Research on shock wave propagation characteristics of coal and gas outburst under different pulverized coal particle size conditions

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Abstract. In order to deeply explore the influence of pulverized coal particle size on coal and gas outbursts, using the self-developed outburst pulverized coal-gas two-phase flow simulation experiment system, the outburst disaster simulation experiment is carried out under the condition of 0.3 MPa carbon dioxide with particle diameters of 3~10 mm, 1~3 mm and 0.5~1 mm, and the characteristics of the wave shape, speed and attenuation law of the shock wave after the highlight are analyzed. The research results show that when the particle size of pulverized coal is 3~10 mm, 1~3 mm and 0.5~1 mm, the maximum shock wave velocity is 358 m/s, 347 m/s and 347 m/s, respectively. The particle size of pulverized coal has little effect on the propagation velocity of the outburst shock wave, but it tends to decrease as the particle size decreases. And the peak overpressure of the shock wave decreases with the decrease of the particle size of the coal. The average attenuation coefficient of the outburst shock wave increases with the decrease of the coal particle size.

1. Introduction
Coal and gas outburst is one of the most serious accidents affecting the safety of underground coal mine production [1, 2]. In the past five years, the number of prominent accidents and fatalities accounted for as high as 32.0% and 33.3% of the larger gas accidents. Once an outburst accident occurs, the high-pressure gas in the coal seam and the resulting broken coal (rock) can move tens to hundreds of meters to the roadway space, resulting in casualties, damage to facilities, and even gas explosions, which can cause great dynamic effect [3]. Among the current research results on the outburst of disasters, domestic and foreign scholars have carried out a large number of studies on the migration and disaster-causing characteristics of coal-gas two-phase flow after outburst, and have achieved rich results [4-8].

However, the current research on the formation mechanism and propagation characteristics of shock waves after coal and gas outbursts is insufficient. Cao et al. [9-10] used a self-developed coal and gas outburst dynamic effect simulation test device to carry out a simulation test of the full-size coal and gas outburst dynamic effect under low pressure conditions, and found that the average propagation velocity of the outburst shock wave front is 405.36m/s, and the peak value of shock wave overpressure shows a decay trend along the roadway. Wang et al. [11] analyzed the characteristics of the outburst gas impact.
force under different pulverized coal particle sizes by developing an outburst pulverized coal-gas two-phase flow simulation test system, and found that the gas impact force increased with the increase of the pulverized coal particle size. Therefore, the author will study the propagation characteristics of outburst shock waves under different pulverized coal particle size conditions, and hope to further study the disaster mechanism of pulverized coal-gas two-phase flow after outburst, which can provide important theoretical guidance for the effective control of outburst disasters.

2. Experimental system composition

In order to observe and study the propagation law of shock wave in the roadway after coal and gas outburst, a set of outburst pulverized coal-gas two-phase flow simulation experiment system is independently developed. The experimental system consists of five parts: an inflation system, a protruding simulation cavity, a protruding pressure relief device, an experimental simulation roadway, and a data acquisition system, as shown in Figure 1.

3. Experimental design

The coal used in the experiment is taken from the M8 coal seam 380 level N2 crosscut in Chongqing Fengchun Coal Mine. The original gas content of the M8 coal seam is 25.87 m³/t, which is an outburst coal seam. In this paper, the pulverized coal particle size 3~10mm, 1~3mm and 0.5~1mm are selected to carry out simulation experiments under the condition of 0.3MPa carbon dioxide. The specific experimental steps are as follows:

(a) Load the sieved coal sample (3~10mm) into the protruding cavity and fix it on the experimental support. At the same time, use bolts and gaskets to connect the protruding cavity to the protruding pressure relief device to make it sealed.

(b) Connect the experimental roadway with the outburst pressure relief device, and use flanges and bolts to connect and seal the remaining roadways in sequence, all of which are fixed on the experimental support to ensure its stability.

(c) Debug the air pressure sensor used for data collection to ensure that it can work normally.

(d) Fill the protruding cavity with carbon dioxide of 0.1 MPa, and then continue to inject high-pressure gas into the protruding cavity to keep it under the pressure of 0.3 MPa for more than 24 hours.

(e) After the outburst is completed, the data acquisition system stops collecting, copies the data, and cleans the coal powder in the outburst cavity and the experimental roadway.

