Experimental Study on Suppression of $NH_4H_2PO_4$ on Cassava Starch Dust Explosion

Yue Sun[a], Shunbing Zhu[b*], Lujia Tao[c], Xuemei Wu[d]

College of Safety Science and Engineering, Nanjing Tech University, Nanjing, Jiangsu, China

[a]sunyue_summer@163.com; [b*]2934399475@qq.com
[c]15534197877@163.com; [d]1738926419@qq.com

Abstract. In order to study the inhibition effect of inert powder $NH_4H_2PO_4$ on the cassava starch dust explosion. Using the 20L spherical explosion experimental device and the Hartmann tube experimental device to test the effects of $NH_4H_2PO_4$ on the dust explosion parameters and flame propagation characteristics of cassava starch. The results show that $NH_4H_2PO_4$ can effectively reduce the maximum explosion pressure, maximum explosion index, maximum flame propagation height and maximum velocity of cassava starch. What's more, the inhibition effect increases with the increase of $NH_4H_2PO_4$ mass fraction and the decrease of particle size. According to the analysis of the explosion suppression mechanism of $NH_4H_2PO_4$, water vapor and free ammonia will be produced during the decomposition of $NH_4H_2PO_4$. The water vapor will absorb heat in the surrounding environment and reduce Oxygen content, and the free ammonia can capture free radical ·OH and terminate the chain reaction. Therefore, $NH_4H_2PO_4$ inhibits the explosion of cassava starch dust through both physical and chemical effects.

Keywords: cassava starch dust; $NH_4H_2PO_4$; dust explosion; suppression.

1 Introduction

Cassava starch is widely used in food, paper making, adhesives and other industrial fields [1]. And a large amount of dust is generated during production and storage, which is easy to cause dust explosion accidents. At the same time, the shock wave generated after the dust explosion will blow the deposited dust, causing secondary explosion accidents [2]. Studying the explosion characteristics of cassava starch dust and the inerting effect of inert powder on dust explosion is helpful to prevent and reduce the occurrence of cassava starch dust explosion accidents.

The relevant parameters of dust explosion characteristics play an important role in reducing the occurrence of dust explosion accidents. Scholars at home and abroad have studied the explosion characteristic parameters of grain dust through a large number of experiments. Ren Chunli[3] et al. measured the ignition energy of corn starch is 2.9mJ by establishing a model. Xiao Guoqing[4] et al. found that the maximum explosion pressure and explosion index of powdered sugar increased with the decrease of dust particle

P. Xiang et al. (eds.), *Proceedings of the 2023 5th International Conference on Hydraulic, Civil and Construction Engineering (HCCE 2023)*, Atlantis Highlights in Engineering 26,
https://doi.org/10.2991/978-94-6463-398-6_69

size, and the lower explosion limit decreased first and then increased with the decrease of particle size. Chen Chunyan[5] et al. studied the factors affecting the explosion pressure of sweet potato dust and found that the influence of dust mass concentration was the greatest, followed by ignition energy, and the influence of dust particle size was the least. Pan Feng[6] et al. found that the minimum ignition energy of corn starch ranged from 40 to 80mJ, the maximum explosion pressure was 0.66MPa, and the maximum explosion index was 17.21MPa·m/s. Zhou Hongwen [7] et al. found that the maximum explosion pressure of corn starch dust is significantly affected by ignition energy, and the maximum pressure boost rate is significantly affected by dust concentration. Adding inert powder calcium carbonate can effectively reduce its explosion pressure. Cao Weiguo [8] et al. found that the minimum ignition energy of wheat starch is 40-80mJ, the maximum explosion pressure is 0.60MPa, and the maximum explosion index is 7.87MPa·m/s, and the dust explosion risk of wheat starch is level I. Zhang[9] et al. found that the thickness of the flame reaction zone of corn starch dust increased with the increase of particle size, and the thickness of the preheating zone was positively correlated with the particle size, with a thickness range of 38mm. A Godbert-Greenwald furnace was employed to perform the experiments to mimic the fundamental characteristics of a dust explosion. A lumped-kinetic model adapted to dust explosion was developed and validated for cellulose.[10]

