Research on horizontal directional staged fracturing technology for roof of surface wells

Chungui Ge¹, Dongling Sun²,³, Xinkun Wang¹, Benqing Yuan²,³, *, Yongjiang Zhang²,³, Jianjun Cao²,³

¹ Huaibei Mining Co., Ltd, China
² State Key Laboratory of gas disaster monitoring and emergency technology, Chongqing 400037, China
³ Chongqing Research Institute Co., Ltd., China Coal Science and engineering group, Chongqing 400037, China

*Corresponding author e-mail: 2012156@cqccteg.com

Abstract. In order to reduce the outburst risk of soft broken high gas coal seam, based on the gas geological conditions of Luling Mine field, the technology of segmented roof fracturing in water level section of U-shaped well in broken soft coal seam was tested. The safe drilling in the roof rock of horizontal section of coal seam was realized by directional drilling, and the trajectory of horizontal section was controlled in the roof rock of target coal seam 10000m³ / d, the pumping effect is good.

1. Technical principle
Coalbed methane horizontal wells in coal mining area are mostly horizontal drilling, cementing and fracturing in coal seams. However, for broken soft and low permeability coal seams, there are some problems, such as drilling easy to collapse and block, coal reservoir pollution, fracturing cross layer, poor pumping effect and so on. With reference to the new CBM stimulation technology of horizontal well staged fracturing technology of shale gas and tight sandstone gas, the target layer of fracturing is changed into the roof of coal seam, and the conductive fracture is formed by rock fracturing to extract coal seam gas. Segmented roof fracturing of water level section of U-shaped well in broken soft coal seam is safe drilling in the horizontal section of coal seam roof rock. The trajectory of horizontal section is controlled within the roof rock of target coal seam, and staged fracturing is carried out to realize reservoir transformation. The application scope of U-shaped well in water level section is improved by sectional fracturing. The wellbore structure of horizontal directional segmented fracturing on the roof of surface well is shown in Fig.1.

2. Layout parameters
The horizontal directional sectional fracturing technology well group of surface well roof includes one horizontal butt well and one drainage and production vertical well. The horizontal section length is generally 500 ~ 1000m, the horizontal section trajectory is controlled within 0.5 ~ 2m above the top boundary of the vertical target coal seam, and the interval of staged fracturing is generally 80 ~ 100m. In well location deployment, the following factors are mainly considered:
1. In order to ensure the production and effect of pumping, there must be enough pumping time. At the same time, without affecting the normal production of the coal mine, the well location should be deployed in the preparation area or planning area of the coal mine.

2. Due to the high geological requirements for the docking well group. Therefore, the deployment area of well group should be selected in the area with simple geological structure, stable coal seam distribution and high control degree.

3. The areas with high gas content, large coal seam thickness, small coal structure damage, relatively high permeability and relatively simple hydrogeological conditions are preferred.

4. Compared with vertical wells, the surface horizontal well group has more and larger drilling and completion and staged perforation and fracturing equipment. In order to facilitate the large tonnage equipment to enter and leave the well site, the traffic conditions are higher and the well site area is larger.

5. In order to form fracture perpendicular to horizontal hole, the trajectory of horizontal well should be parallel or nearly parallel to the direction of minimum principal stress and coal seam strike.

Fig. 1 Well bore structure of staged fracturing horizontal well group

3. Applicable conditions
The horizontal directional fracturing technology for roof of surface drilling is mainly applicable to the gas geological conditions of soft and broken coal seam, simple geological structure, high gas content in coal seam, simple hydrogeological conditions, large thickness of coal seam and stable distribution.

4. Application
(1) Mine overview
The designed annual production capacity of Luling Mine is 1.5 million t/a. The well was built in 1960 and put into operation at the end of 1969. In 1976, the designed production capacity was reached or exceeded, and 1.61 million tons of coal was produced. After several times of local technical transformation, the annual output of the mine was stabilized at more than 1.8 million tons, and the maximum annual output exceeded 2.4 million t/a.
The mine adopts the horizontal development mode of vertical crosscut and three horizontal mining along the inclined direction, namely -400m, -590m and -800m. The mining sequence is from the top to the bottom of the level, the mining of the uphill mining area is from the shaft to the mine boundary; the mining of the downhill mining area is from the boundary to the shaft direction, and the mining sequence of the coal seam is from top to bottom. Mining area development forward type, working face mining backward type, the implementation of cross mountain no pillar mining, mining face mining technology for comprehensive mining, fully mechanized caving and simple caving.

