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Experimental Research on Effect of Different Inert Powders on the Minimum Ignition Energy and Suppression Effect of Sucrose Dust

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Abstract: In order to prevent sucrose dust explosion, the suppression effect of four inert dusts (such as $NH_4H_2PO_4$, Al $(OH)_3$, NaCl and $NaHCO_3$) on the minimum ignition energy (MIE) of sucrose dust was studied by 1.2L Hartmann apparatus. The experimental results shown that the fire sensitivity of sucrose dust can be reduced by adding inert powders, and the MIE of sucrose dust significantly could be increased. The higher the mass fraction of inert powders and smaller particle size, the better the suppression effect. The best suppression effect on the sucrose dust flame propagation was $NaHCO_3$. The mass fraction of $NaHCO_3$, $Al(OH)_3$, $NH_4H_2PO_4$, NaCl (38-47μm) reaching 20%, 60%, 35% and 40% respectively, the sucrose dust were completely inerted. The mass fraction of four inert powders which particle size was 25-37μm were reached 20%, 60%, 30% and 35% respectively, the sucrose dust were completely inerted. Therefore, the suppression effect of four inert powders on sucrose cloud of dust combustion flame was: $NaHCO_3$ > $NH_4H_2PO_4$> NaCl > Al $(OH)_3$.

1. Introduction

The sucrose dust was concomitant organic dust produced in the process of sucrose production, which was easy to deposit around the corners and equipment, and formed dust clouds in confined spaces. So the dust explosion were likely occurring with sufficient energy. For example, in 2008, there was extremely serious sugar dust explosion accidents that caused a large number of casualties at Imperial Sugar manufacturing facility in Port Wentworth[1] . In order to reduce the risk and probability of dust explosion, the ignition sensitivity of combustible dust or terminate dust explosion could be reduced by adding inert powders.

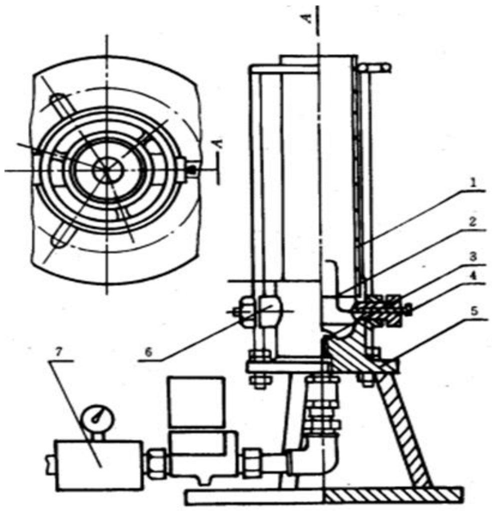
Many scholars and researchers had achieved certain results on the research of various types of dust explosion suppression. Li and Pei et al [2,3].found that the MIE and minimum ignition temperature(MIT) of metal dust could be increase by adding $CaCO_3$ and $NH_4H_2PO_4$, the smaller particle size, the better inhibitory effect, and inhibition effect of NH4H2PO4 was more obvious than $CaCO_3$. Huang et al [4] found that ABC powder can effectively inhibit the over pressure and reaction process of aluminum powder explosion,the inhibition effect became more obvious and the explosion was gradually weakened with increasing inert powder concentration. Jiang et al [5-6] studied the effect of $NH_4H_2PO_4$ and $NaHCO_3$ on the explosion suppression of aluminum powder, and it showed that the inert effect of $NH_4H_2PO_4$ was better than $NaHCO_3$. Enrico et al [7] tested the MIT of four mixtures of flour, lactose, sucrose and sulfur by adding limestone and dry powder extinguishing agent, shown that the MIT increased with the amount of inert substances. Emmanuel et al [8] studied the effects of ammonium sulfate, magnesium oxide and sand on the MIE and MIT of lignite, starch, coloring agent and polyethylene, respectively, and found that the MIT and MIE of combustible dust could be increased by adding inert agent, and MgO had significant influence on the MIT and MIE of four combustible dusts. Li [9] studied the suppression effect of $NaHCO_3$, $NH_4H_2PO_4$, $Al(OH)_3$ and $CaCO_3$ on the flour dust explosion and found that all four inert powders had inhibition effect on flour dust explosion, and there was good explosion suppression effect for physical-chemical synergic suppression of $NaHCO_3$ and $NH_4H_2PO_4$. Meng et al. [10] studied explosion flame suppression of two different kinds of oil shale dusts by selecting five commonly used inert powders, and found that the rank of inhibition performance on the explosive flame was: ABC dry powder>$Al(OH)_3$>$Mg(OH)_2$>$NaHCO_3$>rock powder. Liang et al [11] found that the inhibition effect of $NaHCO_3$, $Al(OH)_3$ and melamine poly-phosphate (MPP) on the explosion of corn starch, which could significantly reduced the risk of corn starch explosion. Zhao and Xie [12-13] found that there was suppression effect of $CaCO_3$ on the ignition characteristics and MIT of wood dust layer and aluminum dust, the smaller the particle size and the larger the concentration of CaCO3, the more significant the inert effect.Wang et al [14] studied the effect of NaCl on the MIE of sucrose dust, but didn't analyze its effect on flame propagation.

