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Experimental study on anti-permeability technology of combined hydraulic fracturing in short-distance soft coal seam

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Abstract

In order to realize efficient gas control in short distance, high gas, low permeability and soft coal seam, and effectively alleviate the tense situation of "drainage, excavation and mining" replacement in mine, taking Wu8, Wu9 and 10 of Pingdingshan No.1 Coal Mine as the engineering background of complex gas occurrence in short-distance soft coal seam, the experimental study on hydraulic fracturing technology of short-distance soft coal seam was carried out. The test results show that the plastic strength of soft coal in the anti-permeability area of combined hydraulic fracturing increases under the action of water, a tree-like fracture is formed inside the coal body after cementation, and the effective radius of fracturing is between 28m and 50m. In the fracturing range, the in-situ stress in the local area of the coal seam above and under the coal seam is redistributed, forming a similar protective layer mining effect, and the pressure relief and permeability increase in the local area is realized. The measured permeability coefficient of coal seam is 0.839896m2/ MPa2.d, which is 25.9 times higher than that in unfractured area. At the initial stage of the fracturing hole, due to the "water lock effect" between the gas in the coal fracture and the fracturing water, the initial concentration is relatively low, and after holding pressure and drainage, the "water locking effect" becomes weaker, and the fracturing fracture provides the optimal channel conditions for gas migration. The gas concentration in the hole quickly climbed to the peak of high concentration and maintained 75.1~91.3% high concentration stability, which was significantly slower than that of unfractured boreholes. The average single hole pumping volume of 0.085 m^3/ min is 4.25 times higher than that of unfractured holes 0.02 m^3/ min. In the joint fracturing area, the boreholes with extraction concentration of less than 70%, 70~90% and more than 90% account for 6%, 65% and 29%, respectively. The average pure 63~79L/min per hole is 3.15~3.95 times higher than that in the unfractured area, and the gas drainage efficiency of cross-layer boreholes is significantly improved. The joint fracturing area drainage system is connected to the surface gas power generation system, the gas power generation is increased to 35000 Kw*h/day, and the gas utilization rate is 23000 m3/day, thus realizing a new breakthrough in mine gas cleaning and reuse. The test has formed the anti-permeability technology of multi-stage cyclic hydraulic fracturing in short-distance coal seam: pump pressure 22-36MPa, single-hole water injection 20-48m3, multi-stage cyclic fracturing 1-3 times, and holding pressure for 72 hours, pressure relief and continuous pumping, which can effectively ensure the combined fracturing effect of short-distance coal seam and efficient gas drainage and utilization.

Keywords

The short-distance coal seam; Soft coal seam; Combined hydraulic fracturing technology; Coal seam permeability enhancement; Water lock effect; Gas extraction.

1. Introduction

The short-distance coal seam is a special complex occurrence condition of coal seam, which is widely distributed in all kinds of coal mines in our country. It is mainly divided according to the distance between coal seams, and has the characteristics of small distance between adjacent coal seams and great disturbance between mining and excavation[1,2]. Therefore, the short-distance coal seam is often difficult to mine. At the same time, the short-distance coal seam is affected by mining, and the ground stress of the coal seam is redistributed, and the gas in the coal seam will be released dynamically. Gas content and pressure will continue to rise, coupled with the short-distance coal seam soft, low permeability, conventional drilling gas drainage is more difficult, long treatment cycle[3-5]. As one of the common technical means to transform low permeability coal seams, hydraulic fracturing technology has been widely used in low permeability coal seams within 100 meters of buried depth in large and medium-sized coal mines in China, and good results have been obtained[6-8]. Combined with the current situation of gas control in short-distance soft coal seam and the development of new technology for gas disaster control, this paper explores the technology of hydraulic fracturing in short-distance, high-gas, low-permeability and soft coal seams, which is of great significance to open up a new way of gas drainage in short-distance soft coal seams, and provides technical guarantee for realizing high-efficiency gas drainage in coal mines [9-10]. Chen Dongdong et al.[11] put forward the gas drainage technology of long borehole sectional hydraulic fracturing for the medium and hard coal seam in Binchang mining area, and achieved good application results. Cui Ruiqing et al.[12] in order to improve the gas permeability and gas drainage effect of low permeability coal seam, the effects of coal seam hydraulic fracturing pore diameter and ground stress on fracturing effect were calculated by simulation software, and engineering tests were carried out. Wen Guangcai et al.[13] put forward a similar simulation experimental method of hydraulic fracturing through boreholes in underground coal seams, and studied the influence of water sensitivity damage on coal seam permeability. Wang Shibin et al.[14] will use COMSOL software to simulate gas extraction from hydraulic fracturing coal seams. Shi Xiaohong et al.[15] adopted hydraulic fracturing technology to improve the permeability of the main mining coal seam aiming at the low permeability and high gas coal seam in the complex structural zone; to sum up, most scholars have only carried out relevant research on the influencing factors and application of hydraulic fracturing gas drainage technology in single coal seam, but there is little research on the technology of combined hydraulic fracturing under the condition of close multi-coal seam and soft coal seam.

