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Experimental Study on Two-Phase Explosion Suppression of Gas/Pulverized Coal by Explosion Suppressant

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ABSTRACT: Pulverized coal is widely distributed in coal mine roadways, which can enhance the power of a gas explosion. Explosion suppression technology can effectively reduce the explosion power. At present, rock powder shed, a water bag, and ABC powder are widely used in most coal mine explosion suppression technologies. In order to verify the explosion suppression effect of rock powder, water, and ABC powder in the pulverized coal environment, a series of experiments on a suppressing gas/pulverized coal two-phase explosion were carried out with a self-built large-scale gas explosion experimental system. The experimental study in this paper can provide some reference for the improvement of explosion suppression technology in coal mines. In this paper, through the suppression of a secondary explosion, flame, and impact of pulverized coal, the explosion suppression effects of three kinds of explosion suppressants are comprehensively analyzed. The results show that rock powder has a good inhibitory effect on a secondary explosion and flame of pulverized coal, and water has a good inhibitory effect on the shock wave. ABC powder has the best explosion suppression effect; the inhibition of a secondary explosion of pulverized coal is 4.17 times that of rock powder, the inhibition of flame is 4.28 times that of rock powder, and the inhibition of shock wave is 2.24 times that of water.
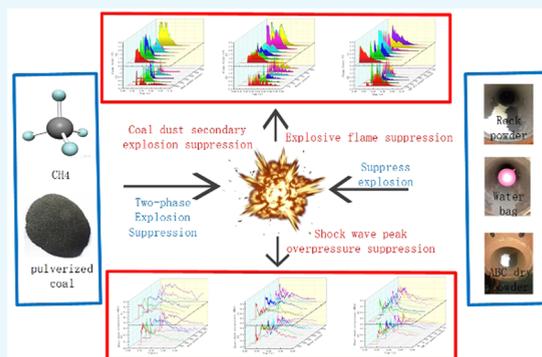
1. INTRODUCTION

As one of the most important energy sources, coal is widely used in industry.[1] With an increase of mining depth, various safety problems have become increasingly prominent. A gas explosion is one of the major disasters faced by coal mines. A gas explosion often causes explosion of coal powder deposited in coal mine roadways,[2,3] and a gas/coal two-phase explosion accident is more harmful.[4,5]

Pulverized coal widely exists in coal mine roadways. A gas explosion can easily cause a secondary explosion of pulverized coal, which can significantly increase the explosion power. Ajrash et al.[6,7] carried out methane/pulverized coal explosion experiments in large cylindrical pipelines. The results showed that the explosion pressure increased nearly two times by adding 30 g/m³ pulverized coal to a 6 vol % methane/air mixture. Kundu et al.[8] conducted a series of explosion experiments of a methane/pulverized coal mixture using a 2813 mm pipe and a 20 L spherical vessel. The results showed that methane could significantly enhance the explosion power of pulverized coal, and the ignition energy would affect the explosion pressure. Jiang et al.[9] studied the effect of turbulence intensity on the flame propagation of a methane/coal dust mixture explosion. The results showed that when the turbulence intensity increased from 1.86 to 2.66 m/s, the flame propagation velocity increased by 78−200%. Li et al.[5] qualitatively and quantitatively analyzed the flame propagation

behavior of a methane/pulverized coal mixture with an improved 20 L spherical explosion reactor. The results show that the preoxidation of pulverized coal increases the explosion power.

Explosion suppression technology can effectively reduce the explosion power. At present, most coal mines adopt explosion suppression technologies such as rock powder and water bags, and ABC powder explosion suppression is also a hot research topic for rock powder explosion suppression technology. On the basis of fluid dynamics and combustion theory, Song et al.[10] simulated the propagation of premixed gas explosion suppression by a sedimentary inert rock dust layer. The results show that the overpressure, flame velocity, and flame length decrease with an increase in sedimentary rock dust. Azam et al.[11] by changing the particle size of rock powder, concentration, and dispersion pressure to explore the impact of a coal powder explosion showed that the best inhibition concentration of rock powder is 427 g/m³; Song et al.[12]
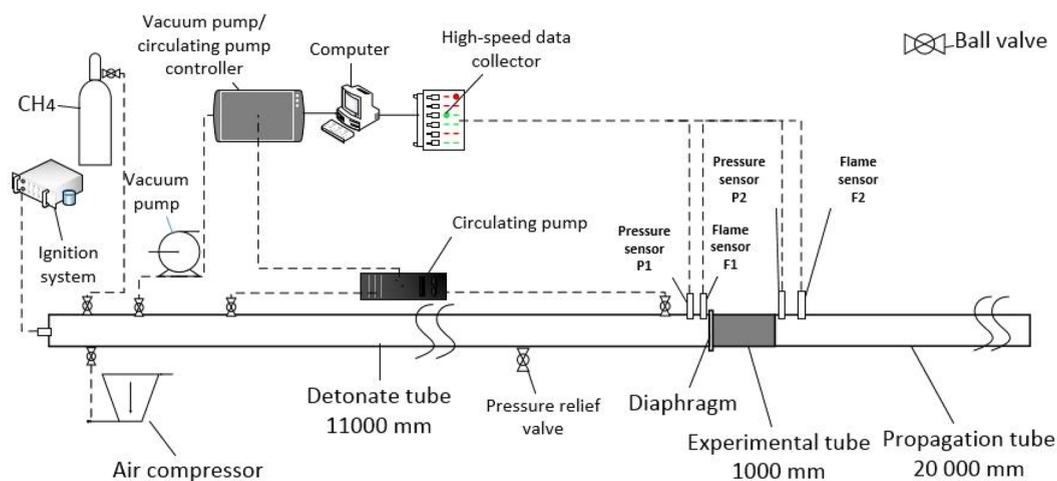
Figure 1. Schematic diagram of gas explosion experimental system.

