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Application of CO_2 Blasting Permeability Improvement Technology in Gas Pre-drainage Test

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For the purpose of improving the low coal seam permeability and overcoming the heavy workload, high cost, drainage concentration and poor effect of gas drainage on the 5917 working face of Longfeng Coal Mine, this paper applies the safe and efficient CO_2 deep hole blasting permeability improvement technology in the experimental study of the object, examines the radius of influence of fracture-inducing hole, gas flow and other related parameters in the means of field test, lab test, etc., and conducts enhanced coal seam permeability improvement with CO_2 fracturing technology. The resulting drill hole gas flow and pure flow of gas drainage are respectively 2.2-4.7 times and 5-12 times of the original values, indicating that the proposed method has significant effect on permeability improvement and high feasibility of enhancing efficiency and increasing production.

1. Introduction

Thanks to the development of the mining industry, coal mining in China has entered a new stage of safe and efficient mining. However, the safe mining of coal mines is still overshadowed by mine gas disasters. As the coal mining gets deeper and deeper, low-gas mines are gradually replaced by high-gas mines and the geological conditions are becoming increasingly complex. What is worse, over 70% of state-owned coal mines in China feature very low gas permeability (Zhao and Wang, 2014) making it immensely difficult to implement direct gas drainage, the essential measure of gas control. Therefore, proper coal seam permeability improvement measures must be taken to achieve the purpose of effective drainage.

At present, the most extensively studied and applied coal seam permeability improvement measures including drilling technology (large aperture drilling, dense drilling, cross drilling; Ridha et al., 2017), cutting technology, deep hole blasting technology, hydraulic fracturing, etc (Gao et al., 2015; Wang, 2012; Lu et al., 2012; Guo et al., 2016; Deng et al., 2016). Nevertheless, these measures more or less have some defects. Specifically, the drilling technology is not applicable to deep buried high-stress coal seams due to the heavy workload and limited permeability improvement (Xu et al., 2014); hydraulic fracturing is dragged by the strict requirements on drill hole drainage and the possible secondary pollution of high pressure water to the coal seam (Zhai et al., 2011); deep hole blasting technology faces constraints like high process risk, potential hazard and likelihood of hole collapse (Rhino et al., 2016). In recent years, CO_2 blasting permeability improvement technology has drawn the attention of numerous researchers owing to the features of safety, pollution-free and reusability. However, the effect of the new technology has not been thoroughly verified by field tests (Sun et al., 2012). In light of this, this paper mainly studies and discusses the mechanism of CO_2 blasting permeability improvement technology and the test results of the gas pre-drainage in Longfeng Coal Mine, Guizhou, China.

2. Mechanism of CO_2 blasting permeability improvement technology

CO_2 blasting permeability improvement technology is a physical blasting measure that applies the high-pressure CO_2 gas (up to 270MPa) generated within 20msec in the gasification of liquid CO_2 under certain conditions instantaneously on the hole wall to crack or fracture the target medium (rock or coal) (Fu et al., 2014). Featuring safety, simple operation and high applicability, the technology is applicable to coal mines, non-coal mines, metallurgy, cement, quarrying and other industries. For example, it offers a viable alternative

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for the traditional explosives in civilian areas, and its unique advantages are best exploited in special areas (Santoro and Gorelli, 2006). In coal mines, the technology can be used for comprehensive gas control, rock burst control, outburst elimination, top coal softening, rock cross-cut coal uncovering, roadway floor heave treatment, coal bunker blockage removal, etc (Yang et al., 2014; Cui and Bustin, 2005). CO_2 fracturing device consists of such six components as filling valve, starting device, liquid storage tube, sealing gasket, constant pressure shear piece, release tube (Figure 1). In engineering projects, the device is used in synergy with auxiliary devices like stop device, hole packer, connecting rod and so on. Unlike traditional explosives, CO_2 fracturing device does not produce any shock wave, open flame, heat source or any of the toxic and harmful gases generated in chemical reactions. As a physical starting equipment, CO_2 fracturing device boasts strong safety, stable performance, and easy operation. The main technical advantages and characteristics of the device are as follows:

1) The starting takes place in the closed tube; the released CO_2 suppresses explosion and inflammation and does not detonate the gas;

2) The fracturing device greatly reduces the probability of gas outburst because it has a small vibration and does not produce a destructive shock or shock wave;

3) The fracturing device boasts high safety during filling, transport and storage as the starting device cannot be started by vibration and impact;

4) The large fracture diffusion radius reduces the number of drill holes for gas drainage;

5) The ability of the fracturing device is controllable, i.e. the energy level can be configured according to specific environments and objects;

6) The fracturing device is conducive to the production of clean block coals thanks to the high rate of coal block, short throwing coal distance and low dust;

7) The fracturing device does not produce toxic and harmful gases, thus cutting back on the distance of avoidance; therefore, it enables coal miners to return to the working face quickly for continuous operation.

8) The fracturing device features good reusability and long service life (10 years).

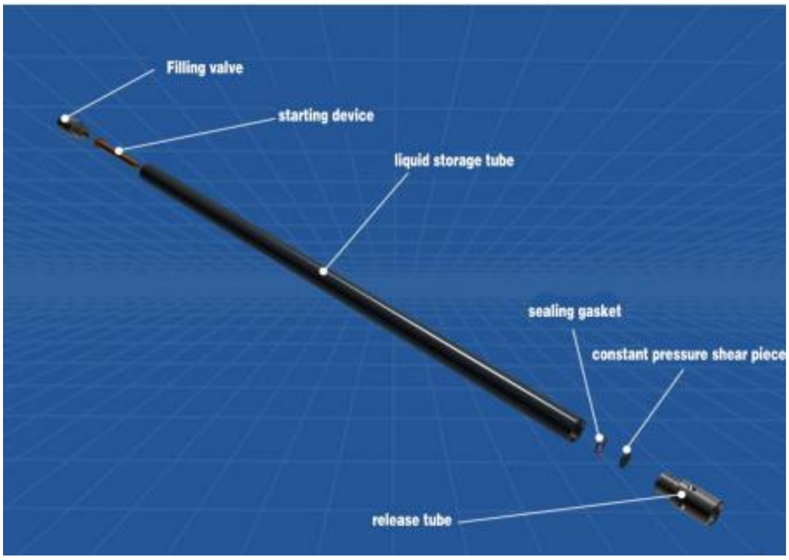

Figure 1: Structure of CO_2 fracturing device

3. Experimental study on the application of CO_2 blasting in gas pre-drainage of Longfeng Coal Mine

3.1 Overview of working face

In Longfeng Coal Mine, the main mining areas are the 9# coal seam in the first and third working fields. The coal seam claims a reserve of about 2.87 million t, and contains 12.93 m^3/t of original gas. Located in Jinsha County, part of a broader outburst mining area, it is designed as a coal and gas outburst mine. According to the *Verification Report on Resource Reserves of Longfeng Coal Mine, Jinsha County, Guizhou Province*, the 9# coal seam boasts a total resource of 331.4455 million m^3, including 125.4475 million m^3 of drainable gas, and the coal seam is free of coal dust explosion hazard. The working face being tested is the excavation working face of the #5917 ventilation roadway in the 9# coal seam. It is installed with gas drainage piping and provided with 8 drainage drill holes down the seam. Arranged at an interval of 3m, the 100m deep drill holes have been connected to the drainage piping network.

3.2 Test plan

3.2.1 Hole layout

In this test, the drill holes (depth: 100m; radius: 75mm) are arranged on the coal walls in the ventilation roadway of the #5917 coal working face. The drill holes are 1.2m above the floor. In the surroundings, there are no geological structures like significant folds, faults or crushed zones. One observation hole is placed on each side of the planned fracture-inducing hole by a spacing of 5m. The two observation holes are denoted as K1 and K2, respectively. After the observation holes are arranged, the temporal variation of the gas emission is measured. Then, the main drainage piping is connected for gas drainage. When the gas drainage is stabilized, the fracture-inducing and permeability improvement hole is arranged and the effect of gas drainage is measured and compared with the extraction effect before the fracturing. See Table 1 for the specific numbers and layout of the holes.

