Field Tests on Permeability Enhancement Technology in Crushed and Soft Coal Seam

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Abstract. Coalbed methane is undergoing vast challenges in the exploration and production process, especially the degasification in low permeability of coal seams with the highest gas concentrations. Enhancing the permeability of soft coal seam should be emphasized. In present work, the field tests on presplitting and blasting technology with deep boreholes have been conducted, besides the permeability variations, including the gas extraction concentration and purity of low permeability coal seam, have been obtained by means of field experiments. Research results have shown that the permeability improved by presplitting and blasting with deep boreholes is 2.5 times higher than that of the original coal seam. Research results promote the prevention and control of coal-gas outburst in low permeability and high gas concentration coal seams.

1. Introduction
In recent years, the enhanced gas extraction method was widely used to solve the problem of difficulty in gas drainage in low permeability coal seam, including extraction with dense boreholes, hydraulic flushing, fracturing and slotting [1]. The enhanced extraction with dense boreholes was proposed for gas drainage according to the seepage theory of professor Zhou shining, and the key point of increasing the amount of gas drainage is reducing the borehole intervals and the negative pressure of extraction hole [2]. Such method can improve the gas drainage effect in a short time, but the gas drainage effect is poor while the permeability of coal seam is low and the drainage time is long.

Initially the hydraulic fracturing technology was successfully applied to Kelpper 1 well in Hugoton gas field, Kansas, USA in the 1950’s [3, 4]. A large amount of drilling fluid with proppants has been injected into the targeted strata by drilling holes, and fractures were subsequently generated in the reservoir, which facilitates the improvement on the permeability of the targeted layer. Gidley [5] and Murdoch [6] have both conducted detailed researches on the technology and principles of hydraulic fracturing, which is widely used in the development of low-permeability oil and gas well fields. In order to increase the permeability of high gas concentration and low permeability coal seam, the hydraulic fracturing technology has been previously applied to the gas drainage borehole by the former Soviet
Union. However, the high-pressure damage caused by hydraulic fracturing of coal roof needs to be solved urgently [7].

The hydraulic flushing and slotting techniques were proposed by the Soviet Union in the early 20th century, and the hydraulic coal mining technology had successfully applied to the gas control and prevention of coal and gas outburst [8]. However, hydraulic coal mining technology can only break the coal seam by jet flow within a certain distance, and the jet flow within this distance is highly efficient, but the coal breaking efficiency is dramatically decreasing while the distance is beyond the assigned scope, in consequence the pressure loss along the hydraulic path is dramatically increased [9].

In order to improve the gas drainage of a coal seam with high gas content and low permeability, the hydraulic-controlled blasting of a deep hole was carried out to increase the permeability [10]. Moreover, the enhanced mining by protective roof has been extensively employed to reducing the pressure and increasing the permeability of coal seams in China, especially in the deep coal extraction of coal seams with high methane content [11]. In present work, the field tests on presplitting and blasting technology with deep boreholes have been conducted, besides the permeability variations, including the gas extraction concentration and purity of low permeability coal seam, have been obtained by means of field experiments.

2. Field tests
The field test site locates in the X10901-3 mining head face of Dawan west coal mine. Neither the upper cover nor the surrounding coal seams of test site has been mined. Based on the characteristics of presplitting and blasting technology with deep boreholes, the geological data and the roadway layout of the working face in the rail roadway of X10901-3, the presplitting and blasting technology with deep blasting boreholes was carried out. Besides the permeability improvement performance of targeted coal seam has been analyzed by the field measurement and statistical analysis. According to the survey suggestions, 3 blasting boreholes and 4 extraction boreholes were arranged in front of working face in the rail roadway of the X10901-3, and the borehole layout is shown in Fig 1. The permeability coefficient, the extraction concentration as well as pure volume, and the methane gas content before and after blasting were investigated in present field tests.