simulated the process of ignition of a coal/rock powder mixture by a methane explosion through numerical simulations and analyzed the influence of rock powder on the explosion overpressure, flame temperature, and flame velocity of methane/coal powder. For the water bag explosion suppression technology, Li et al.[13] tested and simulated gas explosion reactions under four different water contents through a 20 L explosion ball test and CHEMKIN 17.0 software. The results showed that water could inhibit the formation of H, O, and OH radicals in explosion energy and reduce the gas explosion intensity; Cao et al.[14] experimentally studied the inhibitory effect of an ultrafine water mist on a methane explosion with concentrations of 6.5%, 8%, 9.5%, 11%, and 13.5% in a closed visual vessel and compared an ultrafine NaCl/water mist with an ultrafine pure water mist, and the results showed that the addition of NaCl could improve the inhibitory effect of an ultrafine pure water mist on a methane explosion. Pei et al.[15] carried out a series of methane explosion suppression experiments with an N_2-double-flow water mist containing NaCl based on a self-built pipeline double-flow water mist explosion suppression system, and the results showed that an N_2-double-flow water mist containing NaCl had a better inhibition effect on a methane explosion. Shen et al.[16] studied the explosion and combustion reference of a methane/air/ saturated water vapor mixture in a standard 20 L spherical explosion vessel. The results show that the explosion limit range of methane is reduced after adding saturated water vapor compared with dry methane/air mixture. Song et al.[17] studied the effect of initial droplet size and spray concentration on explosion suppression by two-dimensional numerical model. The results showed that the suppression of water mist is mainly reflected in the suppression of the explosion flame temperature. Wang et al.[18] established an experimental system to explore the suppression effect of a methane/air explosion in pipelines by water mist and studied the effects of droplet size and pipeline size of water mist on an explosion. The structure showed that 45 and 100 mm water mists could not suppress explosion and that a water mist with a droplet diameter greater than 160 mm could effectively suppress an explosion. For the explosion suppression of ABC powder, Deng et al.[19] used a 20 L spherical explosion suppression experimental system to study the explosion suppression effect of ultrafine ABC powder and diatomite powder. The results showed that, when the methane concentration was 9.5%, the maximum explosion pressure of

ABC powder decreased by 23%, and that of diatomite powder decreased by 18%. Luo et al.[20] studied the inhibition effect of different concentrations of an ABC powder/CO_2 mixture on gas explosion by using a self-improved 20 L spherical experimental system. The results show that there is a synergistic effect between ABC powder and CO_2. CO_2 plays a key role in the whole explosion and can effectively inhibit the positive reaction of gas and oxygen; in the middle and late stages of the explosion, ABC powder plays a key role. Jiang et al.[21] designed a semiclosed pipeline with an explosion suppression device. The active explosion suppression effect of nitrogen-coupled ABC powder on methane explosion was studied by experiments. The results showed that the injection of nitrogen and ABC powder has an obvious inhibitory effect on the explosion overpressure and flame propagation velocity. Wang et al.[22] studied the effect of a gas–solid two-phase inhibitor on gas explosion. The results showed that an inhibitor composed of $NaHCO_3$ (BC) powder/inert gas had better inhibition performance in comparison to an inhibitor composed of $NH_4H_2PO_4$ (ABC) powder/inert gas. Li et al.[23] used the combination of an inert gas and ABC powder to suppress methane explosion. On the basis of the flame morphology, flame propagation velocity, explosion pressure, and booster rate, the explosion suppression mechanism was explained by the physical and chemical aspects. Thus, the basic research on coal mine powder explosion suppression technology is divided into two categories. The first type is to study the suppression effect of a certain type of explosion inhibitor on a gas explosion. Its advantage is that it can systematically analyze the explosion suppression effect of a certain type of explosion inhibitor, while the deficiency is that most scholars have tended to focus on a gas explosion, without considering the reality that there is a large amount of pulverized coal in the coal mine roadway itself. The second type is to study the inhibition effect of a certain type of antiexplosion agent on a gas/pulverized coal two-phase explosion. The advantage is that the pulverized coal explosion is taken into account. The disadvantage is that most scholars have focused on the antiexplosion effect of a certain type of antiexplosion agent. There is no comparative study of the rock powder shed and water bag commonly used at present, and it is impossible to obtain the advantages in comparison with the existing antiexplosion technology. Therefore, it is necessary to carry out scientific research on rock powder, water bag, and

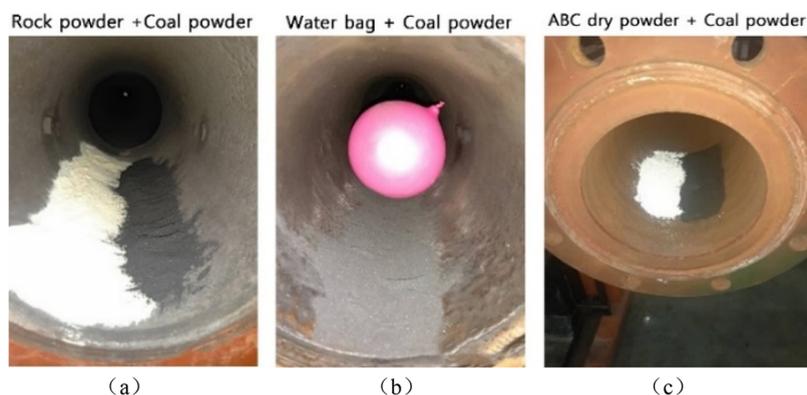**Figure 2.** Physical map of gas explosion experimental system.

