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Variation Law of Hybrid Explosion Characteristic Parameters of Gas and Coal Dust Coupled with Multiple Factors

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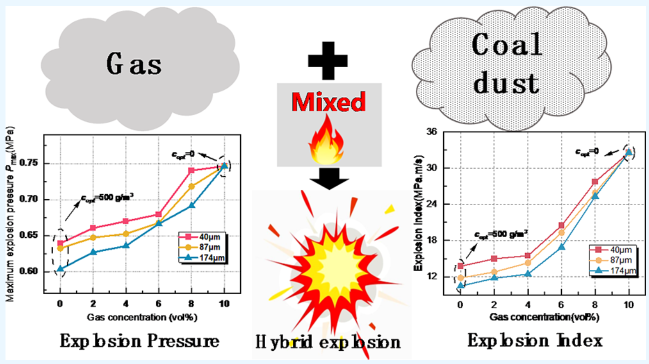
ABSTRACT: This study aims at extensively investigating the explosion characteristics of a hybrid mixture of gas and coal dust. Accordingly, the standard 20 L spherical explosion system was applied to measure parameters such as the lower explosion limit, maximum explosion pressure, and index of the hybrid mixture of different concentrations of gas and coal dust. Moreover, different coal dust particle sizes and components were measured. With regard to coal dust with different particle sizes and components, the obtained results revealed that, while the addition of gas significantly reduced the lower explosion limit, the maximum explosion pressure and index were increased; that is to say, the presence of gas will increase the explosion risk of coal dust. However, under conditions in which the particle size of the coal dust was large or the volatile content was low, the addition of gas was found to lead to a higher decrease of the lower explosion limit; this is, while the maximum explosion pressure and explosion index were increased. Consequently, gas can be argued to have a greater influence on the explosion risk of coal dust with a large particle size or low volatile content. Furthermore, regardless of the particle size or the volatile content of coal dust, the maximum explosion pressure and explosion index of the hybrid mixture were observed to be higher than that of the pure coal dust but lower than that of the pure gas. That is to say, the explosion intensity of the gas/coal dust composite system is higher than that of pure coal dust but less than that of pure gas. The research results can provide theoretical basis for coal mine explosion disaster prevention and control and have important significance.



1. INTRODUCTION

As a major safety accident in coal mines, gas and coal dust explosion has significantly restricted the safe production of coal in the mines. Surveys have demonstrated that of the 24 China's mine safety accidents since the foundation of PRC with the death toll reaching over 100 people, gas and coal dust explosions were found to be responsible for 21, of which 9, 4, and 8 were identified as gas explosion, coal dust explosion, and gas and coal dust composite explosion, respectively. This is an indication of gas/coal dust composite explosion being one of the main reasons for explosion disasters in the mines. Therefore, in order to prevent and control such catastrophes, the study of the characteristics of gas/coal dust composite explosions is of great significance.

The characteristics of gas/coal dust compound explosion are reflected in parameters such as the maximum explosion pressure, maximum rate of explosion pressure rise, explosion index, explosion limit, minimum ignition energy, and variation rule of minimum ignition temperature. Accordingly, these parameters can be considered as references for designing explosion protection and safety evaluations in underground coal mines. To date, the variation law of the explosion characteristic parameters of gas/coal dust composite (hereafter referred to as "the variation law") have been extensively studied. The research works include investigating such areas as the lower limit of composite explosion,[1−7] the maximum explosion pressure,[8−14] and the explosion index[15−17] the findings of which corroborate the significant reduction of the lower explosion limit of coal dust by gas. Moreover, the maximum explosion pressure and explosion index of coal dust are revealed to be increased. Furthermore, the higher sensitivity and intensity of the explosion were also confirmed for the gas/coal dust composite system. Hence, these findings can be significantly referenced and used in preventing coal mine explosion disasters.