(f) Repeat steps (a)~(e) to carry out experiments with coal particle size of 1~3mm and 0.5~1mm respectively.
4. Experimental result analysis

4.1. Outburst Shock wave propagation

Figure 2 is the shock wave waveform diagrams of monitoring points at different locations of the pipeline under the conditions of different pulverized coal particle sizes and 0.3 MPa carbon dioxide. It can be seen from Figure 2 that the shock wave waveform generated under this condition shows a pulsating development alternately with positive pressure and negative pressure.

![Figure 2](image-url)

**Figure 2.** The waveform of outburst shock wave at different positions of pipe

Table 1 lists the protruding shock wave overpressure at different locations of the pipeline under this condition. It can be seen from Table 1 that when the particle size of coal powder is 3–10 mm, 1–3 mm and 0.5–1 mm, the peak overpressure of the shock wave generated are 12.40 kPa, 4.70 kPa and 4.70 kPa, respectively. The peak overpressures of the negative phase of the shock wave are -11.55 kPa, -6.09 kPa and -4.39 kPa, respectively. The maximum value appears at the first or second measuring point. The peak value of shock wave overpressure decreases with the decrease of coal particle size.
Table 1. Outburst shockwave overpressure at different positions of pipe

| Sensor number | Distance (m) | Peak positive overpressure (kPa) | Peak negative overpressure (kPa) |
|---------------|--------------|----------------------------------|----------------------------------|
|               |              | 3–10mm | 1–3mm | 0.5–1mm | 3–10mm | 1–3mm | 0.5–1mm |
| 1#            | 0.5          | 10.72  | 4.70  | 2.86    | -11.55 | -5.94 | -4.39  |
| 2#            | 1.75         | 12.40  | 4.56  | 4.70    | -11.50 | -6.09 | -4.08  |
| 3#            | 2.75         | 10.35  | 4.27  | 3.04    | -10.52 | -5.18 | -3.07  |
| 4#            | 3.75         | 10.16  | 4.26  | 3.11    | -10.16 | -4.85 | -2.85  |
| 5#            | 4.75         | 10.30  | 3.43  | 3.39    | -10.52 | -4.14 | -2.47  |
| 6#            | 5.75         | 9.47   | 3.03  | 2.23    | -6.74  | -3.54 | -1.72  |
| 7#            | 6.75         | 6.96   | 1.99  | 1.46    | -3.96  | -2.22 | -1.15  |
| 8#            | 7.75         | 1.98   | 0.67  | 0.53    | -1.15  | -0.86 | -0.40  |

4.2. Outburst shock wave propagation velocity

Table 2 shows the shock wave propagation velocity at different positions in the pipeline under different coal particle size conditions. It can be seen from Table 2 that when the particle size of coal powder is 3–10 mm, 1–3 mm and 0.5–1 mm, the maximum shock wave velocity appears at No. 1 or No. 2 measuring points, which are 358 m/s and 347 m and 347 m/s, the average speed is 353 m/s, 345 m/s and 344 m/s, respectively.

In general, the particle size of pulverized coal has a small effect on the propagation velocity of the outburst shock wave, but it tends to decrease as the particle size decreases. The formation of the protruding shock wave is mainly due to the instantaneous release of high-pressure methane gas into the pipeline when the pressure is released from the cavity. However, the motion state of the pulverized coal-gas two-phase flow into the pipeline in the later stage has a certain influence on the propagation of shock waves. When the particle size of the pulverized coal is large, the pulverized coal-gas two-phase flow mostly moves in the state of stratified flow in the pipeline. That is, the airflow moves above the pipe, while the pulverized coal particles move below the pipe, and the pulverized coal particles hinder the movement of the airflow less. When the particle size of the pulverized coal is small, the pulverized coal-gas two-phase flow mostly moves in the form of a mixed flow. At this time, part of the kinetic energy of the airflow is transferred to the pulverized coal particles, and the velocity of the pulverized coal particles increases, but the airflow velocity decreases.

