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Experimental Research on the Suppression Effect of Different Types of Inert Dust on Micron-Sized Lignite Dust Explosion Pressure in a Confined Space

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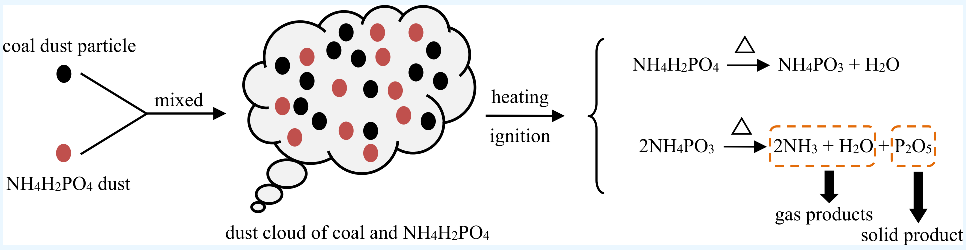

ABSTRACT: Coal is an important strategic resource in the world; coal production safety has always been widely concerned. In coal mine production, inert dust can effectively reduce coal dust explosion accidents in mine tunnels. To reveal the suppression effect of inert dust on lignite dust explosion, $CaCO_3$, SiO_2, and $NH_4H_2PO_4$ are selected for suppression experiments. It is found that the lignite dust explosion pressure decreases continuously as the mass percentages of inert dust mixed into lignite dust increase. By calculating the molar mass, the suppression effects of $CaCO_3$ and SiO_2 on lignite dust explosion are compared. The lignite dust no longer explodes when the mass percentage of $NH_4H_2PO_4$ dust mixed into lignite dust is 70%, indicating that $NH_4H_2PO_4$ is more effective than that of $CaCO_3$ and SiO_2. The smaller the particle size of $NH_4H_2PO_4$, the better the suppression effect on explosion. The lignite dust does not explode when the mass percentage of $NH_4H_2PO_4$ is 60% and the particle size of $NH_4H_2PO_4$ is 25–38 μm, which proves that decreasing the particle size of $NH_4H_2PO_4$ is important to suppress explosion. The research results are of great significance for grasping the explosion suppression effect of inert dust on lignite dust.

1. INTRODUCTION

Coal dust explosion is one of the major accidents affecting the safety production of coal mines, which usually causes huge casualties and property losses.[1] In the process of coal dust explosion, high-temperature flame and high-speed propagating pressure shock wave will be generated. The propagation speed of the pressure shock wave is much greater than the propagation speed of the flame; theoretical research shows that the flame propagation speed of the coal dust explosion can reach more than 1120 m/s and the propagation speed of the pressure shock wave can reach more than 2340 m/s, both of which are extremely destructive.[2,3] At the same time, the average theoretical pressure of the coal dust explosion in coal mine tunnels is 736 kPa, and the explosion pressure increases rapidly with the increase of the distance from the explosion source.[4,5] Nowadays, with the development of dust explosion test methods, it is of great significance for coal mine safety production to master the variation law of coal dust explosion pressure characteristics and the suppression effect of different types of inert dust on coal dust explosion.[6,7]

Fundamentally, coal dust explosion is a combustion chemical reaction with an extremely fast reaction rate, in which rapidly propagating pressure shock waves are generated. Previous studies have found that the mechanism of combustible gas explosion is different from that of coal dust explosion.[8−15] In the process of coal dust explosion, volatile matter and moisture of coal dust are first released from coal dust particles under the action of an ignition source, which can make the explosion intensity far greater than the explosion intensity of the combustible gas.[16−18] Based on the experimental testing and analysis methods of dust explosion, different types of dust are used as samples; Eckhoff[19] researched on the effects of particle dispersion and dust cloud concentration on explosion characteristics and the effects of dust cloud turbulence and particle aggregation on explosion intensity. Oran[20] studied the flame propagation speed and flame structure of dust explosion caused by gas explosion in the

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duct space. Kosinski and Hoffmann[21] revealed the propagation process of primary dust explosion by using the connected vessels and carried out the simulation research on explosion characteristics by establishing numerical models.

In the field of coal dust explosion, the method of suppressing coal dust explosion by inert dust is mainly used in coal mine tunnels,[22−26] because in the coal mine tunnels, due to the coal mine production and transportation, a large amount of suspended coal dust and deposited coal dust will be generated in the tunnel. If there is an ignition source, the coal dust will explode, and the consequences will be very serious. Therefore, the use of inert dust can effectively suppress the intensity of the explosion, prevent the spread of the explosion, and even completely suppress the occurrence of the explosion.[27,28] Even if a large amount of explosion-suppressing dust is required, it is also a safe and effective method to control explosion accidents, which is very important to ensure the safe production of coal mines. In addition, when suppressing coal dust explosion, if a smaller amount of inert dust can be used to effectively suppress the explosion, such inert dust should be selected. However, at present, new types of inert dust are still under continuous research and development, and developing an inert dust that can more effectively suppress coal dust explosion is an important research direction for coal dust explosion in the future.