However, to analyze the characteristic parameters of the variation law, the concentration of gas and coal dust has predominantly been utilized as the variables of the studies,

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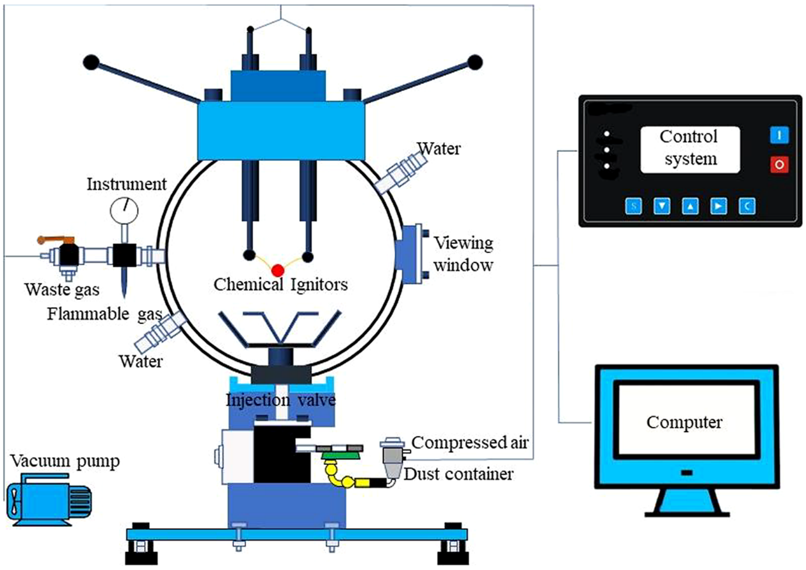

Figure 1. Schematic of the 20 L spherical explosion system.

which is remarkably limited considering the range of the selected variables in the experiments. Consequently, it can be argued that the variation law failed to be fully reflected in the obtained results. Furthermore, studies have demonstrated the characteristics of coal dust explosion to be greatly affected by the particle size and composition of the dust.[18−21] Therefore, as an important part of a gas/coal dust composite system, the variation law can be suggested to be affected by its particle size and composition. Thus, the investigation of the influence of coal dust particle size, composition, and other factors can provide a comprehensive analysis of the variation law in the full concentration range, which as a result can be more conducive to a systematic and comprehensive examination of the characteristics of gas/coal dust composite explosion.

Hence, this study aims at investigating the characteristic parameters of gas/coal dust composite explosion under different concentrations, particle sizes, and components. Furthermore, in order to more comprehensively show the explosion characteristics of the gas/coal dust composite, their variation law is analyzed under multiple factors. As a result, the findings of this study are expected to provide a theoretical basis for the prevention and control of coal mine explosion disasters.

2. EXPERIMENTAL PROCEDURE AND MATERIALS

2.1. Apparatus. A 20 L spherical stainless-steel double-wall explosion vessel was used in the study, as shown in Figure 1. To ensure the constant temperature of the vessel and thereby to reduce the experimental error caused by the temperature change in the sphere, constant temperature water was circulated in the interlayer of the vessel. The powder spraying system consisted of a 0.6 L dust bin, an air-powder two-phase valve, and a dispersing valve. Moreover, a 10 kJ chemical ignition head with an ignition delay time of 60 ms and a powder injection pressure of 2 MPa were used according to EN 14034.[22] The partial pressure method was applied to configure a certain concentration of gas in a spherical container and to form a gas/coal dust composite system with coal dust injected into the container.

2.2. Material. In order to systematically analyze the influence of particle size on the change rule of explosion characteristic parameters of the gas/coal dust composite, bituminous coal was used (the components are shown in Table 1). Also, three types of coal dust with different particle sizes

Table 1. Composition of Bituminous Coal

coal samples/%	moisture/%	ash/%	volatile/%	fixed carbon/%
bituminous coal	8.49	10.12	25.86	55.53

were prepared. Figure 2 shows the particle size distribution, with the median particle sizes of 40, 87, and 174 μm, respectively.

