Experimental study on minimum ignition energy of tapioca starch

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Abstract. The minimum ignition energy of tapioca starch was studied by using 1.2L Hartmann tube, and the three main influencing factors: tapioca starch quality, ignition delay time and dusting pressure were tested. The experimental results show that the effect of dusting pressure on the minimum ignition energy is the most obvious. With the increase of powder pressure, the minimum ignition energy first decreases and then increases, and when the powder pressure is 90Kpa, the minimum ignition energy is the smallest, which is 58mj; ignition delay time is different, the degree of dust dispersion is different, and the optimum ignition delay time is 30ms. The minimum ignition energy decreases first and then increases with the increase of the quality of tapioca starch. When the mass is 0.5 g, the ignition energy is the smallest. It is 60mJ.

1. Introduction

Tapioca starch is an important basic raw material widely used in food, beverage, candy, chemical, paper, textile, pharmaceutical and cosmetic, biodegradable materials and other industries. Tapioca starch is prone to burning and explosion, so it is meaningful to study the minimum ignition energy of tapioca starch. The minimum ignition energy is the minimum spark energy that can ignite dust and maintain combustion. Ignition energy has a significant effect on dust explosion behavior [1-2]. An important criterion for judging the danger of a certain dust explosion is its ignition sensitivity [3], and ignition sensitivity is usually described by the minimum ignition energy, therefore mastering the change law of minimum ignition energy of dust is one of the important prerequisites to prevent dust explosion accidents. Many scholars at home and abroad have carried out a large number of research and experimental measurements on the minimum ignition energy of dust clouds, and have achieved many results. In 2004, Choi et al. [4] studied the minimum ignition energy of polymer coated dust. In 2006, Erlend Randeberg et al. [5] studied dust with minimum ignition energy of less than 1mJ. Huang Liyuan et al. [6] tested the minimum ignition energy of lycopodium powder, and analyzed the influence of powder pressure and ignition delay time on the minimum ignition energy of lycopodium powder and its regularity. Bi Mingshu et al. [7] proved through experiments that the presence of methane will reduce the lower explosion limit of coal dust and increase the explosion pressure. In 2014, Yuan Chunmiao et
al. [8] measure the minimum ignition energy of nano-titanium, and study the inert effect of titanium oxide on it. Li Enke et al. [9] analyzed the explosion process, characteristics and explosion conditions of grain dust, and proposed corresponding control measures. Although there are many studies on the minimum ignition energy, little research has been done on the minimum ignition energy of tapioca starch. This experiment used 1.2L Hartmann tube to test the minimum ignition energy of tapioca starch under different conditions. Considering the many factors affecting the minimum ignition energy and the limited experimental conditions, only the influence of ignition delay time, tapioca starch dust quality and dusting pressure on the minimum ignition energy is analyzed. Judging the ignition sensitivity of tapioca starch by determining the minimum ignition energy, It is helpful to study the explosive properties of tapioca starch. It also provides a reference for the on-site production and prevention of explosions in the main producing area of China's tapioca starch, Guangxi Province.

2. Experimental device
This experiment uses the test equipment recommended by the German Engineers Association VDI2263 [10] and the International Electro technical Commission IEC Standard [11] to use the minimum ignition energy of the dust cloud, namely the HY16428A dust minimum ignition energy experimental device (1.2L Hartmann tube), for cassava Starch dust was tested for minimum ignition energy. As shown in Figure 1.

![Figure 1. Schematic diagram of the Hartmann tube structure](image)

1-quartz glass tube; 2-electrode; 3-diffuser; 4-steel sleeve; 5-base; 6-electrode joint; 7-gas storage tank.

3. Experimental samples and conditions
The raw tapioca starch powder supplied by Guangxi Nongken Mingyang Biochemistry Group Co., Ltd, was used as a sample. Tapioca starch burns intensely, forming a yellow flame. The particle size distribution of the sample is shown in Figure 2.

![Figure 2. Particle size distribution of tapioca raw starch](image)
Figure 3. Electron micrograph of tapioca raw starch

The test was carried out under the conditions of a laboratory humidity of 40% to 60% and a temperature of 25 to 35 °C. The tapioca starch was dried in an experimental advance oven at 60 °C for 24 h, and the electrode spacing was fixed at 6 mm.