In the study of inert media inhibiting dust explosion, Qin Xiaoling[11] et al. found that $NH_4H_2PO_4$ can effectively inhibit the explosion of sucrose dust, and the smaller the particle size of $NH_4H_2PO_4$, the more obvious inhibition effect. Guan Wenling[12] et al. found that adding 4A zeolite more than 9.09% to 10g wheat starch could completely inhibit the explosion of wheat starch. Liang Rui[13] et al. found that adding $NaHCO_3$, $Al(OH)_3$ and MPP inerting agents respectively reduced the explosion index of corn starch dust by 70.4%, 74.8% and 80.2%. Zhao[14] et al. found that adding 25% of $(NH_4)_2HPO_4$ could effectively inhibit the flame propagation of wheat starch. Zhang [15]et al. found that when $Mg(OH)_2$ was added more than 40%, the starch explosion process was completely inhibited. A specific range of frequencies and humidity contents in which the permittivity presents low steady values that reduces the electrical charge storage process in the starch, therefore preventing ignition events.[16] Pure starch with MEC of 250 g/m^3 could still be ignited at a concentration at or even below 10 g/m^3 that usually would not be considered to be ignitable when gas or vapor are added.[17]

To sum up, there is a lot of research on dust explosion characteristics and inserting explosion prevention, but the research on cassava starch dust is relatively limited. This paper takes cassava starch dust as the research object, chooses $NH_4H_2PO_4$ as the inert powder, studies the effects of $NH_4H_2PO_4$ mass fraction and particle size on the maximum explosion pressure, explosion index and flame propagation characteristics of cassava starch dust, and analyzes the explosion suppression mechanism of $NH_4H_2PO_4$, to supplement the issues related to grain dust combustion and explosion, and to provide an important reference for preventing cassava starch dust explosion accidents.

2 Materials and Methods

2.1 Experimental Material

The particle size of the powder materials used in the experiment was tested with the Bettersize 2000 laser particle size distributor. Figure 1 and figure 2 respectively show the particle size distribution and SEM diagram of cassava starch dust and $NH_4H_2PO_4$. As shown in the figure, cassava starch dust particles vary in size, with near-spherical particles and large pores between particles. $NH_4H_2PO_4$ powder has no fixed regular shape and is mostly cuboid, with small particles attached to the surface.

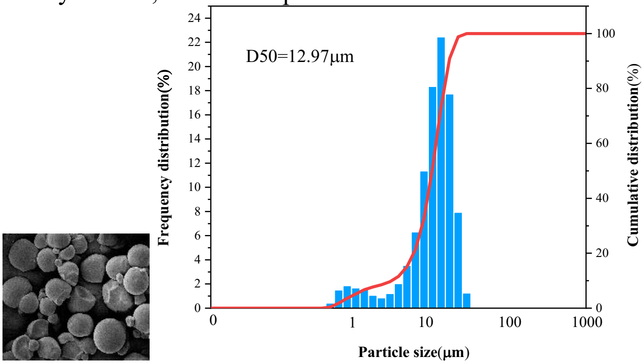

Fig. 1. Particle size distribution and SEM image of cassava dust

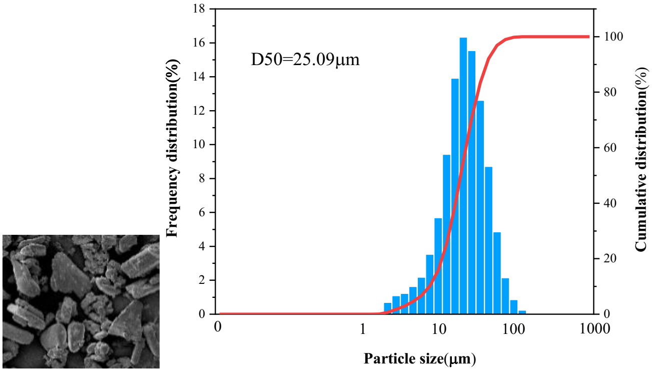

Fig. 2. Particle size distribution and SEM image of $NH_4H_2PO_4$

2.2 Experimental Device

The 20L spherical explosion test system, Hartmann tube test equipment and high-speed camera were used to test the explosion characteristics, and flame propagation characteristics of cassava starch and $NH_4H_2PO_4$ mixed dust.

