International Journal of Mining Science (IJMS)
Volume 7, Issue 1, 2021, PP 20-28
ISSN 2454-9460 (Online)
DOI: http://doi.org/10.20431/2454-9460.0701003
www.arcjournals.org

Dust Explosion Hazard – A Review

Satesh Kumar Devrajani, Ihsan Wassan, Tamat Ul Nisa, Mehran Ali Qureshi, Uzma Imran

USPCAS-W, Mehran University of Engineering and Technology

Corresponding Author:** ***Satesh Kumar Devrajani, *USPCAS-W, Mehran University of Engineering and Technology*

Abstract: *Dust explosion, one of the most serious and widespread explosion hazards, which is recently a topic of concern for the developed countries are not even identified as a serious threat in developing countries. In this paper we present a review on the concept of dust explosion, by critically reviewing the work done in this domain, a brief on the equipment used for studying this field, followed by possible directions this research could be furthered in*

Keywords: *Dust explosion, Nano-dust, HSE, Hazard, Equipment, Awareness.*

1. Introduction

1.1.1. Definition

The rapid combustion of a dust cloud constitutes a dust explosion. In a confined or almost confined space, the explosion is characterized by a relatively rapid evolution of the flame propagation pressure and the evolution of large amounts of heat and reaction products. For this combustion, the necessary oxygen is mostly supplied by the combustion air. The condition necessary for a dust explosion is a simultaneous presence of dust cloud of proper concentration in air that will support combustion and a suitable ignition source.

The industries where the hazard of combustible and explosive dust can be commonly found are:

- Wood processing and storage
- Grain elevators, bins and silos
- Flour and feed mills
- Manufacture and storage of metals such as Al and Mg
- Chemical production
- Plastic production
- Starch or Candy producers
- Spice sugar and cocoa production and storage
- Coal handling or processing area
- Pharmaceutical plants
- Dust collection bins or bags
- Shelves, nooks, crannies, inside of equipment and above false ceilings in all facilities.

1.1.2. Operations Involving Dusts

Operation in which dusts are generated or handled comprise of the following:

1. Size reduction
2. Conveying.

3. Separation
    - Settling chambers
    - Cyclones
    - Filters
    - Scrubbers
    - Electrostatic precipitator
4. Driers
    - Tray driers
    - Rotary driers
    - Fluidized bed driers
    - Pneumatic driers
    - Spray driers
5. Screening and Classifying
6. Mixing and Blending
7. Storage
8. Packing
9. Fired heaters

On the one hand, most developed countries recognize and notice all potential instances of dust explosion and its causes, while on the other hand, in developing countries there is little or negligible understanding of this form of threat. In most countries, there are no regulations or guidelines that will help us recognize potential dust explosion hazards and, accordingly, design and install suitable equipment to control these accidents. It takes time to come up with dust explosion standards and enforce these standards across different industries that handle these types of dust, which could be potentially explosive and ultimately harmful.

According to ISO 4225 [7] dust is defined as “small solid particles, conventionally taken as those particles below 75 μm in diameter, which settle out under their own weight but which may remain suspended for some time.” And ISO 12025:2012 defines Nano-scale as 1nm to 100nm (1nm = 10^{-9}m). Due to advancements in technology, the particulate size in many industries is getting smaller by orders of magnitude. This may be true for industries which are involved in manufacturing or processing of cosmetics, semiconductors, toners, etc. Main advantages of Nano-materials are they have more specific surface area, which enhances chemical, electrical and mechanical properties. However, this also leads to an increase in the risk of combustion.

Combustible dusts are fine particles that present an explosion hazard when suspended in air under certain conditions [8]. A dust explosion can be catastrophic and can lead to irreversible damage like deaths, injuries, and destruction of entire buildings. In many combustible dust incidents, employers and employees were unaware that a hazard even existed. Looking at the various types of dust being handled by companies across industry types, it is imperative that the companies are made aware of such hazard, and if it is found to exist, action needs to be taken to prevent tragic consequences.