Figure 3. (a) Pulverized rock coupled with pulverized coal photograph. (b) Water bag coupled with pulverized coal photograph.(c) ABC dry powder coupled with pulverized coal photograph.

ABC powder to suppress a gas/pulverized coal two-phase explosion. The novelty of this study is that it combines the actual situation of a large amount of pulverized coal in coal mines, which is of great significance to the improvement of coal mine explosion suppression technology.

2. EXPERIMENTAL SECTION

2.1. Experimental System. A large-scale gas explosion experimental system with a diameter of 200 mm and length of 32 m was built. The experimental system is composed of a gas distribution subsystem, a pipeline subsystem, a ignition subsystem, and a data acquisition subsystem. The experimental system is shown in Figure 1, and a photo of the system is shown in Figure 2. The pipeline subsystem is composed of steel pipelines with a wall thickness of 100 mm and inner diameter of 200 mm, which is divided into a detonate tube, experimental tube, and propagation tube. The detonate tube length is 11 m, the experimental tube length is 1 m, and the propagation tube length is 2 m. The gas distribution subsystem is mainly composed of an air compressor, vacuum pump, gas cylinder, circulating pump, and electronic pressure gauge. The ignition subsystem is mainly composed of an ignition controller, power supply, fuse, and electrode. The data acquisition system is mainly composed of a pressure sensor, flame sensor, high-speed data acquisition instrument, and data processing software. The gas used in the experiment is high-purity methane gas with a purity of 99.9%. The ignition energy is 10 J. The range of the pressure sensor is 0−3 MPa, and the accuracy grade is 0.5% FS. The maximum sampling rate of the flame sensor is 20 MSPS, and the accuracy is 0.1% FS.

2.2. Experimental Scheme. Gas and pulverized coal were fixed quantities in this experiment. Rock powder, water, and ABC powder were selected as explosion suppressants. The rock powder and ABC powder particle size is 0.015 mm, and water was placed in a water bag. The filling amounts of rock powder and water were 100, 200, 300, 400, 500, and 600 g, respectively. The filling amounts of ABC powder were 20, 40, 60, 80, 100, 120, and 140 g, respectively.

Through multiple sets of field experiments, it has been found that when 40 g of pulverized coal is filled in the experimental tube, the explosion power of pulverized coal is the greatest; thus, 40 g pulverized coal was selected to be laid at the entrance of the experimental tube. The pulverized coal was laid along the side of the axis of the pipeline. The thickness of pulverized coal was 2 mm, the length was 100 mm, and the width was 50 mm. The rock powder and ABC powder were laid on the other side of the central axis of the pipeline, symmetrically with the coal powder. The water bag was placed on the coal powder. The placement of rock powder and coal powder is shown in Figure 3a, the placement of the water bag is shown in Figure 3b, and the placement of ABC powder and coal powder is shown in Figure 3c.

2.3. Experimental Process. The flame sensor labels are F1 and F2, and the pressure sensor labels are P1 and P2, respectively. The positions of sensor installation are shown in Table 1. First, the pulverized coal and antiexplosion agent were laid in the experimental pipeline according to the experimental scheme, and the experimental pipeline was sealed with the initiation pipe and the propagation pipe by using a sealing ring and a flange. The diaphragm was placed between the initiation pipe and the test pipe, and a sealing ring was used for a sealing treatment. After the pipeline connection was completed, the

Table 1. Location of Pressure and Flame Sensors

sensor	measuring point position (m)
pressure sensor P1	10.7
pressure sensor P2	12.4
flame sensor F1	10.8
flame sensor F2	12.5

gas distribution subsystem was used to configure the gas with a concentration of 9.5% in the detonation tube and the mixed gas in the pipeline was circulated through the circulating pump for 20 min. After this preparation, the acquisition subsystem was debugged to a work state, the ignition subsystem was used for ignition, and the data processing system was used to save the collected data. Every trial was repeated three times.

3. EXPERIMENTAL RESULT ANALYSIS

The advantages and disadvantages of explosion suppressants were determined by the suppression of a pulverized coal explosion, explosion flame, and explosion shock wave. The shock wave intensity is characterized by the peak overpressure, which is equal to the maximum value of the relationship curve between the overpressure of the blast shock wave and time. The peak overpressure of a shock wave indicates the maximum breaking pressure. The flame intensity is characterized by the

continuous light intensity collected by the flame sensor, which is numerically equal to the area enclosed by the curve of continuous light intensity and time. The criterion of a pulverized coal explosion is that multiple peak flame fronts appear in F2 sensor data.