4. Experimental regulations and experimental procedures
In the experiment, if the dust is ignited and the flame leaves the spark position and spreads to 60 mm, the dust is considered to be on fire, otherwise the dust is not considered to be on fire. The measured minimum ignition energy Emin is between the maximum energy value E1 of 20 consecutive un-fires and the minimum energy value E2 of 20 consecutive ignitions [12], namely: E1 < Emin < E2. The minimum value that does not satisfy 20 consecutive un-fires is regarded as the minimum ignition energy. The experimental steps are as follows:

1) First fix the powder pressure and ignition delay time, change the quality of tapioca starch, and find the minimum ignition energy of tapioca starch under different quality conditions;

2) On the basis of the previous step, select the most sensitive tapioca dust quality, keep the spray pressure constant, change the ignition delay time, and find the minimum ignition energy under the corresponding conditions;

3) Select the best tapioca starch dust quality and the optimal ignition delay time, change the powder pressure, and find the corresponding minimum ignition energy.

5. Analysis of experimental results

5.1. Effect of dust quality on minimum ignition energy of tapioca starch
During the experiment, the dusting pressure was set to 100kPa and the ignition delay time was 100ms. The minimum ignition energy experiments were carried out on tapioca starch dust with masses of 0.3, 0.4, 0.5, 0.6 and 0.7 g, respectively. Repeat the experiment several times to find the minimum ignition energy under the corresponding conditions and fit the experimental data, as shown in picture 2.
Figure 4. Relationship between the quality of tapioca starch and the minimum ignition energy

It can be seen from Fig. 4 that the minimum ignition energy of tapioca starch dust decreases first and then increases with the change of tapioca starch dust quality, and when the tapioca starch quality is 0.5g, the minimum ignition energy Emin is the smallest, which is 60mJ. The cassava starch dust cloud concentration is the most sensitive concentration. When the quality of tapioca starch dust is greater than or less than 0.5g, the minimum ignition energy required starts to increased, and the increase is more obvious. The tapioca starch propagates upward in the body of the Hartmann tube. Under the condition of the powdering pressure and the ignition delay time, when the quality of tapioca starch is small, the cassava starch particles in the Hartmann tube are less, the particle spacing is larger, and the particles are between the particles. The energy required for heat transfer is higher, and the required ignition energy is larger. As the quality of tapioca starch dust increases, the amount of cassava starch dust particles involved in combustion per unit volume increases, and the spacing between particles decreases relatively, that is, the heat transfer path changes. Short, the reaction rate is increased, and the generated heat is further transmitted to the surrounding unlit particles. The activated particles of the tapioca starch dust particles per unit volume increase, the combustion efficiency is increased, the flame propagation speed is increased, and the minimum ignition energy required is gradually reduced. When the quality of the tapioca starch dust reaches 0.5g, the degree of dispersion of the dust cloud is the most uniform, and the energy required at this time is the smallest. Then, with the further increase of the quality of tapioca starch dust, the number of dust particles around the electrode continues to increase. First, excessive tapioca starch particles absorb the energy around the electrode, hindering the propagation of energy, and reducing the combustion efficiency of the dust cloud. Second, because the dusting pressure is the same, the high-quality tapioca starch is settled by its own gravity, and some of it adheres to the electrode, so that the electrode release energy is less than the actual energy. Third, when the concentration of the tapioca starch dust is too large, the particles gather too densely. The particle gap is too small to hinder contact with oxygen, so the minimum ignition energy required to ignite the tapioca starch dust begins to increase again.

From Fig. 4, it can be seen that the degree of fitness is $R^2 = 0.914$, and the fitting effect is good. The relationship between cassava starch dust mass $m$ and minimum ignition energy $E_{min}$ is in accordance with quadratic polynomial.

$$E_{min} = 554.29m^2 - 520.69m + 186.85$$

5.2. Effect of ignition delay time on minimum ignition energy of tapioca starch

The ignition delay time is different, the disperse and sedimentation behavior of the tapioca starch dust in the device is different during the reaction, and the ignition is generated when the most uniform dust cloud is formed after the dusting. This time is the optimal ignition delay time, and the dust combustion is also the most full. During the experiment, the dusting pressure was set to 100KPa, and the minimum ignition energy experiment was performed on the tapioca starch dust at the ignition delay time of 15, 30,
60, 90, 120, 150, and 180 ms, respectively. Repeat the experiment several times to find the minimum ignition energy under the corresponding conditions and fit the experimental data, as shown in Figure 5.