Therefore, the W8, W9, 10 short-distance soft coal seams of Pingdingshan Coal Mine are taken as the engineering background, the complex gas occurrence geological conditions are comprehensively analyzed, and the representative hydraulic fracturing test area of short-distance soft coal seams is determined. Ten through-layer fracturing boreholes are arranged to complete the combined hydraulic fracturing test of W8, W9 and 10 close-range soft coal seams. The fracturing effect is comprehensively evaluated from the aspects of influence range after fracturing, permeability enhancement of coal seam, gas extraction and gas cleaning and reuse, etc., and the fracturing scheme is optimized and the implementation technology of hydraulic fracturing and permeability increasing technology of close-distance soft coal seam is formed. The experimental results will provide a certain reference for other mines to implement combined hydraulic fracturing technology under the condition of similar short-distance soft coal seam.

2. The technical principle of hydraulic fracturing anti-permeability in coal seam

The hydraulic fracturing of underground coal seam borehole is through the high-pressure water generated by external mechanical force to realize fracturing in the original rock coal body and form the channel of gas flow, which can effectively increase the permeability of coal seam and make the coal body relieve pressure. a measure to increase the amount of gas drainage [16,17]. At the initial stage of fracturing, due to the influence of coal defects, the damage area is randomly distributed, so the damage zone or fracture is mostly scattered in the form of disconnection, and the higher the connectivity of the damage fracture zone in the area with dense initial defect distribution. and show a reticular distribution [18]. With the continuous invasion of the fracturing fluid, the area of the damage zone at the fracturing orifice is larger than that in other areas, so the fracture first runs through the orifice and gradually expands and shifts to the depth, and the expansion direction obeys the principle of minimum action. The expansion path extends along the damage weak zone, forms the main fracture under the action of scouring, and becomes the main channel of fracturing fluid flow [19]. The main fracture of fracturing develops from one at the orifice to several coexisting cracks, and they are connected with each other, and there are a large number of secondary fractures around them. The secondary fractures are interlaced with each other and coexist with the main fractures, forming a network distribution. In the process of fracture development, the local turning phenomenon of fracture expansion will occur due to the existence of local damage. if the expansion resistance of adjacent fractures is small or the flow resistance of fracturing fluid is small, the adjacent fractures with large expansion resistance will also be closed[20]. In the area where there is no damage around the crack, due to the existence of all levels of cracks, it will have a pressure relief effect, the gas permeability of the coal will also increase accordingly, the gas flow resistance will be reduced, and the extraction efficiency will be improved [21,22].

