Dust Explosion

Every process involving combustible finely divided solids or dusts is associated with explosion hazards. According to a 2006 U. S. Chemical Safety and Hazard Investigation Board (CSB) report, 281 combustible dust incidents took place in the United States from 1980 to 2005, killing 119 workers and injuring 718 others. On February 7th, 2008, 14 workers died due to a series of sugar dust explosions in Georgia. On August 2nd, 2014, a metal dust explosion in Kunshan, Jiangsu, China caused 146 fatalities.

Five indispensable elements of dust explosion – combustible dusts, confinement, mixing, oxidant, and an ignition source - constitute the “dust explosion pentagon”. After an initial dust explosion, additional dust dispersed into the air may cause catastrophic secondary explosions. Dust explosion is a complicated process and the dust explosibility are affected by chemical composition, particle size, moisture content, oxygen concentration, and inert gas and inert dust concentration.

A 36 L dust explosion vessel was customized in MKOPSC. Several properties of combustible dusts can be determined in this equipment, such as deflagration index, maximum explosion overpressure, minimum explosive concentration, and limiting oxygen concentration. The capability of the equipment and laboratory is also extended to test nanomaterials as well as hybrid mixture of combustible dust and gas.

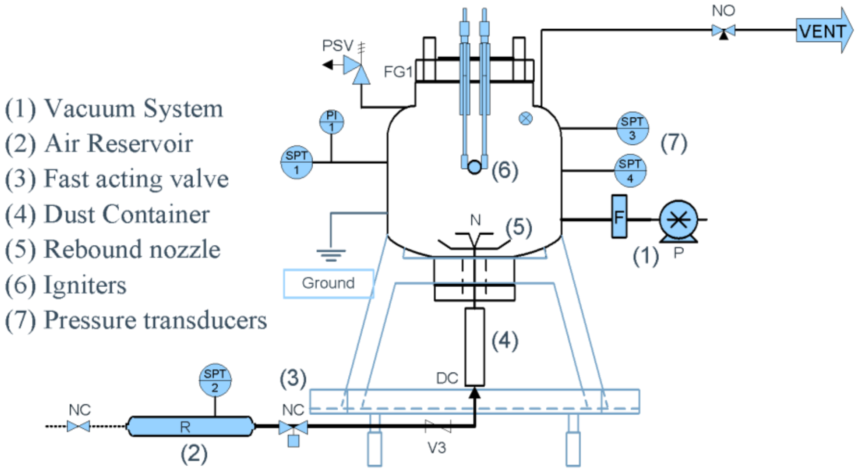

Figure 1. Schematic diagram of 36-L dust explosion vessel [1]

The effect of particle size polydispersity on the explosibility characteristics of aluminum dust have been studied for aluminum samples with similar D_{50} and varying size polydisperity [2]:

- P_{max} and K_{St} values of aluminum samples increase with size polydispersity
- D_{50} and $D_{4,3}$ are inadequately related to K_{St} values of samples having broad PSD
- $D_{3,2}$ exhibits the best correlation between particle size and explosion severity

Influence of particle size and crystalline level on the efficiency of dust explosion inhibitors were also studied [3]:

- The efficiency of dust inhibitors increased by decreasing particle size
- Particularly, DAP and MAP presented a critical diameter where the inhibitor efficiency was enhanced
- The performance of α-ZrP as an inhibitor was not considerably affected by the variation of particle size and crystalline level
- A semiempirical model was developed to identify the factors dominating the reduction of cornstarch explosion severity.

While the effect of particle size on explosion behavior is well established for common materials, nanoparticles' flammability and explosion were also studied [1]:

- Validated the previous "rule of thumb"
- Disclosed Fe-NPs' promotion effect on CNFs' explosibility due to CNFs' favorable topology for radiation energy transfer and pyrophoric properties of Fe-NPs (Figure 2)
- Proposed a heterogeneous model based on a dynamic perspective to evaluate the influences of agglomerate size and Fe-NPs on the heat transfer process and ultimately the explosibility

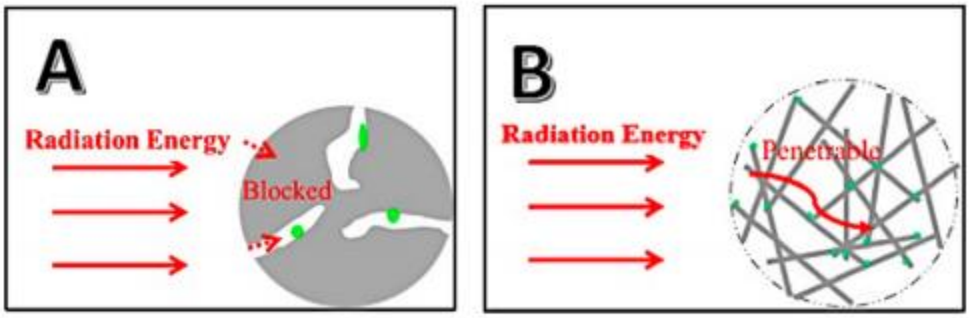

Figure 2. Radiation energy path in (A) conventional bulky particles and (B) nanofiber agglomerates [1]