3 Results & Discussion

3.1 Inhibition Effect of $NH_4H_2PO_4$ on Cassava Starch Dust Explosion Severity

The relationship between the explosion pressure and explosion index and the cassava starch dust concentration is shown in figure 3. With the increase of dust concentration, the explosion pressure and explosion index of cassava starch both show a trend of first rising and then decreasing. When the mass concentration of dust is 750g/m^3, it reaches the maximum value. The maximum explosion pressure and explosion index are 0.6917MPa and 8.901MPa·m/s.

The cassava starch with the concentration of 750g/m^3 was used as the explosion suppression object to analyze the effect of $NH_4H_2PO_4$ on the explosion characteristics, to test the explosion pressure and explosion index of cassava starch dust with different mass fraction and $NH_4H_2PO_4$ ratio. The experimental results are shown in figure 4 and figure 5. With the increase of mass fraction $NH_4H_2PO_4$, the explosion pressure and explosion index of cassava starch dust decrease gradually. When the mass fraction of $NH_4H_2PO_4$ is 60%, D50=25.09μm $NH_4H_2PO_4$, makes the maximum explosion pressure of cassava starch reduce from 0.6917MPa to 0.2534MPa, a decrease of 63.37%, and makes the explosion index reduce from 8.9023MPa·m/s to 0.9765MPa·m/s, a decrease of 89.03%. D50=50μm $NH_4H_2PO_4$, makes the maximum explosion pressure and explosion index of cassava starch decreased to 0.3336MPa and 1.1661MPa·m/s, decreased by 51.77% and 86.90% respectively. D50=91.31μm $NH_4H_2PO_4$, makes the maximum explosion pressure and explosion index of cassava starch decreased to 0.3908MPa and 2.2425MPa·m/s, decreased by 43.50% and 74.81% respectively. It shows that the smaller particle size of $NH_4H_2PO_4$, the greater the decrease of the maximum explosion pressure and explosion index of cassava starch.

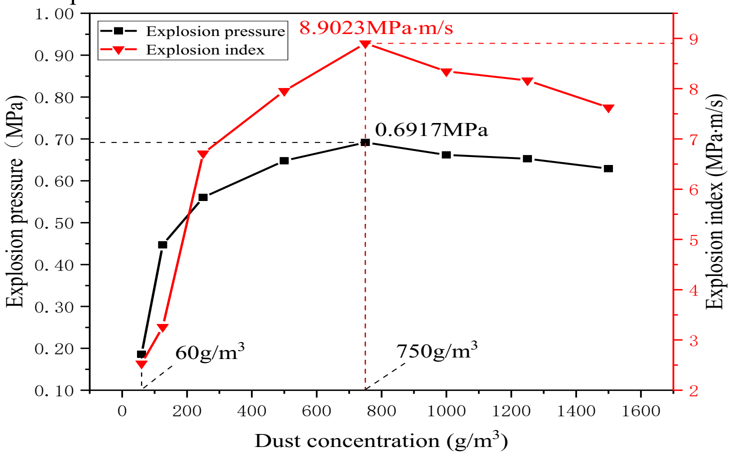

Fig. 3. Curve of cassava dust explosion pressure and explosion index changing with concentration