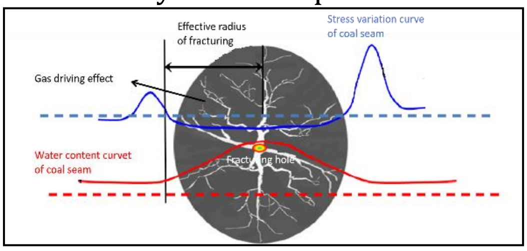

Fig.1 Stress-fracture evolution process in coal near fracturing hole

3. The general situation of short-distance soft coal seam engineering

The surface elevation of Wu8-32140 working face in Pingdingshan No. 1 Coal Mine is + 137cm 156m, and the elevation of working face is-788mm. The low extraction roadway of machine roadway, air roadway and cut-hole low pumping roadway are all arranged in the stable rock layer of 15cm and 20m below the floor of Wu10 coal seam. The strike length of the working face is 1288m, the dip length is 240m, the average thickness of the W8 coal seam is 2m, the average thickness of the W9 and 10 coal seams is 3.9m, while the average interval between the W8, W9 and 10 coal seams is only 5m. The measured maximum original gas pressure 4.0MPa, the maximum original gas content 11.01m^3/t, the coal seam permeability coefficient 0.032415m2/MPa2*d, the firmness coefficient of the coal in this area is 0.4m. It belongs to the soft and difficult coal seam in short distance. Therefore, the W8-32140 working face is selected as the engineering background of the experimental research on the combination of hydraulic fracturing and antipermeability technology in the short-distance soft coal seam.

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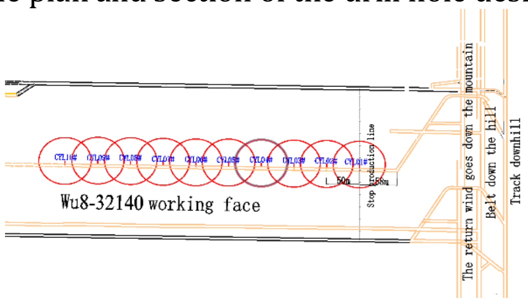
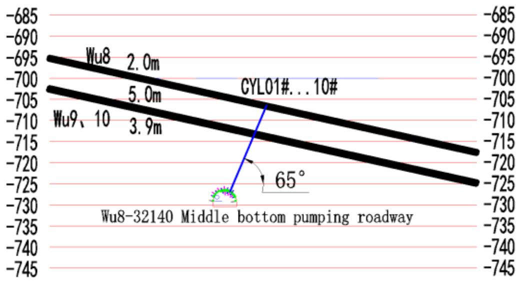
4. The test of combined hydraulic fracturing technology in short-distance soft coal seam

4.1. Combined hydraulic fracturing drilling design

Combined with the layout of the W8-32140 working face, the geological survey data of the coal seams W8, W9 and 10 in the area, and the actual construction situation of the bottom pumping roadway of the air roadway, the first fracturing drill hole is arranged 45m inward at the opening of the bottom pumping roadway of the air roadway, and one fracturing drill hole is arranged on each roadway at an interval of 50m. The hole number is: the dip angle of CYL1#-CYL10#, borehole is 65°. The azimuth of the borehole is vertical downslope(278°), and the drilling is stopped at 1m to ensure that the final hole point is in the middle of the coal seam and the final hole depth is about 28m. The plan and section of the drill hole design are shown in Figure 2.



(a)Drill hole plan of cross-layer fracturing



(b)Cross-layer fracturing borehole profile

Fig.2 Borehole design of through-layer hydraulic fracturing

4.2. The combined hydraulic fracturing anti-reflection test

Test of anti-permeability technology of hydraulic fracturing in short distance soft coal seam maximum pump pressure 36MPa, average pump pressure 32MPa, total fracturing water 401m^3, single hole fracturing water up to 48m^3, average water injection per hole is 40.1m^3. After the fracturing borehole holds pressure for 3 to 7 days, or the holding pressure drops to 2MPa, the end of holding pressure is determined, and the water discharge is controlled. The implementation process of joint hydraulic fracturing is shown in Figure 3, and the monitoring data curve of joint hydraulic fracturing parameters is shown in Figure 4.