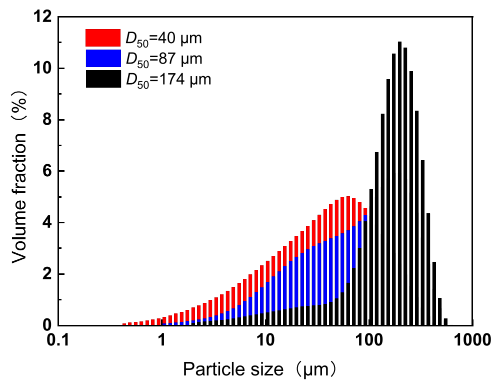

Figure 2. Particle size distribution of coal dust.

For the study of the influence of the coal dust components on the variation law, four different components with similar particle sizes were selected. To make a comparison, they were divided into groups A and B according to the principle of similar particle size, each of which was further divided into two subgroups. Accordingly, the four groups were titled as A1 (with the median particle size of 21.3 μm), A2 (with the median particle size of 19.7 μm), B1 (with the median particle size of 36.5 μm), and B2 (with the median particle size of 35.3 μm), the volatiles of which were 2.25, 25.01, 13.9, and 30.33%, respectively. The specific components and the particle size distribution are shown in Table 2 and Figure 3, respectively.

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Table 2. Composition of 4 Types of Coal Dust with Different Particle Sizes

samples	fixed carbon content/%	volatile content/%	moisture content/%	ash content/%
A1	60.58	2.25	0.43	36.74
A2	51.44	25.01	9.73	13.82
B1	61	13.9	4.5	20.6
B2	56.94	30.33	3.88	8.85

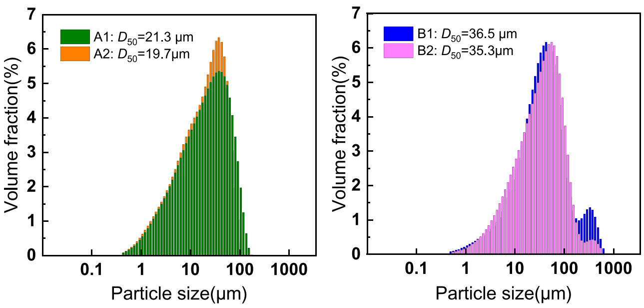

Figure 3. Particle size distribution of coal dust.

Instead of using gas, methane with a purity of 99.9% was used in the experiment. Prior to the test, all of the coal dust samples were dried in a 60 °C blast oven for 24 h. To ensure the reliability of the obtained results, each experiment was repeated three times. The data shown are the average of the three experimental data, and the error between the three experimental data is less than 5%.

3. RESULTS AND DISCUSSION

3.1. Variation Law of Lower Explosion Limit Coupled with Multiple Factors. The volume fraction of 1% was used as the gas concentration gradient in the experiment. The standard EN 14034[22] was also used to measure the lower limit of the coal dust explosion under different gas concentration conditions. Figures 4 and 5 display the variation of the lower

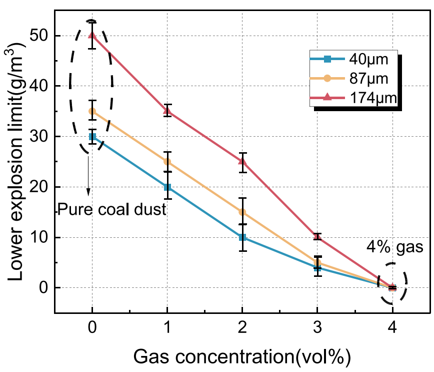

Figure 4. Lower explosion limit of coal dust with different particle sizes at different gas concentrations.

explosion limit of the coal dust with gas concentration by three different particle sizes and four different components. As can be seen in the figures, an increase in the gas concentration led to a decrease in the lower explosion limits of the seven different coal dusts. Also, when the concentration of the gas volume increased to 4%, the lower explosion limits of the dust decreased to 0 g/m^3. This is because the lower limit of gas