3.1. Suppression Law of Pulverized Coal Explosion. Figure 4 gives flame effect diagrams of rock powder, water, and ABC powder to suppress a gas/pulverized coal two-phase explosion. F1 represents the F1 flame sensor, and F2 represents the F2 flame sensor. In order to verify the suppression of a gas/pulverized coal two-phase explosion by the addition of different amounts of explosion suppressants, the filling amounts of rock powder and water bag were 100, 200, 300, 400, 500, 600, 700, and 800 g, respectively, and the filling amounts of ABC powder were 20, 40, 60, 80, 100, 120 and 140 g, respectively. According to the data collected by F2 sensors corresponding to rock powder, water, and ABC powder, 500 g of rock powder and 120 g of ABC powder can completely inhibit the explosion of pulverized coal and 600 g of water cannot inhibit the explosion. Therefore, the inhibition effect of ABC powder on coal explosion is 4.17 times that of rock powder, and the inhibition effect of water on coal explosion is not obvious. According to the comprehensive analysis, the order of inhibition performance of three kinds of
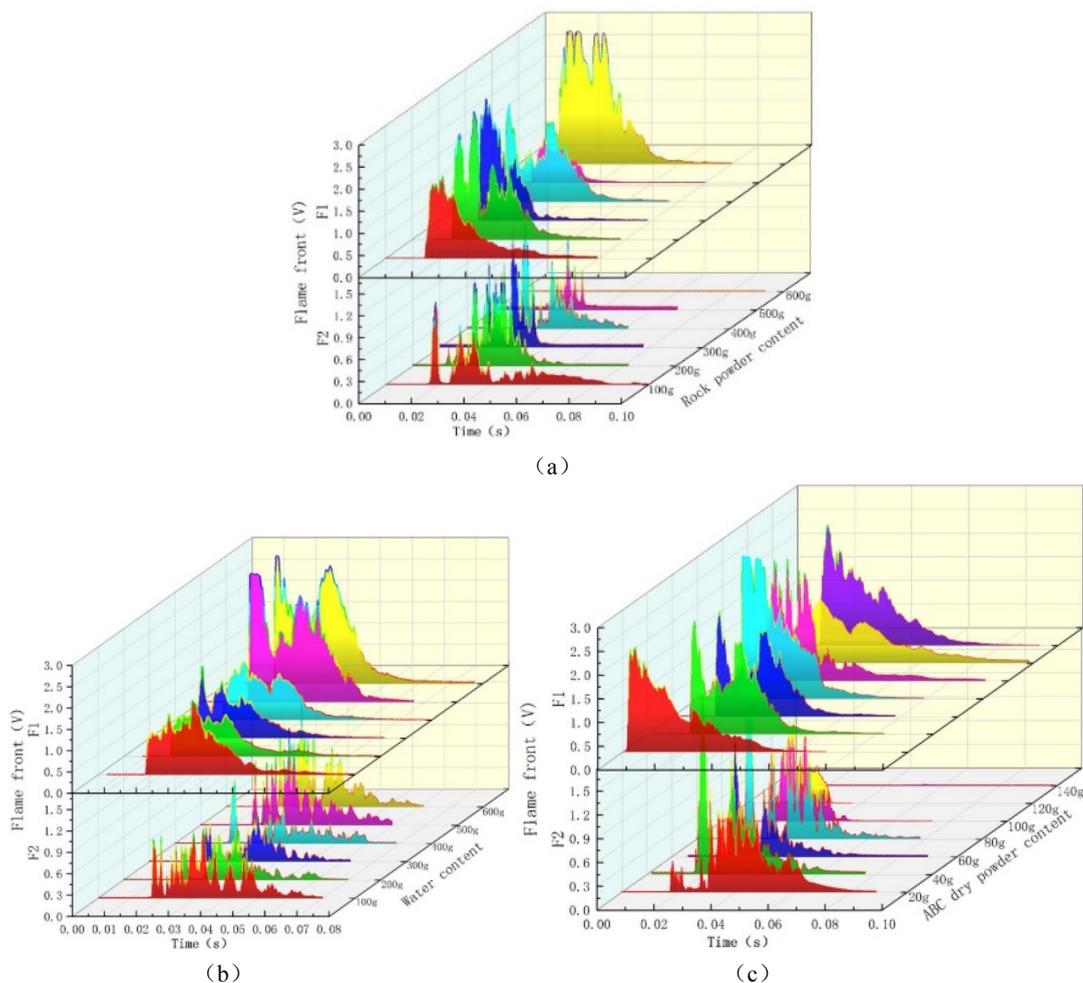

(a)

(b)

(c)