In previous research, the author of this paper revealed the ignition characteristics and flame propagation process of different types of coal dust cloud under different conditions[29−32] and also discovered the explosion characteristics of deposited coal dust driven by airflow carrying coal dust and the suppression effect of inert dust $CaCO_3$ on explosion.[33] Using inert dust is a very economical and effective method to control coal dust explosion. The particle size and type of inert dust used in related research at home and abroad are relatively simple; in most previous research, a single particle size of $CaCO_3$ was selected as the inert dust; the comparative research results on the explosion suppression effects of different types of inert dust are insufficient. Therefore, this paper selects different types and particle sizes of inert dust to suppress coal dust explosion, which is innovative in the research content. To further study the suppression effect of different types of inert dust on the coal dust explosion pressure, in this paper, the 20 L spherical dust explosion experimental device was used to test the explosion pressure, and the micron-sized explosive lignite dust was used as the sample. $CaCO_3$, SiO_2, and $NH_4H_2PO_4$ were selected as three different types of inert dust to conduct an experiment on the suppression effect of lignite dust explosion pressure, by which the suppression mechanism of inert dust on coal dust explosion can be better understood. Meanwhile, the research results are of great significance for guiding the use of inert dust for coal dust explosion suppression.

2. EXPERIMENTAL SECTION

2.1. Experimental Apparatus. There are mainly two parameters that can be used to describe the coal dust explosion pressure characteristics; they are the maximum explosion pressure P_{max} and the maximum pressure rise rate $(dP/dt)_{max}$. The 20 L spherical explosive experimental apparatus is shown in Figure 1, which is used to test the coal dust explosion pressure characteristics in this study. The test process of the experiment refers to the Chinese national standard "GB/T 16426-1996 Determination for maximum explosion pressure and maximum rate of pressure rise of dust cloud". The experimental apparatus is used internationally, which is mainly composed of an automatic dust spraying system, an ignition data acquisition system, a data transmission system, and an automatic water circulation system. It can be got that the volume of this spherical experimental apparatus is 20 L and the volume of the dust storage tank is 0.6 L. The experimental test range of the explosion pressure is from −0.1 to 2 MPa, and the test accuracy is 0.001 MPa. The interval time of the pressure sensors to collect the explosion pressure data is 0.2 ms, and the maximum acquisition time of the experimental data can be up to 12 s, which can meet the requirements of collecting pressure data in the whole explosion process.

Figure 1. Experimental apparatus.

The structure of the 20 L spherical explosive experimental apparatus is shown in Figure 2. Before the experiment, put the dust sample in the dust storage tank. During the experiment, the dust particles are driven into the spherical space by high-pressure airflow under the action of the dispersion valve and then explode under the action of ignition; in addition, the pressure sensors would collect the pressure data in real time. After the experiment, the temperature inside the experimental apparatus can be quickly lowered by using the automatic water circulation system in a few minutes.

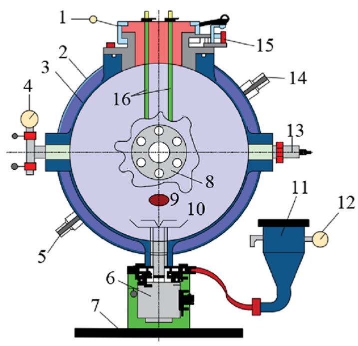

Figure 2. Structure of the experimental apparatus. 1 sealing cap; 2 outer side of mezzanine; 3 inside of mezzanine; 4 vacuum gauge; 5 outlet of circulating water; 6 mechanical two-way valve; 7 base; 8 observation window; 9 vacuum hole; 10 dispersion valve; 11 dust storage tank; 12 pressure gauge; 13 pressure sensor; 14 inlet of circulating water; 15 safety limit switch; 16 ignition rod.

The parameters of the explosion experiment are set as follows. When testing the explosion pressure of the coal dust, the coal dust injection pressure is set to 2 MPa, and the

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ignition delay time is set to 100 ms; the setting of the ignition delay time is determined under the premise of continuous testing so that the explosion pressure can reach the maximum, which can make the coal dust particles fully diffuse in the spherical space and achieve a uniform suspension state before being ignited. Experiments were carried out according to the Chinese national standard "GB/T 16426-1996 Determination for maximum explosion pressure and maximum rate of pressure rise of dust cloud"; when the coal dust particles enter the interior of the 20 L sphere under the action of a dust injection pressure of 2 MPa, after a period of an ignition delay time of 0.6 s, two chemical ignition heads with an ignition energy of 10 kJ are ignited at the same time; the suspended coal dust cloud will be instantly ignited and exploded, which can also be observed through the circular quartz glass window with a diameter of 20 mm. Ten experiments are carried out in each pressure experiment, and the mean value is calculated. If the relative error between the measured P_{max} result and the mean value is less than 4%, then the experimental result is reliable. Otherwise, the experiment needs to be repeated.