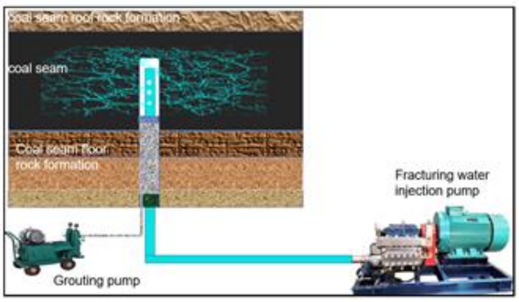


Fig. 3 Experimental implementation technology of anti-permeability technology of combined hydraulic fracturing

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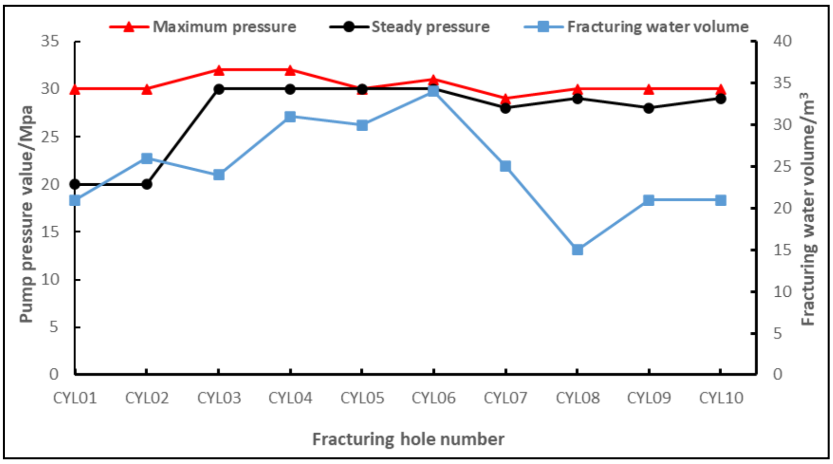

Fig. 4 Monitoring data curve of combined hydraulic fracturing parameters

5. The effect analysis of combined hydraulic fracturing technology in short distance soft coal seam

5.1. Effective radius analysis of influence range of combined hydraulic fracturing

In order to visually investigate the influence range of high-pressure hydraulic fracturing, the change of roadway morphology on both sides is used to determine the influence range. The shape of the roadway on both sides of the observation hole is observed and described before hydraulic penetration, especially in the vicinity of the more developed structure and the development zone of coal fractures. the description range of the roadway should be more than 50m away from the hole, which can be adjusted according to the scale of hydraulic penetration. After hydraulic antipermeability, the influence radius of hydraulic fracturing is determined by observing whether the coal wall is out of water and whether the roadway is deformed. Combined with the fracture migration and seepage morphology of surrounding rock on both sides of the fracturing test site, it is concluded that the effective influence radius of CYL01-10# fracture hole fracturing is expected to be 32m, 38m, 29m, 32m, 35m, 35m, 33m, 28m, 50m and 46m respectively. To sum up, the effective influence range of hydraulic fracturing in the test area is 28-50m. After fracturing, the movement and seepage of surrounding rock fissures on both sides of the roadway and the statistical diagram of the scope of influence are shown in Figures 5 and 6.

Fig. 5 Fracture migration and water seepage in surrounding rock of fracturing roadway

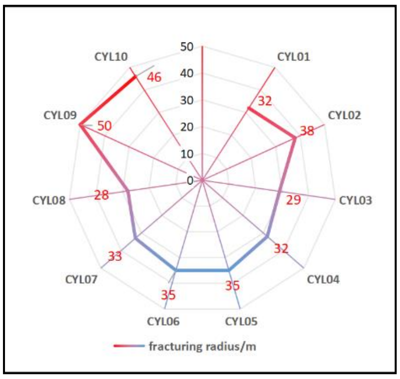

Fig. 6 Statistics of the radius of fracturing influence area

5.2. Analysis of Gas drainage effect of permeability increasing by combined hydraulic fracturing.

After the joint hydraulic fracturing construction of short distance coal seam and the end of holding pressure, 5m × 5m,6m × 6m, 7m × 7m and 8m × 8m penetrating boreholes were designed and constructed in the fracturing affected area, with a total of 111 boreholes.