Figure 4. (a) Rock dust suppression explosion flame diagram. (b) Water suppression explosion flame diagram. (c) ABC dry powder suppression explosion flame diagram.
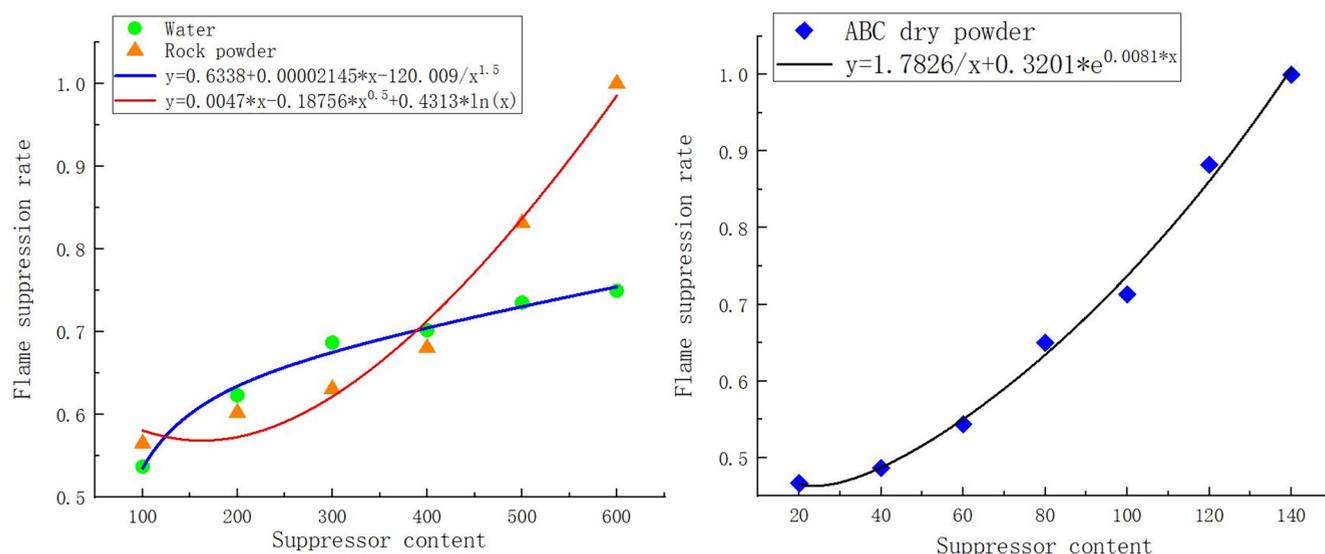
Figure 5. Explosion flame suppression law.

explosion suppressants for a pulverized coal explosion is ABC powder > rock powder > water.

The pulverized coal explodes when it is heated to a certain temperature. The gas explosion flame front heats the pulverized coal to the explosion temperature, mainly through the heat radiation between the combustion particles and the unburned particles in the reaction zone. Therefore, as long as the thermal radiation between coal particles is isolated, a coal explosion can be effectively suppressed.

The rock powder has a good inhibitory effect on a coal powder explosion. When a dust cloud composed of rock powder and coal powder meets the explosion flame front, the rock powder particles are doped between the coal powder particles. The rock powder particles isolate the thermal radiation between the coal powder particles and the noncoal powder particles, so that the noncoal powder particles cannot reach the deflagration temperature.

Water has no obvious inhibitory effect on a pulverized coal explosion. Water quickly becomes water vapor after encountering the explosion flame front, and the evaporation process is an endothermic process, which reduces the ambient temperature. However, water vapor cannot effectively prevent thermal radiation; therefore, it cannot effectively suppress coal explosion.

ABC powder showed a good inhibition effect on a pulverized coal explosion. When a dust cloud composed of ABC powder and pulverized coal meets the explosion flame front, the ABC powder absorbs heat and reduces the flame temperature. The thermal decomposition of ABC powder into the solid product P_2O_5 is similar to the role of rock powder, which can effectively isolate the thermal radiation between the burned particles and the unburned particles, so that the unburned powder particles cannot reach the deflagration temperature.

3.2. Law of Explosion Flame Suppression. The flame inhibition rate expressed as $\beta = \frac{F_1 - F_2}{F_1}$, where F_1 represents the flame intensity measured by the F1 flame sensor and F_2 represents the flame intensity measured by the F2 flame sensor. Figure 5 shows the relationship among the explosion suppressants with different filling amounts and flame explosion suppression rates. The light signal intensity measured by the

flame sensor represents the explosion flame energy by integrating the light intensity with time, which is numerically equal to the area surrounded by the curve of the flame signal intensity and time. The functional relationship between the rock powder filling amount and the flame explosion suppression rate is expressed as $y = 0.0047x - 0.18756x^{0.5} + 0.4313 \ln x$. The functional relationship between the water filling amount and the flame inhibition rate is expressed as $y = 0.6338 + 0.00002145x - 120.009/x^{1.5}$. The functional relationship between the filling amount of ABC powder and the flame inhibition rate is expressed as $y = 1.7826/x + 0.3201e^{0.0081x}$. The expressions of function relations can provide some reference for further research.

It can be seen from Figures 4 and 5 that 600 g of rock powder and 140 g of ABC powder can completely inhibit the explosion flame and that 600 g of water still cannot inhibit the explosion flame. The reason for the slow increase of flame suppression rate of 20−80 g of ABC powder and 100−400 g of rock powder is that the explosion of pulverized coal increases the flame strength. Therefore, the inhibition effect of ABC powder on an explosion flame is 4.28 times that of rock powder, and the inhibition effect of water on explosion flame is poor. According to a comprehensive analysis, the order of inhibition performance of the three kinds of explosion suppressants for an explosion flame is ABC powder > rock powder > water.

The three kinds of explosion suppression agents in the inhibition of an explosion flame can refer to the mechanism of coal powder explosion suppression. The heat absorption reaction of rock powder can absorb the heat of the explosion flame front, and rock powder can effectively inhibit a coal powder explosion; thus, rock powder has a good inhibitory effect on a gas/pulverized coal explosion flame.

