Experimental Study on Permeability Enhancement of Hydraulic Fracturing with Sand in Strong Outburst Coal Seam

Benqing Yuan1,2,3*, Qihan Ren2,3
1 Anhui University of Science and Technology, Huainan, China
2 Chongqing Research Institute CO., Ltd of China Coal Technology Engineering Group, Chongqing, China
3 National Key Laboratory of Gas Disaster Monitoring and Emergency Technology, Chongqing, China

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

Abstract. Abstract: Based on the gas geological conditions of 17102(3) working face in Pansan Coal Mine, using theoretical analysis, engineering practice and other methods, the hydraulic fracturing sand permeability technology and technology are studied. Through the comparative analysis of permeability enhancement and drainage effect between fractured area and non fractured area, it can be seen that after sand fracturing, the permeability coefficient of coal seam is increased by 13.31 times, the average 100 hole purity is increased by 2.3 times, the time of reaching the standard of drainage is reduced by 26 days, and the hydraulic fracturing sand permeability enhancement technology ensures the safe and efficient mining of working face.

1. Project overview
Pansan Coal Mine in Huainan mining area is a typical coal and gas outburst mine. The main coal seams are 13-1 and 11-2, which are all coal and gas outburst seams. Since the establishment of the mine, 14 coal and gas outburst accidents have occurred, of which 13 occurred in 13-1 coal seam. The permeability coefficient of 13-1 coal seam is between 0.013~0.022 m²/(MPa²·d). The gas content of coal seam in the depth of 600m reaches 5.90~ 10.51m³/t, the gas pressure is 1.05~3.80MPa, the average f value is 0.52, and the lowest is 0.26. It is a typical soft, low permeability and high gas outburst coal seam, which is difficult to be drained. In order to solve the existing technical problems of 13-1 coal seam drainage in Pansan mining area, Pansan Coal Mine carried out the engineering experimental research on "hydraulic fracturing and aggregate permeability increasing technology of through layer drilling" in 17102(3) working face, and developed the corresponding sand fracturing device, so as to improve the gas drainage efficiency of 13-1 coal seam and reduce the gas pressure.

17102(3) working face is the 13-1 fully mechanized working face in the first level East Fourth mining area of Pansan Coal Mine, with an elevation of -680m to -724m. The mining strike length of the working face is 1820m (including 1048m solid section) and the dip width is 200m. 13-1 coal seam is 3.2~4.7m thick with an average thickness of 4.1m and an average dip angle of 8°. 17102(3) working face is in outburst danger area, the measured gas pressure is 2.8MPa, and the gas content is 8.4m³/t. The original water content of coal seam is 1.6%, and the permeability coefficient of coal seam is 0.022 m²/(MPa²·d).
The test of hydraulic fracturing and aggregate permeability enhancement of through seam drilling is carried out in the East Wing track roadway of -817m, which is located in the floor of 13-1 coal seam, with a normal distance of 35~42m and a lateral displacement of 17102 (3) of 55m (horizontal distance).

2. Principle of hydraulic fracturing sand permeability enhancement technology

Hydraulic fracturing in coal mine is a common technology for increasing permeability in low permeability coal seam. At present, after water fracturing is used in coal mine, the cracks formed will inevitably close again[1-2]. To solve this problem, sand can be added to support the fracture, improve the fracture conductivity and improve the gas drainage effect after fracturing. Fracturing makes the fracture system of coal seam filled with proppant, which is effectively supported and forms a large number of interconnected fracture channels. The effective permeability of coal seam is greatly improved, and the seepage and diversion conditions of coal seam are significantly improved, which provides a high-speed channel for gas drainage and reduces the gas content of coal seam faster[3-4].

3. Drilling layout of hydraulic fracturing sand permeability enhancement test

A total of 42 hydraulic fracturing boreholes are designed in the -817m East Wing track roadway. All the boreholes were drilled in the 41 ~ 22# drilling site, with 17102(3) cut in the West and F18∠65～70° H=10m in the East, fault 60m. Among them, QY1 and QY2 are constructed to 17102(3) cut, Y1～Y20 are constructed to 17102(3) conveyance road, GY1～GY20 are constructed to 17102(3) run smoothly, 67m away from 17102(3) conveyance road in 17102(3) working face, as shown in Fig. 1.

All pressure boreholes have been constructed from west to East. Due to the fracturing water leakage, 14 boreholes were constructed, including supplement Y2, supplement Y3, supplement Y4, supplement Y5, supplement Gy5, supplement Y6, supplement Y7, supplement Y9, supplement Y8, supplement Y9, supplement Y10 and supplement GY17.