To sum up, those inert powders, such as $NaHCO_3$, $Al(OH)_3$, $NH_4H_2PO_4$ and NaCl, all had suppression effect on the explosion and combustion of metal and non-metal dust, but it wasn't clear which was better on sucrose dust explosion. The investigation on inert material mainly in metal dust, but there was only a little research on the suppression effect on sucrose dust explosion, and that was why we carried out a series of experiments. So experiments would be carried out to investigate the suppression effect of those four inert powders on the MIE and flame propagation of sucrose dust. Four inert powders were mixed with a certain mass of sucrose dust in different mass fraction and particle size respectively, and their MIE would be tested respectively.

2. Experimental devices, samples and methods

2.1 Experimental devices

The 1.2 L Hartmann apparatus was used to inactivate the sucrose dust, shown in Fig. 1. It was mainly composed of a quartz glass tube, an ignition electrode and a dusting system, which could provide ignition energy ranging from 0.1 to 999.9mJ. There were many advantages, such as small volume, easy disassemble, easy clean combustion residues and so on. According to the standard, the spark gap was set at 6mm [15]. During the experiment, the dust was evenly dispersed on the umbrella diffuser at the bottom of the Hartmann apparatus and dispersed in the Hartmann apparatus under the action of compressed air, and then the MIE of dust cloud was tested by ignition of electrode. The ignition electrode position was located on the vertical axis of symmetry of the Hartmann apparatus, about 60mm from the bottom. When the ignition energy was higher than the MIE of the dust, there was a severe flame burning phenomenon.



(a) Schematic diagram setup

(b) The photo of Hartmann apparatus (c) SST-8010/8 Direct-connected compressor

1-quartz glass tube, 2-electrode, 3-diffuser, 4-steel bushing, 5-pedestal, 6-electrode socket, 7-storage tank

Figure 1: Diagrammatic setup of 1.2L Hartmann apparatus

2.2 Sample preparation

According to the requirements of experiment, the analytical grades of four inert powders were purchased. After being ground by a mechanical crusher, the standard sample sieve was used to screen out three different particle sizes (48-74μm, 38-47μm, 25-37μm). The range particle size of sucrose dust was 48-74μm. All samples were dried in room temperature activated carbon oven for 12h before tests, and then stored in dry bottle.

2.3 Experiment methods

On the condition that mass of sucrose dust was 0.5g, texted the MIE of sucrose dust by adding different mass fractions and particle sizes of inert powders until the mixture wasn't be ignited. When the flame was separated from the electrode tip and radius exceeds 60mm, it was considered as catch fire. Each mass fraction of four inert powders were tested repeatedly, if mixed dust was subjected to intense flame combustion or the flame radius exceeds 60mm, reduced its ignition energy and tested repeatedly until no fire phenomenon, then this energy level was Emin. And then the particle size of inert powders were changed and repeated experiment in sequence as above. In order to avoid the quenching effect of the spark, the electrode gap should not be less than 2mm, and the optimum electrode gap was 6mm. If the ignition energy was very low, the electrode gap could be shortened to achieve a lower breakdown voltage, or changed the electrode spacing if no ignition phenomenon was observed.

3. Experimental results and analysis

3.1 Effect of mass fraction of inert powders on MIE of sucrose dust

The experimental conditions were set on: dust pressure 60kPa, ignition delay 90ms, sucrose dust 0.5g. The four inert powders ($NaHCO_3$, Al $(OH)_3$, $NH_4H_2PO_4$ and NaCl) were added to sucrose dust in mass gradient of 5% respectively, and fully stirred well.