When water encounters the front of the explosion flame, it evaporates and absorbs heat to generate water vapor, which takes away the heat of the explosion flame. Due to the limited heat absorption effect and the poor suppression effect of water on a coal powder explosion, the suppression effect of water on a gas/pulverized coal two-phase explosion flame is poor.

After ABC powder encounters the explosion front, an endothermic reaction occurs, which takes away a great deal of
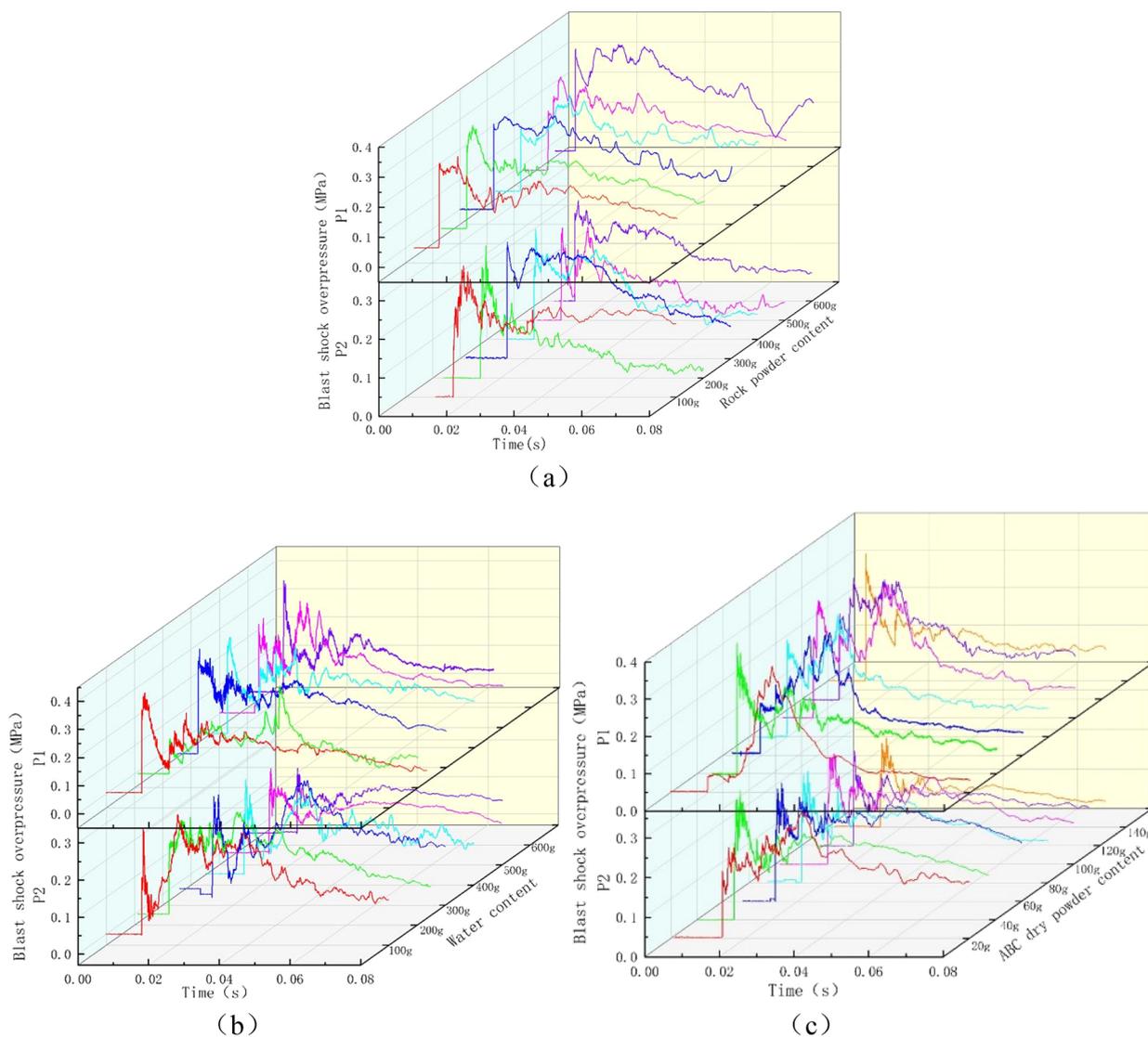
(a)

(b)   (c)