(2) Coal seam gas geology

The distribution of coal seams 8 and 9 is relatively stable and thick; The roof and floor are dense sandy mudstone and siltstone, and the gas sealing and preservation conditions are good; The gas content of coal seam is high, and the distance between 8 and 9 coal seams is about 3.5 m, so the combined seam drainage can be carried out. In addition, the preliminary exploration test also shows that the gas production effect of coal seams 8 and 9 is good. Therefore, 8 and 9 coal seams are taken as development target coal seams.

8 coal seam is extra thick coal seam, the whole area can be mined, the coal thickness is 0.30 ~ 17.75m, with an average of 8.96m; The coal seam thickness in the eastern area is stable, with an average of 10.58m. The coal seam thickness changes greatly in the central area, while the coal seam thickness changes relatively stable in the western mining area; The structure of 8 coal seam is complex, containing 1 ~ 2 layers of gangue.

9 coal seam is a medium thick coal seam with a thickness of 0 ~ 7.88m, with an average of 3.01m. The change of coal seam thickness below -400m level is beaded, and the thickness above -400m level changes little along the strike, and the trend is thick in the shallow part and thin in the deep part; 9 coal seam has a simple structure and a small distance from coal seam 8, with an average of 3.5m. 10 coal seam is a medium thick coal seam with a thickness of 0-4.99m, with an average of 1.86m; the coal seam structure is relatively simple. The top and bottom slate of 8, 9 and 10 coal seams are mainly mudstone or siltstone.

8 and 9 coal seam has high gas content, poor permeability and large thickness, and its structure belongs to extremely soft and broken type. The average firmness coefficient of coal is between 0.1 and 0.3, and the initial velocity of gas emission is 13-30 mmHg, which belongs to outburst coal seam. The results show that the gas pressure of coal seam 8 and 9 is 2.59 MPa and the gas content is 18.95 m³/t at the elevation of -400m (the lower limit elevation of the first level); the gas pressure of coal seam 8 and 9 is 2.59 ~ 4.43 MPa and the gas content is 18.95 ~ 22.67 m³/t in the range of -400 ~ -590m elevation (second level); In the elevation range of -590 ~ -800m (three levels), the gas pressure of 8 and 9 coal seams is 4.43 ~ 6.47 MPa, and the gas content is 22.67 ~ 25.40 m³/t.

In view of the soft and broken coal seam 8, the directional horizontal drilling along the coal seam is prone to pipe sticking and other accidents. Therefore, in the roof mudstone and siltstone of 0.8 ~ 1.3m above the top boundary of 8 coal seam, directional horizontal drilling, downward directional perforation, staged fracturing and gas extraction from 8 and 9 coal seams are determined.

(3) Fracturing drilling layout

Comprehensive analysis of Luling minefield mining planning, coal and coalbed methane geological conditions, traffic topography and early WLG01, WLG02, WLG03, WLG04 and WLG05 successful pumping experience and other factors. The horizontal well group is deployed on the west side of the line between WLG01 well and WLG02 well in III102 mining area.

The micro seismic pressure fracture monitoring of 8 + 9 coal seam in well wlg03 shows that the main fracture direction is ne 41.3°. Therefore, the horizontal projection orientation of horizontal well group is approximately perpendicular to the main fracture orientation, which can obtain better gas production effect. In addition, the length of horizontal section is also an important factor, too short affects the CBM production, can not give full play to the advantages of horizontal wells, and the input / output ratio is low; too long will increase the complexity of the project and increase the risk of the project. Comprehensive analysis shows that the designed horizontal section length is 580m, and the horizontal section is drilled along the upper part of 8 coal seam.
The horizontal projection length of two wells in horizontal well group is 800m, and the horizontal section is about 600m. The terrain of this area is flat, the distance from the fault and the existing exploration boreholes is moderate, there is no ground building, and the traffic is convenient. Along the vertical well to the butt well, the elevation of 8 coal seam shows a gradual upward trend, and the rising angle is about 4°. The geographical coordinates of well group are shown in Table 1.

