Distributed optical fiber monitoring the influence scope of liquid CO₂ fracturing device for rockburst prevention

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Abstract. The liquid CO₂ fracturing device has been applied well in the coal mine dynamic disaster, and the influence scope of fracturing can guide the construction parameters. In this paper, the mechanism of liquid CO₂ fracturing is studied. By means of CO₂ phase transformation process, the volume CO₂ is expanded rapidly, and the fracturing and pressure relief is impacted by the excitation device. The influence scope of liquid CO₂ fracturing is determined, which provides an important basis for field experiments. Industrial tests were carried out in coal mine with different diameters of fracturing apparatus. Distributed fiber optic cables were preburied in advance. Boreholes were arranged directly below the fiber optic cables to cause fracturing. The strain of surrounding rock was monitored by BOTDR demodulator and the fracture parameters were optimized.

1. Introduction
As a kind of fracturing equipment, as early as 20th century, liquid CO₂ fracturing technology was studied and applied in some developed countries⁽¹⁾. In the last ten years, more and more scholars are using the technology⁽²⁾. Liquid CO₂ fracturing technology has been introduced into China and used frequently in coal mining⁽³-⁴⁾. There are few methods at present to investigate the influence scope of liquid CO₂ fracturing. The distributed optical fiber sensing technology is widely used in the monitoring field of rock and soil health structure⁽⁵-⁶⁾. The paper uses this method to monitor the influence scope of liquid CO₂ fracturing, and optimize the parameters so that it can improve the working efficiency.

2. Mechanism of rockburst prevention by liquid CO₂ fracturing device
CO₂ is a colorless, odorless and non-combustible gas at room temperature and atmospheric pressure. It is easy to be liquefied when the temperature is lower than 31.1 °C or the pressure is more than 7.35 MPa. When the heat absorption temperature of liquid CO₂ exceeds 31°C, it enters the supercritical state and changes with the temperature. Above the critical temperature, the gaseous substance will remain in its original form and will not continue to be liquid even if the pressure is higher. According to the phase change process of CO₂, the liquid CO₂ is filled in the lead of the cleavage, and the explosive coil is rapidly activated by the initiator. The liquid CO₂ is vaporized and expanded instantly to produce high pressure. When the pressure reaches the ultimate strength of the shear sheet,

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the shearing plate breaks and high pressure gas is released from the discharge head, realizing the directional fracture of the coal-rock mass. The energy released by liquid CO$_2$ fracturing device can be simplified as figure 1. The coal destruction area is approximately regarded as part of sphere and the influence scope of liquid CO$_2$ fracturing is deduced as follows:

$$L = \frac{6E}{5\sigma_c^2 \theta K - 1} \left[ 1 - \left( \frac{P_2}{P_1} \right)^{\frac{K-1}{K}} \right]$$  \hspace{1cm} (1)

In the formula: $P_1$—gas pressure in the tube, MPa; $P_2$—normal atmospheric pressure, 0.101MPa; $V$—the volume of tube, m$^3$; $K$—CO$_2$ adiabatic index, 1.304; $L$—fracturing radius, m; $\theta$—Angle of fracturing influence scope; $\sigma_c$—uniaxial compressive strength, MPa; $E$—modulus of elasticity, GPa.

Select three types of fracturing device, ZLQ-38/300, ZLQ-38/600 and ZLQ-53/800 to be tested, which drill diameters are respectively 50 mm, 50 mm and 65 mm. The parameters and influence scope of the device are shown in Table 1.

| Size specifications | External diameter /mm | Bore size /mm | Length of tube/mm | Drug coil length /mm | Shear strength /MPa | Gas volume /kg | Influence scope /m |
|---------------------|-----------------------|--------------|-------------------|---------------------|-------------------|----------------|-------------------|
| ZLQ38/300           | 38                    | 24           | 300               | 150                 | 300               | 0.084          | 0.62 ~ 0.79       |
| ZLQ38/600           | 38                    | 24           | 300               | 150                 | 300               | 0.168          | 0.79 ~ 0.99       |
| ZLQ53/800           | 53                    | 37           | 800               | 250                 | 300               | 0.530          | 1.16 ~ 1.46       |

3. Distributed optical fiber monitoring the influence scope of liquid CO$_2$ fracturing device

3.1. Test objective and monitoring principle

In order to determine the influence scope of liquid CO$_2$ fracturing for rockburst prevention, distributed optical fiber sensing technology is used to monitor the effect of fracturing in panel 8939. Compared with the conventional borehole pressure relief measure, the effective influence scope and reasonable borehole spacing are determined.