2.2. Experimental Materials. *2.2.1. Coal Dust Sample.* In this experiment, the selected experimental sample is lignite with a low degree of metamorphism. The data of the proximate and ultimate analyses of lignite dust are shown in Table 1. It can be seen that the lignite dust sample is a type of highly volatile coal dust and the main components of the sample are carbon and oxygen elements. Generally, the volatile matter is the combustible gas, which is first released from the coal dust particles after the coal dust cloud is heated. So the greater the volatile content of the coal dust, the greater the corresponding explosion risk. The air-dried volatile content of the sample is 43.31%, which is greater than 40%; this indicates that the experimental dust samples have a great explosion hazard. Meanwhile, the particle size analyzer is used to observe the distribution of coal dust particles; the results are shown in Figures 3 and 4. It is found that the particle size of the lignite dust sample is greater than 58 μm and less than 75 μm; under such conditions, the risk of dust sample explosion is great. In addition, within the observation range, the particle size of all coal dust particles conforms to a normal distribution, indicating that the distribution of coal dust particles is relatively uniform.

Table 1. Proximate and Ultimate Analyses of the Coal Dust Sample[a]

proximate analysis (%)				ultimate analysis (%)			
M_{ad}	A_{ad}	V_{ad}	FC_{ad}	C	H	O	N
6.29	5.25	43.31	45.15	63.75	3.48	29.26	3.51

[a] M_{ad}, air-dried moisture content; A_{ad}, air-dried ash; V_{ad}, air-dried volatile; FC_{ad}, air-dried fixed carbon.

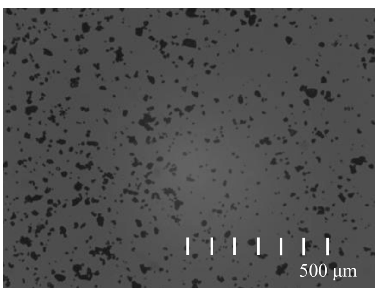

Figure 3. Observed coal dust particles.

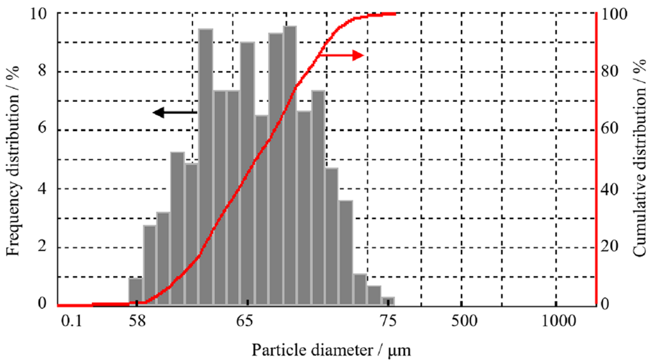

Figure 4. Diameter distribution of coal dust.

2.2.2. Inert Dust Samples. In coal mine tunnels, inert dust can effectively suppress coal dust ignition and explosion. In this paper, the suppression effect of different types of inert dust on the coal dust explosion pressure is studied by mixing inert dust into coal dust. Three types of inert dust selected are $CaCO_3$, SiO_2, and $NH_4H_2PO_4$, which are shown in Figure 5. It is found that three types of inert dust are all white inorganic particles under normal temperature, among which the melting points of $CaCO_3$ and SiO_2 dust are greater than 1500 K, indicating that $CaCO_3$ and SiO_2 dust are difficult to be involved in the chemical reaction of coal dust explosion and can effectively reduce the explosion intensity. However, the melting point of $NH_4H_2PO_4$ is only 453.15 K. After mixing $NH_4H_2PO_4$ into the coal sample, it will undergo a decomposition reaction under the action of high temperature generated by explosion.