The fracturing boreholes and inspection boreholes are incorporated into the drainage pipeline system, and the extraction data are tracked periodically, and the extraction concentration and pure quantity of single hole are investigated from the gas permeability coefficient of short distance coal seam after fracturing, single hole of fracturing boreholes and gas extraction. The specific application effect of gas drainage technology of high concentration and high pure gas in surface power generation system is comprehensively analyzed in all aspects, such as high concentration, high pure gas clean and reuse, etc. The detailed analysis is as follows:

(1) the permeability coefficient of short distance coal seam is greatly increased after combined hydraulic fracturing.

The plastic strength of coal body increases under the action of water, and tree-shaped cracks are formed in the coal body after cementation of powder coal body, and the permeability coefficient of coal seam increases greatly. The permeability coefficient of coal seam affected by short-distance coal seam combined hydraulic fracturing is 0.839896m^2/ MPa^2.d, which is 25.9 times higher than that before the implementation of short-distance soft coal seam combined anti-permeability technology. The comparison of coal seam permeability between fractured area and unfractured area is shown in Figure 7.

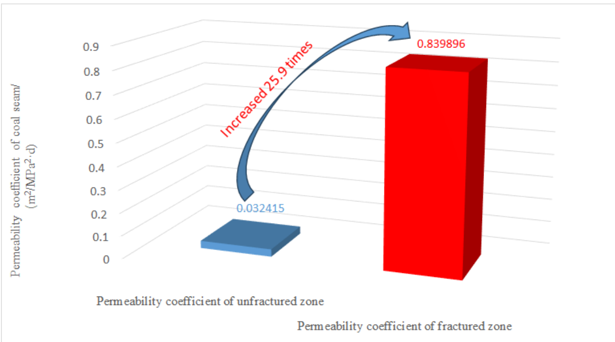

Fig. 7 Comparison of coal seam permeability between fractured area and unfractured area

(2) Unprecedented breakthrough of single hole pumping concentration and scalar quantity in cross-layer fracturing boreholes

The hydraulic fracturing boreholes of short distance coal seam combined with hydraulic fracturing have been measured continuously for 150 days. it is found that the initial concentration of boreholes in the hydraulic fracturing area is lower than that in the unfractured area. however, after 49 days, the extraction concentration of fracturing boreholes in the fracturing area climbed to a peak of 92.1%. Maintain high concentration of 75.1-91.3%. On the other hand, the borehole extraction concentration in the non-fracturing area climbs to the peak value of 62.8% after 25 days, and then sharp angle attenuation occurs, keeping the low concentration 30.4-40.1% stable. This is due to the existence of fracturing water in the initial stage of the fracturing hole, which has a "water locking effect" on the coal gas fracture channel, resulting in slow gas migration, but after waiting for the pressure retention and drainage in the fracturing hole, the "water locking effect" becomes weak. the coal fractures guided by fracturing water provide the optimal channel conditions for gas release and migration, and the gas permeability of the regional coal seam can be improved, so the gas concentration in the fracturing hole will climb to the peak value of high concentration in a short time. In the later stage of high and stable concentration, it is found that the attenuation of gas drainage concentration in fracturing boreholes is slower than that in unfractured boreholes, which ensures that the boreholes can realize high concentration gas drainage. The monitoring curve of gas drainage concentration in fracturing boreholes and unfractured common boreholes is shown in Figure 8.

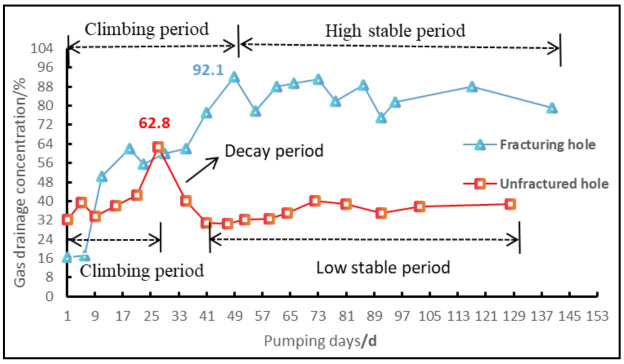

Fig. 8 Monitoring curve of gas drainage concentration in fracturing boreholes and unfractured common boreholes

In addition, the single-hole pumping mixture of some hydraulic fracturing holes is tracked and counted by installing a gas meter at the orifice, and the average single-hole pumping pure quantity is calculated to be stable at 0.085 m ^{3}/ min, which is 4.25 times higher than that of all kinds of ordinary boreholes in the mine.