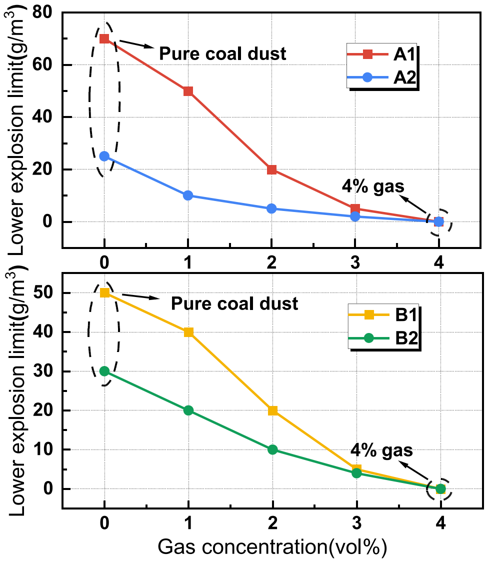

Figure 5. Lower explosion limit of coal dust with different components under different gas concentrations.

explosion measured under the experimental conditions was 4%, i.e., 4% of the pure gas can explode.

In order to examine the influence of particle size as well as the composition of the coal dust on the change law of the lower limit of composite explosion, different concentrations of gas were used. Accordingly, the lower limits of explosion of the seven types of coal dust (Figures 4 and 5) were induced, the obtained results of which are provided in Figures 6 and 7. It

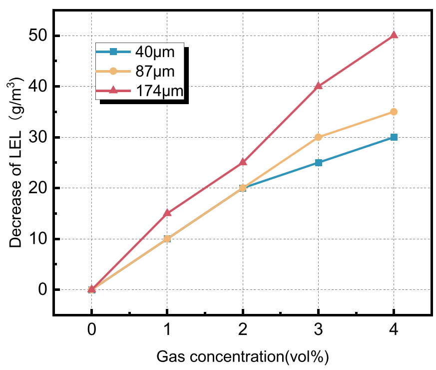

Figure 6. Reduction of the lower explosion limit of coal dust with different particle sizes induced by gas.

can be seen from Figures 6 and 7 that the same concentration of gas leads to a higher decrease in the lower explosive limit of coal dust with large particle size and low volatile. In other words, the larger the particle size of the coal dust and the lower the volatile content are, the greater the influence of gas on the lower explosion limit becomes. This is because the coal dust explosion is essentially the combustion of combustible gas released by coal dust thermal desorption. Besides, the content of the combustible gas produced by pyrolysis of the large particle size and low volatile coal dust is correspondingly small during the explosion. Therefore, the addition of the same concentration of gas has a more significant effect on the concentration of the combustible gas in the system after the pyrolysis of large particle size and low volatile coal dust.[23,24] As

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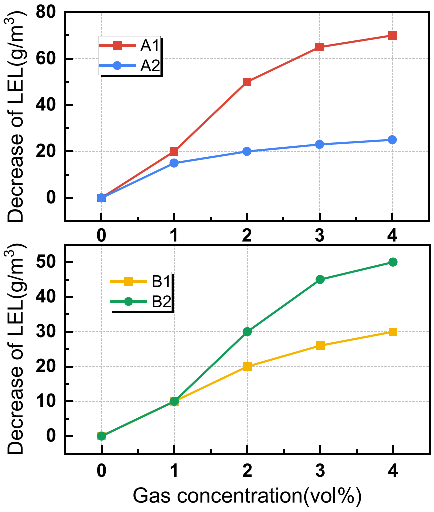

Figure 7. Reduction of the lower explosion limit of coal dust with different components induced by gas.

a result, the lower explosion limit of the large particle size and low volatile coal dust decreased more.