3. RESULTS AND DISCUSSION

3.1. Explosion Pressure of Micron-Sized Lignite Dust in a Confined Space. The micron-sized lignite dust is used to test the explosion pressure in the spherical explosive apparatus. During the experiment, 6 g of coal dust is placed in the dust storage tank, so that the coal dust cloud mass concentration inside the 20 L spherical space could reach 300 g/m^3, which can ensure that the coal dust cloud can be ignited. By using the data transmission system, the explosion pressure curve is obtained, and the result is shown in Figure 6. It can be found that as the time after ignition increases, the explosion pressure increases continuously in a short period of time. At a time of 0.8 s after ignition, the coal dust explosion pressure increases to the maximum value, indicating that the P_{max} in this explosion experiment is 0.71 MPa, which is seven times the standard atmospheric pressure and can cause huge harm to the human skin and vital organs. Meanwhile, within a time of 0−0.8 s after ignition, $(dP/dt)_{max}$ in this coal dust explosion reaches 65.69 MPa/s, indicating that a violent explosion occurred in the interior of the spherical space.

However, although the lignite dust cloud with a mass concentration of 300 g/m^3 has exploded, it does not mean that the coal dust explosion intensity has been already at its most violent state. Therefore, to study the influence of the coal dust cloud mass concentration on the coal dust explosion pressure characteristics and to obtain the coal dust cloud mass concentration under the condition of maximum explosion intensity, in the course of subsequent research, the explosion pressure characteristics experiments under the condition of different coal dust cloud mass concentrations are carried out.

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Figure 5. Inert dust samples: (a) $CaCO_3$, (b) SiO_2, and (c) $NH_4H_2PO_4$.

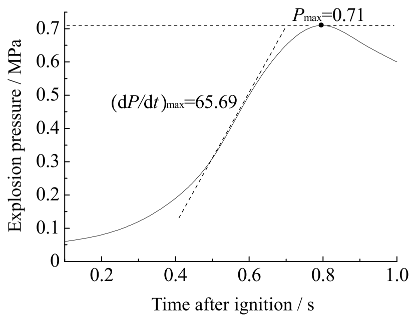

Figure 6. Coal dust explosion pressure curve.

3.2. Explosion Pressure under the Condition of Different Lignite Dust Cloud Mass Concentrations.

According to the Chinese national standard "GB/T 16426-1996 Determination for maximum explosion pressure and maximum rate of pressure rise of dust cloud", experiments can be carried out with different dust concentrations to obtain the relationship between explosion pressure and dust concentration. Therefore, under the condition that the particle size of the lignite dust sample is still greater than 58 μm and less than 75 μm, in subsequent experiments, the mass of lignite dust put into the dust storage tank each time has been increased from 6 to 6.5, 7, 7.5, 8, 8.5, 9, 9.5, and 10 g, which means that the mass concentration of the lignite dust cloud in the 20 L spherical space has been increased from 300 to 325, 350, 375, 400, 425, 450, 475, and 500 g/m^3, respectively. To study the effect of increasing the mass concentration of the lignite dust cloud on the explosion pressure, the mass concentration of the lignite dust cloud is set to increase continuously with 25 g/m^3 as the step size.

The lignite dust explosion pressure characteristics obtained from the experimental tests are shown in Table 2, and the variation trend of explosion pressure characteristics with the lignite dust cloud mass concentration is shown in Figure 7. The experimental data in this paper are the average value of the data obtained after multiple tests. The average value is calculated by multiple tests, which can effectively reduce the experimental error. It can be seen that as the lignite dust cloud mass concentration increases in the range of 300 to 500 g/m^3, both P_{max} and $(dP/dt)_{max}$ increase first and then decrease. When the lignite dust cloud mass concentration is 400 g/m^3, P_{max} and $(dP/dt)_{max}$ increase to the local maximum values of 0.82 MPa and 76.19 MPa/s, respectively, which indicates that there are local maximum points in the curve of lignite dust explosion pressure characteristics with the lignite dust cloud mass concentration. Based on the current experimental results,

Table 2. Explosion Pressure under the Condition of Different Lignite Dust Cloud Mass Concentrations[a]

		explosion pressure characteristics	
c (g·m^{-3})	m (g)	P_{max} (MPa)	$(dP/dt)_{max}$ (MPa·s^{-1})
325	6.5	0.75	68.21
350	7	0.79	71.55
375	7.5	0.80	73.80
400	8	0.82	76.19
425	8.5	0.77	73.54
450	9	0.73	71.68
475	9.5	0.71	69.61
500	10	0.70	68.08

[a] c, lignite dust cloud mass concentration; m, the mass of lignite dust put into the dust storage tank.

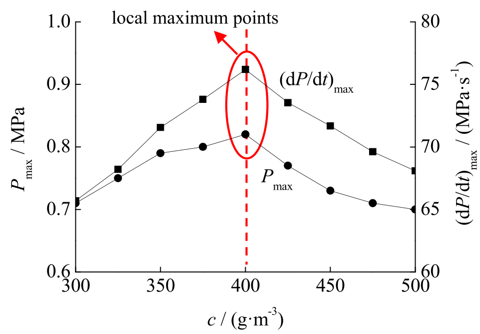

Figure 7. Explosion pressure under the condition of different lignite dust cloud mass concentrations.

the lignite dust cloud mass concentration corresponding to this local maximum point is 400 g/m^3, which means that when the lignite dust cloud mass concentration is 400 g/m^3, the lignite dust explosion pressure characteristics in the 20 L spherical space are at the most violent state.