The comparative analysis of through-layer fracturing boreholes in terms of extraction concentration and single hole scalar has achieved an unprecedented breakthrough in the application of mine gas drainage technology. The comparison of single-hole extraction volume between fracturing boreholes and unfractured common boreholes is shown in Figure 9.

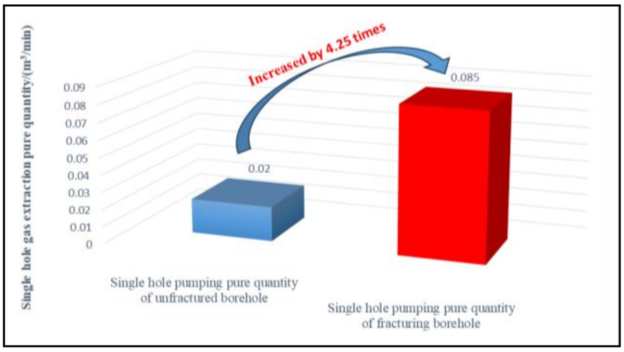

Fig. 9 Comparison of single-hole pumping pure quantity between fracturing boreholes and unfractured common boreholes

(3) Gas drainage investigation borehole single hole drainage concentration and scalar quantity are greatly increased

After the completion of combined hydraulic fracturing and pressure holding in short-distance coal seams, there were 32 boreholes with an initial concentration of more than 90%, accounting for 29%, 72 boreholes with an initial concentration of 70%, accounting for 65%, and 7 boreholes with an initial concentration of less than 70%, accounting for 6%. Under 5m × 5m, 30 6m × 6m, 24 7m × 7m, 21 8m × 8m grids, the average single-hole extraction pure amount 63~79L/min is 3.15 ~3.95 times higher than that of other unfractured areas in the same unit, and the maximum single-hole extraction pure amount is 280L/min, and the average single-hole extraction pure amount is 79L/min, which is about 3.95 times higher than that of other unfractured areas in the same unit. The statistics of the initial concentration of single hole in the fracturing area is shown in Figure10.

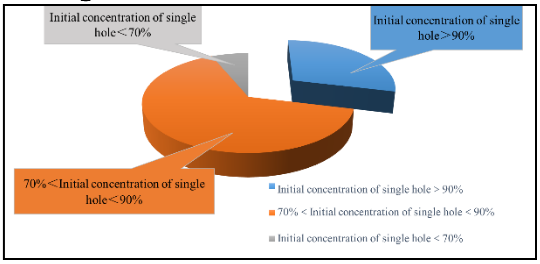

Fig. 10 Statistics of initial concentration of single hole in fracturing area

5.3. Analysis of gas cleaning and reuse by combined hydraulic fracturing

Since the gas drainage borehole in the short distance coal seam combined hydraulic fracturing area was incorporated into the extraction system, the extraction concentration of the system has been stable at 45% ~55% for a long time, the mixed flow rate has been stable at 8 ~ 10 m/min, and the pure volume has been stabilized at 4 ~ 5 m/min. At the same time, the gas drainage system has been incorporated into the ground discovery system to provide stable gas supply for surface gas generator sets. To realize the full-load operation of two gas generator sets on the ground, the gas generation capacity has been increased from a maximum of 16000 Kw*h/day, gas utilization rate of 11000 to 35000 Kw*h/ day and gas utilization rate of 23000m^3/day, which has achieved a new breakthrough in mine gas utilization. The gas concentration and scalar monitoring curves of the extraction system in fractured and unfractured areas are shown in Figures 11 and 12.