3.2. Coupling Multifactor Gas/Coal Dust Composite Explosion Pressure Variation Law.

The volume fraction of 2% was used as the gas concentration gradient in the experiment. Moreover, the maximum explosion pressure of the coal dust under the six different gas concentrations of 0, 2, 4, 6, 8, and 10% was measured by systematically changing the coal dust concentration. Figures 8 and 9 display the variation

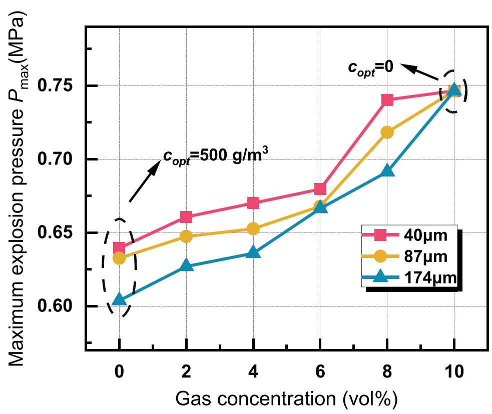

Figure 8. Maximum explosion pressure of coal dust with different particle sizes under different gas concentrations.

of the maximum explosion pressure of the coal dust with three different particle sizes and four different components of gas concentration. As can be seen in the figures, an increase in the gas concentration led to an increase in the maximum explosion pressure of the seven types of coal dust. Also, when the gas concentration increased to 10%, the maximum explosion pressure reached its maximum value, and the corresponding coal dust concentration was 0 g/m^3. In other words, the maximum explosion pressure of the coal dust under the condition of 10% gas concentration is the explosion pressure of 10% pure gas, which is due to the optimum explosion concentration (c_{opt}) of the gas measured under the experimental conditions being 10%. Under the conditions of such gas concentration, the gas phase gas preferentially reacts with the oxygen during the gas/coal dust composite explosion

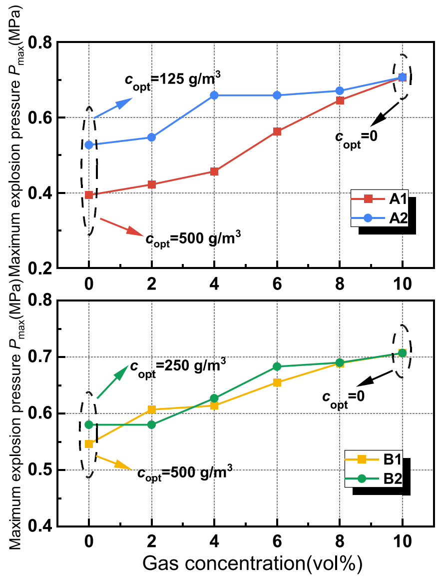

Figure 9. Maximum explosion pressure of coal dust with different components under different gas concentrations.

in the system. Being mainly endothermic, the coal dust particles are mainly inert particles, and accordingly, any concentration of coal dust in 10% gas leads to a decrease in the explosion pressure. It can also be inferred that while the maximum explosion pressure of the gas/coal dust composite system is greater than that of pure coal dust, it is less than that of pure gas.

In order to further investigate the effect of particle size and composition on the gas/coal dust composite explosion pressure, the growth rates of the maximum explosion pressures of the seven types of coal dust were calculated. The coal dusts were induced by different gas concentrations, the growth rates of which were calculated according to Figures 8 and 9. The obtained results are also shown in Figures 10 and 11. As can be

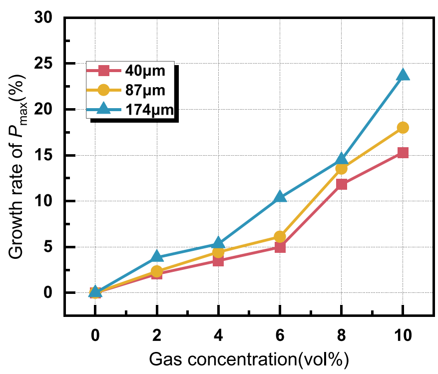

Figure 10. Growth rate of the maximum explosion pressure of coal dust with different particle sizes induced by gas.