Hybrid mixtures explosion

Hybrid mixtures are widely encountered in industries such as coal mines, paint factories, pharmaceutical industries, or grain elevators. Hybrid mixtures explosions involving dust and gas can cause great loss of lives and properties. The lower flammability limit (LFL) is a critical parameter when conducting a hazard assessment or developing mitigation methods for processes involving hybrid mixtures. Unlike unitary dust or gas explosions, which have been widely studied in past decades, only minimal research focuses on hybrid mixtures, and data concerning hybrid mixtures can rarely be found. Although methods to predict the LFL have been developed by using either Le Chatelier's Law, which was initially proposed for homogeneous gas mixtures, or the Bartknecht curve, which was adopted for only certain hybrid mixtures, significant deviations still remain. A more accurate correlation to predict an LFL for a hybrid mixtures explosion is necessary for risk assessment. The research at MKOPSC focuses on the study of hybrid mixtures explosions in a 36 L dust explosion apparatus including mixtures of methane/niacin, methane/cornstarch, ethane/niacin and ethylene/niacin in air. By utilizing basic characteristics of unitary dust or gas explosions, a new formula is proposed to improve the prediction of the LFL of the mixture. The new formula is consistent with Le Chatelier's Law [4]. The effect of varying the ignition energy and turbulence intensity to the proposed formula is also studied [5].

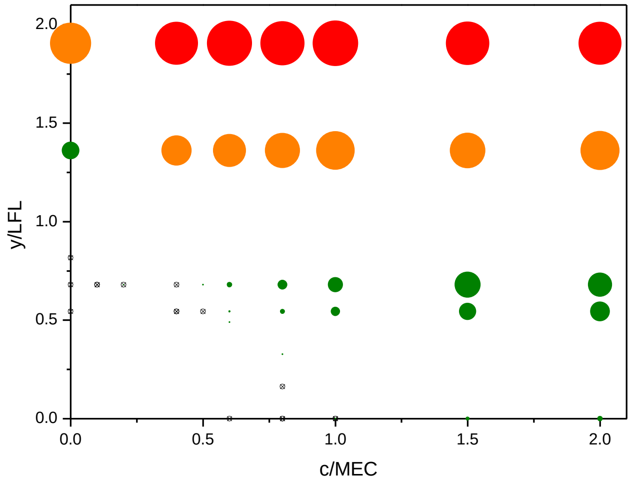

Figure 3. K_{St} in the plane methane content/cornstarch concentration: blank circle means no explosion; green circle means K_{St} is less than 200 bar·m/s; Orange circle means K_{St} is less than 300 bar·m/s but higher than 200 bar·m/s; red circle means K_{St} is above 300 bar·m/s

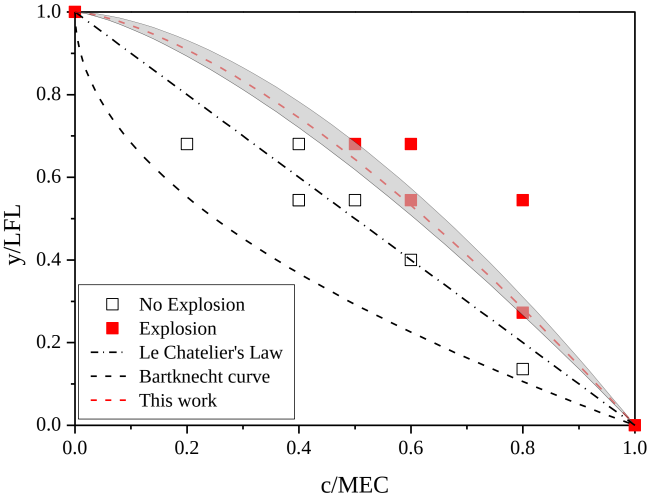

Figure 4. Confidence interval of the new formula: methane/cornstarch

In addition, cooperation with professors in Texas A&M University expands the research areas of dust explosion. Associated with Dr. Eric Petersen from Mechanical Engineering, researches about the effect of shockwave on particle distribution are undergoing in Turbo Machinery Lab. Shock tube is used were combustible dust particles are subjected to shock wave of different strength to study dust could formation mechanism to identify significant parameters for developing industrial scale simulation tool for secondary dust explosion hazard assessment. Figure 5. demonstrates schematic of shock tube with features for optical flow visualization in order to understand dust-air interaction behind propagating shock front. More combustible dust properties like particle size distribution, minimum ignition energy, can be determined with Dr. Mashuga from Chemical Engineering.