The result of adding different mass fraction of inert powders on MIE of sucrose dust was shown at Figure 2. It shown that the mass fraction of inert powders reached 10%, the MIE of sucrose dust wasn't changed so much. When the mass fraction of inert powders reached 20%, the MIE of sucrose dust which added NaHCO3 was increased significantly, there was no fire until test 20 repetitions when the mass fraction of NaHCO3 reached 25%. This indicated that sucrose dust wasn't ignited anymore, meanwhile the MIE of sucrose dust was changed a small amount by adding same conditions of Al (OH)3, NH4H2PO4 and NaCl. When the mass fraction of inert powder reached 35%, the MIE of sucrose dust which added NaCl was increasing obviously, until the mass fraction of $NH_4H_2PO_4$ and NaCl reached 40%, there wasn't fire with 20 times repetitions, but the sucrose dust was completely inerted when the mass fraction of $Al(OH)_3$ reached 60%.

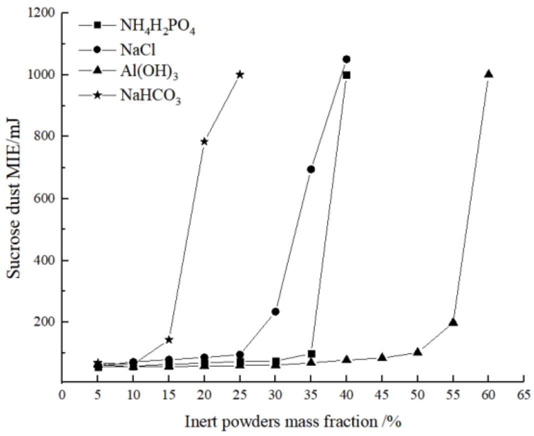
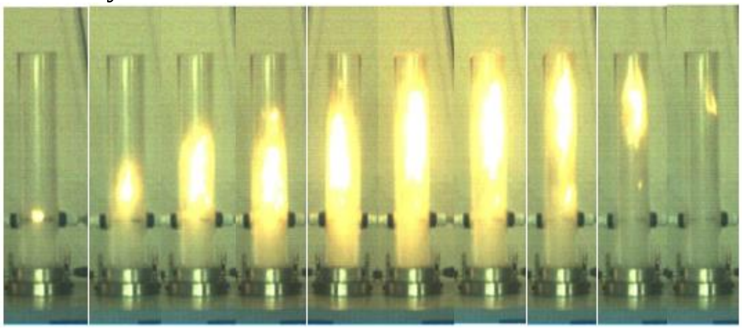


Figure 2: Effect of four inert powders in different mass concentration on sucrose dust

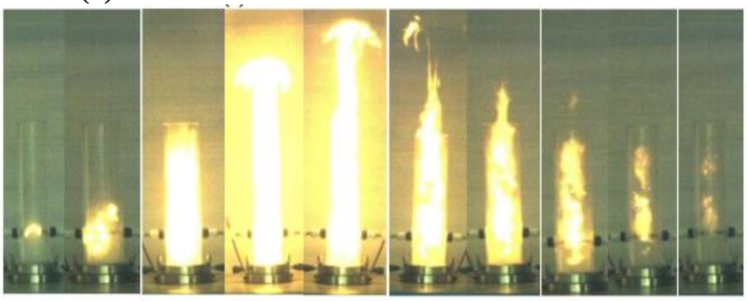
3.2 Effect of inert powders on flame propagation of sucrose dust

Set up parameters: the mass fraction of inert powders 15%, ignition energy 100 mJ. GigaView high-speed camera was used to observe the change of sucrose dust flame propagation, as shown in figure 4.