For e.g., if we observe a 1 m^3 cube having sides 1m each, its surface area is calculated to be 6m^2 and when we divide this cube in 8 equal cubes, the area increases to 12m^2. If we divide the cube into smaller cubes of 100nm sides, which results in 10^{21} cubes and total surface area adds up to a significantly large number of $6x10^7$ m^2 which is 10^7 times that of initial cube of 1 m sides. This degree of sub-division of the solid can be expressed in terms of the total area per unit volume or unit mass of solid and is known as specific surface area [3]. Hence, as the particle size decreases, specific surface area increases which leads ultimately to an increase in contact with oxygen, available for oxidization. This enhanced area leads to better mixing of the dust and oxygen thereby facilitating in quick and easy combustion.

2. BACKGROUND

A mention of dust explosion in literature dates back to 1785 [3]. The related systematic records are available only from the early 20th century majorly from developed countries. One of the earliest records of dust explosion dates back to January 12, 1807, occurred at Leiden, Netherland [1].

On January 29, 2003, an explosion and fire destroyed the West Pharmaceutical Services plant in Kinston, North Carolina, causing six deaths, dozens of injuries and hundreds of job losses. The facility produced rubber stoppers and other products for medical use. The fuel for the explosion was a fine plastic powder, which accumulated above a suspended ceiling over a manufacturing area at the plant and got ignited.

Few days later, on February 20, 2003, an explosion and fire damaged the CTA Acoustics manufacturing plant in Corbin, Kentucky, fatally injuring seven workers. The facility produced fiberglass insulation for the automotive industry. CSB investigators have found that the explosion was fueled by resin dust that accumulated in a production area, likely ignited by flames from a malfunctioning oven. The resin involved was a phenolic binder used in producing fiberglass mats.

Although combustible dust hazard is now more widely recognized, combustible dust accidents and fatalities continue to occur at an alarming rate. On the evening of October 29, 2003, a series of explosions severely burned two workers, injured a third, and caused property damage to the Hayes Lemmerz manufacturing plant in Huntington, Indiana. One of the severely burned men subsequently died. The Hayes Lemmerz plant manufactures cast aluminum automotive wheels, and the explosions were fueled by accumulated aluminum dust, a flammable byproduct of the wheel production process.

The most publicized and scrutinized combustible dust accident in the United States occurred on February 7, 2008, when a huge explosion and fire occurred at the Imperial Sugar refinery located at port Wentworth, Georgia, USA. A total of 14 were killed and 38 injured, including 14 with serious and life-threatening burns. The presence of all five factors leading to dust explosion can be seen in this accident. The explosion was fueled by massive accumulations of combustible sugar dust throughout the packaging building. The conveyer belt would get blocked by clumps of sugar from time to time and spill sugar dust onto the floor. In 2007 the company enclosed the conveyer belt which led to confinement. And on February 7th, 2008, the clumps of sugar blocked the conveyer belt and sugar dust got dispersed in the confinement. This dispersed dust in air came in contact with the nearby heated bearing, which acted as source of ignition and lead to explosion.

The only systematic record of dust explosion by developing country, was of Harbin Linen Textile Plant, People's Republic of china. A catastrophic explosion in the plant on 15 March 1987, killing 58 persons, injuring another 177 and destroying 13,000 m^2 of factory area. The ignition was due to an electric spark in one of the dust collector and the explosion propagated to the other seven dust collecting units, causing secondary explosions. [1]

3. THE DUST EXPLOSION MECHANISM

For fire, the essential three factors (often known as fire triangle) are – fuel, oxidant and ignition source:

Fuel + Oxidant + Ignition→Oxides + Heat

Explosion takes place when the fuel is ignited under pressure, which adds one more factor i.e. confinement

Fuel (Confined) + Oxidant + Ignition →Oxides +Heat + blast waves

Whereas in case of a dust explosion along with the above mentioned three essential factors, confinement and dispersion are the two equally critical factors. Dust explosion takes place only when all these five factors comes together. This explosion may be deflagration or detonation depending on the rate of reaction and resulting burning velocity [6]. It needs to be understood that by isolating any one of these factors, the explosion can be averted.