According to the lignite dust explosion mechanism, when the lignite dust cloud mass concentration is greater than 300 g/m^3 and less than 400 g/m^3, the lignite dust particles will fully undergo a redox reaction with oxygen after being ignited. Under such conditions, there is sufficient and surplus oxygen in the explosion space, so that there is still a tendency for the explosion to be more violent. When the lignite dust cloud mass concentration is greater than 400 g/m^3 and less than 500 g/m^3, after the lignite dust cloud is ignited, the volatile release rate of the lignite dust particles becomes larger; it means that the volume of the volatile gas released from lignite dust particles increases due to the increase in the number of lignite dust

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Table 3. Suppression Effect of Three Types of Inert Dust on the Lignite Dust Explosion Pressure Characteristics[a]

	$CaCO_3$		SiO_2		$NH_4H_2PO_4$	
p (%)	P_{max} (MPa)	$(dP/dt)_{max}$ (MPa·s^{-1})	P_{max} (MPa)	$(dP/dt)_{max}$ (MPa·s^{-1})	P_{max} (MPa)	$(dP/dt)_{max}$ (MPa·s^{-1})
0	0.82	76.19	0.82	76.19	0.82	76.19
10	0.76	70.63	0.75	69.15	0.71	62.78
20	0.68	65.73	0.63	64.48	0.62	55.26
30	0.61	60.19	0.57	56.03	0.55	48.09
40	0.56	50.31	0.53	46.62	0.47	39.72
50	0.50	44.15	0.45	37.17	0.35	30.64
60	0.44	35.49	0.40	32.27	0.16	16.78
70	0.39	29.16	0.35	26.42	0	0

[a] p, mass percentage of inert dust mixed into lignite dust.

particles. Meanwhile, compared with the explosion pressure characteristics when the mass concentration of the lignite dust cloud is 400 g/m^3, more oxygen is consumed per unit time, resulting in insufficient oxygen concentration among lignite dust particles, which decreases the combustion rate of lignite dust particles in a short period of time. The insufficient explosion reaction of lignite dust interrupts the chain reaction of explosion, and at the same time, the explosion intensity is greatly reduced.

3.3. Suppression Effect of Different Types of Inert Dust on the Lignite Dust Explosion Pressure.

Three types of inert dust are selected for lignite dust explosion suppression experiments in the 20 L spherical explosion space; they are $CaCO_3$ dust, SiO_2 dust, and $NH_4H_2PO_4$ dust. In the explosion suppression experiment, the particle size of the lignite dust sample is greater than 58 μm and less than 75 μm, and the mass concentration of the lignite dust cloud is 400 g/m^3; it means that the mass of lignite dust put into the dust storage tank is 8 g, because the explosion intensity of the lignite dust cloud is in the most violent state under this experimental condition, which is more conducive to analyzing the suppression effect of inert dust on lignite dust explosion. The particle size of three types of inert dust is also greater than 58 μm and less than 75 μm, which is the same as the particle size of lignite dust. During the explosion suppression experiment, different types of inert dust will be mixed into the lignite dust sample in different mass percentages. The test results of the explosion suppression experiment are shown in Table 3; to analyze the explosion suppression effect more intuitively, the experimental data are drawn as Figures 8 and 9. It can be found that the P_{max} and $(dP/dt)_{max}$ of lignite dust explosion decrease continuously as the mass percentages of three types of inert dust mixed into lignite dust increase from 0 to 70%, indicating that the inert dust of $CaCO_3$, SiO_2, and $NH_4H_2PO_4$ have a significant suppression effect on the lignite dust explosion.

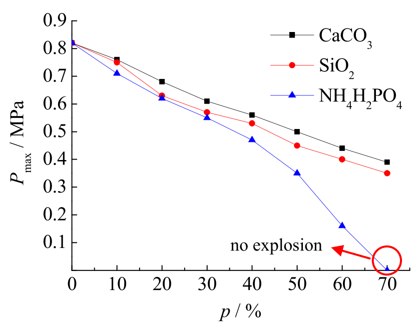

Figure 8. Suppression effect of inert dust on P_{max}.