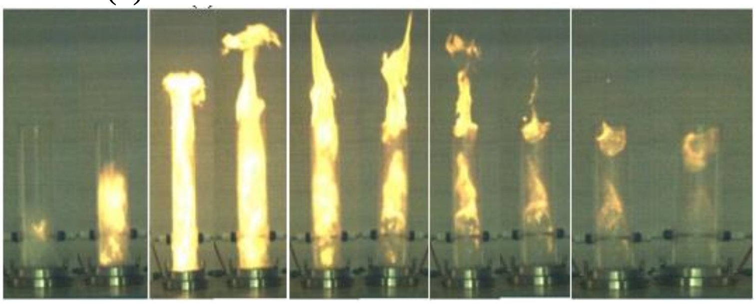
In figure 4(a), after electrode discharge, there was yellowish-white flame between electrodes, the dust at the top of hartmann tube was ignited with moving flames up gradually, but flame didn't escape nozzle on account of oxygen depletion in the tube and CO_2 sinks that generated by thermal decomposition of $NaHCO_3$, the flame was extinguished gradually. In figure 3(b), yellowish-white flame was formed immediately between electrodes, because only physical inhibition of NaCl, the flame was quickly rushed out and formed the "mushroom head" flame on the top of the nozzle, and then quickly burn out by the sufficient oxygen, but the dust burned slowly on the nozzle by less oxygen, the flame was extinguished with oxygen depletion in the tube. In figure 3(c), the flame was quickly rushed out of the nozzle when the mixed-dust was ignited, and the front-end flame presented a discrete and chaotic state, the last burning was weaken until the flame extinguished with dust concentration declining. So, at the same as NaCl, there was only physical inhibition in $Al(OH)_3$, but in the aspect of endothermic process, the effect of NaCl was better than $Al(OH)_3$. In figure 3(d), at the beginning, speed of flame propagation that added $NH_4H_2PO_4$ into sucrose dust was faster than 3(a), the reason was that the decomposition temperature of $NH_4H_2PO_4$ was higher than $NaHCO_3$, at the same time, NH_3 that produced by thermal decomposition of $NH_4H_2PO_4$ was burned slightly in the nozzle. Due to the increase of water vapor and P_2O_5, and lacking of O_2 in the tube, it made the flame extinguished gradually. Therefore we can concluded that the effect of $NaHCO_3$ was more effective on hindering the flame propagation, NH4H2PO4 secondly, the suppression effect of Al $(OH)_3$ and NaCl was relatively weak.



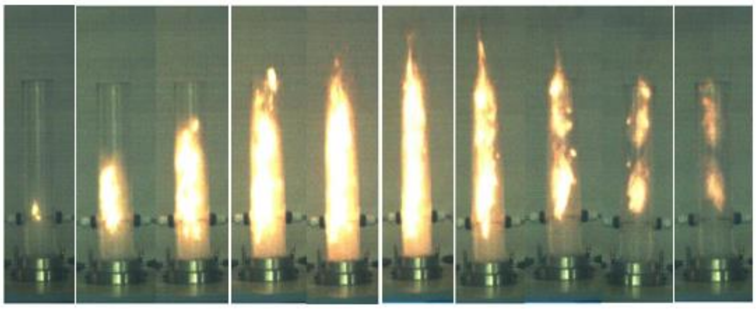
(a) Mixture dust of $NaHCO_3$ and sucrose dust



(b) Mixture dust of NaCl and sucrose dust



(c) Mixture dust of Al (OH)3 and sucrose dust



(d) Mixture dust of NH4H2PO4 and sucrose dust

Figure 3: Image of explosion development of four inert powders on sucrose dust in Hartmann apparatus

3.3 Effect of inert dust in different particle size on MIE of sucrose dust

Under the same condition as 3.1, adding four inert powders (38-47μm and 25-37μm) into sucrose dust with a gradient of 5% mass fraction respectively and mix uniformly. The experimental results were shown in figure 4. It could be seen that when the mass fraction of inert powders ($NaHCO_3$, $Al(OH)_3$, $NH_4H_2PO_4$ and NaCl) that particle size range of 38-47μm reached 20%, 60%, 35% and 40% respectively, sucrose dust won't be ignited anymore with repeating 20 times experiment. The mass fraction of inert powders ($NaHCO_3$, $Al(OH)_3$, $NH_4H_2PO_4$ and NaCl) that particle size range of 25-37μm reached 20%, 60%, 30% and 35% respectively, there was no fire on sucrose dust with repeating 20 times experiment. It can be seen from this that the MIE of sucrose dust would be rose at different level with adding inert powders, and smaller the particle size of inert powders, the better suppression effect on sucrose dust. The effect of $Al(OH)_3$ on sucrose dust wasn't obvious, the best inhibitory effect on sucrose dust was $NaHCO_3$ which particle size range of 25-37μm. The sort of suppression effect of four inert powders was: NaHCO3>NH4H2PO4>NaCl>Al (OH)3.