**Figure 5. Ignition delay time and minimum ignition energy**

It can be seen from Fig. 5 that the minimum ignition energy of tapioca starch decreases first and then increases with the increase of ignition delay time. When the ignition delay time is 30 ms, the measured minimum ignition energy is the smallest, and the ignition delay time is the most good ignition delay time. In the experiment, the Hartmann tube is a cylindrical pipe and the upper end is open, and the dust propagates upward under the action of the dusting pressure, and gradually forms a dust cloud state. When the ignition delay time is too short, most of the cassava dust does not reach the electrode, the electrode has been ignited, the concentration of cassava starch dust around the electrode is too low, the number of cassava starch dust particles involved in combustion is small, and the energy required to ignite the particles is large. The ignition energy is larger; as the ignition delay time increases, the dust cloud concentration of the tapioca starch dust around the electrode gradually increases, reaching the optimum, and the minimum ignition energy required is gradually reduced to the minimum value; the ignition delay time is continuously increased. After the dust rises, it settles and agglomerates by its own gravity, the particle size becomes larger, the specific surface area increases, and the required ignition energy increases. Subsequently, when the ignition delay time is too large, the tapioca starch dust has settled, most of which has settled at the bottom of the Hartmann tube. When re-igniting, the optimal dust cloud state has been missed, and the tapioca starch dust concentration in the tube has become lower, the reaction is more difficult, it is necessary to further increase the ignition energy.

It can be seen from Fig. 5 that the degree of fit $R^2=0.9508$, the fitting effect is good, and the relationship between the ignition delay time $t$ and the minimum ignition energy $E_{min}$ is in accordance with the quadratic polynomial:

$$E_{min} = -0.0006t^2 + 0.2301t + 54.222$$

(2)

5.3. Effect of dusting pressure on minimum ignition energy of tapioca starch

Under the condition of ignition delay time of 30 ms, the minimum ignition energy experiment of tapioca starch dust was set when the dusting pressure was 40, 60, 80, 90, 120, 150, 180 KPa. Repeat the experiment several times to find the minimum ignition energy under the corresponding conditions, and fit the experimental measured data, as shown in Figure 6.
Figure 6. Relationship between dusting pressure and minimum ignition energy

It can be seen from Fig. 6 that with the increase of the dusting pressure, the minimum ignition energy of the tapioca starch dust first decreases and then increases, and the increase is more obvious than the reduced slope. The minimum ignition energy is 58mJ at a dusting pressure of 90KPa.

At the beginning of the experiment, as the pressure increases, the power of the cassava starch dust to propagate upward increases. When the ignition delay time is the same, the dust particles around the electrode increase, the dust cloud concentration becomes larger, and the required energy decreases. Dust particles are easier to ignite, and the particles transmit energy to surrounding particles after ignition. The minimum ignition energy is reduced. When the pressure reaches a certain value, just when the electrode is ignited, a local optimum dust cloud concentration is formed around the electrode. The ignition energy is the smallest; the dust pressure is further increased, the dust is increased by force, most of the dust has left the electrode during ignition, the electrode ignition misses the optimal dust concentration, the surrounding dust particles are small, and the required ignition energy begins to increase again. It can be seen from Fig. 6 that the degree of fit \( R^2 = 0.9042 \), the fitting condition is good, and the relationship between the dusting pressure and the minimum ignition energy \( E_{\text{min}} \) conforms to the quadratic polynomial:

\[
E_{\text{min}} = 0.0056P^2 - 0.8421P + 98.679
\]  

6. Conclusion
Three main factors influencing the minimum ignition energy were selected: cassava starch dust quality, ignition delay time and dusting pressure. The following conclusions were drawn:

(1) The change of the quality of tapioca starch directly affects the distribution of dust cloud, resulting in the change of the minimum ignition energy required to ignite the cassava starch dust. The best mass measured is 0.5 g, and the minimum ignition energy is 60 mJ.

(2) The ignition delay time also has an influence on the minimum ignition energy of tapioca starch dust. With the change of ignition delay time, the dispersion of dust is different. When the dust is dispersed into the most uniform state, there is an optimal ignition delay time of 30ms.

(3) As the powder pressure increases, the minimum ignition energy decreases first and then increases, and when the powder pressure is 90 KPa, the minimum ignition energy is 58 mJ.

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