Application practice of hydraulic fracturing in close range coal seam protection layer bedding drilling

Fengyuan Qin[1,2]

[1]State Key Laboratory of Coal Mine Disaster Prevention and Control, Chongqing 400037, China;

[2]China Coal Technology and Engineering Group Chongqing Research Institute, Chongqing 400037, China

Abstract

Due to the slow progress of gas extraction in the protective layer of the first mining in Four Seasons spring coal mine as well as the shortage of time and space for gas treatment, hydraulic pressure relief and fracturing of 16# coal seam were conducted using directional drilling and fracturing technology. With the help of self-developed complete sets of hydraulic fracturing technology and equipment, combined with the occurrence of coal seam, the backward stage fracturing process suitable for the protective layer along the layer was formed. Engineering tests were carried out on working face 1166, with a total of 60 stages of fracturing operations and a total injection volume of 2522m3. Results indicate that the extraction volume fraction from direct fracturing boreholes is between 55% to 65%, while in the affected area it ranges from 45% to 57%, averaging at about 52%. According to the water seepage in the hole and microseismic monitoring data, the fracturing influence range of a single borehole is determined to be 17~31m. After fracturing, there was a significant increase in net flow rate, with maximum net flow rate reaching up to 0.3m3/min - an average increase by about three times. During stable pumping periods, wind exhaust gas content decreased by approximately 18%~23%, maintaining between 30%~36% of total pumped gas content. Under the same extraction time, the spacing of drilling holes increased from the original 3.6m to 6.4m, and the drilling construction efficiency increased by 43.7%. The successful implementation of this technology has greatly alleviated the tension of mining succession, and laid a solid foundation for the overall gas management idea of "combining large-area gas management with protective layer mining to ultimately form a working face mining, a working face preparation, and a working face extraction" of the Siji Chun Coal Mine.

Keywords

First mining protection layer；Directional drilling along the layer；Hydraulic fracturing；Gas extraction.

1. Introduction

China's coal mining advances year by year to the deep ground, the proportion of complex hard-to-extract coal seams increases, the risk of coal seam gas protrusion intensifies, and the efficient management of gas is still a decisive factor restricting the safe and efficient production of mines with prominent coal seams [1-2]. At the same time, close coal seam protective layer mining has become an effective measure for regional gas unloading management [3]. However, the gas control measures for the protective layer itself are still mainly based on conventional extraction drilling, especially for the low permeability hard-to-extract coal seams, whose gas control costs and drilling construction works are large, and some high-gas mines have the problems of tight extraction succession, and the serious shortage of time and space for gas control.

For this type of mines, how to improve the gas extraction efficiency and reduce the time of gas treatment are the primary considerations. In recent years, there have been a number of measures to increase the permeability of coal rock body, and compared with chemical fracturing and pyrotechnic fracturing, hydraulic fracturing has gradually become the preferred treatment measure for high gas hard-to-extract coal seams due to its fast construction, low cost, wide applicability, and high popularity. At the same time, many scholars have carried out a large number of researches based on the differences of coal storage characteristics in different mining areas, and have successively formed the composite fracturing methods such as fracturing through the layer, fracturing on the top plate, repeated fracturing, inverter fracturing, and segmental fracturing [4-7]. In terms of fracturing fracture expansion mechanism, Kang Hongpu et al. have carried out research from the aspects of stress variables and seepage-induced stress [8-10]. In terms of engineering application, it mainly focuses on Huainan, Huaibei, Hancheng, Pingdingshan, etc., and has successively completed the tests of fracturing through layers, top plate fracturing, and fracturing along layers, and optimized its fracturing process [11-15]. However, the application of this technology in the southwestern area is relatively small, especially for Guizhou and other high gas-endowed areas, which have a large demand for gas control, and are limited by the influence of topographic endowment, and the over-planning of the mining area, resulting in the tension of its mining and extraction succession projects, and urgently need to study the corresponding measures of decompression and fracturing technology.

Therefore, based on the on-site engineering needs of the Siji Chun Coal Mine, the author analysed the storage condition of the 16# coal seam, and combined with the overall idea of gas management, carried out the research on the downhole hydraulic fracturing process for the key protection layer of the first mining, and carried out the application practice of downhole directional drilling hydraulic fracturing with the help of self-developed complete sets of fracturing equipment in the working face of 1166, and formed a suitable system for the mine to manage efficient extraction and management of gas, on the basis of the mastering of the influence scope of fracturing and the effect of extraction. On the basis of understanding the impact range and extraction effect of fracturing, the company has formed a highly efficient extraction and management system suitable for the mine, which has greatly alleviated the tightness of its mining and excavation succession, and laid the foundation for the subsequent overall gas management.