Figure 6. (a) Rock dust suppressed explosion shock wave data. (b) Water suppressed blast shock wave data. (c) ABC dry powder suppression shock wave data.
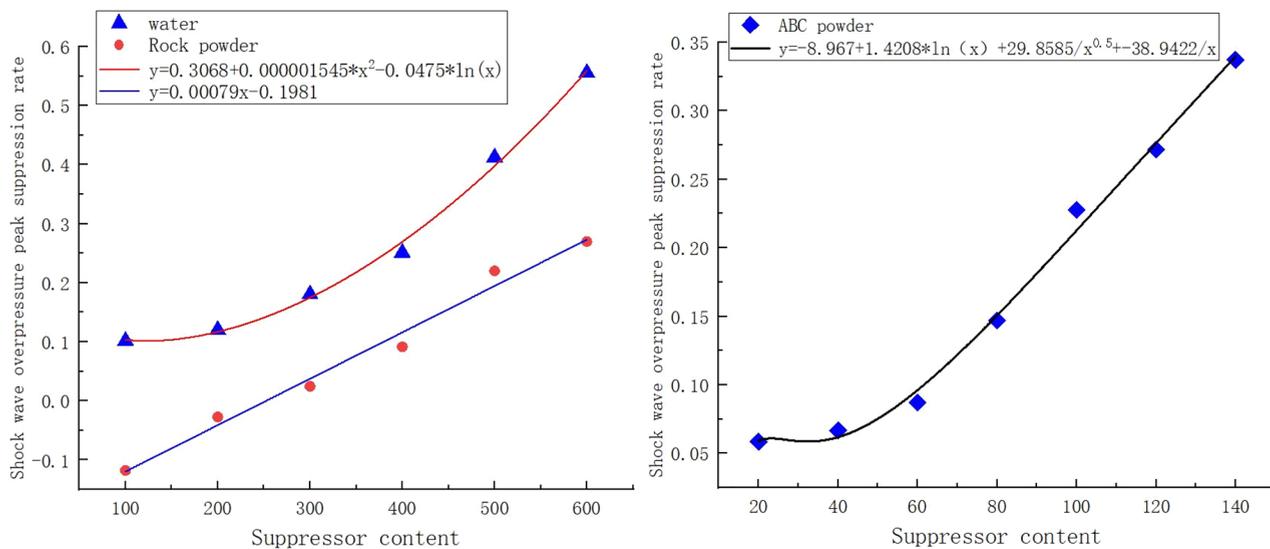

Figure 7. Suppression law of shock wave overpressure peak

heat. At the same time, the gaseous products NH_3, H_2O, N_2, and SO_2 are decomposed to dilute the oxygen concentration. ABC powder decomposes the intermediate free radicals containing P atoms, and the free radicals can combine with $OH^\bullet$ and $H^\bullet$ active free radicals in the explosion combustion reaction to form the relatively stable product H_2O. ABC powder terminates the combustion chain reaction by consuming the number of active free radicals in the explosion combustion reaction and has a chemical inhibitory effect. Under physical and chemical synergistic inhibition, ABC powder has a good inhibition effect on anexplosion flame.

3.3. Shock Wave Suppression Law. Figure 6a−c gives shock wave overpressure data under the conditions of rock powder, water, and ABC powder, respectively. P_1 represents overpressure data of the P1 pressure sensor, and P_2 represents overpressure data of the P2 pressure sensor. Figure 7 shows the suppression law of shock wave overpressure peak under different explosion suppressants. It can be seen from Figures 6 and 7 that the peak suppression rate of shock wave overpressure was −11.79% when 100 g of rock powder was filled, 10.18% when 100 g of water was filled, and 22.78% when 100 g of ABC powder was filled. Therefore, the inhibitory effect of ABC powder on the peak overpressure of a gas/pulverized coal two-phase explosion shock wave is 2.24 times that of water. According to the comprehensive analysis, the order of the three kinds of explosion suppressants for shock wave suppression performance is ABC powder > water > rock powder.

The shock wave overpressure peak pressure inhibition rate is defined as $\alpha = \frac{P_1 - P_2}{P_1}$, where P_1 represents the peak over-pressure measured by the P1 pressure sensor and P_2 represents the peak overpressure measured by P2 pressure sensor. A pressure sensor tests the pressure of a shock wave; thus, the unit of parameters P_1 and P_2 is Mpa. As shown in Figure 7, the functional relationship between the rock powder filling amount and the shock wave overpressure peak inhibition rate is $y = 0.00079x − 0.1981$. The functional relationship between the water filling amount and the peak suppression ratio of shock wave overpressure is $y = 0.3068 + 0.000001545x^2 − 0.0475 \ln x$. The functional relationship between the filling amount of ABC powder and the peak suppression rate of shock wave overpressure is $y = 8.967 + 1.4208 \ln x + 29.9585/x^{0.5} + 38.9422/x$. The expression of function relations can provide some reference for further research.

The main component of rock powder is $CaCO_3$, which has good thermal stability and can be decomposed into CaO and CO_2 at 800 °C. The shock wave of the explosion precursor lifted the rock powder to form a rock powder cloud, and some rock powder underwent an endothermic decomposition, which reduced the shock wave energy. Rock powder has a good inhibitory effect on a pulverized coal explosion and reduces the subsequent energy of a shock wave.

When water encounters a shock wavefront with great energy, it will produce motion, compression, and rupture, accompanied by evaporation; thus, water can absorb a large amount of shock wave energy, which effectively weakens the shock wave. A gas explosion is a violent and fast branched chain reaction. Water molecules absorb a large amount of free radicals and the energy of free atoms, reducing the concentration of the active center of the branched chain reaction and interrupting the branched chain reaction. Water

reduces the explosive power by interrupting a branched chain reaction, thereby suppressing explosive shock waves.

When ABC powder encounters a shock wavefront with high temperature and high pressure, a chemical reaction will occur, and a large amount of energy exchange and energy transfer will be carried out with the shock wave, which consumes most of the shock energy. ABC powder has a good inhibition effect on a pulverized coal explosion and explosion flame, reducing the subsequent energy of a shock wave.

3.4. Analysis of Explosion Suppression Mechanism. The main component of rock powder is $CaCO_3$, which is decomposed into CaO and CO_2 by heating. In the explosion moment, a small amount of rock powder undergoes an endothermic reaction, and the main inhibition is physical isolation. $CaCO_3$ is a very fine powder. During the explosion, the rock powder adheres to the surface of the pulverized coal particles, which blocks the contact area between the pulverized coal and oxygen and absorbs a certain amount of heat, playing a dual role of dilution of oxygen and cooling. At the same time, the decomposition also reduces the oxygen concentration.