Fig. 1 Layout of hydraulic fracturing and aggregate permeability increasing boreholes in soft and low permeability coal seam
4. Hydraulic fracturing sand penetration technology

4.1. Sealing technology of hydraulic fracturing borehole

The fracturing casing pipe is ⌀25mm steel pipe, which goes down to 1/2 section of 13-1 coal seam. The coal section is perforated pipe, and the other 4 parts are grouting pipe 4m. The slurry return pipe adopts the hose used on the bag hole packer. The slurry return pipe goes down to 2m outside the ⌀25mm perforated pipe, and the slurry return pipe 1m at the bottom of the hole is tied up[5-6].

The outer plug shall be set at the casing pipe 2m inward from the orifice, and the length of the outer plug shall not be less than 2m, which shall be made by wrapping polyurethane. After the polyurethane at the outer plug is fermented and solidified, the adjusted cement slurry is injected into the hole through the grouting pipe at the orifice with the grouting pump, and the grouting amount is subject to the grouting return pipe at the orifice. After the slurry is returned, appropriate amount of clean water is injected from the slurry return pipe to clean the pipe, so as to prevent the cement from setting and blocking the pipe.

After 12 hours of the first grouting, the second grouting shall be conducted from the slurry return pipe. After the slurry return of seamless steel pipe, the orifice gate valve of seamless steel pipe shall be closed and the slurry return pipe shall be used for grouting under pressure. The grouting pressure shall not be less than 4MPa. After the grouting, the orifice gate valve of seamless steel pipe shall be opened and the seamless steel pipe shall be cleaned with clean water.

Cement slurry is prepared according to water: Cement = 0.8:1 (mass ratio); Polyurethane was used in the ratio of 1:1 (4.6 kg for each hole A and B). Each joint of seamless steel pipe is connected by special joint and wrapped with raw material belt to enhance air tightness.

4.2. Sanding process

In the process of hydraulic fracturing and sand adding in the East Wing track roadway of –817m, we continuously summarized and improved the sand adding device for four times, which is safe, reliable and easy to operate, as shown in Fig. 2.

The fourth generation of high pressure sanding device is composed of φ194mm aggregate cavity (wall thickness 22mm), φ19mm high pressure inlet, φ19mm high pressure outlet, φ31.5mm sanding hole, φ31.5mm pressure relief port, which is composed of welding, with a cavity volume of 25.6L and a pressure of 60MPa.

Brw200 / 56 fracturing pump produced by Nanjing Liuhe was used for hydraulic fracturing. The flow rate was 200 L/min, the inner diameter of the fourth generation sand adding device was 75mm, and the calculated flow rate was about 0.19m/s. In order to ensure that the sanding device is not blocked, when the high-pressure water enters the chamber, the quartz sand is washed away and pressed into the coal body by water flow. The volume of each sanding is about 6.4L, and the weight is 9.6kg. After many tests and observations, all the quartz sand is pressed into the hole within 30 minutes.

In order to ensure that the quartz sand can enter into the coal body smoothly after being pressed into the hole, it is necessary to form cracks on the coal body before adding sand. It is necessary to press 50t water before adding sand. In the process of sand fracturing, when the water pressure increases, it is necessary to stop adding sand, and continue adding sand after the water pressure is normal. According to statistics, adding sand 9.6kg per 10m$^3$ water can complete the work safely and smoothly.

4.3. Remote control device of high pressure gate valve

In hydraulic fracturing, due to the need of sand adding, it is often necessary to operate the high-pressure gate valve at the orifice and high-pressure pipeline, and there is a hidden danger of personnel injury due to fluid discharge. Therefore, we developed the "remote control device of high-pressure gate valve", which uses compressed air as power and remote control, and eliminated the safety accidents caused by the high-pressure working system, as shown in Fig. 3.
4.4. Sand addition in hydraulic fracturing

At present, a total of 25 boreholes have been hydraulically fractured, of which QY1, GY1, GY2, GY3, GY4 and Gy5 were originally affected by the "one hole two elimination" experiment due to the leakage of water at the orifice during the fracturing due to the lax sealing of the boreholes. 36# during the fracturing of Y6 and GY6 in the drilling field, the hole leakage still occurs after multiple hole repair, so the drilling field is no longer qualified for hydraulic fracturing.

A total of 25 fractured boreholes have an average single hole water inflow of 230m$^3$, of which the largest single hole water inflow is 312m$^3$ of Y1 water inflow in 41# drilling field. The aggregate size is 60~80 mesh, 20~40 mesh and 10~20 mesh. The maximum single hole size of the aggregate is 35. The average single hole size of the aggregate is 135 kg.