Table 1: Drill hole parameters

Drill hole number	Aperture (mm)	Azimuth (°)	Horizontal angle (°)	Remarks
G1 hole (17-0040)	75	32	-5	Observation hole
G2 hole (17-0042)	75	32	-6	Observation hole
Z1 hole (17-0041)	75	33	-6	Fracture-inducing and permeability improvement hole

3.2.2 Fracturing device parameters

This research plans to use the MZL200-51/1400 fracturing device. It is a CO_2 fracturing device, falling into the category of physical blasting equipment for mines. CO_2 fracturing permeability improvement technology utilizes the high pressure generated in the instantaneous expansion (within 20msec) of liquid CO_2 under certain conditions to cut coal mass, improve the efficiency in permeability, induce fracturing, and expand coal fissures, aiming to increase the permeability of coal and promote gas displacement. The technology can effectively increase the radius of coal seam gas drainage and improve the efficiency of gas control.
The parameters of CO_2 fracturing device are shown in Table 2.

Table 2: Main technical parameters of CO2 fracturing device

Model	MZL200-51/1400
Outer diameter of liquid storage tube (mm)	51
Length of liquid storage tube (mm)	1400
Volume of liquid storage tube (L)	1.0
Thickness of constant pressure shear piece (mm)	2.5
Discharge pressure (MPa)	200
Heating material specifications and model / mass (g)	60
CO_2 filling volume (g)	900±100
Maximum designed CO_2 filling pressure (MPa)	7
Dimensions (diameter × length) mm	Φ51 × 1560

3.2.3 Overall plan for fracturing permeability improvement

The number of fracturing devices in a single hole is determined by the depth of the fracture-inducing hole. The author adopts the deep hole fracturing device arrangement plan for this research: drill 100m deep holes on the 120m long coal mass. The external 20m of the coal mass is defined as the pressure relief area and is not treated with enhanced permeability improvement, while the internal 80m is defined as the enhanced permeability improvement area, in which the CO_2 fracturing devices are arranged evenly from the bottom to the top. One fracturing device is accompanied by 3 extension bars (or 4 extension bars depending on the actual situation). In total, there are 18 CO_2 fracturing devices and 48 extension bars (Figure 2).

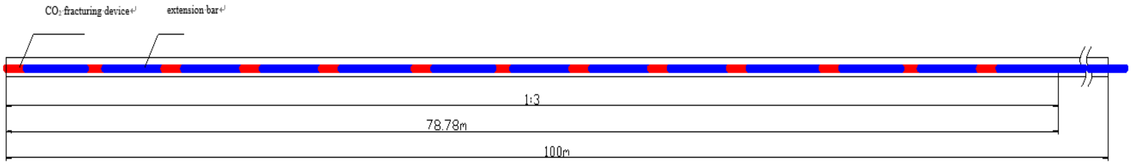

Figure 2: Arrangement of fracturing device in fracture-inducing hole

The construction process of CO_2 fracturing device specifies the steps (Figure 3) for various operations of the CO_2 fracturing device, ranging from the assembly on the ground, the filling of liquid CO_2, the testing of the device, the installation or removal of the device into/from the underground drill hole, to the connection to the connecting rod and other accessories.

The whole implementation of pre-fracturing permeability improvement goes as follows:

a) Assemble, fill and test CO_2 fracturing device;

b) Transport and install fracturing device installation underground (the number and sequence of fracturing devices and connecting rods are determined according to actual demand) and detect pre-fracturing parameters;

c) Evacuate the personnel (for no less than 300m), set up security cordon, conduct fracturing as per design procedures;

d) After fracturing, the starting device operator, gas inspector, team leader and safety inspector (blaster) should jointly carry out the safety inspection, and allow no one into the test area if the area fails to pass the inspection;

e) After fracturing, the liquid storage tube and accessories of fracturing device should be removed by the push device and transported to the ground;

f) Test the effect of the fracturing permeability improvement.