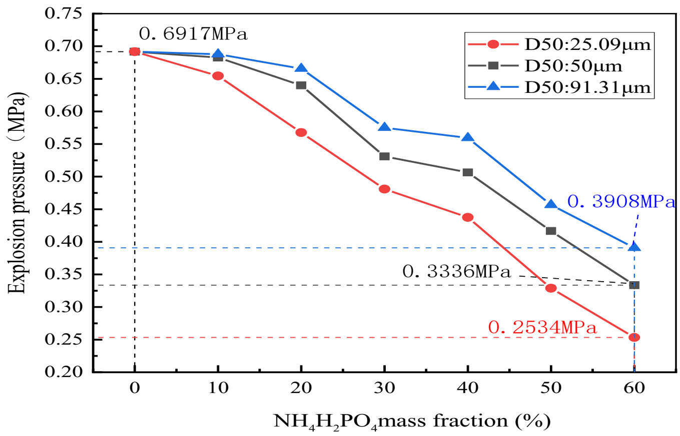

Fig. 4. Relationship between mass fraction and particle sizes of $NH_4H_2PO_4$ and explosion pressure of cassava starch dust

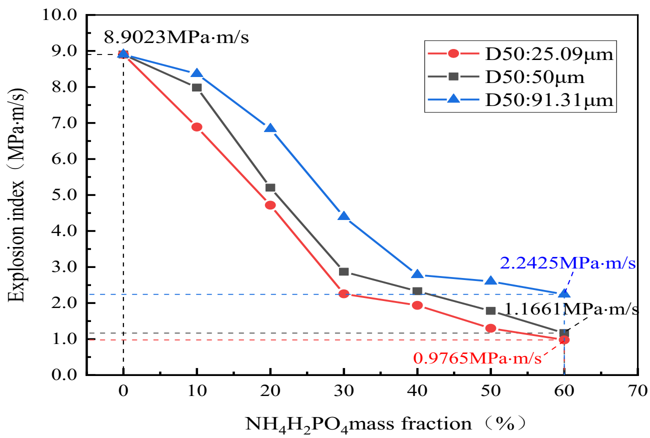

Fig. 5. Relationship between mass fraction and particle sizes of $NH_4H_2PO_4$ and explosion index of cassava starch dust

3.2 Inhibition Effect of $NH_4H_2PO_4$ on Cassava Starch flame propagation characteristics

The mass of cassava starch dust was 1.8g, the dusting pressure was 0.6MPa, and $NH_4H_2PO_4$ was mixed with cassava starch according to the mass fraction of 5%, 7.5% and 10%. The particle size of $NH_4H_2PO_4$ was 50μm. And the result of flame propagation process image is shown in figure 6. With the increase of the $NH_4H_2PO_4$ mass fraction, the flame brightness obviously darkens and the bright area gradually decreases. When the mass fraction of $NH_4H_2PO_4$ is increased to 10%, only a weak flame can be formed and the burning intensity of the flame is weak.

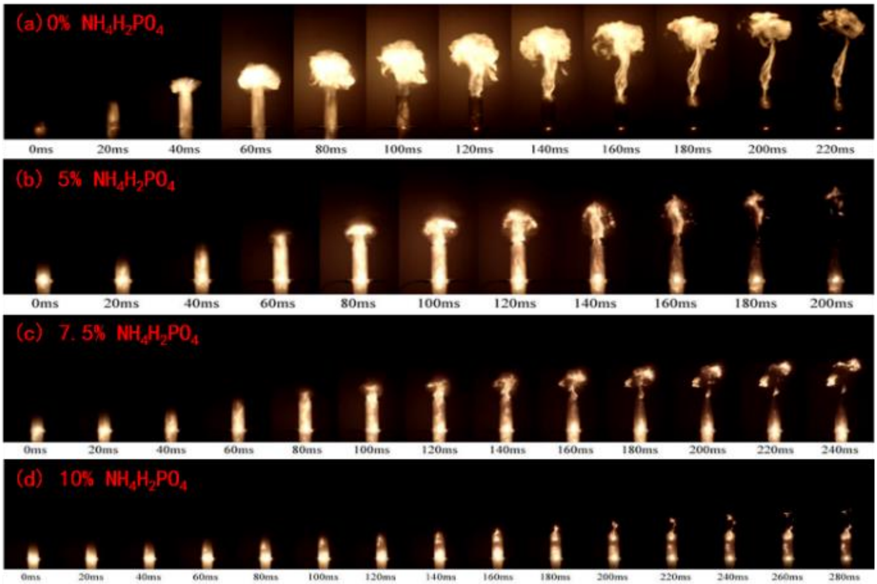

Fig. 6. Flame propagation images of pure cassava dust cloud and cassava dust cloud with different mass fraction of $NH_4H_2PO_4$