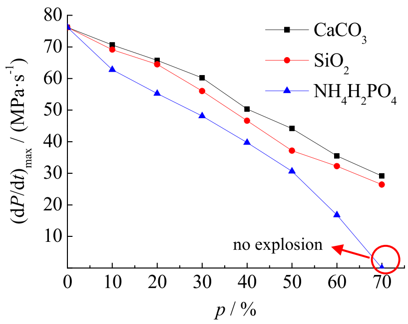

Figure 9. Suppression effect of inert dust on $(dP/dt)_{max}$.

Some previous studies also have related results on the suppression effect of inert dust on coal dust explosion;[25−28] to compare with the previous research results, in Table 4, it shows the comparison between the results of this paper and the previous research results of explosion suppression on P_{max}. It is found that when the mass percentage of inert dust mixed into coal dust is 50%, the percentage reduction of P_{max} by mixing $CaCO_3$ into coal dust in this study is 39.0%, while the percentage reduction of P_{max} in previous research is 42.9%, indicating that the results obtained in this study are very close to the results obtained in previous studies. When the inert dust SiO_2 or $NH_4H_2PO_4$ is mixed into coal dust, the percentage reduction of P_{max} in this paper is also close to the result of previous research. Although the research results show that the effect of $NH_4H_2PO_4$ on the explosion suppression of coal dust is relatively better, in previous studies, the influence of the particle size of $NH_4H_2PO_4$ on the explosion suppression effect of coal dust is seldom considered, and this content will be discussed later in this article.

Table 4. Comparison between This Paper and the Previous Research Results of Coal Dust Explosion Suppression on P_{max}[a]

	$CaCO_3$		SiO_2		$NH_4H_2PO_4$	
p (%)	ε_1%	ε_2%	ε_1%	ε_2%	ε_1%	ε_2%
50	39.0	42.9	45.1	46.5	57.3	55.2

[a] p, mass percentage of inert dust mixed into coal dust; ε_1, percentage reduction of P_{max} under explosion-suppressed conditions obtained in this study; ε_2, percentage reduction of P_{max} under explosion-suppressed conditions obtained in previous research.

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Table 5. Suppression Effect of the Particle Size of the Inert Dust $NH_4H_2PO_4$ on the Lignite Dust Explosion Pressure[a]

	0−25 μm		25−38 μm		38−48 μm		48−58 μm		58−75 μm	
p (%)	P_{max} (MPa)	$(dP/dt)_{max}$ (MPa·s^{-1})	P_{max} (MPa)	$(dP/dt)_{max}$ (MPa·s^{-1})	P_{max} (MPa)	$(dP/dt)_{max}$ (MPa·s^{-1})	P_{max} (MPa)	$(dP/dt)_{max}$ (MPa·s^{-1})	P_{max} (MPa)	$(dP/dt)_{max}$ (MPa·s^{-1})
0	0.82	76.19	0.82	76.19	0.82	76.19	0.82	76.19	0.82	76.19
10	0.58	50.39	0.63	52.61	0.66	56.42	0.68	59.20	0.71	62.78
20	0.47	41.28	0.54	44.05	0.57	47.98	0.59	51.72	0.62	55.26
30	0.39	36.55	0.45	39.57	0.49	43.14	0.52	45.36	0.55	48.09
40	0.30	25.86	0.33	29.04	0.41	32.50	0.44	35.88	0.47	39.72
50	0.17	12.84	0.22	16.72	0.28	22.87	0.31	26.79	0.35	30.64
60	0	0	0	0	0.12	9.60	0.13	11.52	0.16	16.78
70	0	0	0	0	0	0	0	0	0	0

[a] p, mass percentage of $NH_4H_2PO_4$ mixed into lignite dust.

As shown in Figures 8 and 9, although three types of inert dust have a suppression effect on coal dust explosion, different types of inert dust have different suppression effects on the coal dust explosion pressure characteristics. When the mass percentages of different types of inert dust mixed into coal dust are the same, the inert dust of $NH_4H_2PO_4$ is relatively more effective in suppressing the coal dust explosion. When the mass percentage of $NH_4H_2PO_4$ dust mixed into coal dust is 70%, the coal dust explosion no longer occurs, indicating that the lignite dust has completely lost its explosiveness under the explosion suppression effect of $NH_4H_2PO_4$ dust. In terms of the explosion suppression effect, compared with the inert dust of $NH_4H_2PO_4$, the inert dust of $CaCO_3$ and SiO_2 have a relatively poor suppression effect on coal dust explosion. Considering that the particle size of inert dust has a significant impact on the explosion suppression effect, therefore, it is necessary to further study the suppression effect of $NH_4H_2PO_4$ dust with different particle sizes on coal dust explosion.