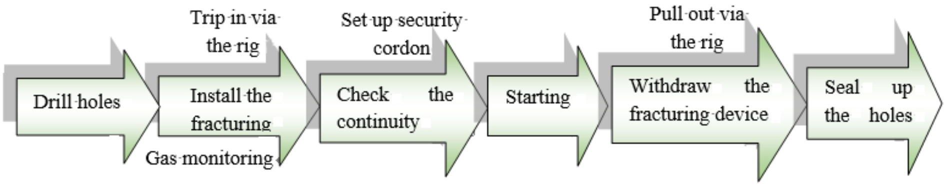

Figure 3: Process flow of underground fracturing permeability improvement

3.2.4 Measurement and recording of experimental data

Table 3. Gas drainage effect results

Hole No.		Location:		Date:	
No.	Name of test item	Unit	Pre-fracturing	Post-fracturing	Comparison
1	Natural emission of gas	m^3/min			
2	Drill hole gas concentration	m^3/t			
3	Gas drainage concentration	%			
4	Pure drainage flow	m^3/min			
5	Effective drainage time	d			
6	Negative pressure	Pa			
7	Pressure difference	Pa			
8	Air pressure	Pa			
9	Temperature	°C			

(1) Upon arranging the observation holes, seal up the holes immediately. Measure the gas flow and concentration of the holes right after the holes are sealed up. For each drill hole, the two parameters are measured five times at an interval of 10min. After the test, drain the gas from the observation holes and record the drill hole gas flow and concentration during the drainage.

(2) Arrange a fracture-inducing hole parallel to the test holes. After the arrangement is completed, measure the flow rate and gas concentration of each test hole for ten times at the interval of 10 min.

(3) Implement enhanced permeability improvement on fracture-inducing and permeability improvement hole. After that, measure the flow rate and gas concentration of each test hole for ten times at the interval of 10 min.
(4) At the end of permeability improvement, seal up the fracture-inducing and permeability improvement hole. The sealing distance should not exceed the depth of drill hole. After the sealing, connect the observation holes to the drainage piping and start the gas drainage.
(5) Measure the gas flow and concentration for each drill hole continuously for 15 days.

3.3 Detection records and analysis

The test results are evaluated by SF6 gas tracer method and flow method. The specific parameters are listed in Tables 4, 5 & 6. After injecting the SF_6 tracer gas is injected into the fracture-inducing hole, samples are taken from the two observation holes next to the fracture-inducing hole every 2 hours. The tracer gas is discovered in both observation holes at 2h and 4h after the injection. Meanwhile, the relevant parameters of gas drainage in the two observation holes are measured and compared. It is found that the gas drainage flow increases from 0.065m^3/min to 0.144m^3/min in the left observation hole, and grows from 0.084m^3/min to 0.396m^3/min in the right observation hole. This means the amount of free gas and coal seam permeability have rocketed up after fracturing permeability improvement.

Table 4: Environmental parameters at the observation place after fracturing

Index	Parameters
Temperature	20°C
CH_4 concentration	0.06%
CO_2 concentration	0.04%
CO concentration	0
O_2 concentration	19.8%
NO_x	0

Table 5: Drill hole gas flows before and after fracturing

Observation holes	Pre-fracturing flow (m^3/min)	Post-fracturing flow (m^3/min)	Parameter comparison (times)
17-0040 (G1 hole)	0.065	0.144	2.2
17-0042 (G2 hole)	0.084	0.396	4.7

Table 6: Drill hole pure gas flows before and after fracturing

Observation holes	Pre-fracturing flow (m^3/min)	Post-fracturing flow (m^3/min)	Parameter comparison (times)
17-0040 (G1 hole)	0.0099	0.1188	12
17-0042 (G2 hole)	0.0003	0.0016	5.3