Dust (Confined and dispersed) + Oxidant + Ignition →Oxides + Heat + blast waves

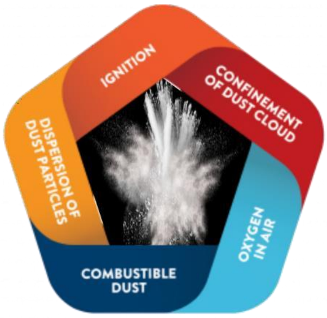

Figure3.1. *Dust explosion pentagon[2]*

As the reactants are dust and gases, the product of combustion is always gas. This reaction is always understood on the basis of ideal gas law:

PV = nRT

As air consists of nitrogen as major component and oxygen present in the air acts as the oxidant, the number of moles of gas do not change much [6]. Therefore, to a first approximation of ideal gas law, a rapid combustion reaction in a closed system results in:

Where, P_{max} is the maximum absolute explosion pressure, $P_i$is the initial absolute pressure. T_b is the absolute temperature of the burnt gases and $T_i$is the initial absolute temperature. The above equation is based on the assumption that the total number of moles is constant (i.e., for closed chambers).

$$\frac{P_{max}}{P_i} = \frac{T_b}{T_i}$$

Maximum pressure will change significantly with change in number of moles (n) [6].

4. Index of Explicability

The Bureau of Mines [5] has developed an index of explosibility in comparison to Pittsburgh coal. This index can be used to rank the dust in relation to its explosion severity and ignition sensitivity [5]

Index of explosibility (IE) = IS x ES

$$IE = \frac{(MIT \ x \ MIE \ x \ MEC)_{Pc}}{(MIT \ x \ MIE \ x \ MEC)_{sample}} x \frac{(MEP \ x \ MRPR)_{sample}}{(MEP \ x \ MRPR)_{Pc}} \text{---------------4.1}$$

Where, IE is index of explosibility, ES and IS explosion severity and ignition sensitivity respectively, MEC is the minimum explosion concentration, MEP the maximum explosion pressure, MIE the minimum ignition energy, MIT the minimum ignition temperature and MRPR is the maximum rate of pressure rise. This index is relative and depends on the apparatus used. Finely pulverized Pittsburgh seam coal dust was used as the standard of comparison because its explosivity behavior had already been extensively studied in both full scale mine experiments as well as in laboratory-scale systems.

5. Classification of Explosive Dust

Various classifications have been developed and used throughout different industries in order to classify dust according to its explosibility, K_{st}values, etc. Classification helps in characterizing the various types of dust and develop optimal procedure and equipment to handle them. The highest value of the maximum rate of pressure rise is used to calculate the K_{st} value of the dust:

$$K_{st} = (dp/dt)_{max} V^{1/3}$$

Table5.1. *Classification of dust according to ISSA, 1998[2] Classified in 6 classes based on their ignitibility*

Sr. No	*Combustion Class*	*Type*
1	CC1	No ignition, no self-sustained combustion
2	CC2	Short ignition and quick extinguishing; local combustion of short duration
3	CC3	Local burning or glowing without spreading; local sustained combustion but no propagation
4	CC4	Spreading of a glowing fire; propagation smoldering combustion
5	CC5	Spreading of an open fire; propagating open flame
6	CC6	Explosible burning; explosive combustion

Table5.2. *Classification of dust according to K_{St}values [2]*

Sr. No	*Group type*	*K_{St}value*
1	Group St0: Non- explosible	0
2	Group St1: Weak explosion	$0 < K_{St} < 200$
3	Group St2: Strong explosion	$200 < K_{St} < 300$
4	Group St3: Very strong explosion	$300 < K_{St}$

Table5.3. *Classification of dust based on its explosibility index [5]*

Sr. No	**Index of explosibility**	**Type of explosion**
1	Less than 0.1	Weak explosion
2	0.1 to 1.0	Moderate explosion
3	1.0 to 10.0	Strong explosion
4	More than 10.0	Severe explosion

6. Dust Explosion Testing Equipment Comparison

As the major factor behind the dust explosion is dispersion and confinement, most of the dust explosion testing is done in a closed vessel having a dispersion source and source of ignition. 1.2 L Hartmann equipment, 20 L (By Swivek) and $1m^3$ (ISO) are the 3 major equipment types, which are used for collecting data on dust explosion [6].