Table 2. The propagation speed of outburst shock wave at different positions of pipe

| Sensor number | u (m/s) | 3–10 mm | 0.3–1mm | 0.5–1 mm |
|---------------|---------|---------|---------|----------|
| 1#            | 355     | 347     | 344     |
| 2#            | 358     | 347     | 347     |
| 3#            | 355     | 346     | 344     |
| 4#            | 354     | 346     | 345     |
| 5#            | 355     | 345     | 345     |
| 6#            | 354     | 344     | 343     |
| 7#            | 350     | 343     | 342     |
| 8#            | 343     | 341     | 341     |

4.3. Outburst shock wave attenuation

Table 3 shows the attenuation coefficient of the outburst shock wave at different positions in the pipeline under different coal particle size conditions. Generally speaking, the relationship between the shock wave attenuation coefficient and the shock wave propagation distance at the front end of the pipeline (No.1–4) is not obvious, but at the end of the pipeline (No.5, No.6 and No.7), the shock wave attenuation coefficient increases with the increase of the propagation distance, and the attenuation coefficient of the negative phase overpressure peak also shows a similar law. When the particle diameters are 3–10mm, 1–3mm and 0.5–1mm, the maximum attenuation numbers of protruding shock waves all appear at the end of the roadway, and the peak attenuation coefficients of normal phase overpressure are 3.52, 2.97, and 2.75, respectively. The peak attenuation coefficients of negative phase overpressure were 3.44, 2.58
and 2.88, respectively. Due to the relatively discrete data at the end of the roadway, the average attenuation coefficient of each series except the end of the roadway is averaged, and it is obtained that when the particle size of the pulverized coal is 3~10mm, 1~3mm, and 0.5~1mm, the average normal phase overpressure peak attenuation coefficients in the pipeline are 1.09, 1.17, and 1.18, respectively, and the average normal phase overpressure peak attenuation coefficients in the pipeline are 1.23, 1.19, and 1.26, respectively. On the whole, the average attenuation coefficient of the outburst shock wave increases with the decrease of the particle size of the pulverized coal.

| Sensor number | Positive phase overpressure peak attenuation coefficient | Negative phase overpressure peak attenuation coefficient |
|---------------|-------------------------------------------------------|-------------------------------------------------------|
|               | 3~10mm | 1~3mm | 0.5~1mm | 3~10mm | 1~3mm | 0.5~1mm |
| 1#            | 0.69    | 0.82   | 0.49     | 0.80   | 0.78   | 0.86   |
| 2#            | 1.02    | 1.07   | 1.55     | 1.09   | 1.18   | 1.33   |
| 3#            | 0.99    | 1.00   | 0.98     | 1.04   | 1.07   | 1.08   |
| 4#            | 1.09    | 1.13   | 0.92     | 0.97   | 1.17   | 1.15   |
| 5#            | 0.92    | 1.24   | 1.52     | 1.56   | 1.17   | 1.44   |
| 6#            | 1.36    | 1.52   | 1.53     | 1.70   | 1.59   | 1.50   |
| 7#            | 3.52    | 2.97   | 2.75     | 3.44   | 2.58   | 2.88   |

### 5. Conclusion

(1) The shock wave waveforms generated by the different particle size conditions of the pulverized coal show a pulsating development alternately with positive pressure and negative pressure, and the peak overpressure of the shock wave decreases with the decrease of the particle size of the coal.

(2) When the particle size of pulverized coal is 3~10 mm, 1~3 mm and 0.5~1 mm, the maximum shock wave velocity is 358 m/s, 347 m/s, and 347 m/s, respectively. The particle size of pulverized coal has little effect on the propagation velocity of the outburst shock wave, but it tends to decrease as the particle size decreases. When the particle size of the pulverized coal is large, the pulverized coal-gas two-phase flow mostly moves in the state of stratified flow in the pipeline. When the particle size of the pulverized coal is small, the pulverized coal-gas two-phase flow mostly moves in the form of a mixed flow.

(3) When the particle diameters are 3~10 mm, 1~3 mm and 0.5~1 mm, the maximum attenuation numbers of protruding shock waves all appear at the end of the roadway, and the peak overpressure attenuation coefficients of the normal phase are 3.52, 2.97, and 2.75. And the peak attenuation coefficients of negative phase overpressure were 3.44, 2.58 and 2.88, respectively. The average attenuation coefficient of the outburst shock wave increases with the decrease of the coal particle size.

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