observed in the figures, under the same gas concentration, the larger the coal dust particle size and the lower the volatile content are, the higher the maximum explosion pressure growth rate becomes. Furthermore, the larger particle size of the coal dust and lower volatile content were found to cause greater influence of gas on the maximum explosion pressure. This can be argued to be due the larger particle size of the coal dust having lower volatile content and then inducing lower heat release amount. Moreover, the lower heat release in the

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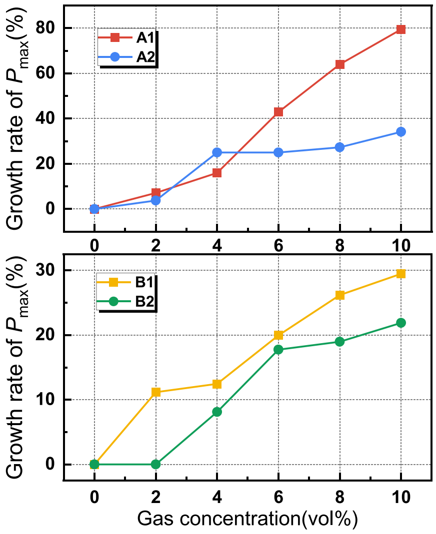

Figure 11. Growth rate of the maximum explosion pressure of coal dust with different components induced by gas.

composite explosion process was observed to cause a weaker leading role of heat as well as a greater impact of gas.

3.3. Coupling Multifactor Gas/Coal Dust Composite Explosion Index Variation Law. While the maximum explosion pressure was measured, the explosion index of the coal dust was calculated under different gas concentrations. The obtained results are shown in Figures 12 and 13. As can be

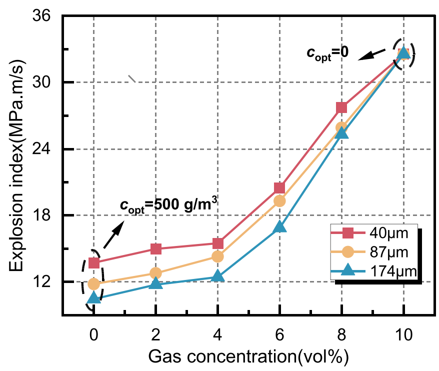

Figure 12. Explosion index of coal dust with different particle sizes under different gas concentrations.

observed in the figures, with an increase in the gas concentration, the explosion index of the seven types of coal dust increased as well. Also, an increase of the gas concentration to 10% resulted in the maximum value of the explosion index, with the corresponding coal dust concentration being 0 g/m^3. This can be argued to be due to the combustion rate of the coal dust being much lower than that of the gas. Also, the combustion rate of the composite explosion containing the coal dust is required to be lower than that of pure gas explosion under the condition of optimal explosion concentration. It also indicates that while the explosion index of the gas/coal dust composite system is larger than that of pure coal dust, it is less than that of pure gas.

Moreover, to further study the influence of the particle size of the coal dust and composition on the explosion index of the gas/coal dust composite, the growth rates of the seven types of coal dust explosion indexes were measured. It needs to be

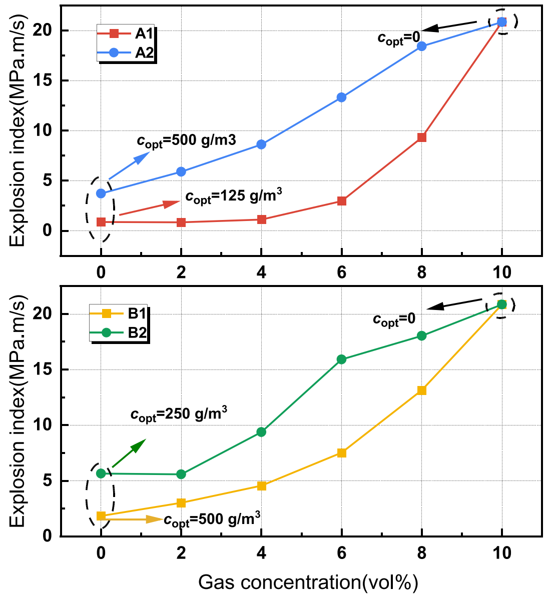

Figure 13. Explosion index of coal dust with different components under different gas concentrations.