Table6.1. *Comparison between the equipment used for testing dust explosion [6]*

	1.2L Hartmann's equipment	**20-L chamber(PRL)**	**$1m^3$(ISO)**
Used for	Preliminary screening test and MIE	Measuring MEP, MRPR, MEC	More realistic measurement of MEC, MEP and MRPR
Disadvantages	Yields false negative for dust that are difficult to ignite	Low accuracy compared to $1m^3$(ISO) chamber	Time consuming and requires more sample
Igniter	At bottom	In the center	In the center
Ignition Delay	170 ms	60 ms	600 ms

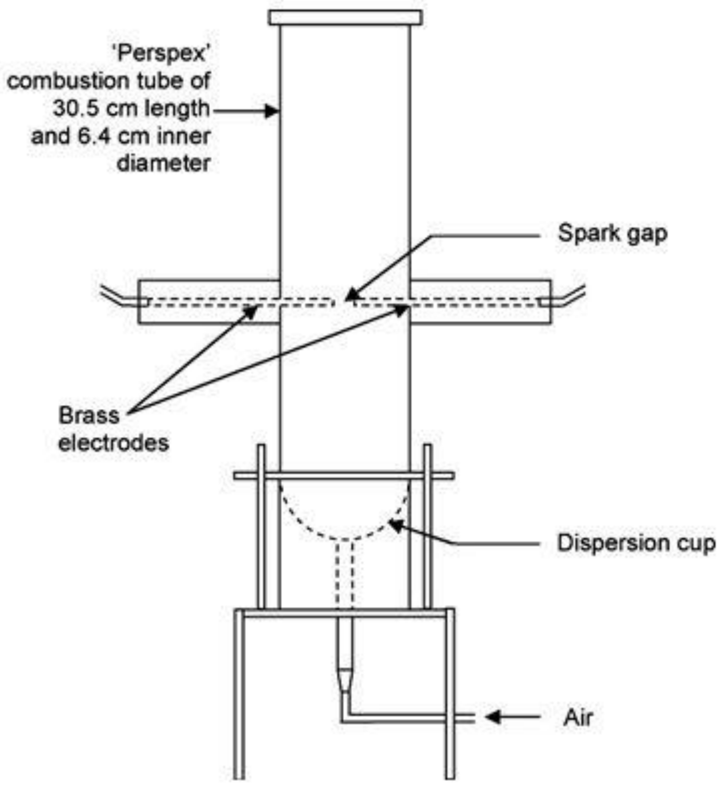

Figure6.1. *Hartmann Vertical tube apparatus[1]*

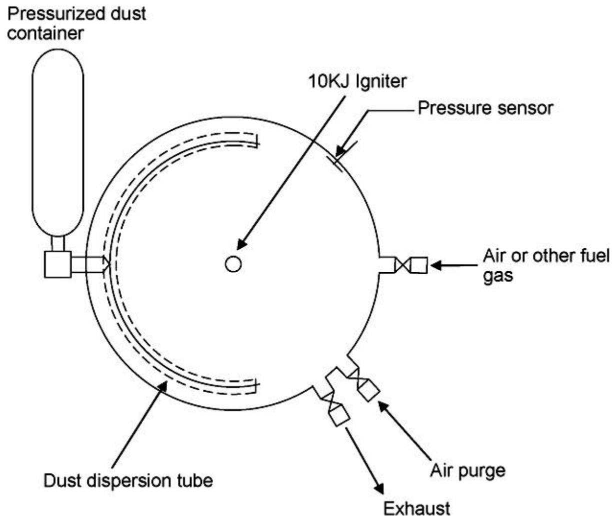

Figure6.2. *ISO 1 m^3 vessel[1]*

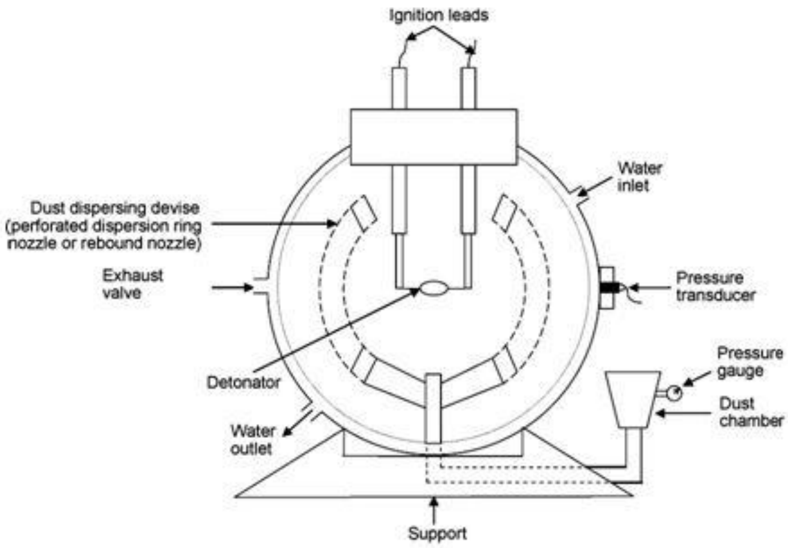

Figure6.3. *20 L spherical vessel[1]*

'Hartmann vertical tube' and '20L sphere' are the most commonly used apparatus for testing dust explosion. Hartmann apparatus has a 1.2 L vertical tube, with a dispersion cup at the bottom. The air is forced in the cup through a small hole in the dispersion cup. This air disperses the sample and a hot wire or a spark igniter serves as ignition source. One more variant is available where the tube is horizontal. As the tube is cylindrical in shape, the flames propagate in only one straight direction, which does not corresponds to the actual conditions. To replicate the actual