Study on the spatio-temporal relationship between ground fracturing and underground drainage holes arrangement

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Abstract. Based on the respective technical advantages of ground fracturing and underground gas drainage, a joint drainage mode of ground wells and underground is proposed, which focuses on utilizing the large-scale advantages of ground fracturing to promote underground gas drainage. Experimental study of two kinds of ground fracturing and underground drainage connection Mode, that is "Ground fracturing lags behind drilling construction" and "drilling construction lags behind the ground fracturing". Through the micro-seismic method and the underground hole exposure method, it is concluded that the cracks in the coal seam are mainly horizontal cracks with a small northeast opening, and the crack length is about 158~203m. According to the law of crack distribution, fracturing investigation schemes of two modes were designed. The reasonable time connection between the ground fracturing and underground drainage is preliminarily determined by the engineering practice, it is effective in increasing the permeability of the coal seam, reducing the abnormal gas emission from the coal seam and the risk of coal and gas outburst by using "ground fracturing lags behind drilling construction"; the gas drainage effect is remarkable when the underground drilling is delayed within 3 months of ground fracturing by using "drilling construction lags behind the ground fracturing".

1. Introduction

Most coal seams in China belong to low permeability coal seams, and gas is extremely difficult to extract. As the mining depth increases, gas pressure and gas content of the coal seam continue to increase, and the difficulty of controlling gas is further increased\cite{1}. In order to meet the needs of coal mine safety production and achieve coal and coal-bed methane simultaneous drainage, surface drilling and gas drainage technology is widely used in many high-gas mining areas in China. The coal-bed methane ground fracturing technology is a mining technology developed on the basis of oil and gas exploitation technology combined with the characteristics of coal-bed methane reservoirs. After the 1980s, on the basis of the introduction of the main technologies and equipment for exploration and ground development, through independent research and development, China's surface well drainage technology has made great progress, especially in the Jincheng mining area of the Qinshui Basin, it has developed a series of key technologies of “clear water drilling, active water fracturing, constant pressure drainage, low pressure gathering and transportation”. The ground well drainage technology has been very mature, forming an industrial scale. The development of coal-bed methane in the southern part of the Qinshui Basin has always played a pivotal role in China's coal-bed methane industry. The drainage of surface wells has the advantages of large scale and wide control range, but
there are also disadvantages that the direction of fracturing cracks is difficult to grasp, it is difficult to accurately control to the target area, and the drainage is slow, however, underground drilling and drainage can make up for the shortcomings of inaccurate positioning and low drainage efficiency. The combination of the two will achieve breakthrough improvement in drainage efficiency\[2-3\]. Since ground well drainage and underground drainage are two independent industrial models, how to effectively combine the technical advantages of the two modes is a technical problem.

In response to this situation, Jincheng Mining Area has developed a “three-zone” linkage drainage model\[4-6\] for coal mine planning areas, development preparation areas and production areas, in which the ground fracturing operations in the production area are closely linked to the underground drilling and drainage in time and space. The cross-influence is large, and the mining operations are reasonably arranged, which can promote each other. For this reason, the relationship between the ground fracturing and the underground drainage in the production area will be discussed.

2. Ground fracturing and underground drilling drainage connection mode in production area

For the production area that already has the conditions for underground drilling, the ground well fracturing and the underground drainage can be connected in time to study on the “pre-fracturing arrangement of underground drill hole” connection mode of ground fracturing after underground drilling. For the production area that does not have the underground drilling construction conditions for the time being, it is possible to study on the “underground drilling lag ground fracturing arrangement” connection mode of the construction of the underground drilling lags the ground fracturing at different times. The reasonable connection relationship between the ground fracturing and the underground drainage in the production area is given, and the gas drainage layout is optimized.

3. Gas drainage mode for laying underground drilling holes before ground fracturing

When arranging underground drilling holes before ground fracturing, it is necessary to coordinate the mine roadway and drilling arrangement with the ground fracturing well position in space, and the drilling holes should be arranged outside the ground fracturing range. Owing to the ground fracturing pressure is large, it can reach more than 30MPa, if the underground drilling holes arranged in advance are in the fracturing area or communicates with the ground fracturing crack, the borehole sealing technology is difficult and drilling is easy to be pressed through. To this end, the ground micro-seismic monitoring method was used in the Zhaozhuang Mine to determine the fracture range and extension law of the ground fracturing well, and to provide a basis for the advanced ground fracturing arrangement of the boreholes in the test area. The measurement results are shown in table 1.

| Well number | Crack length (m) | Crack orientation (°) | Crack occurrence |
|-------------|------------------|-----------------------|-----------------|
|             | East side | West side | Whole crack | NE62.3° | Horizontal |
| 1           | 74.5     | 83.2     | 157.7       | NE62.3° | Horizontal |
| 2           | 95       | 100      | 195         | NE49°   | Horizontal |
| 3           | 96       | 107      | 203         | NE81°   | Horizontal |
| 4           | 91       | 97       | 188         | NE70°   | Horizontal |

In the fracturing process, the ground micro-seismic method was used to detect the cracks in 4 ground wells. The monitoring results show that the cracks in the coal seam are mainly horizontal cracks, and the crack orientation is North east (NE49°~NE81°). The total length of the crack is about 158~203m. The crack is dominated by a small opening main crack.