noted that they were induced by different concentrations of the gas, the calculations of which can be seen in Figures 12 and 13. The obtained results are also shown in Figures 14 and 15. As

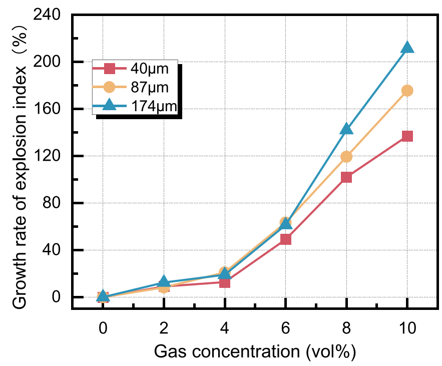

Figure 14. Growth rate of the explosion index of coal dust with different particle sizes induced by gas.

can be seen in the figures, comparable to the maximum explosion pressure, larger particle size of the coal dust and lower volatile content led to the higher growth rate of the explosion index under the same gas concentration. Moreover, they also found to cause greater influence of the gas on its explosion index, which can be argued to be due to the fact that these two factors can lead to the smaller combustion rate in the explosion process and, accordingly, the weaker leading role of heat release rate, as well as the greater impact of the gas.

4. CONCLUSIONS

In this study, factors such as gas and coal dust concentration, coal dust particle size, and composition were comprehensively looked into. The variation rules of parameters such as the lower explosion limit, maximum explosion pressure, and explosion index of gas/coal dust composite system were also analyzed under the influence of multiple factors. The following conclusions are drawn:

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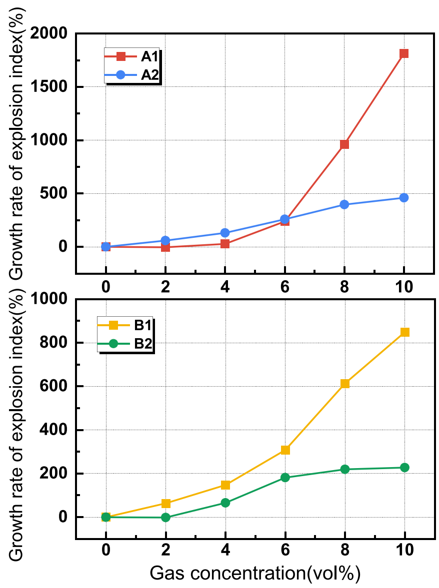

Figure 15. Growth rate of the explosion index of coal dust with different components induced by gas.

1. For coal dusts of different particle size and component, the addition of gas was found to result in a decrease in the lower explosion limit. However, in cases in which the coal dust particle size was large or the volatile content was low, the addition of gas led to a higher lower explosion limit, indicating the gas having a greater influence on the lower explosion limit of large particle size or low volatile coal dust.
2. For coal dust with different particle sizes and compositions, the addition of gas was found to increase its maximum explosion pressure and explosion index. However, in cases in which the particle size of the coal dust was large or the volatile content was low, the addition of gas was observed to lead to higher maximum explosion pressure, and accordingly, the explosion index increased. In other words, gas can be argued to have a greater influence on the explosion intensity of large or low volatile coal dust.
3. Regardless of coal dust particle size or volatile content, while the maximum explosion pressure and explosion index of composite system were observed to be higher than pure coal dust, they were found to be less than pure gas.

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Notes

The authors declare no competing financial interest.

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