2. Project overview and sources of problems

2.1. Project overview

The Siji Chun Coal Mine is a double-wing multi-seam joint mining, the whole area can be mined as 5-2, 6, 7, 14, 16, 32, 35 coal seams, and the majority of the mine can be mined as 5-3, 6 lower, 8 coal seams. The mine is a typical coal and gas prominent mine, combined with the actual situation of the region and the mine's coal seam endowment, the protective layer mining (especially the 16# coal seam of the lower coal group and the 7# coal seam of the upper coal group) as a way of regional coal seam gas management is extremely favourable to the full pressure relief and release of the gas and the elimination of the suddenness. However, for the 16# and 7# coal seams, which are the key protective seams of the first mining, the regional gas control measures are still based on the combination of pre-pumping by drilling through the layer in the bottom discharge lane and the control by drilling down the layer in the two lanes of the working face. Due to the slow progress of the construction of the gas discharge tunnel and the large volume of gas extraction drilling works, which led to the tense mining succession, the time and space for gas control are facing compression, so how to greatly improve the effect of gas control under the limited time and space conditions has become the main problem faced by the mine.

2.2. Overall gas management ideas

In order to alleviate the contradiction between the tightness of mining succession and the time and space required for gas treatment, the mine proposes to adopt the overall gas treatment idea of "large-area gas treatment + protective layer mining + one mining and one extraction".

For the basic engineering requirements of large-area gas control: adopt TBM system (TBM tunnel boring machine) to construct large-area bottom slab gas drainage tunnel (gas drainage tunnel is used to control gas in one level, one wing or two to three sections of coal seams).

Adopt ZDY-6500 directional drilling rig combined with hydraulic penetration enhancement technical measures to carry out regional deep hole (200-500m) and large hole diameter (150-300mm) extraction drilling construction, in order to improve the effect of gas extraction within the limited time and space, and to achieve the balance of extraction, excavation and mining.

Eliminate the blind area of gas control through regionalised gas control, and extend the effective time of gas extraction (it is expected that the extraction time can be extended by 1-2 years).

Optimise the mining arrangement, improve the coal mining process, and adopt the regional continuous mining face arrangement without coal pillars for rapid mining after adopting regionalised gas control measures in the same coal seam.

Changing the joint arrangement between coal seams through regional continuous mining arrangement, realising regional mining of the same coal seam, forcing the protected coal seam to unload pressure in a large area, greatly increasing the time and space for gas treatment, and enhancing the effect of gas treatment. Reasonable layout of mine face mining is achieved. "One working face to mine, one working face to prepare, and one working face to extract."

Directional long drilling construction and hydraulic penetration enhancement technology measures have become the foundation and important part of the mine's gas control, and the key to greatly increase the effect of gas control in limited time and space lies in the implementation of hydraulic pressure relief fracturing.

3. Hydraulic fracturing programme

The construction progress of the bottom extraction lane of the 16# coal seam in the Siji Chun Coal Mine is slow, and the overall project volume of the extraction drilling holes in the lower seam is large. According to the estimation of the existing digging speed, the progress of the construction of the bottom extraction lane in the preparation stage of the 1166 working face will be difficult to match the demand of the gas treatment of the working face, and in order to alleviate the trend, it is decided to construct directional holes to carry out hydraulic fracturing for the segmented hydraulic fracturing of the present coal seam in this working face. The use of retrievable packers for segmental sealing can meet the requirements of rapid sealing and fracturing. The high-pressure pipeline with packer and safety connector is sent to the designated position, and then the packer is seated at one time. After seating, backward fracturing is carried out step by step from the inside to the outside. The schematic diagram of the segmented hydraulic fracturing process in this coal seam is shown in Figure 1.

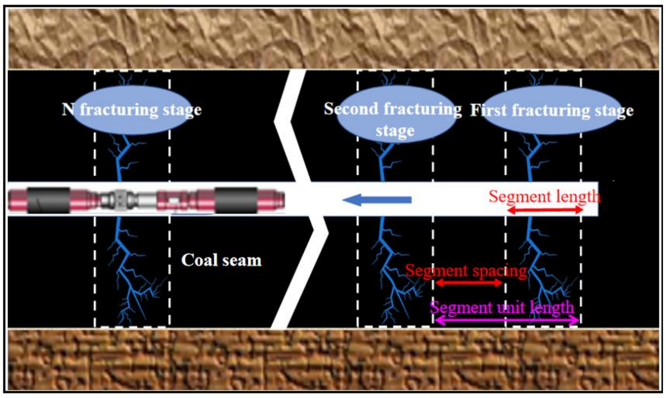


Fig.1 Segmented hydraulic fracturing technology for this coal seam

3.1. Test working surface

The 1166 comprehensive mining face is located in the west wing of the 16# seam of the Siji Chun Coal Mine and extends to the boundary of the well field, and the neighbouring 1164 face has been mined back to the end of the mining area. The average coal thickness of the face is 1.45m, the dip angle of the coal seam is 13°, the length of the strike is 1037.8m, the length of the slope is 191m, the capacity is 1.55, the 16# coal seam is non-explosive, the propensity to spontaneous combustion is Ⅲ not easy to spontaneous combustion, the coefficient of coal solidity is 0.69, the gas pressure is 0.96Mpa, the type of destruction of the seam is Ⅲ, and the risk of gas protrusion of the coal seam is present. According to the analyses of the neighbouring 1164 working face and the exposed data of the adjacent roadway, the geological structure and hydrogeological conditions within the boring range are simple.