The optical fiber sensing technology is a sensing technology which adopts light wave as the carrier and fiber as a medium to perceive and transmit external measured signals. It has the advantages of strong resistance to electromagnetic interference, high sensitivity, waterproof and moisture-proof, and can be monitored over a wide distance. The distributed optical fiber sensing technology is based on
Brillouin optical time domain analysis technology. It can measure the strain of every point in the optical fiber in a distributed way, realize the precision continuity and universality of the monitoring. The distributed optical fiber cable and test pipe are cemented together with the surrounding coal-rock mass after grouting to seal the hole, then the cable, test pipe and coal-rock mass are consolidated together. The cable will deform harmoniously with surrounding coal-rock mass. Pressure relief borehole and liquid CO\textsubscript{2} fracture hole are constructed directly under the distributed optical fiber cable, resulting in the deformation of coal. The fiber-optic cable laid around the pipe will follow the bending and tensile deformation of the coal, it can show the pressure relief influence scope of coal as figure 2.

3.2. Test design and construction
A distributed optical fiber monitoring hole is constructed in the winch nest (1254m) in roadway 5939. The parameters are as follows: 1.4 m from the coal wall, 1.2 m from the bottom, the angle between the fiber-optic monitoring hole and the coal wall is 5°, the elevation angle of the hole is 1°, the hole diameter is 65 mm, and the hole depth is 50 m. After the completion of optical fiber hole, a 44 m long distributed fiber-optic cable is arranged. The pressure relief borehole and liquid CO\textsubscript{2} fracture hole were constructed with a 3kW crawler drill at 0.2m directly below the fiber. According to the theoretical calculation results, the spacing of fracture holes is unified to 3m. Nine boreholes were drilled to monitor the effect of pressure relief, which is shown as figure 3.

3.3. Analysis of monitoring data
The strain of distributed fiber-optic cable reflects the deformation characteristics of the borehole. The tensile strain is generally defined as positive and the compressive strain is negative. Figure 4 is the strain distribution curve of the distributed fiber-optic cable. The monitoring data showed tensile strain
in general, which indicated that tensile deformation was produced around the borehole, and the pressure relief effect was achieved to a certain extent.

Table 2 obviously shows that the surrounding coal is loosened and deformed, and the plastic range increases by 25.0% to 62.5% compared with Φ108mm pressure relief hole after taking liquid CO₂ fracturing measures. Therefore, fracturing device ZLQ53/800 matches borehole Φ65mm, the pressure relief effect is better than others.

![Figure 4. Distributed fiber-optic monitoring curve](image)

Table 2. Monitoring effect of different holes

| type                              | Maximum strain /με | Maximum influence scope/m | Year-on-year increase |
|-----------------------------------|--------------------|----------------------------|-----------------------|
| Φ108mm pressure relief hole       | 127.6              | 1.6                        | —                     |
| Φ50mm fracture hole (ZLQ38/300 and ZLQ38/600) | 143.1              | 2.0                        | 25.0%                 |
| Φ65mm fracture hole (ZLQ53/800)   | 147.8              | 2.6                        | 62.5%                 |

4. Conclusion

(1) The paper studied the mechanism of liquid CO₂ fracturing and calculated the influence scope of liquid CO₂ fracturing device, which provided important basis for field test.

(2) The effect of liquid CO₂ fracturing was monitored by distributed optical fiber sensing technology. The results show that the pressure relief effect of ZLQ53/800 matching Φ65mm hole is better. The effective influence scope reached 1.3 m which increases 62.5% compared with Φ108mm pressure relief hole.

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