Minimum Ignition Temperature of Hybrid Mixtures Of Burnable Dusts and Gases

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Abstract

Investigation of the ignition behavior (minimum ignition temperature (MIT)) of hybrid mixtures of dusts and gases has been undertaken. This was achieved by performing series of test in the modified Godbert-Greenwald furnace. The materials used are, gases (methane, propane and hydrogen) and dust (starch, lycopodium, toner, wood and CN4 (mixture of bituminous and brown coal)). The test protocol for testing the MIT for dust was according to E1491–06 while in the case of gas and hybrid mixture the same standard was used but with slight modification. The experimental results demonstrate the significant decrease of the MIT of either gas or dust and increase in explosion likelihood when small amount dust which is either below the minimum explosion concentration or not ignitable itself are admixture with gas and vice versa. For example the MIT of methane decreases from 600°C to 530° when small amount of toner which is not ignitable at the MIT of methane was added to it. The same effect was noticed when a small amount of gas was added to dust for example, wood with MIT of 460°C decreases to 420°C when a small amount of methane which is not ignitable at the MIT of wood was added. The result also confirm that an explosion is possible for a process or a system where hybrid mixtures are generated even if the temperature is below the MIT of a single substance and hence the MIT of hybrid mixtures cannot be predicted by simply overlapping the effects of the single dust or gas.

Keywords; minimum ignition temperature, hybrid mixture explosion, dust explosion, gas explosion

1. Introduction

An explosion is a rapid increase in volume and release of energy in an extreme manner usually with the generation of high temperature and pressure [1]. Explosions can arise from either exothermic chemical reactions of combustible dust suspended in the air, gases or from hybrid mixtures (mixture of combustible gas, vapor or dust).The risk of dust and hybrid mixture explosion exists in systems where there are possibilities of simultaneous presence of an explosive dust/air mixture and a source of ignition. Dust and hybrid mixtures explosion could cause fatalities, injuries, property damage and environmental contamination problems [2]. In order to prevent and mitigate the risk arising from these operations, the explosion parameters such as maximum pressure, maximum rate of pressure rise, minimum explosible dust concentration and minimum ignition temperature have to be determined. Among these parameters is the minimum ignition temperature at which dust clouds could ignite in the presence of hot surfaces. Hot surfaces capable of igniting dust clouds exist in a number of situations in industry such as furnaces burners and dryers of various kinds [3]. In addition, hot surfaces can be generated accidentally by overheating bearings and other mechanical parts. If an explosible dust cloud is generated in an uncontrolled way in the proximity of a hot surface at a temperature above the actual minimum ignition temperature, a dust explosion can result. As a consequence, in the prevention and mitigation of dust explosions, it is important to know the minimum ignition temperature (MIT), minimum explosive dust concentration or lowest explosive limit of dusts in order to take adequate precautions to ensure that hot surface temperature does not reach this value so that this kind of explosion risk could be prevented or mitigated.

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For pure dust, the MIT depends on the materials properties such as, composition and particle size distribution, geometry concentration, chemical structure etc. Furthermore, the environments conditions have also to be taken into account e.g. oxygen availability, surrounding temperature, environmental temperature and so forth [4]. For hybrid mixtures, the conditions become more complex as the MIT of hybrid mixtures cannot be predicted by simply overlapping the effects of the only one substance. Moreover, there is no systematic study that is able to quantify the roles of dust and gas in driving the explosion. Although an extensive works have been carried out on hybrid mixtures, there are still no clear conclusions on the combination of the values obtained from the pure substances to the complex hybrid mixtures. It is therefore necessary to investigate more deeply on this combination influences and achieve better understanding in order to prevent accidents and protect properties.

In order to demonstrate the specific behaviors of such mixtures, since Engler's first experiments in 1885 [5], gas/dust explosions have been studied mainly through hybrid mixtures of dust and gases, as coal dust and methane, flour and propane. Recently, researches have also been carried out on vapor/dust mixtures explosions [6]. The main conclusions of these studies could be summarized non-exhaustively by the following assertions: The ignition sensitivity of the powder can be strongly increased by the addition of a few percent of combustible gases or vapors, even with contents lower than the LEL. It has notably been shown that hybrid mixtures can also be explosive when both the concentrations of the dust and the gas are below their respective minimum explosion concentration (MEC) or lower explosion limit (LEL) [7].

In the case of minimum ignition temperature of hybrid mixtures (MIT hybrid), research data are not available or few or no research work has been done. Hence, the work of this paper is to investigate on the MIT of hybrid mixtures of dust and gas. In order to achieve this, five dust samples (starch, toner, wood, CN4 and lycopodium) and three gases (hydrogen, propane and methane) and their hybrid combinations were tested. All these tests were performed in the modified Godbert-Greenwald furnace.