3.2. Hydraulic fracturing design programme

This time, we choose to use directional drilling machine to drill holes in 1166 transport lane, the direction of drilling is along the working face tendency, and after the construction, we use segmental hydraulic fracturing process to weaken the coal body to fracture and increase the seepage. Considering the tectonic simplicity of the area, in order to ensure that the coal quality is not affected by fracturing, clean water is used as the fracturing fluid.1# fracturing hole is 25m away from the stopping line, with the construction angle of 13°, the spacing of fracturing holes is 45m, and the total number of fracturing holes is 22, the length of fracturing holes from Y1# to Y22# is 140m, and the angle of fracturing holes are all at 13°. Multi-stage fracturing is carried out in the borehole, and the designed length of the 140m borehole is divided into 3 sections, with 10m fracturing length in each section and 30m interval. The design scheme of the fracturing borehole is shown in Figure 2.

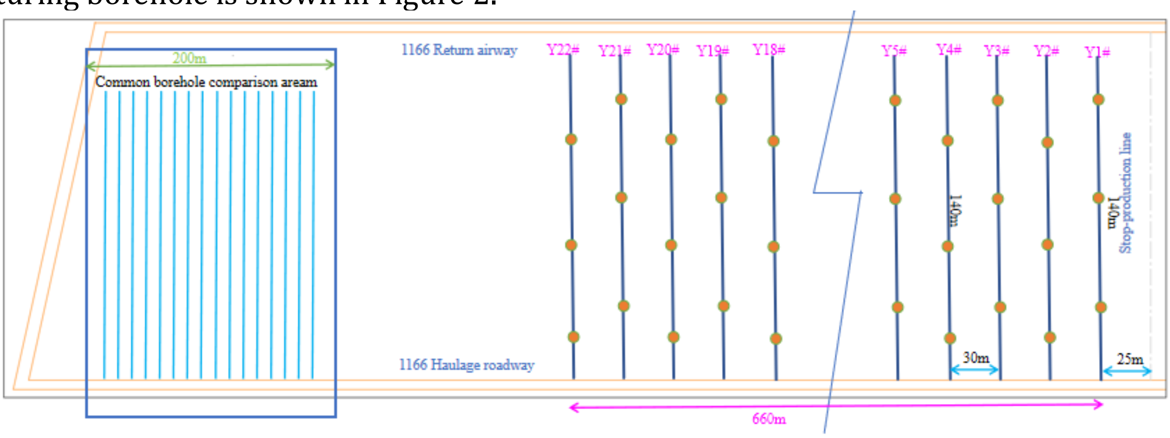


Fig.2 Fracturing borehole design schematic diagram

3.3. Hydraulic fracturing equipment

The hydraulic fracturing test in the Shun coal seam adopts the independently developed BYW type fracturing pump set, and the hydraulic fracturing complete equipment mainly includes the BYW type fracturing pump set, the naked eye segmented hydraulic fracturing tool string, the fracture sealing pipe column, the orifice device, the safety and security and the monitoring system and so on.

