

Research on Enhancing Underground Coal Seam Gas Drainage Effect through Surface Fracturing Drilling

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Abstract

In response to the characteristics of high gas content and low permeability coal seams in Coal Mine, a systematic study was conducted to improve the underground coal seam gas drainage effect using surface fracturing drilling technology. The focus was on examining the impact of surface fracturing drilling on various indicators before and after fracturing of the underground coal seam, including permeability, gas pressure and content, gas drainage concentration, drainage volume and pure volume, gas emission rate, and the K1 value. A quantitative analysis was carried out to investigate the influence of surface fracturing drilling on the underground coal seam gas drainage effect. The results indicate that surface fracturing drilling significantly enhances the permeability of coal seams, effectively reduces gas pressure and content, increases gas drainage concentration and pure volume, decreases gas emission rate, and mitigates the risk of coal and gas outbursts.

Keywords

Surface fracturing drilling; coal seam gas; drainage effect; permeability; gas content; gas emission rate; K1 value.

1. Introduction

Coalbed methane (gas) is a high-quality, efficient, and clean energy source, but it is also a significant factor contributing to dynamic disasters in underground coal mines [1-2]. Gaohe Coal Mine is characterized by coal seams with high gas content and low permeability, for which traditional gas drainage methods have shown limited effectiveness. Surface fracturing drilling technology is currently the primary means of exploiting unconventional oil and gas resources with low or ultra-low permeability [3-5]. This technology first utilizes a high-pressure pump unit on the surface to inject a large volume of high-viscosity fluid into the formation through the wellbore, building up high pressure at the bottom of the well. When this pressure exceeds the formation's bearing capacity, fractures are created in the formation near the well bottom. The continuous injection of fluid carrying proppant allows the fractures to gradually extend forward, with the proppant serving to support the fractures, forming sand-filled fractures with a certain size and high conductivity. This enables oil and gas to flow easily through the fractures into the well, thereby achieving the effect of increasing permeability and production.

Gaohe Coal Mine is located approximately 4 km west of Changzhi City, falling under the administrative jurisdictions of the suburbs of Changzhi City, Changzhi County, and Zhangzi County. The coal seams within the mine field are mainly distributed in the Lower Permian Shanxi Formation (P1s) and the Upper Carboniferous Taiyuan Formation (C3t), with the No. 3 coal seam being the primary mining seam, having an average thickness of 6.71 m and classified as a stable coal seam. The geological structure of the mining area is complex, with multiple

faults and collapse columns present, which have a significant impact on gas occurrence and drainage. Gaohe Coal Mine is a typical coal seam with high gas content and low permeability [6-7]. Due to the low permeability of the coal reservoirs in this region, surface fracturing well technology is employed to improve the seepage conditions of the coal seams. By establishing main fractures in the coal reservoirs, this technology effectively connects the cleat fissures in the coal reservoirs, enhances their seepage capacity, and increases the productivity of coalbed methane wells.

2. Overview of Surface Fracturing Drilling Implementation

2.1. Construction Plan

The surface fracturing drilling wells in Gaohe Coal Mine are categorized into two types based on their purpose: outburst elimination wells and drainage-production wells. The selection of fracturing fluids and proppants is determined according to the geological conditions, mainly including schemes such as active water + quartz sand, and active water with nitrogen co-injection + quartz sand. The construction sequence is divided into drilling engineering, fracturing engineering, and drainage-production engineering.

2.2. Construction Technical Parameters

Due to variations in the geological conditions and coal seam occurrence within the mine field, the construction parameters for each fracturing well differ slightly to ensure optimal fracturing effects. Taking the Huagao 109 surface fracturing well as an example, Well 109 is a drainage-production well that employs active water with nitrogen co-injection as the process, with quartz sand used as the proppant. The fracturing method employed is plain casing fracturing. The main construction parameters for this well are as follows:

- (1) Fracturing fluid: 804.5 m³, comprising 460.01 m³ of pad fluid, 374.85 m³ of sand-carrying fluid, and 5.5 m³ of flushing fluid.
- (2) Injected liquid nitrogen: 50.42 tons.
- (3) Added (20/40 mesh) quartz sand: 40 m³, and (12/20 mesh) quartz sand: 10.25 m³, totaling 50.25 m³ of sand.
- (4) General displacement: 6.56 m³/min, fracture initiation pressure: 11.50 MPa, general operating pressure: 16.17 MPa, and shut-in pressure: 11.15 MPa.
- (5) Fracturing fluid displacement during construction: 3.0-6.0 m³/min, nitrogen displacement: 245 Nm³/min, average sand concentration: 12.9%, and maximum pressure limit: 35 MPa.