2. Experimental work

2.1 Preliminary Analysis

In order to perform the various experimental work, the preliminary analysis for both dusts and gases were performed. Table 1 summarized the data of various preliminary analysis of the dusts used. The parameters considered are the elemental analysis, median particle sizes, moisture content, heat of combustion and molecular weight of the dusts which were calculated from elemental analysis while Table 2 also gives the basic, thermodynamic, ignition or combustion properties of the gases used.

Table 1: preliminary analysis of the dust used

	Toner (W/W%)	CN4 (W/W%)	wood (W/W%)	lycopodium (W/W%)	starch (W/W%)
Molecular Formula	$C_{7.17}H_{7.75}O_{0.33}$	$C_{6.70}H_{1.31}O_{0.88}N_{0.02}$	$C_{4.19}H_{6.26}O_{2.71}S_{0.004}$	$C_{5.77}H_{9.59}O_{1.23}S_{0.001}N_{0.08}$	$C_{3.69}H_{6.34}O_{3.06}S_{0.01}$
Media diameter(um)	13.4	60	307	31.6	29.2
Volatile Content (%)	17.04	18.94	27.86	46.49	84.35
Moisture Content (%)	0.92	0.23	0.2	0.35	0.5
Heat of combustion (KJ/Kg)	35792	26630	16446	28447	15302
Elemental analysis					
C	86.05	80.37	50.33	69.26	44.34
H	7.7.2	1.31	6.26	9.59	6.34
O	5.23	14.01	43.28	19.62	48.94
S	1	3.02	0.13	0.38	0.38
N	0	0.34	0	1.15	0

Table 2: properties of gases and solvents used

Properties	methane	propane	Hydrogen
Molecular formula	CH_4	C_3H_8	H_2
Purity (%)	99.87	99.00	99.99
Density (g/cm3)	6.6E-4	4.93E-4	8.99E-4
Molecular weight	16	44.1	2
Explosible range	4.4-17	1.7-10.8	4.0-77
melting point °C	−161	-187	-259
Specific heat capacity (J/molK)	35.69	73.60	28.80
Boiling point (°C)	−182.52	-42.1	-253
Heat of vaporization (kJ/mol)	−74.87	-103.80	0.00
maximum explosion pressure	8.1	9.8	8.3
MIT °C	595	490	570
MSG	1.14	0.92	0.29
Temperature class	T1	T1	T1
Explosion Group	IIA	IIA	IIC
LOC (vol. %)	12	9.4	4.3

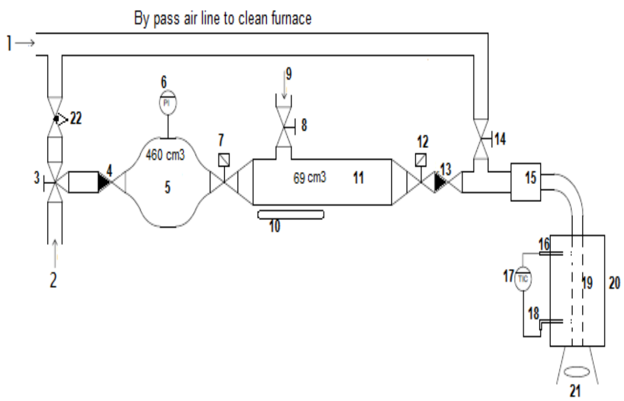
2.2 Experimental Work

The experimental setup consists of a Godbert-Greenwald furnace (GG furnace) which is usually used to determine the MIT of dust clouds. In the case of hybrid mixture of dust and gas, modifications were done on the equipment as shown in Figure 1.

For the test with only dust, E1491–06 testing procedure was used whereas a slight modification was done for gases and hybrid mixtures test. The furnace tube was heated and fixed at the desired temperature and the weighed amount of dust (with precision of +/- 0.005) was placed in the dust chamber. The air reservoir was filled with air up to the desired dispersion pressure and the dust sample was then dispersed through the furnace tube by a blast of air. The criterion for indicating an explosion was an observation of a flame at the bottom open mouth of the furnace with the help of a mirror. Both the pressure (0.1 to 0.5 bar above atmospheric pressure) and mass of dust (0.1 to 0.5 gram) were varied until a vigorous explosion was obtained. The conditions at which a vigorous explosion was obtained is called best explosion region as indicated in Figure 2. This region was maintained and the furnace temperature was lowered and testing continued until no flame was observed in ten tests. The difference in temperature between explosion and no explosion was 5°C. The lowest temperature at which explosion with flame occurred was taken as the minimum ignition temperature. Testing was further done at 5°C below the MIT to verify whether explosion will be obtained or not. Figure 2 explains the summary of result of individual test and how the MIT was obtained for dust test.