Adding different mass fractions of $NH_4H_2PO_4$ to cassava starch dust clouds, the relationship curves of flame propagation distance and speed over time are shown in figure 7 and figure 8. When no $NH_4H_2PO_4$ inert powder was added, the flame propagation height reached 86.4cm, and the flame propagation speed reached 10.05m/s at 30ms after ignition. When the mass fraction of $NH_4H_2PO_4$ is 5%, 7.5% and 10%, the flame propagation height reached respectively 65.4cm, 59.1cm and 49.4cm. And the flame propagation speed reached the maximum respectively at 40ms, 70ms and 20ms, the corresponding values were 9.15m/s, 3.75m/s and 2.85m/s. With the increase of mass fraction of $NH_4H_2PO_4$, the flame propagation speed gradually slowed down, and there was a decreasing trend with oscillation.

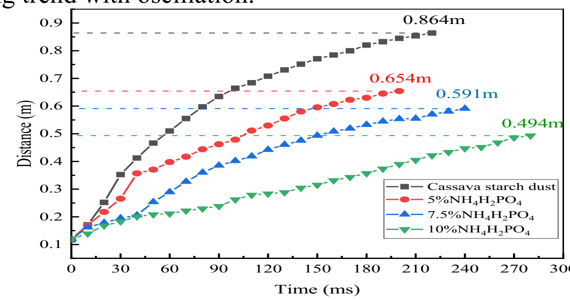

Fig. 7. The flame propagation distance of cassava starch dust cloud varies with time under different mass fraction of $NH_4H_2PO_4$

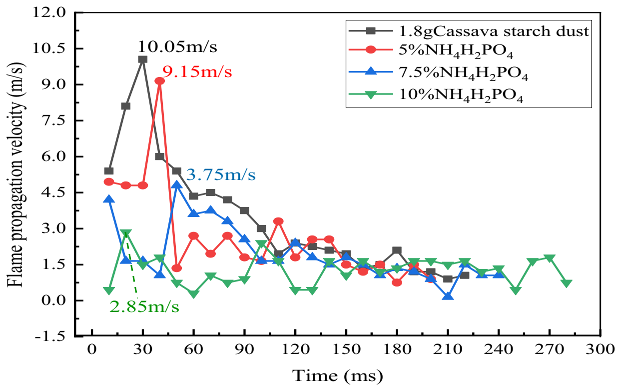

Fig. 8. The flame propagation velocity of cassava dust cloud varies with time under different mass fraction of $NH_4H_2PO_4$

3.3 Inhibition Mechanism Analysis

The above studies show that $NH_4H_2PO_4$ has a good inhibition effect on cassava starch dust explosion, and the inhibition effect gradually increases with the increase of $NH_4H_2PO_4$ mass fraction and the decrease of particle size. In order to analyze the inhibition mechanism of $NH_4H_2PO_4$ on cassava starch explosion characteristics, Thermogravimetric tests were conducted on the mixed dust of cassava starch and different mass fractions $NH_4H_2PO_4$. The test results are shown in figure 9 and figure 10. The cassava starch lost water, devolatilization and gradual carbonization during the pyrolysis process, and when the pyrolysis completed, only 4.9% of the initial mass was left. The pyrolysis process of $NH_4H_2PO_4$ can be divided into three stages, the temperature range is 208℃ ~ 282℃, 282℃ ~ 639℃ and 639℃ ~ 731℃, and the mass loss rates are 10.75%, 26.82% and 21.71%, respectively. During the pyrolysis process, $NH_4H_2PO_4$ and its products undergo multiple decomposition:

$$NH_4H_2PO_4 \rightarrow NH_3 + H_3PO_4 \quad (1)$$

$$2H_3PO_4 \rightarrow H_4P_2O_7 + H_2O \quad (2)$$

$$H_4P_2O_7 \rightarrow 2HPO_3 + H_2O \quad (3)$$

$NH_4H_2PO_4$ inhibits the dust explosion of cassava starch through both physical and chemical effects. On the one hand, the water vapor from $NH_4H_2PO_4$ decomposition will absorb the heat in the environment, reduce the ambient temperature and reduce the combustion reaction rate. At the same time, water vapor will dilute the Oxygen concentration, separate the Oxygen from the cassava starch dust particles, prevent the heat conduction and heat radiation between the dust particles, and then inhibit the combustion of cassava starch dust. On the other hand, the decomposition product free ammonia can capture the free radical ·OH, reduce the number of free radical ·OH, decelerate the combustion reaction rate, and interrupt the chain reaction. Then the decomposition product metaphosphate can inhibit flame propagation. Therefore, $NH_4H_2PO_4$ inhibits cassava starch dust explosion mainly through both physical and chemical effects.

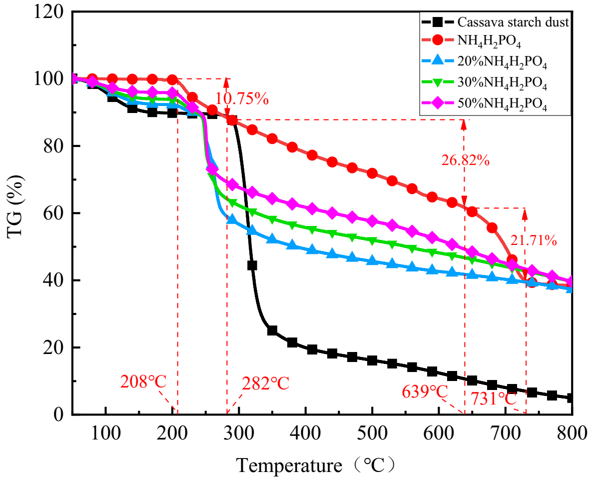

Fig. 9. TG curves of cassava dust, $NH_4H_2PO_4$ and cassava dust / $NH_4H_2PO_4$ mixture

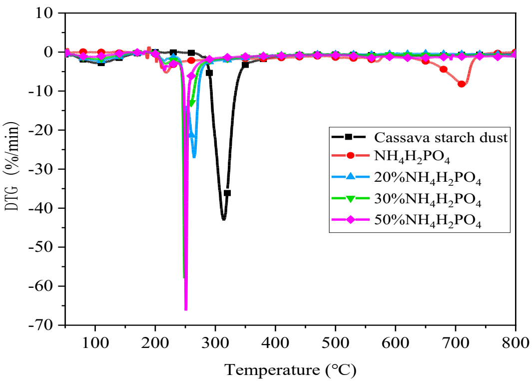

Fig. 10. DTG curves of cassava dust, $NH_4H_2PO_4$ and cassava dust / $NH_4H_2PO_4$ mixture

4 Conclusions

(1) The maximum explosion pressure and explosion index of cassava starch dust were 0.6917MPa and 8.90MPa·m/s. When $NH_4H_2PO_4$ with a mass fraction of 60% was added, its maximum explosion pressure and explosion index were reduced to 0.2534MPa and 0.9765MPa·m/s. $NH_4H_2PO_4$ can significantly reduce cassava starch dust explosion severity. The larger mass fraction and the smaller the particle size of $NH_4H_2PO_4$, the more obvious inhibition effect on cassava starch dust explosion.

(2) When the dust mass was 1.8g, the maximum flame propagation height and speed of cassava starch was 86.4cm and 10.05m/s. When the mass fraction of $NH_4H_2PO_4$ was 10%, the maximum flame propagation height and speed of cassava starch was reduced

to 49.4cm and 2.85m/s. With the increase of $NH_4H_2PO_4$ mass fraction, the flame propagation speed gradually slowed down, and there was a decreasing trend with oscillation.