propagation of flames, Swivek came up with a 20L spherical model. In this, the dispersion cup is replaced with the perforated dispersion tube which is attached to pressurized dust container. Dust is dispersed with the help of this dispersion tube and ignited with a spark plug placed at the center of the sphere. This 20 L sphere, with some modifications is the widely used apparatus due to its small size, lesser amount of sample and fast results. The 1 m^3 vessel is similar to 20 L sphere with larger volume. This is used to get more realistic measurements. It is found that the best agreement occurred between 20L vessel data with 2.5 KJ igniters and 1 m^3 vessel data with 10 KJ igniter.[9]

7. Significance of Particle Size on Explosion Severity and Ignition Sensitivity

Particle size distribution plays an important role in the explosion severity. Smaller particles have more surface to mass ratio and participate more easily in combustion as compared to the larger particles. Polythene having particle size less than 10 m has a k_{st}value of 156 compared to the k_{st}value of 54 for average particle size of 150 m [3].

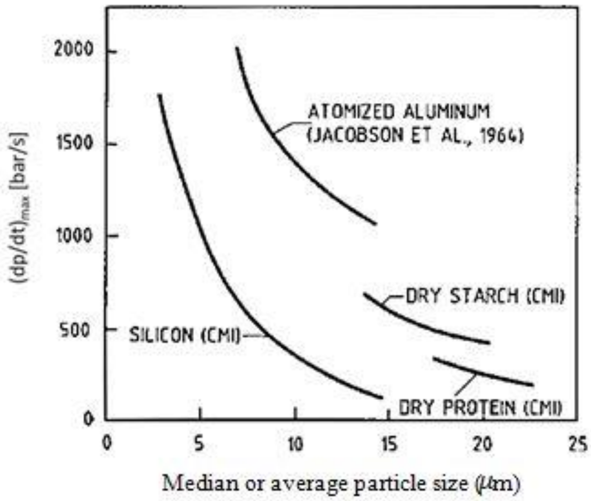

Figure7.1. *(dp/dt)max in Hartmann bomb of clouds in air silicon dust, aluminumdust and dust from natural organic materials, as functions of particle size [3]*