![Figure 1. Blasting and extraction boreholes in field test site.](image)

3. Results and discussions

3.1. Permeability coefficient of tested coal seam
According to the calculation method proposed by China University of Mining and Technology, the gas permeability coefficient of coal seam can be obtained by the methane gas content. The installation and sealing of gas pressure gauge have to be completed once the extraction borehole was drilled, thereby the
natural gas flow rate of extraction borehole can be daily measured while the pressure is stable. The obtained natural gas flow rate of targeted coal seam is shown in Table 1.

Table 1. The measured natural gas flow rate of coal seam after pre-splitting

| Test time (days) | 1# measuring borehole | 2# measuring borehole |
|-----------------|------------------------|------------------------|
| 1               | 1.48                   | 1.52                   |
| 2               | 1.46                   | 1.49                   |
| 3               | 1.44                   | 1.47                   |
| 4               | 1.42                   | 1.45                   |
| 5               | 1.40                   | 1.44                   |
| 6               | 1.39                   | 1.43                   |
| 7               | 1.39                   | 1.42                   |

It can be indicated that the maximum natural gas flow rate of targeted coal seam is 1.52 L/min after blasting with multiple deep boreholes, and the variation of measured gas flow is slight, thus the permeability of gassy coal seam is improved. Moreover, the calculated average permeability of fractured coal seam is $1.72597 \text{ m}^2/\text{MPa}^2 \cdot \text{d}$, which is 2.5 times higher than that of the original permeability with $0.68325 \text{ m}^2/\text{MPa}^2 \cdot \text{d}$.

3.2. Average extraction concentration

As shown in Fig 2, the extraction concentration and pure volume of 1# borehole has been respectively increased by 210% and 320% comparing with the original concentration and pure volume of the coal seam. During extraction with 14 days, the total volume of produced methane gas is $1643 \text{ m}^3$. It can be founded that the extraction performance of 1# borehole is remarkably decreasing within the 14 days, and the maximum extraction concentration is shifting from 40% to 18%, which nearly drops in percentage of more than 55%. Likewise, the maximum extraction pure volume of 1# extraction borehole is ranging from $0.12 \text{ m}^3/\text{min}$ to $0.06 \text{ m}^3/\text{min}$, which decreases more than 50%.

Figure 2. Variation on the average extraction concentration of 1# borehole before and after presplitting.
3.3. Variation on methane gas content
At the first day of blasting, the residual gas content of measured coal seam has reduced by 1.62 m$^3$/t, and the total residual gas content has been reduced by 4.37 m$^3$/t within 6 days of extraction, thus the methane content in the roadways of Dawan coal mine has been remarkably reduced by blasting with deep boreholes. It can be inferred that the methane content decreases with the increase of extraction time, and the reduction rate is rarely slow. Nevertheless, when the distance between heading face and the investigation borehole is larger than 80m, the coal near the investigation borehole will be excluded in the fractured zones, thus at least 7 days of extraction is required if the gas content should be reduced from 10.15 m$^3$/t (original gas content) to 7m$^3$/t (safety and qualified gas content).

It can be concluded that the high-pressure gas formed from explosion interacts with the surrounding coal rock mass, simultaneously the coal and rock will be crushed by the instantaneous compressive stress produced by the explosion, and then the coal body is initially fractured. After the coal body is impacted, the surface of the coal is subjected to a sudden high pressure, which will be exponentially attenuated with the extraction time. Meanwhile, the residual stress waves continue to form the pressure pulse, and then the pressure wave will propagate forward as the form of shock waves, afterwards the strain wave will be gradually generated. The stress from strain waves crush the coal mass to form further fractures, and the initial fractures will be extended to form the new cracks. The formation and evolution of cracks in coal seam increase total volume of fractures, eventually leading to the increase of coal seam permeability coefficient. Thus, the permeability of gassy coal seam has been improved, which guarantee the safety mining and extraction of underlying coal sources.

4. Conclusion
The permeability of gassy coal seam will be enhanced by presplitting and blasting technology with multiple deep boreholes, after 7 days of extraction, the average extraction concentration of extraction borehole was 40%, which is 3 times higher than the original data. Likewise, the average extraction concentration of the extraction hole will be 21% after being extracted within 14 days, which is twice higher than that of the original average extraction concentration.

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