(3) $NH_4H_2PO_4$ inhibits cassava starch dust explosion mainly through both physical and chemical effects. Water vapor, the decomposition product of $NH_4H_2PO_4$, can absorb heat in the environment, dilute Oxygen concentration, and affect heat conduction and radiation between dust particles. And the free ammonia can capture the free radical ·OH, reduce the number of free radical·OH, interrupt the chain reaction. The metaphosphate can inhibit flame propagation.

Acknowledgment

The authors wish to acknowledge the support to this work by the National Natural Science Foundation of China (No.51876088) and the Jiangsu University Instrument Open sharing independent research record project (NJTU 2204).

References

1. Yang G.Z., You B.C., Wang Y.F., et al. (2015) Research and application of tapered multi-outlet cassava silo. J. Chemical Management, 19:143-144.
2. Zhang R.C., Deng H.W., Xie C.Y. (2019) Explosion characteristics of cassava starch dust cloud. J. Mining and Metallurgy Engineering, 3: 16-19.
3. Ren C.L., Li X.G., Wang F.L., et al. (2010) Numerical simulation of Corn starch spark ignition. J. China Powder Technology, 16: 9-11.
4. Xiao G.Q., Wang Q.H., Liang L., et al. (2015) Experimental study on effect of particle size of powdered Sugar on its explosion characteristics. J. China Safety Science Journal, 25: 85-90.
5. Chen C.Y., Long S.H., Xiao G.Q., et al. (2017) Study on dust explosion of sweet potato based on response surface method. J. China Safety Science Journal, 2: 42-47.
6. Pan F., Ma C., Cao W.G., et al. (2011) Study on explosion risk of corn starch dust. J. China Safety Science Journal, 21: 46-51.
7. Zhou H.W., Zhao F. (2016) Orthogonal test study on explosion of corn starch dust. J. Fire Science and Technology, 35: 1368-1371.
8. Cao W.G., Pan F., Xu S., et al. (2012) Study on explosion characteristics of wheat starch dust. J. Journal of Safety and Environment, 12: 213-216.
9. Zhang H.M., Chen X.F., Zhang Y., et al. (2017) Effects of Particle Size on Flame Structures through Corn Starch Dust Explosions. J. Journal of Loss Prevention in the Process Industries, 50: 7-14.
10. Matteo Pietraccini, Peter Badu, Theo Tait, et al. (2023) Study of flash pyrolysis and combustion of biomass powders using the Godbert-Greenwald furnace: An essential step to better understand organic dust explosions. J. Process Safety and Environmental Protection, 169: 458-471.
11. Qin X.L., Li X.Q. (2020) Experimental study on the inerting effect of $NH_4H_2PO_4$ on sucrose dust explosion. J. China Safety Science Journal, 30: 41-46.
12. Guan W.L., Wang H.Q., Dong C.J., et al. (2022) Experimental study on inhibiting wheat starch explosion with 4A zeolite. J. Fire Science and Technology, 41: 1380-1383.

13. Liang R., Li L., Li B.B., et al. (2022) Study on explosion inhibition of corn starch by inert powder. J. Applied Chemical Industry, 51: 1960-1964.
14. Zhao Q., Chen X. F., Dai H. M., et al. (2020) Inhibition of Diammonium Phosphate on the Wheat Dust Explosion. J. Powder Technology, 367: 751-761.
15. Zhang H.M., SI F.Y., Dou J.W., et al. (2023) Inerting Characteristics of Ultrafine $Mg(OH)_2$ on Starch Dust Explosion Flame Propagation. J. Journal of Loss Prevention in the Process Industries, 82: 104991.
16. J.V. Seidel, O.A. Castañeda-Uribe, S. Arevalo, F. Muñoz, W. Proud, A. Avila. (2019) Relative permittivity estimation of wheat starch: A critical property for understanding electrostatic hazards. J. Journal of Hazardous Materials, 368: 228-233.
17. Emmanuel Kwasi Addai, Dieter GabelUlrich Krause. (2015) Explosion characteristics of three component hybrid mixtures. J. Process Safety and Environmental Protection, 98: 72-81.