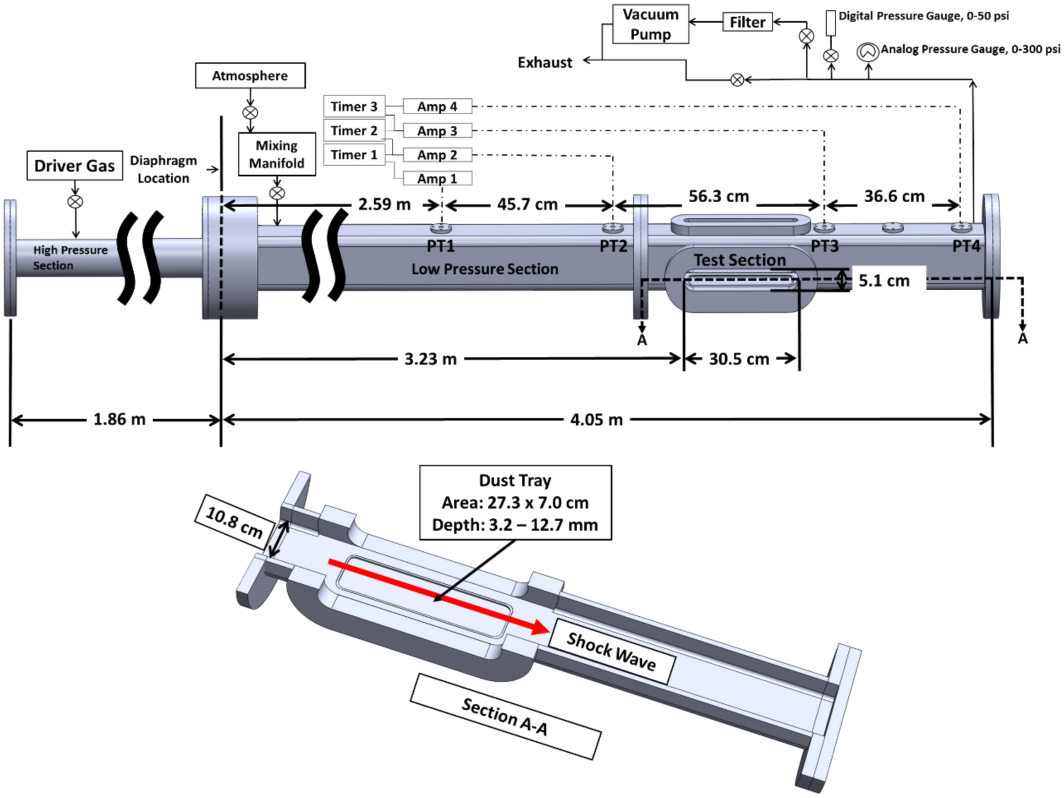

Figure 5. Schematic diagram of Shock tube with window for optical flow visualization [6]

Deflagration-to-Detonation Transition (DDT)

A deflagration is a combustion wave which propagates at subsonic speeds. When a deflagration occurs the pressure front (shock wave) and the reaction front (flame) are far apart from each other. On the other hand, a detonation is a combustion wave that travels at supersonic speeds. In this case, both the pressure front and the reaction front are very close to each other and it is very hard to distinguish them with the naked eye. Under the right conditions, the flame speed can accelerate making the combustion process to undergo a transition from deflagration to detonation.

Currently, the MKOPSC has associated with Dr. Eric Petersen from Mechanical Engineering to perform experimental and numerical studies (CFD – FLACS) in order to get a better understating of this phenomenon. Previous research has been done on DDT, focusing on a uniform distribution of obstacles (similar shape, same blockage ratio and same distance between the obstacles). However, this layout does not represent an industrial setup. For instance, a facility has pumps, vessels, reactors, pipe racks, *etc*. all of different sizes. Therefore, experiments are being performed in a way to mimic this characteristics, *e.g.*, non-uniformity distribution of obstacles, to understand the flame acceleration mechanism and determine the effect the variation of the shape, blockage ratio and separation distances of the obstacles has on the combustion process.

References:

[1] Zhang, J., Chen, H., Liu, Y., Elledge, H., Mashuga, C., & Mannan, M. S. (2015). Dust Explosion of Carbon Nanofibers Promoted by Iron Nanoparticles.*Industrial & Engineering Chemistry Research*.

[2] Castellanos, D., Carreto-Vazquez, V. H., Mashuga, C. V., Trottier, R., Mejia, A. F., & Mannan, M. S. (2014). The effect of particle size polydispersity on the explosibility characteristics of aluminum dust. *Powder Technology*, *254*, 331-337.

[3] Castellanos, D., Lewandowski, A., Diaz, A., Mejia, A. F., Carreto, V., Mashuga, C., ... & Mannan, M. S. (2014). Influence of Particle Size and Crystalline Level on the Efficiency of Dust Explosion Inhibitors. *Industrial & Engineering Chemistry Research*, *53*(28), 11527-11537.

[4] Jiang, J., Liu, Y., & Mannan, M. S. (2014). A correlation of the lower flammability limit for hybrid mixtures. *Journal of Loss Prevention in the Process Industries*, *32*, 120-126.

[5] Jiang, J., Liu, Y., Mashuga, C. V., & Mannan, M. S. (2015). Validation of a new formula for predicting the lower flammability limit of hybrid mixtures. *Journal of Loss Prevention in the Process Industries*, *35*, 52-58.

[6] Chowdhury, A. Y., Shock interaction with dust layers, Texas A&M University Doctoral Thesis, College Station, 2015