Table 1. Design parameters of well group LG01

| Well number | Orifice coordinates /m | Final hole depth /m |
|-------------|------------------------|---------------------|
|             | X                      | Y                   | Z       |                     |
| LG01-V      | 3713910.20             | 39516260.23         | 24      | 816                 |
| LG01-H      | 3714510.70             | 39515709.16         | 24      | 1438                |

(4) Fracturing pumping scheme

In Luling minefield, a horizontal test well group of surface CBM staged fracturing is arranged, including one horizontal butt well and one drainage and production vertical well. In the process of horizontal well drilling, geosteering technology is used to control the horizontal section trajectory in the sand and mudstone above the top boundary of vertical 8 coal seam; After the completion of horizontal well drilling and cementing, downward directional perforation and staged fracturing are carried out in the horizontal section to realize the communication between horizontal well and coal seam 8 and 9, and transform the coal reservoir; Finally, the drainage and production equipment is installed in the vertical well, and the mode of pumping unit + tubular pump drainage and oil casing annulus gas production is adopted to exploit the coalbed methane in 8 + 9 coal seam.

(5) Fracturing and pumping engineering

Since August 10, 2014, the field preparation work of the fracturing project has been started. The pumping bridge plug perforation fracturing combined process is used for staged fracturing of horizontal wells, and reservoir reconstruction is carried out in 7 sections. From August 31 to September 5, the horizontal well LG01-H was formally fractured. According to the relevant standards and design, the flushing, perforation, fracturing and fracturing effect evaluation were completed. After the wellhead pressure reached 3.5MPa, the blowout was started.

① The well flushing and pressure test before LG01-H well have been completed. The construction of flushing and pressure test meets the requirements of relevant standards, and the construction is qualified.

② The perforating operation of LG01-H well is completed. Cable pumping bridge plug perforation combined mode is adopted. Each section is perforated for 3m, and the deep penetrating perforating charge is adopted, and the hole density is 10 holes / m. MAGNUM/4.3 "easy drilling bridge plug is selected as bridge plug with pressure difference of 68.9MPa. The cumulative perforation length is 21.0m, the cumulative perforation number is 210, and the perforation firing rate is 100%. The perforation construction is in accordance with the code for perforating construction and quality control (SY/T 5325-2005). The specific perforation data are shown in Table 2.

③ The fracturing operation of 7 sections of horizontal well has been completed. Active water was used as fracturing fluid, the formula was 1% KCL + 0.05% bactericide. The proppant is quartz sand of two sizes: medium sand (425 ~ 850 μm) and coarse sand (850 ~ 1180 μm).

During the 7-Stage fracturing operation, 4230.7m³ fracturing fluid and 277m³ quartz sand were injected, with an average sand ratio of 11% ~ 13%. The fracturing construction process is smooth, the sand adding task required by the design is completed, and the construction quality meets the relevant fracturing operation technical specifications. The fracturing data of section 7 are shown in Table 3.
Table 2. Perforation and bridge plug sealing position of well LG01-H

| Serial number | Perforated interval /m | Number of perforations /Pieces | Perforation interval /m | Bridge plug position /m |
|---------------|------------------------|-------------------------------|-------------------------|------------------------|
| Section 1     | 1443.0~1446.0          | 30                            | Distance from vertical well: 39.96 | 1465.0                |
| Section 2     | 1339.0~1342.0          | 30                            | 101                     | 1367.0                 |
| Section 3     | 1253.0~1256.0          | 30                            | 83                      | 1288.0                 |
| Section 4     | 1182.0~1185.0          | 30                            | 68                      | 1220.0                 |
| Section 5     | 1095.0~1098.0          | 30                            | 84                      | 1119.0                 |
| Section 6     | 1012.0~1015.0          | 30                            | 80                      | 1047.0                 |
| Section 7     | 937.0~940.0            | 30                            | 72                      | 970.0                  |