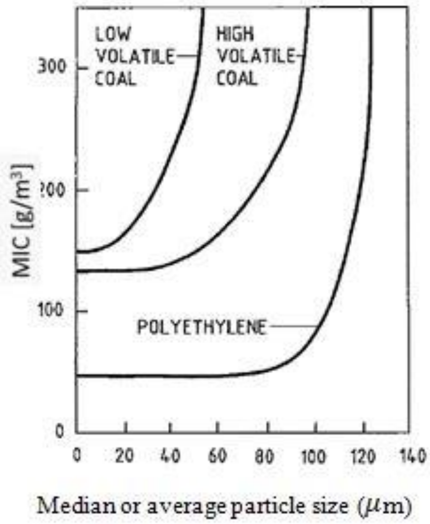

Figure7.2. *Influence of mean particle diameter on minimum explosible concentration for three different dusts in 20L USBM vessel[3]*

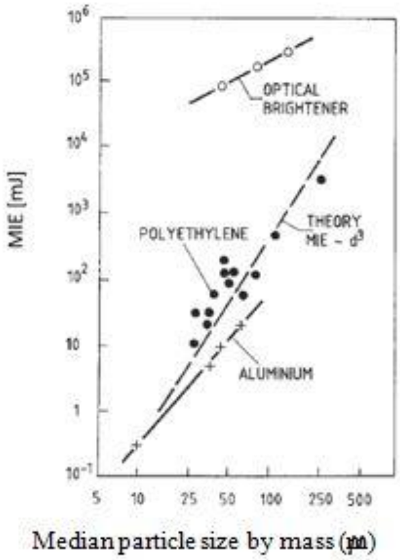

Figure7.3. *Minimum electric spark ignition energy of clouds in the air of an optical brightener, polyethylene and aluminum, as function of medium particle size and theoretical line for polyethylene [3]*

From Figure 7.1, we can see that as the values of MRPR [or. (dp/dt) max] increases with decrease in particle size and MIC, MIE decreases with decrease in particle size [Fig.7.2 and 7.3]. Form equation 4.1, we can say that these changes due to decrease in particle size will ultimately increase its explosion severity and ignition sensitivity ultimately increasing its Index of explosivity.

8. Discussion

As the industry is moving towards advanced technologies using Nano materials, we can expect huge amount of dust in particle size of less than 100 nm, which are highly explosive compared to the conventional dust. Dust explosion needs to be identified as one of the major hazards and standards need to be set for all the Industries dealing with dust. We need a lot of data such as MEC, MRPR, MIT, MEP about various dust across the industry as the data available is only for few of the typical dust types that too for certain particle sizes. The data for various other materials need to be generated and made public so that facilities and safety systems can be designed. Industry personal should be made aware of dust explosion hazards and they should be trained to handle such hazards. We can see from the literature; particle size is a major factor that play an important role in the severity of a dust explosion along with other factors such as its dispersion and confinement. This dust has carcinogenic effect on the health of operators or personnel working in dust industry, with this data it will be possible to design appropriate PPEs. By investing in dust handling equipment, companies can provide a safe working environment and save human lives.

9. Summary and Conclusion

A detailed review regarding previous work performed on the topic of Dust explosion was given in this study. A critical assessment of the previous work that was performed leads us to the following conclusions:

2. There is a need to identify and categorize the dust according to the ignitibility and explosivity.
3. Equipment design should consider all the factors mainly dispersion and confinement.
4. Index of explosibility and K_{St}can be used to classify the dust.
5. All the 3 equipment (1.2 Hartmann, 20L special vessel and ISO 1 m^3vessel) should be used to collect information for a dust sample. Correlation between these reading should be established.
6. Size of the particle plays a major role on explosion severity and ignitibility. Size of particle is inversely related to K_{St}value.
7. Data of dust across industries need to be collected, mainly its properties such as MIT, MIE, MEC, MEP and MRPRP, which will help us to identify the explosive behavior of dust.