3.4. Suppression Effect of the Inert Dust $NH_4H_2PO_4$ with Different Particle Sizes on Lignite Dust Explosion.

To discuss the suppression effect of the particle size of $NH_4H_2PO_4$ on lignite dust explosion, on the basis that the particle size of $NH_4H_2PO_4$ is greater than 58 μm and less than 75 μm, $NH_4H_2PO_4$ with particle sizes of 0−25, 25−38, 38−48, and 48−58 μm are selected for further explosion suppression experiments. The parameters of lignite dust are as follows; the mass concentration of the lignite dust cloud is 400 g/m^3, and the particle size of lignite dust is greater than 58 μm and less than 75 μm. The experimental results of lignite dust explosion suppression by $NH_4H_2PO_4$ with different particle sizes are shown in Table 5, and the experimental data are plotted in Figures 10 and 11. It can be found that in the particle size range of 0−75 μm, the smaller the particle size of the $NH_4H_2PO_4$, the better the suppression effect on the explosion pressure of micron-sized lignite dust.

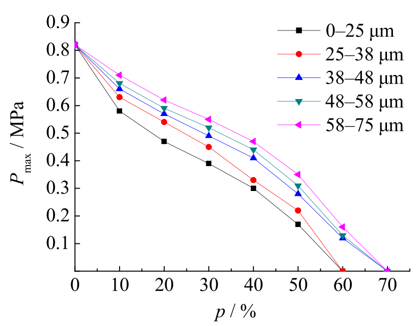

Figure 10. Suppression effect of $NH_4H_2PO_4$ on P_{max}.

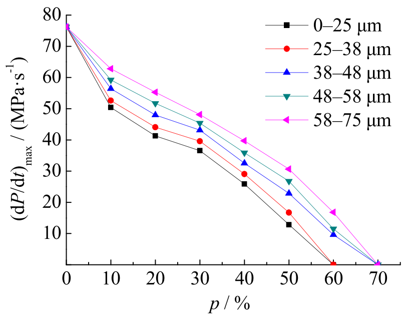

Figure 11. Suppression effect of $NH_4H_2PO_4$ on $(dP/dt)_{max}$.

In Figure 10, it is found that when p is less than 10%, the suppression effect of $NH_4H_2PO_4$ dust on P_{max} is very obvious, and the downward trend of the explosion suppression curve is very large. However, when p is greater than 10% and less than 40%, the downward trend of the explosion suppression curve is smaller than that when p is less than 10%, which indicates that the suppression effect of $NH_4H_2PO_4$ on P_{max} is not linear. When p is greater than 10% and less than 40%, the suppression effect of the inert dust particles on P_{max} becomes smaller. When p is greater than 40%, since the concentration of the $NH_4H_2PO_4$ dust particles increases, so that the heat transfer between lignite dust particles and the surrounding space can be better controlled. Therefore, the suppression effect of the inert dust particles on P_{max} increases again; the downward trend of the explosion suppression curve also becomes larger again.

By comparing the explosion suppression effects of $NH_4H_2PO_4$ dust with different particle sizes on the explosion pressure characteristics of lignite dust, it can be seen that under the condition that the particle size of the inert dust $NH_4H_2PO_4$ is 25−38 μm, when the mass percentage of $NH_4H_2PO_4$ dust mixed into lignite dust is 60%, the lignite dust no longer explodes, which further verifies that the $NH_4H_2PO_4$ dust has a good suppression effect on the lignite dust explosion. When the particle size of the $NH_4H_2PO_4$ dust mixed into the lignite dust is 0−25 μm, the explosion intensity is relatively minimal. Under the condition that the mass percentage of $NH_4H_2PO_4$ dust mixed into lignite dust is 50%, when the particle size of the $NH_4H_2PO_4$ dust is reduced from 58−75 to 0−25 μm, the P_{max} under the explosion suppression condition is reduced from 0.35 to 0.17 MPa; at the same time, the $(dP/dt)_{max}$ under the explosion suppression condition is reduced from 30.64 to 12.84 MPa/s, indicating that decreasing the particle size of the

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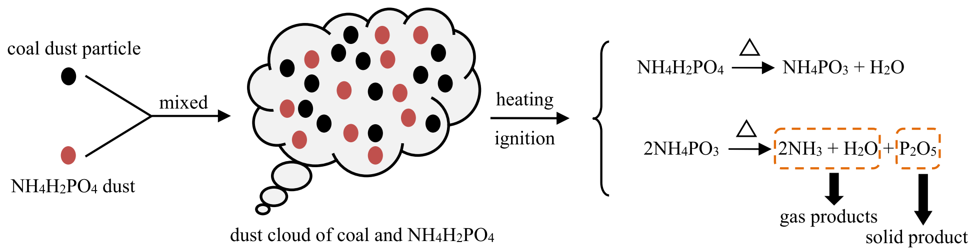

Figure 12. Suppression effect of $NH_4H_2PO_4$ dust on coal dust explosion.

