, Elsevier Sci Ltd.

Chatrathi, K. and J. Going (2000). Dust deflagration extinction, Amer Inst Chemical Engineers.

Daniel A. Crow1, J. F. L. (2002). Chemical Process Safety. Fundamentals with Applications. USA, Prentice Hall PTR.

Dastidar, A. G., P. R. Amyotte, et al. (1999). "Flammability limits of dusts: Minimum inerting concentrations." Process Safety Progress **18**(1): 56-63.

Eckhoff, R. (1997). Dust Explosions in the Process Industries. Great Britain
St Edmundsbury Press Ltd.

Eckhoff, R. K. (2005). Current status and expected future trends in dust explosion research, Elsevier Sci Ltd.

Krasnyansky, M. (2006). "Prevention and suppression of explosions in gas-air and dust-air mixtures using powder aerosol-inhibitor." Journal of Loss Prevention in the Process Industries **19**(6): 729-735.

Maness, J. E. "Grain Industry approach to Dust Explosions."

Moore, P. E. (1987). Suppression of Maize Dust Explosions. Symposium on Industrial Dust Explosions. A. s. f. t. a. Materials. Philadelphia, Industrial Dust explosions**:** 281-293.

Moore, P. E. (1996). "Suppressants for the control of industrial explosions." Journal of Loss Prevention in the Process Industries **9**(1): 119-123.

Nifuku, M. and H. Katoh (2001). Incendiary characteristics of electrostatic discharge for dust and gas explosion, Elsevier Sci Ltd.

OSHA. (2009). "MSDS, Nitrogen gas ", 2009, from http://www.osha.gov/SLTC/healthguidelines/nitrogen/index.html.