5. Application effect

5.1. Water content investigation

The original water content of 13-1 coal is 1.6%. After hydraulic fracturing of Y4 hole in 38# drilling field, the drilling hole is constructed. The influence radius of hydraulic fracturing is determined by investigating the water content. The water content of 2#, 3#, 4# and 5# boreholes in 38# drilling field was tested 35 days after hydraulic fracturing and 25 days before hydraulic fracturing. 10-4 borehole is 33.1m away from Y4 borehole, and the water content is 3.8%, which is greater than that of the original coal, indicating that the influence range of hydraulic fracturing is greater than 33.1m. Through the water cut test of hydraulic fracturing borehole after water release, the water cut decreased. The average spacing of hydraulic fracturing boreholes in -817m East Wing track roadway is 45m, which can achieve full coverage of hydraulic fracturing.

5.2. Gas pressure investigation

The original gas pressure of the study area is 2.8MPa. After hydraulic fracturing, five observation holes are constructed at 30m away from the hydraulic fracturing hole, of which, hole 1 is the drainage hole, 2#, 3#, 4# and 5# are the pressure measuring holes. The measured gas pressure is 0.2MPa, 0.9MPa, 0.68MPa and 0.2MPa respectively at 5m, 7m, 3m and 6m away from hole 1. After 1 month of drainage, the pressure of 3# is reduced to 0.8MPa. The pressure of 4# is reduced to 0.46MPa, and the gas pressure of 2# and 5# has no change. After hydraulic fracturing, the original gas pressure of coal seam changes greatly, and the influence radius of drainage reaches 7m.

5.3. Gas content investigation

The original gas content of the investigated area is 8.4m$^3$/t. After one month of gas drainage, 6 boreholes were selected to measure the gas content. The gas content of boreholes 5~8 decreased to 4.79m$^3$/t, and the radius of influence reached 7.9m.
5.4. Extraction statistics
The permeability coefficient of coal seam is 0.173 m²/(MPa·d) and the permeability coefficient of original coal is 0.013 m²/(MPa·d) in the influence area of hydraulic fracturing and aggregate permeability enhancement. The permeability coefficient of coal seam is increased by 13.31 times after fracturing. According to the investigation of 100 hole pumping pure quantity in fractured area and unfractured area, one month after the completion of drilling construction, the average 100 hole pure quantity in unfractured area is 1m³/min, and the average 100 hole pure quantity in fractured area is 2.3m³/min, and the 100 hole pure quantity in fractured area is stable (Fig. 4); The time of reaching the standard of drainage in the area with increased permeability is 26 days less than that in the area without increased permeability.

Fig. 4 Comparison of pore purity in antireflection and non antireflection regions

6. Conclusion
After hydraulic fracturing and sand permeability increasing, the permeability coefficient of coal seam in permeability increasing area is increased by 13.31 times, and the average 100 hole purity is increased by 2.3 times. Moreover, the 100 hole purity of hydraulic fracturing section is stable, and the time of pumping up to standard is reduced by 26 days. The preliminary results show that under the condition of the same type of aggregate and the same particle size, increasing the proppant proportion is helpful to improve the fracturing permeability. Hydraulic fracturing sand permeability technology ensures the safe and efficient mining of working face.

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

References
[1] Cui Y L. Study on hydraulic fracturing mechanism and application of Niudong volcanic reservoir in Santanghu Basin [D]. China University of Geosciences (Beijing), 2010.
[2] Du J S, Zhong Q F. Diagnosis of fracture height / length in hydraulic fracturing [J]. Journal of Xinjiang Petroleum University, 2001, 13 (003): 35-38.
[3] Zhao Y Z, Cheng Y Y, Qu L Z, et al. Finite element simulation of dynamic fracture formation in hydraulic fracturing [J]. Acta petrologica Sinica, 2007, 28 (006): 103-106.
[4] Du C Z, Mao X B, Bu W K. Fracture propagation analysis of coal seam during hydraulic fracturing [J]. Journal of mining and safety engineering, 2008 (02): 231-234.
[5] Wang S L, Jiang M Z, Liu H. Study on 3D fracture morphology of hydraulic fracturing based on damage mechanics analysis [J]. Geotechnical mechanics, 2011, 032 (007): 2205-2210.
[6] Lu Y C. Application of hydraulic fracturing technology in high gas and low permeability mine [J]. Journal of Chongqing University, 2010,33 (07): 102-107.