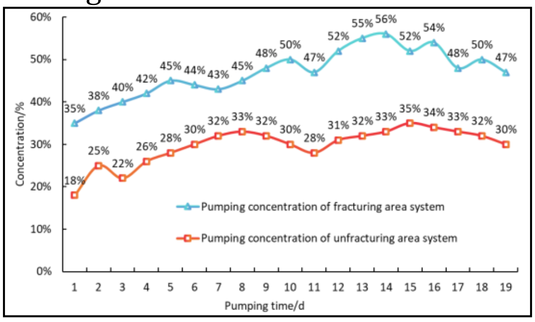

Fig. 11 Gas concentration monitoring of extraction system in fractured and unfractured area

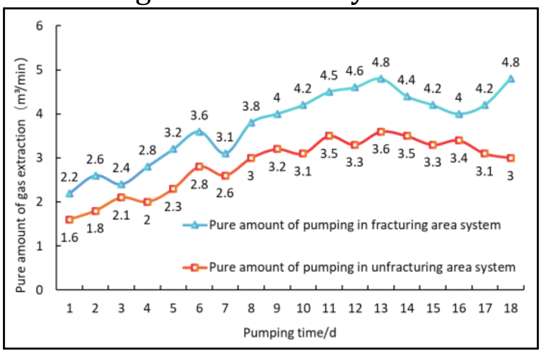

Fig. 12 Gas pure quantity monitoring of extraction system in fracturing and unfractured area

6. Conclusion

The plastic strength of soft coal increases under the action of water in the anti-permeability area of combined hydraulic fracturing, and tree-like fissures are formed inside the cemented coal body, and the effective radius of fracturing is more than 50m. Within the fracturing range, the in-situ stress in the local area above and under the coal seam is redistributed, forming a similar protective layer mining effect, and the pressure relief and permeability increase in the local area is realized. The measured permeability coefficient of coal seam is 0.839896m^2/ MPa^2·d, which is 25.9 times higher than that before the implementation of the combined permeability enhancement technology of short distance soft coal seam.

In the initial stage of the fracturing hole in the anti-permeability area of combined hydraulic fracturing, due to the "water locking effect" between gas and fracturing water in coal fractures, the initial concentration is low, and the "water locking effect" becomes weaker after holding pressure and draining. Fracturing fissures provide optimal channel conditions for gas migration, and the gas concentration in the hole quickly climbs to the peak of high concentration and maintains the high concentration stability of 75.1~91.3%. Compared with unfractured boreholes, the concentration attenuation slows down obviously. The average single hole pumping volume of 0.085 m ^{3}/ min is 4.25 times higher than that of unfractured holes 0.02 m ^{3}/ min.

In the joint fracturing area, the boreholes with extraction concentration of less than 70%, 70~90% and more than 90% account for 6%, 65% and 29%, respectively. The average pure amount of 63~79L/min per hole is 3.15~3.95 times higher than that in the unfractured area, and the gas drainage efficiency of through-layer boreholes in the fracturing area is significantly improved.

The drainage system of the short distance coal seam combined with hydraulic fracturing area is connected to the surface gas power generation system, the gas power generation is increased to 35000 Kw*h/ days, and the gas utilization rate is 23000 m^3 / day. The gas drainage in the fracturing area has achieved a new breakthrough in mine gas cleaning and reuse.

The joint fracturing test was carried out on the special high pressure pipeline for pre-buried fracturing in both upper and lower coal seams, and the multi-stage cyclic hydraulic fracturing technology of close coal seams was optimized and formed: fracturing hole pump pressure 22-36MPa, single hole water injection 25-48m^3, cyclic water injection 1-3 times, and pressure retention for 72 hours, pressure relief and continuous pumping, which can effectively ensure the combined fracturing effect and efficient gas extraction and utilization of short-distance coal seams. The test results will provide a certain reference for other mines to implement the combined hydraulic fracturing technology under the condition of similar short-distance soft coal seam.

Acknowledgments

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