4. Conclusion

(1) It is safe and reliable to apply CO_2 fracturing device in deep hole pre-fracturing enhanced permeability improvement for the pre-fracturing neither produce fume or harmful gases (e.g. CO, NO_x), lead to CO_2 overrun, nor undermine roadway stability.
(2) The application of CO_2 fracturing technology in coal seam enhanced permeability improvement manages to create a large number of new fissures around the pre-fracturing hole and drive the propagation of the original fissures. The resulting drill hole gas flow and pure flow of gas drainage are respectively 2.2-4.7 times and 5-12 times of the original values, indicating that the proposed method has significant effect on permeability improvement.
(3) Through the field tracer gas inspection and comparison between the gas drainage parameters before and after the fracturing, the effective fracturing radius is greater than 5.3m, which is 3.5 times of that before fracturing.
(4) If the CO_2 fracturing permeability improvement plan is adopted for gas drainage at #5917 working face, it can reduce the original 189 gas drainage holes to 57, saving 70% of the workload. Apart from reducing the engineering cost, the adoption also shortens the construction cycle and greatly improves the drainage effect. The research demonstrates that the proposed method guarantees the safe and efficient mining of the relevant coal seam and shows excellent economic and social benefits.

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Reference

Cui X., Bustin R.M., 2005, Volumetric strain associated with methane desorption and its impact on coalbed gas production from deep coal seams. Aapg Bulletin, 89, 1181-1202.

Deng S.S., Guo L.H., Guan J.F., Guo G.D., Yang X., 2016, Research on the prediction model for abrasive water jet cutting based on ga-bp neural network, Chemical Engineering Transactions, 51, 1297-1302, DOI: 10.3303/CET1651217

Fu J., Fu X., Sun M., Guo Q., 2014, Gas Control Technology Based on the Hydraulic Measures of "Drilling Cutting Pressuring. Safety on Coal Mines. 5, 47-51. DOI: 10. 13347/j.cnki.Mkaq. 2014. 05.013.

Gao Y., Lin B., Yang W., Li Z., Pang Y., Li H., 2015, Drilling large diameter cross-measure boreholes to improve gas drainage in highly gassy soft coal seams. Journal of Natural Gas Science & Engineering, 26, 193-204.

Guo L.H., Deng S.S., Yang X., 2016, Numerical simulation of abrasive water jet cutting chemical pipeline based on sph coupled fem, Chemical Engineering Transactions, 51, 73-78, DOI: 10.3303/CET1651013

Lu T., Tao Z., Chang F., Zhao Z., 2012, Outburst control in soft and outburst prone coal seam using the waterjet slotting technique from modeling to field work. Journal of Coal Science and Engineering (China), 18(1), 39-48.

Rhino K., Loisy C., Cerepi A., Roux O.L., Garcia B., Rouchon V., 2016, The demo-co 2, project: monitoring and comparison of two shallow subsurface co 2, leakage experiments with gas tracer associated in the carbonate vadose zone. International Journal of Greenhouse Gas Control, 53, 207-221.

Ridha S., Pratama E., Ismail M.S., 2017, Performance assessment of co2 sequestration in a horizontal well for enhanced coalbed methane recovery in deep unmineable coal seams, Chemical Engineering Transactions, 56, 589-594, DOI: 10.3303/CET1756099

Santoro M., Gorelli F.A., 2006, High pressure solid state chemistry of carbon dioxide. Cheminform, 35(10), 917-930.

Sun C., Zhai C., Lin B., Li X., Ni G., 2012, Numerical simulation on characteristics of borehole stress disteibution and technique of pressure relief and permeability improvement. China Coal, 38(8), 95-100.

Wang H.D., 2012, Study on the mechanism of enhancing permeability of high stressed and low permeable coal seam in deep mining by pre-splitting controlled blasting technology. Harbin: Institute of Engineering Mechanics, China Earthquake Administration.

Xu J., Yang X., Lai F., 2014, Present situation and development of permeability improvement technology for enhanced gas drainage in our mines. Mining Safety and Environmental Protection, 41(4), 100-103.

Yang W., Lin B., Yan Q., Zhai C., 2014, Stress redistribution of longwall mining stope and gas control of multi-layer coal seams. International Journal of Rock Mechanics & Mining Sciences, 72, 8-15.

Zhai C., Li X., Li Q., 2011, Research and application of coal seam pulse hydraulic fracturing technology. Journal of China Coal Society, 36(12), 1996-2001.

Zhao B., Wang H., 2014, Different technologies of permeability enhancement of single coal seam in china and new technique of high pressure gas shock. Blasting. 31(3). DOI: 10.3963/j.issn.1001－487X. 2014.03.007.