As shown in figure 1, according to the experience of revealing the underground crack in the roadway, the crack width is generally about 10cm, and the fracturing center is the widest. As the two ends extend, the crack gradually narrows until it is pinched. Under the influence of fracturing, there
are micro-fracture development around the main crack, and the underground drilling which advanced ground fracturing should avoid the main crack and the micro crack area [7-9].

![Diagram of Underground Drilling Layout](image)

**Figure 1.** Underground drilling layout diagram before and after ground fracturing.

4. **Gas drainage model of underground drilling construction lag ground fracturing at different times**

Because of no space limitation, the ground fracturing operation is easy to implement, and in actual production, it often precedes the construction progress of the underground drilling. In order to explore the reasonable lag time of the underground drilling, as shown in figure 2, the underground drilling was arranged at the 3 months and 6 months after the fracturing of the ground well, and the construction was carried out to the fracturing zone. Under the same condition of the hole, the parameters such as difficulty level, borehole formation rate, borehole flow rate and concentration of the borehole were investigated with different lag time. The reasonable lag time for underground drilling after ground fracturing was determined through research.

![Diagram of Drilling Lags behind Ground Fracturing Construction](image)

**Figure 2.** Diagram of drilling lags behind the ground fracturing construction with different time.

5. **Engineering applications**

The ground fracturing combined mining experiment was carried out in the test area, and the time connection relationship between ground fracturing and underground drainage was studied separately. For the drainage mode of the underground drilling hole before the ground fracturing, two ground well
tests were selected, and the drilling holes were arranged in the outer micro-fracture area of one of the ground wells for interception and drainage, and the other one took drilling drainage after the ground fracturing. According to the drainage model of underground drilling lag the ground fracturing at different time, the construction drilling holes which passed through the bottom of the fracturing well were delayed by 3 months and 6 months respectively after the two ground wells were fractured. All the test drilling drainage data are grouped and measured.

5.1 Comparative study on the drainage effect of underground drilling before and after ground fracturing

Through the analysis of the drainage monitoring data, it is effective in increasing the permeability of the coal seam, reducing the abnormal gas emission from the coal seam and the risk of coal and gas outburst by using “ground fracturing lags behind drilling construction”.

(1) Drilling gas drainage efficiency is obviously improved, and coal seam gas drainage time is effectively shortened.

The average initial flow rate of the 100-meter boreholes arranged before and after the ground fracturing are 0.0453 and 0.032 m³/(min·hm), respectively. The former is 1.42 times of the latter. The gas flow attenuation coefficient of the borehole before and after ground fracturing are 0.032 d⁻¹ and 0.054 d⁻¹, respectively, the latter is 1.7 times of the former. The borehole flow attenuation rate after ground fracturing is significantly faster than that of the borehole arranged before the fracturing.

The average daily gas drainage volume of the boreholes arranged before and after the ground fracturing are 500m³/d and 125.6m³/d, respectively. The former average 100-meter borehole flow rate is 0.023 m³/(min·hm), which is 3.4 times that of the latter 0.0067 m³/(min·hm); The time that the gas concentration of the borehole drainage is attenuated from 50% to less than 10%, the former is 4 weeks, and the latter is 2 weeks. Due to the improvement of the above drainage parameters, compared with the boreholes arranged after the fracturing, the drilling drainage volume arranged before the ground fracturing increased by 4 times in one month; The gas drainage time of reaching standards has been reduced from 90 days to 40 days, and the drainage efficiency has increased by 56%.

(2) By using underground drilling for advanced ground fracturing, it can promote the release and circulation of coal seam gas, and actively control the gas emission from the coal seam to the roadway.

After the fracturing, the average roadway gas emission rate in the fracturing area that using underground drilling for advanced ground fracturing drops to 2.05 m³/min (the gas emission rate from the roadway where the borehole is arranged after the fracturing is 2.28 m³/min) during the tunneling process, and the largest gas emission amount is 4.1 m³/min (the largest gas emission rate from the roadway where the borehole is arranged after the fracturing is 7.3 m³/min). It can be seen that compared with the drilling after the fracturing, the drilling is arranged before the ground fracturing, which reduces the difficulty of ventilation in the roadway and is beneficial to the ventilation safety during the roadway excavation.