2.3. Fracturing Effect Monitoring

The microseismic method is employed to monitor the generation and propagation patterns of fractures during the fracturing process, providing an initial assessment of the fracturing range. The monitoring results indicate that the fracturing fractures develop asymmetrically in multiple directions, with an effective influence range forming an irregular circular area with a radius of 75m and a maximum influence range forming an irregular circular area with a radius of 150m.

3. Impact of Surface Fracturing Drilling on Underground Gas Drainage Effect

3.1. Coal Seam Permeability

The coal seam in the E2307 working face belongs to the No. 3 coal seam of Gaohe Coal Mine, which is characterized by high gas content. The coal seam's permeability coefficient ranges from 0.1597 to 0.2621 m²/(MPa²·d), and the decay coefficient of gas flow from boreholes

ranges from 0.1833 to 0.4389 d⁻¹, indicating that the No. 3 coal seam is relatively difficult to drain gas from. The permeability of the coal reservoir in the E2307 working face is obtained through numerical simulation inversion using logging data based on the permeability formula (1). The permeability formula is as follows:

$$Q = \frac{Z_{sc} T_{sc}}{P_{sc} Z T} \frac{\pi K h (P_c^2 - P_w^2)}{\bar{\mu} L n(r_e / r_w)} \quad (1)$$

The surface fracturing wells Huagao 102, 104, 105, and 107 in the E2307 working face were selected. Based on the drainage-production results, the average daily production per single well was found to be 340.794 m³, 32.43 m³, and 396.609 m³, respectively. (Note: The production data for Well 107 is not included in the specific values listed here as it seems to be an oversight in the original enumeration; typically, all four wells' data would be presented if available.) The gas compressibility factor under standard conditions (ZSC) was taken as 1; the Kelvin temperature under standard conditions (TSC) was taken as 293.15 K; the atmospheric pressure under standard conditions (PSC) was taken as 0.10133 MPa; the average initial gas pressure of the coal seam (Pe) was taken as 1.331 MPa; the coal seam thickness was represented by h; the average fracturing radius (re) was taken as 102 m; the gas well radius (rw) was taken as 0.139 m; Z represented the gas compressibility factor; and the fluid viscosity (μ) was taken as 101.255×10⁻³ MPa·s. The calculated coal reservoir permeabilities are shown in the Table 1. Based on an approximate estimation using the coal seam permeability coefficient, the pre-fracturing coal seam permeability was estimated to be around 0.0656 mD. Without considering factors such as variations in the coal seam's geological structure, changes in the fracturing range, or local fluctuations in gas pressure, a comparison between the inverted permeability data and the pre-fracturing permeability values indicates that the permeability increased by factors of 13.3, 13.1, and 19.2, respectively. This demonstrates that the surface fracturing drilling effectively enhanced the permeability of the coal seam.

Table 1. Inversion of coal seam permeability from logging data

| Well No. | Huagao 102 | Huagao 104 | Huagao 105 |
|----------------------------------|------------|------------|------------|
| Daily production /m ³ | 340.794 | 324.303 | 396.409 |
| Reverse permeability/mD | 0.8842 | 0.8677 | 1.2679 |

3.2. Gas Concentration and Pure Volume of Drainage

In the non-fractured zone, the average gas concentration of the borehole groups ranged from a minimum of 35.4% to a maximum of 44.58%, with an average value of 41.032%. In contrast, in the fractured zone, the average gas concentration of the borehole groups varied from a minimum of 59.72% to a maximum of 78.88%, averaging 70.462%. The influence of surface fracturing wells on the gas concentration of coal seam boreholes is illustrated in Figure 1, which shows the increase in gas concentration. The maximum increase observed was 122%, while the minimum increase was 34%, with an average increase of 71%. Consequently, given that the total volume of gas being drained remains constant, the increase in gas concentration within the boreholes effectively enhances the pure volume of gas in the confluence pipelines, thereby improving the efficiency of gas drainage from underground coal seam boreholes.

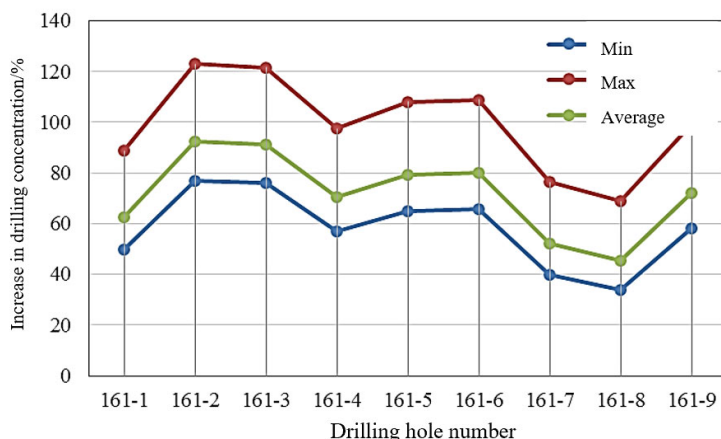


Figure 1. Increase in gas concentration in fracturing area drilling

3.3. Gas Emission Rate

Surface fracturing drilling effectively reduces the amount of gas emitted by ventilation in the heading face. In the E2307 working face, when the intake and return air tunnels were excavated near the fracturing wells, a significant decrease in the gas emission rate through ventilation was observed. This indicates that surface fracturing drilling can effectively reduce the gas emission rate in the mining face of the fractured coal seam.