For the test with gases, the GG furnace was modified by introducing a gas feed line to the air reservoir as shown in Figure 1. The same experimental principle as explained for dust was also use for the gas test. The only different in this case was that, the air was premixed with the combustible gas in the air reservoir and the dust chamber was left empty. Even though the method used for the MIT of gas is different from the standard method but due to hybrid mixture testing, it was vital to use the same equipment in testing for MIT of gases. A comparison was also done with literature which were in good agreement with the standard results. The concentration of gases was determined based on partial pressure. The chosen pressures were between 0.1to 0.5 bar above atmospheric pressure and the concentrations were also with in the explosible range of individual substance. Again, Figure 3 explains the summary of result of individual test and how the MIT was obtained for gas test.

Finally, for the test with hybrid mixtures, the same experimental principle as explained before was used. But in this case, it was just the combination of the test method with pure dust and pure gas. Firstly, the required amount of dust was weighed and placed in the dust chamber and the required amount of gas was premixed with air in the air reservoir. The proceeding steps follow the same test principle for pure dust. It must emphasize that, the amount of dust used for the hybrid mixture test were all below their various minimum dust concentration or not ignitable itself at the respective testing temperature.



1. Air supply
2. Gas supply
3. T- shape ball valve
4. Check valve to prevent back flow of air or gas mixture
5. Air / gas reservoir or gas –air mixing chamber.
6. Digital pressure gauge
7. Vacuum control valve
8. Ball valve
9. Solvent or liquid supply
10. Heating filament.
11. Solvent reservoir
12. Vacuum control valve
13. check valve to prevent back flow of bypass air
14. ball valve
15. dust Chamber / reservoir
16.Thermcouple
17. Temperature controller
18. Electric power supply
19. Quartz furnace tube
20. Furnace shell
21. Mirror
22. Air regulating valve.

Figure.1. schematic diagram for experimental work

3. Results and discussion

The minimum ignition temperature (MIT) of dust clouds, gases and hybrid mixtures of combustible dusts and gases were investigated using modified Godbert-Greenwald Furnace. This was achieved by investigating three different gases namely (hydrogen, methane and propane) and five different dust namely (starch, lycopodium, toner, wood and CN4). Two main testing conditions were considered in this work. Which include:

1. Test for the MIT of single substance
2. Testing for the MIT of hybrid mixtures

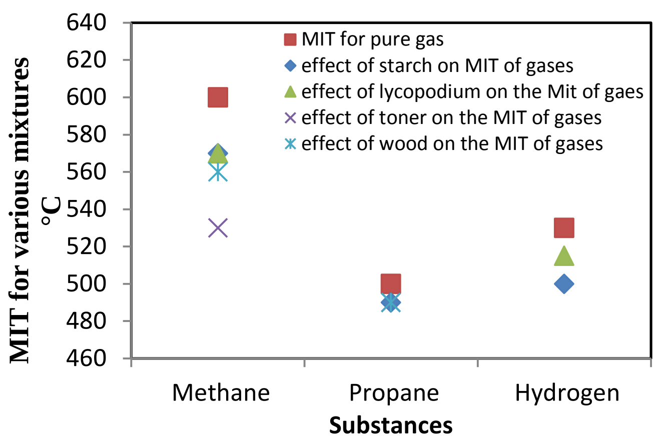


Figure 3 MIT of hybrid mixtures of dust and gas

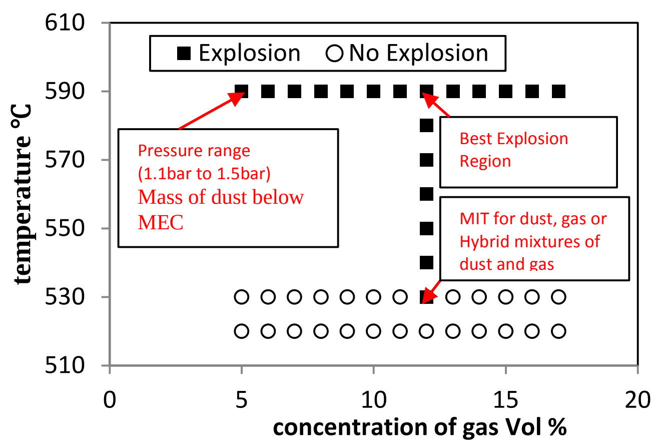


Figure 2. A representation of the test for both the MIT for individual substances and hybrid mixture

In the case of the first condition, Table 1 summarize all the tests results obtained for MIT for individual substances, with 380°C, 400°C, 460°C, 460°C and 640°C for starch, lycopodium, wood, toner and CN4 respectively. In considering the gases the MIT obtained were 600°C, 500°C and 530°C for methane, propane and hydrogen respectively which are comparable with the results obtained by E. Brande, and W. Möller [8] of which they obtained 595°C, 490°C and 536°C for methane, propane and hydrogen respectively. As already explained in chapter 2, each result summarized in Table 3 follows the same determination pattern as shown in Figure 2.