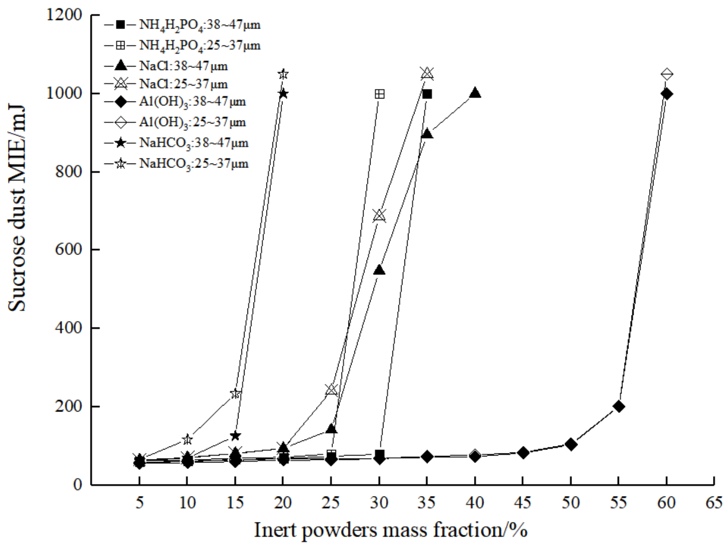


Figure 4: The effect of four inert powders in different mass concentration and particle size on sucrose dust

4. Discussion

The thermal decomposition temperature of $NH_4H_2PO_4$ was very low, the process of decomposition production, such as ammonia, water, P_2O_5 and phosphate and so on, could absorb a part of ignition energy. P2O5 was an oxide that easily attached to the surface of sucrose dust particles, it resulted in lighting sucrose dust with difficulty. The smaller particle size and bigger specific surface area of NH4H2PO4, the faster decomposition rate. Therefore suppression effect on sucrose dust was more significant.

Al $(OH)_3$ was a kind of inorganic flame retardant additives that mainly used in some plastic, rubber, building materials products. Al $(OH)_3$ began to decompose H_2O at about 200℃. Because ignition time was relatively shorter in hartmann tube, the decomposition time of Al $(OH)_3$ wasn't enough, $Al(OH)_3$ particle adhered on the surface of sucrose dust, and affected sucrose dust particles to contact with oxygen, hence suppression effect on sucrose dust explosion mainly depend on its physical properties.The suppression mechanism of NaCl was similar to $Al(OH)_3$. It was mainly depended on adhering effect that interrupted the interaction of sucrose dust and oxygen. Thus thermal radiation that produced by ignition energy was shielded, so the burning temperature and heat transfer efficiency were reduced.

There were large amounts of water and CO_2 at the decomposition process of $NaHCO_3$, it can not only reduced combustion environment temperature quickly, but reduced the flame brightness and transmission speed greatly, at the same time, the oxygen content of the combustion environment was decreasing, so as to achieve the effect of reducing sucrose dust cloud flame propagation rapidly. Therefore, the suppression effect of $NaHCO_3$ on dust flame propagation and MIE of sucrose dust was better than other inert powders because of physics and chemistry effect of $NaHCO_3$.

5. Conclusion

In this paper, the research of four types of inert powders on the MIE and flame propagation of sucrose dust in 1.2L Hartmann apparatus was determined. The conclusions could be summarized as follows.

1) The experiment shown that added four kinds of inert powders into sucrose dust, the ignition sensitivity was decreased and the MIE was increased, what's more, variation trend would be more obvious with increasing the mass fraction of inert powders. The suppression effect of $NH_4H_2PO_4$ and $NaHCO_3$ were more obvious than $Al(OH)_3$ and NaCl on flame propagation of sucrose dust explosion. It indicated that $NaHCO_3$ and $NH_4H_2PO_4$ could be used as effective inert agent for preventing sucrose dust explosion.

2) The mass fraction of $NaHCO_3$, $Al(OH)_3$, $NH_4H_2PO_4$, NaCl (particle size range of 38~47μm) reached 20%, 60%, 35% and 40% respectively, sucrose dust wasn't ignited with 20 times experiments. Or the mass fraction of four inert powders that particle size range of 25-37μm were reached 20%, 60%, 30% and 35% respectively, the sucrose dust was completely inerted. It shown that the smaller the particle size and higher mass fraction of inert powders, the better suppression effect on sucrose dust.

3) There were chemical inhibition and synergistic inhibition effect of $NaHCO_3$ and $NH_4H_2PO_4$ on sucrose dust, so greatly reduced the risk of sucrose dust explosion. While there was only physical inhibition of $Al(OH)_3$ and NaCl, therefore the suppression effect wasn't obvious relatively. The suppression effect of four inert powders on the combustion flame and MIE of sucrose dust cloud was as follows: $NaHCO_3 > NH_4H_2PO_4 > NaCl > Al(OH)_3$.

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