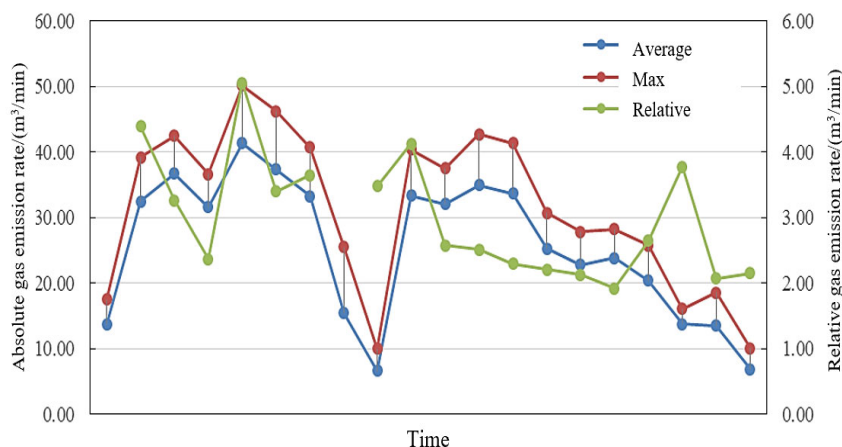


Figure 2. Trend of gas emission changes

3.4. K1 Value

The K1 value is an important indicator for predicting the outburst risk of coal seams. The average K1 values measured in the intake airway, return airway, auxiliary transportation airway, and belt conveyor airway were 0.31, 0.32, 0.31, and 0.33, respectively. As can be seen from Figure 3, during the entire advancement process of the four roadways (return airway, intake airway, auxiliary transportation airway, and belt conveyor airway), the K1 values mostly remained between 0.3 and 0.4, with a small portion staying between 0.2 and 0.3. Sampling was conducted to measure the K1 values in the areas near fracturing wells 105, 107, and 110 in the intake airway, as well as near fracturing wells 97, 103, and 105 in the belt conveyor airway. The average measured K1 values were 0.23 and 0.21, respectively. From a numerical perspective,

surface fracturing drilling has reduced the K1 values in the working face, indicating a decrease in coal seam gas pressure and a reduced risk of coal and gas outbursts.

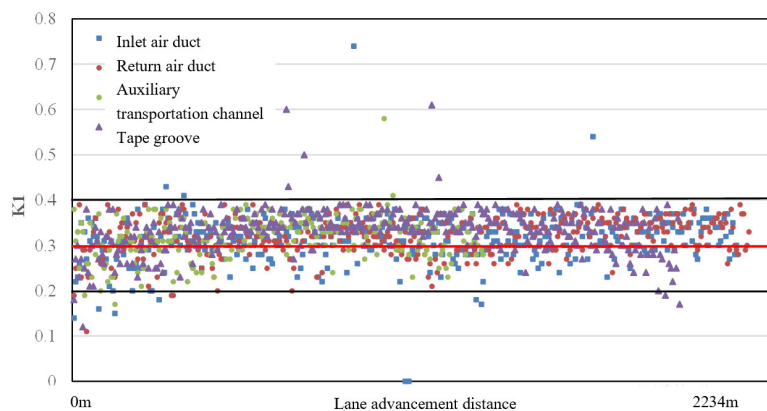


Figure 3. Trend of K1 value change during the process of tunnel advancement

4. Conclusion

Through inversion of logging data, it was found that the coal seam permeability increased by a factor of 13.3 to 19.2 after fracturing, providing strong support for gas drainage through underground boreholes. The average increase in gas concentration from individual boreholes near the surface fracturing wells was 71%, and the pure volume of gas from the boreholes exhibited a linearly increasing trend over time, thereby enhancing the efficiency of gas drainage. Surface fracturing drilling effectively reduced the amount of gas emitted by ventilation in the heading face, minimizing gas emissions from the mining face of the fractured coal seam and lowering the risk of coal and gas outbursts. Additionally, surface fracturing drilling decreased the K1 value in the working face, indicating a reduction in coal seam gas pressure and a corresponding decrease in the risk of coal and gas outbursts.

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