$NH_4H_2PO_4$ dust plays an important role in reducing the explosion intensity of lignite dust.

3.5. Analysis on the Suppression Effect Mechanism of Different Types of Inert Dust on Lignite Dust Explosion.

In the experimental part of this paper, the reason for selecting $NH_4H_2PO_4$ dust for explosion suppression research is that the inorganic compound $NH_4H_2PO_4$ is the main component of fire extinguishing agents in many industrial fire extinguishers. Based on the experimental results, the explosion suppression effects of $CaCO_3$ and SiO_2 can be compared. It is known that the relative molecular masses of $CaCO_3$ and SiO_2 are 100 and 60, respectively, so the molar masses of $CaCO_3$ and SiO_2 are 100 and 60 g/mol, respectively, and the ratio of their molar masses is 5:3. To compare the explosion suppression effects of $CaCO_3$ and SiO_2 under the same molar conditions, the explosion suppression analysis should be carried out under the condition that the ratio of p of $CaCO_3$ and SiO_2 is also 5:3. In Table 3, according to the explosion suppression data of $CaCO_3$ under the condition of $p = 50\%$ and the explosion suppression data of SiO_2 under the condition of $p = 30\%$, it can be obtained that the P_{max} values under the inhibition of two types of inert dust are 0.5 and 0.57 MPa, respectively, and the $(dP/dt)_{max}$ values are 44.15 and 56.03 MPa/s, respectively. This shows that under the same mole of inert dust, $CaCO_3$ has a more significant suppression effect on the lignite dust explosion than SiO_2. However, the explosion suppression effect of both is not as effective as that of $NH_4H_2PO_4$ dust.

Compared with the suppression effect of $CaCO_3$ dust and SiO_2 dust on lignite dust explosion, $NH_4H_2PO_4$ dust has a more effective explosion suppression effect; it is mainly because the explosion suppression process of $NH_4H_2PO_4$ dust includes chemical explosion suppression. The physical suppression effect of $CaCO_3$ dust and SiO_2 dust in the process of lignite dust explosion is mainly reflected in that when they are mixed into lignite dust particles, the heat transfer among lignite dust particles is reduced. However, $NH_4H_2PO_4$ dust not only plays the role of diluting oxygen concentration and reducing temperature but also can be decomposed to generate NH_3, H_2O, and P_2O_5 under heating conditions, as shown in Figure 12. As a solid product, P_2O_5 can be mixed with lignite dust particles, which will physically suppress the explosion by isolating oxygen. As two gas products, NH_3 and H_2O can dilute the concentration of oxygen. In addition, the thermal decomposition reaction of $NH_4H_2PO_4$ is endothermic, which can reduce the ambient temperature, making the lignite dust particles unfavorable for ignition, so that the combustion chain reaction is interrupted.

4. CONCLUSIONS

The aim of this study is to get better understanding of the suppression effect of different types of inert dust on the lignite dust explosion pressure characteristics. The following results are obtained.

The lignite dust cloud mass concentration has an obvious effect on the lignite dust explosion pressure characteristics. As the lignite dust cloud mass concentration increases in the range of 300 to 500 g/m^3, both P_{max} and $(dP/dt)_{max}$ increase first and then decrease. When the lignite dust cloud mass concentration is 400 g/m^3, the lignite dust explosion in the spherical space is at the most violent state.

By carrying out the explosion suppression experiment of inert dust on lignite dust, it is found that the P_{max} and $(dP/dt)_{max}$ of lignite dust explosion decrease continuously as the mass percentages of inert dust mixed into lignite dust increase from 0 to 70%, indicating that the inert dust of $CaCO_3$, SiO_2, and $NH_4H_2PO_4$ have a significant suppression effect on the lignite dust explosion. When the mass percentage of $NH_4H_2PO_4$ dust mixed into lignite dust is 70%, the lignite dust explosion no longer occurs, indicating that the explosion suppression effect of $NH_4H_2PO_4$ dust is more effective than that of $CaCO_3$ and SiO_2.

The smaller the particle size of the inert dust $NH_4H_2PO_4$ in the particle size range of 0−75 μm, the more obvious the suppression effect on the lignite dust explosion pressure characteristics. Under the condition that the particle size of the inert dust $NH_4H_2PO_4$ is 25−38 μm, the lignite dust no longer explodes when the mass percentage of $NH_4H_2PO_4$ dust mixed into lignite dust is 60%, which verifies that decreasing the particle size of the $NH_4H_2PO_4$ dust is important to reduce the lignite dust explosion intensity.

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Notes

The authors declare no competing financial interest.

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