References

[1] Tasneem Abbasi, S.A. Abbasi., "Dust explosion-cases, causes, consequences and control". Journal of Hazardous Materials, 7 – 44(2007)

[2] G. Vijayaraghavan., "Dust explosion – A major industrial hazard", International Journal of Advanced Engineering Technology, E-ISSN0976-3945

[3] Rolf K. Eckhoff. "Dust explosion in process industry", 3rd Edition. Gulf professional publishing,USA(2003)

[4] Adnan D., Samarth P., Nilesh S., Akshay A. and Sagar W. "Mathematical modelling and analysis of Nano-dust explosion" In: Proceeding of the 4th International conference in Ocean Engineering, pp 1033-1046. Springer, India(2019)

[5] M. Hertzber. "A critique of the Dust explosibility Index: an alternative for estimating Explosion Probabilities" Bureau of Mines Report of Investigation, USA(1987)

[6] K. L. Cashdollar. "Overview of dust explosibility characteristics", J. Loss prevent. Process Ind.pp193-199,13(2000)

[7] ISO 4225:1994(en).: Air quality – Generalaspects

[8] OSHA Fact sheet.: Hazard Alert: Combustion dustexplosion.

[9] J. E. Going, K. Chatrathi, K.L.Cashdollar, "Flammability limit measurements for dusts in 20-L and 1-m^3 " J. Loss Prevent, Process Ind. (2000) 209-2.

[10] NicholasS. Redingand Mark B, "Metal Dust Explosion Hazards: A Technical Review" Industrial & Engineering Chemistry Research. DOI:10.1021/acs.iecr.8b02465

[11] Rolf K. Eckhoff, "Dust Explosion Prevention and Mitigation,Status and Developments in Basic Knowledge and in Practical Application", Hindawi Publishing Corporation International Journal of Chemical Engineering.Volume2009, Article ID569825,12pages, doi:10.1155/2009/569825

[12] Ritsu Dobashi 2009 *J. Phys.: Conf. Ser.* 170012029, "Risk of dust explosions of combustible nanomaterials".

[13] *Sustainability* 2020, *12*, 4130; doi:10.3390/su12104130.

[14] hi Yuan, NimaKhakzad, Faisal Khan, Paul Amyotte,

[15] Dust explosions: A threat to the process industries,

[16] Zhi Yuan, NimaKhakzad, Faisal Khan, Paul Amyotte, "Process Safety and Environmental Protection",Volume 98,2015,Pages 57-71,ISSN 0957-5820,https://doi.org/10.1016/j.psep.2015.06.008.

AUTHORS' BIOGRAPHY

Satesh Kumar Devrajani, M.S. Scholar (Environmental Engineering), U.S Pakistan Centre for Advance Studies in Water (USPCAS-W), Mehran University of Engineering and Technology.

Ihsan Wassan, M.S. Scholar (Environmental Engineering), U.S Pakistan Centre for Advance Studies in Water (USPCAS-W), Mehran University of Engineering and Technology.

Tamat Ul Nisa, M.S. Scholar (Environmental Engineering), U.S Pakistan Centre for Advance Studies in Water (USPCAS-W), Mehran University of Engineering and Technology.

Mehran Ali Qureshi, M.S. Scholar (Environmental Engineering), U.S Pakistan Centre for Advance Studies in Water (USPCAS-W), Mehran University of Engineering and Technology.

Uzma Imran, Assistant Professor (Environmental Engineering), U.S Pakistan Centre for Advance Studies in Water (USPCAS-W), Mehran University of Engineering and Technology.

Citation: *Satesh Kumar Devrajani et al.., (2021) " Dust Explosion Hazard – A Review", International Journal of Mining Science (IJMS), 7(1), pp. 20-28. DOI: http://doi. org/10.20431/2454-9460.0701003*