Water can suppress a gas/pulverized coal two-phase explosion mainly because water molecules can act on free radicals or free atoms in explosive chain reactions; the chemical reaction formulas are $H^\bullet + H_2O \rightarrow H_2 + OH^\bullet$, $O^{\bullet\bullet} + H_2O \rightarrow 2OH^\bullet$, and $HO_2 + H_2O \rightarrow H_2O_2 + OH^\bullet$. Water molecules can reduce the concentration of several chain carriers such as $H^\bullet$ and $O^\bullet$ in the system, which makes the reaction activity of the system decrease. More importantly, more water molecules can act as good third bodies, and water molecules can enhance the role of third bodies in the explosion reaction mechanism, such as $H^\bullet + CO + M \rightarrow HCO^\bullet + M$, $O^\bullet + CO + M \rightarrow CO_2 + M$, and $H^\bullet + OH^\bullet + M \rightarrow H_2O + M$. During the explosion, the ternary collision frequency is higher than the binary collision frequency, and the water molecules transfer the energy of many free radicals or free atoms, which reduces the concentration of the branched chain reactive center, and thus the reaction capacity of the system.

The ultrafine powder of ABC inhibits an explosion flame mainly due to its dual physical and chemical effects. When the flame surface enters the explosion suppression area, the dry powder of ABC particles absorbs heat from the flame, causing its temperature to increase, and when the temperature reaches a certain value, the dry powder will gasify. At this time, $NH_4H_2PO_4$ in ABC dry powder quickly breaks down into NH_3 and H_3PO_4 at high temperature, while H_3PO_4 decomposes further to HPO_3 and $H_4P_2O_7$, and finally to P_2O_5. Each step of the decomposition reaction is an endothermic reaction, absorbing a large amount of heat released in the combustion explosion reaction process, and thus has a good cooling effect, so that the explosion flow field temperature is reduced and the heat transfer is blocked. The attenuation of the shock wave pressure peak is mainly due to the momentum exchange, energy transfer, and the corresponding chemical reaction between the ABC powder suspension mixture and shock wave during the process of a shock wave passing through the explosion suppression zone, resulting in partial shock wave energy loss. More importantly, the inhibitory effect of ABC powder on the flame causes the flame propagation velocity to decrease rapidly after the explosion suppression area, so that the distance between the flame front and the shock wave vibration surface increases gradually, and the flame cannot effectively provide energy for the development of the shock

wave, with the result that the shock wave energy cannot be supplemented.

4. DISCUSSION

In this paper, a series of experiments on the suppression of a gas/coal two-phase explosion by rock powder, water and ABC powder were carried out by using a self-built large-scale gas explosion experimental system. Through the inhibition of the pulverized coal explosion, explosion flame, and explosion shock wave, the three kinds of explosion suppressants were comprehensively analyzed and the functional relationship between different filling amounts of explosion suppressants and the inhibition rate was fitted. The following outcomes were observed.

The performance of the three kinds of explosion suppressants on coal explosion suppression is in the order ABC powder > rock powder > water. The inhibition effect of ABC powder on a coal explosion is 4.17 times that of rock powder, while the inhibitory effect of water on a pulverized coal explosion is not obvious. The order of inhibition performance of three kinds of explosion suppressants on a gas/pulverized coal two-phase explosion flame is ABC powder > rock powder > water. The inhibitory effect of ABC powder on a gas/pulverized coal two-phase explosion flame is 4.28 times that of rock powder, and the inhibitory effect of water on an explosion flame is poor. The functional relationship between the rock powder filling amount and the flame explosion suppression rate is expressed as $y = 0.0047x - 0.18756x^{0.5} + 0.4313 \ln x$. The functional relationship between the water filling amount and the flame inhibition rate is $y = 0.6338 + 0.00002145x - 120.009/x^{1.5}$. The functional relationship between the ABC powder filling amount and the flame inhibition rate is $y = 1.7826/x + 0.3201e^{0.0081}x$.

The performance of the three kinds of explosion suppressants on gas/pulverized coal two-phase explosion shock wave suppression is in the order ABC powder > water > rock powder. The inhibitory effect of ABC powder on the peak overpressure of gas/pulverized coal two-phase explosion shock wave is 2.24 times that of water. The functional relationship between rock powder filling and the shock wave overpressure peak inhibition rate is $y = 0.00079x - 0.1981$. The functional relationship between the water filling amount and the peak suppression ratio of shock wave overpressure is $y = 0.3068 + 0.000001545x^2 - 0.0475 \ln x$. The functional relationship between the amount of ABC powder and the peak suppression rate of shock wave overpressure is $y = 8.967 + 1.4208 \ln x + 29.9585/x^{0.5} + 38.9422/x$.

According to the comprehensive analysis, the rock powder and water commonly used in coal mines are not as effective as ABC powder in inhibiting a pulverized coal explosion, explosion flame and explosion shock wave. ABC powder can provide a reference for improving explosion suppression technology in coal mines. However, this paper did not consider the effects of different particle sizes, concentrations, and distributions of pulverized coal on a gas explosion. In order to be more suitable for the actual situation of coal mines, future studies can systematically study the forms of various types of pulverized coal.

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Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

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