For the second condition, (i.e. testing for MIT for hybrid mixtures). This was done by mixing various dusts which is below their MEC or not ignitable itself with gases.

Two variables were considered which includes the effect of dust on the MIT of gas and the effect of gas on the MIT of dust. In order to achieve this, the MIT of various gases and dusts were determined. The temperature was further decreased below the MIT to check if an addition of dust will decrease the MIT of gas or not. The first variable was achieved by adding a small concentration of dust which is not ignitable or below the minimum explosion concentration to the dust.

Figure 3 present the result of effect of dust on the MIT of gas where the red square sign symbolizing the MIT of various gases and the rest of the symbols symbolizing hybrid mixtures explosions. It could be seen that, explosion were obtained below the MIT of the various gases by adding small amount of dust which is itself not ignitable at that particular temperature. For example, considering methane with the MIT of 600°C becomes ignitable at 530°C when small amount of toner which is even not ignitable at even 600°C was added. The same explosion behavior could be seen with the mixture of propane and the various dusts as well as hydrogen and the various dusts. The summary of these results are presented in Table 3. These results have shown that the MIT of hybrid mixtures cannot be predicted by simply overlapping the effects of only dust or gas.

Table 3: Summary of result for MIT test for individual substances and hybrid mixtures

Materials	MIT for pure substance (°C)	MIT for Hybrid mixtures for methane with dust (MIT for Methane =600 °C)				MIT for Hybrid mixtures for propane with dust (MIT for Propane =500°C)				MIT for Hybrid mixtures for Hydrogen with dust (MIT for Hydrogen =530°C)			
		Effect of dust on Gas (°C)	ΔT (K)	Effect of Gas on dust (°C)	ΔT (K)	Effect of dust on gas (°C)	ΔT (K)	Effect of Gas on dust (°C)	ΔT (K)	Effect of dust on gas (°C)	ΔT (K)	Effect of gas on dust (°C)	ΔT (K)
starch	380	570	30	370	10	490	10	360	20	500	30	370	0
lycopodium	400	570	30	No	0	No	0	No	0	515	15	No	0
wood	460	560	40	420	40	490	10	430	30	No	0	430	30
toner	460	530	70	No	0	490	10	No	0	No	0	No	0
CN4	640	No	0	630	10	No	0	590	50	No	0	620	20
Methane	600	The mass of dust used are not ignitable at the MIT of the gas temperature of below the MEC of the dust				The mass of dust used are not ignitable at the MIT of the gas temperature of below the MEC of the dust				The mass of dust used are not ignitable at the MIT of the gas temperature of below the MEC of the dust			
Propane	500												
Hydrogen	530												

The second variable considered was the effect of gas on the MIT of dust. In order to execute this test, the lower explosible limits (LEL) of the gases were initially tested at the MIT of the dust. The effect of gas on dust was performed in order to check if explosion could be obtain at a temperature where both the gas and dust are not explosible. The result obtained show that, the MIT of the dust decreases when a small amount of gas which is itself not ignitable was added. For example, wood has MIT of 460°C, when a small amount of gas which is not ignitable was added it decreases to 420°C, 430°C and 430°C for methane, propane and hydrogen respectively. Table 3 presents the summarize results of the various test. Shaikh Zunaid [9] did a work on the determination of minimum sparks temperature for dust mixture. He found that, some dust generate a lot of spark below its MIT. He then concluded that, if these sparks are strong enough it could ignite gases. This could be the reason why explosions were obtained below the no explosion temperature of the dust. From these results, it could also be notice that not all spark generated by the various dust could ignite gas. This could be seen in lycopodium and toner where there was no effect at all on the addition of methane, propane and hydrogen. Based on the above discussion, it could be noticed that, one could not rely on only the MIT of a single substance to predict the MIT of a system or process where hybrid mixtures exist.

4. Conclusion

Hybrid mixtures of burnable substances can occur in different industrial processes. This work was focused on the MIT of hybrid mixtures. Unlike the pure substance no standardized method or data are available. Whenever two or more substances are mixed, it is not sufficient to just measure one component to avoid an explosion. Based on the result obtained from this work, the following conclusion could be made.

- The MIT of gas decreases when a small amount of dust which is either below the MEC or not ignitable itself is added.
- The MIT of dust decreases when small amount of gas which is either below the LEL or not ignitable itself is added.
- The sparks generated by dust below the MIT can be sufficient to ignite a gas.
- The MIT of hybrid mixtures cannot be predicted by simply overlapping the effects of the single dust or gas.

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