Table 3. Fracturing data of well LG01-H

| Serial number | Actual liquid and sand volume /m³ | Actual sand ratio /% | Completion rate of sand addition /% |
|---------------|-----------------------------------|----------------------|-------------------------------------|
|               | Liquid volume                     | Sand quantity        |                                     |
| Section 1     | 979.0                             | 63.8                 | 9.27                                | 100                    |
| Section 2     | 976.0                             | 65.5                 | 9.77                                | 100                    |
| Section 3     | 927.0                             | 80.0                 | 13.19                               | 110                    |
| Section 4     | 920.0                             | 80.0                 | 13.37                               | 110                    |
| Section 5     | 1019.0                            | 86.9                 | 12.48                               | 109                    |
| Section 6     | 972.0                             | 83.4                 | 12.66                               | 104                    |
| Section 7     | 834.0                             | 82.9                 | 15.48                               | 104                    |
| Subtotal      | 6627.0                            | 542.5                |                                     |                        |

In the process of fracturing, micro seismic fracture monitoring was carried out on section 1 and section 4, and the monitoring process was smooth and met the design requirements. The monitoring results are shown in Table 4.

Table 4. Fracturing microseismic monitoring results of section 1 and section 4 of well LG01-H

| Project                  | Section 1 /1433.0~1446.0m | Section 4 /1182.0~1185.0m |
|--------------------------|----------------------------|---------------------------|
| Length of east wing slot /m | 90.5                      | 89.8                      |
| Length of west wing slot /m | 78.6                      | 73.4                      |
| Total length /m           | 169.1                     | 163.2                     |
| Single wing average /m    | 84.6                      | 81.6                      |
| Fracture orientation /°   | 45.2                      | 46.1                      |
| Influence height /m       | 20.5                      | 17.6                      |
| Influence width /m        | 58.3                      | 65.2                      |
| Occurrence                | Vertical                   | Vertical                   |

(6) Pumping effect
The well group began to discharge production formally on January 19, 2015, and began to produce gas on April 16, 2015. During the extraction process, the intelligent monitoring system was applied to obtain the dynamic parameters of horizontal well drainage in real time. According to the different stages
of drainage and production, the corresponding drainage system was put forward reasonably to realize the refined drainage and production of CBM wells.

In January 1, 2016, the daily gas production was 10038 m³, and the daily gas production on January 12 was 10758 m³. By December 19, 2017, the cumulative gas production was 5.1 million m³, and the coal seam gas content was reduced by 2.91 m³/t. The daily gas production from April 16, 2015 to April 5, 2016 is shown in Figure 2.

![Fig. 2 Daily and cumulative gas production of Luling Mine](image)

5. Main conclusions
The demonstration project of staged fracturing horizontal well CBM extraction in Luling minefield realized that the horizontal well trajectory was placed on the roof of the target coal seam, and then the fractured soft coal seam was staged fractured to realize the reservoir reconstruction, which made a new breakthrough in the daily gas production of more than 10000 m³/d. The successful demonstration of this project has opened up a new way for the surface development of coalbed methane in broken soft coal seam and made an unprecedented breakthrough. Meanwhile, a series of achievements have been made in the process of completing the project, such as safe drilling of broken soft coal seam roof, stress distribution monitoring of coal seam and its roof and floor, staged fracturing technology of coalbed methane horizontal well, and accumulated rich experience.

Acknowledgments
This work was financially supported by the National Key Research and Development Program of China (2017YFC0804206).

References
[1] Zhang Q, Ge C G, Li W, et al. High efficiency CBM extraction mode of fractured soft and low permeability roof horizontal well [J]. Acta coal Sinica, 2018, 43 (001): 150-159.
[2] Wang G Y, Feng Q T, Li P. Study on staged fracturing technology of coalbed methane along coal seam roof horizontal well [J]. Journal of Shanxi Datong University (Natural science edition), 2013 (4): 68-70.
[3] Yao T Q, Wang J, Xu Y B, et al. Practice of staged fracturing enhanced extraction method for horizontal wells in broken soft coal seam [J]. Liaoning chemical industry, 2015 (12): 1466-1470.
[4] Jia J, Chen C, Dong K, et al. Study on staged fracturing and high-efficiency extraction of coalbed methane from fractured soft and low-permeability Roof Horizontal Wells [J]. Natural Gas Geoscience, 2017, 28 (12): 1873-1881.
[5] Ren F, Zhang S A, Li X Z, et al. Optimization design of fracture parameters for staged fracturing of coalbed methane horizontal wells [J]. Natural gas and oil, 2014 (01): 58-62.