(3) The coal and gas outburst risk prediction indicators in the drainage area that using underground drilling for advanced ground fracturing are significantly reduced, and the risk of coal and gas outburst is reduced.

In the drainage area where the underground drilling is used for the advanced ground fracturing, the ratio of the K₁ index during the drainage to more than 0.4 ml/gmin⁻¹/² is 50%, and the drainage area where the borehole is arranged after the fracturing is 21.5%. The influence factors of coal and gas outburst in the drilling area of the advanced ground fracturing arrangement are significantly reduced, which directly reduces the risk of coal and gas outburst and ensures the safety of mining operations under the well.
5.2 Comparative study on the gas drainage effect of underground drilling with delayed ground fracturing at different times

As shown in figure 3, after the ground fracturing, the cracks are driven by the high-pressure fracturing fluid, expand along the primary cracks and the joint weak surface, and will undergo three stages of “rapid expansion-crack retention-tend to close”. The permeability of coal seams has also undergone three stages of “rapidly increasing-maintaining stability-gradually decreasing”. The drilling construction has three stages of “relative difficulty-relatively easy -return to normal”. In the time connection, the underground drilling construction should be finished before the fracturing forms a relatively stable dynamic equilibrium phase (crack retention phase).

In order to investigate the reasonable lag time of the drilling, the drilling to the bottom of the fracturing well was carried out at different time in the test area, and the effect of gas drainage at different time of drilling lag was investigated. As shown in table 2, investigation on drilling construction and drilling field drainage effect be done with underground drilling delayed ground fracturing for 3 months and 6 months.

Table 2. Drilling construction and drilling field drainage of drilling lags behind the ground fracturing construction with different time.

| Hole in fracturing area | Lag time | Hole formation rate | Drilling day footage (m) | Average concentration (%) | 100 meters hole gas pure flow (m³/min) |
|-------------------------|----------|---------------------|--------------------------|----------------------------|--------------------------------------|
| 3months                 | 84%      | 215                 | 75                       | 0.0142                     |
| 6months                 | 83%      | 210                 | 61                       | 0.0107                     |
| Hole in unfractured areas | 85%      | 190                 | 54                       | 0.0082                     |

It can be seen from the above table that when the underground drilling is delayed ground fracturing for 3 months, the drilling day footage is increased, the drainage efficiency is significantly improved, and 100 meters hole flow rate is 0.0142 m³/min, which is 1.5 times that of the unfractured area; the underground drilling which lag behind the ground fracturing for 6 months, compared with the lag of 3 months, the hole forming rate and the daily footage are not much different, the drilling gas concentration is decreased, and the 100 meters hole flow rate is obviously reduced, which shows that the gas permeability of the coal body is significantly reduced; however, compared with the borehole in the unfractured area, the drainage effect is improved.

In summary, it is a reasonable connection time for the underground drilling to lag behind the ground for 3 months. Preliminary analysis shows that the crack is in the holding stage at this time. The
fracturing fissure and the coal body have formed a new dynamic equilibrium and are in a relatively stable state. The pressure is released, the hardness of the coal body becomes larger, and the plasticity is enhanced.

5.3 The relationship between ground fracturing and underground drainage is determined

In the production area, for the use of ground fracturing to promote underground drainage and solve the problem of gas control, for those already equipped with drilling conditions, the underground drilling holes may be arranged in advance in the periphery of the micro-fracture zone of the fracturing well before the implementation of the ground well fracturing, and a large amount of gas displaced during the propagation of the fractured cracks by the constructed drilling holes may be utilized. For the case that there is no drilling construction condition before the ground fracturing, the construction operation should be arranged reasonably, and the construction drilling should be selected within a short period of time. The lag time obtained from the preliminary investigation is less than 3 months.

6. Conclusions

(1) Two types of articulation modes for arranging underground boreholes before ground fracturing and arranging underground boreholes lag behind ground fracturing at different times.

(2) By comparing the effects of gas drainage in the underground boreholes arranged before and after ground fracturing, it is preferred to arrange underground drilling holes before the ground well fracturing, and use these constructed boreholes to intercept and drainage large volumes of gas from the fracturing displacement.

(3) For the drainage mode of underground drilling hole lag behind ground fracturing with different time, the preliminary investigation shows that the reasonable relationship between the ground fracturing operation and the underground drilling is that drilling construction delayed ground fracturing within 3 months.

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