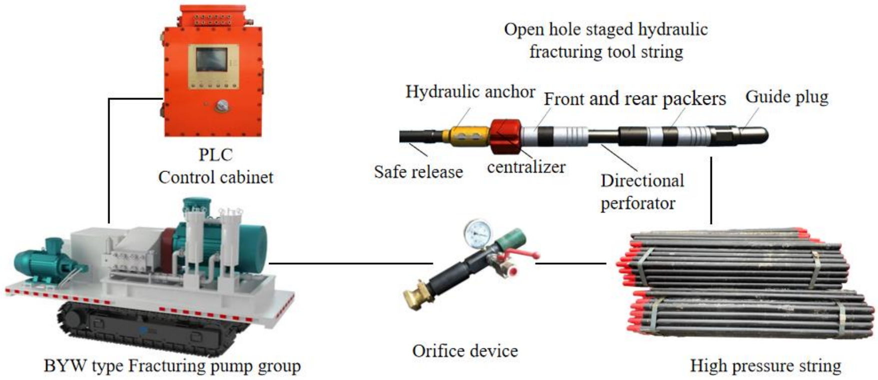


Fig.3 Hydraulic fracturing complete equipment

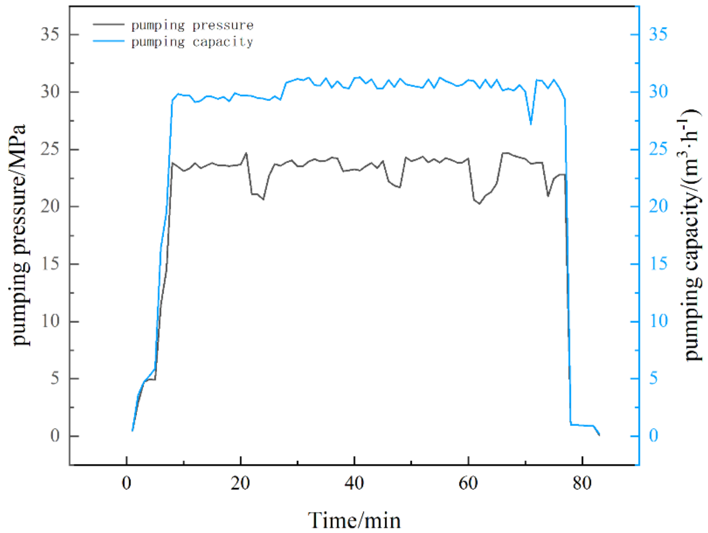
The operation process of this coal seam directional long-drilling segmental fracturing process mainly includes: equipment coupling performance test → fracturing drilling construction → lowering of naked-eye segmental fracturing tool string → low-pressure seated sealing of septum → high-pressure fracturing → pumping parameter monitoring and recording → unloading of pressure and unsealing of the tool string → dragging of the tool string to the next designated position → repeating the fracturing process until the completion of fracturing of this drilling and recovery of the pipe columns.

4. Effectiveness of hydraulic fracturing treatment

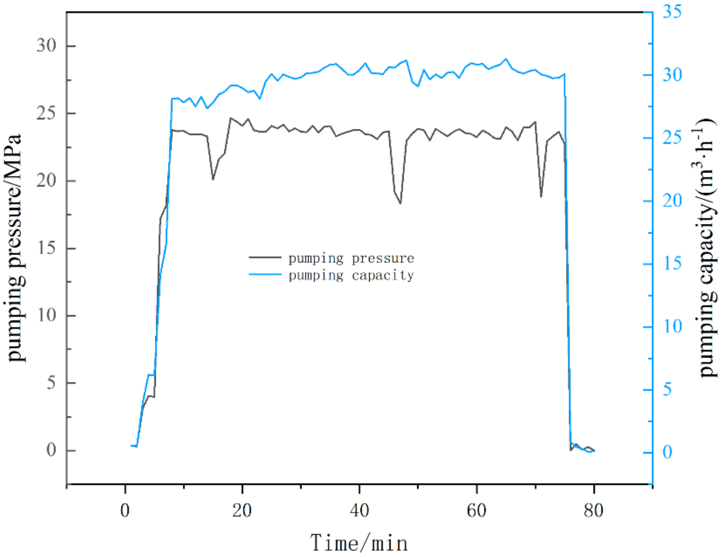
4.1. Analysis of hydraulic fracturing pumping parameters

Along the 16# coal seam, the construction of this coal seam drill holes, a total of Y1#~Y22# fracturing drill holes (of which the construction of Y7# and Y15# drill holes failed without fracturing), the cumulative fracturing operation of 60 segments, a single segment of the fracturing displacement of 26.81-33.95m^3/h, a single segment of the fracturing time consumed 62-87min, and a cumulative amount of pressed into the water of 2,522m^3. In order to further analyse the characteristics of fracturing in the region, the Extracting the typical pumping curves of 1# and 9# boreholes, it can be seen that after the bare eye segmented hydraulic fracturing seating tool string arrives at the fracturing point, it can be divided into two stages: low pressure seating and sealing septum and high pressure fracturing. The seating start pressure is about 0.45MPa, at which time the packer starts to deform, and the seating is completed when it reaches 5MPa, and then the pressure rises further and transitions to the high-pressure fracturing stage.

With the rise of pumping displacement, the pressure inside the pipe column system increases, the coal body is ruptured under pressure, and the fracture is in the cyclic phase of "newborn-expansion-connection", which is manifested by the sawtooth-like cyclic change of pumping pressure and displacement.In the fracturing operation of the first section of the Y1# borehole, this trend is the most obvious, and there are four large coal body breaks, the first break pressure is 23.7MPa, which tends to stabilise after 60min, and the pressure drops sharply after 76min, indicating that the fracturing area of this borehole is through. The first fracture pressure is 23.7MPa, which tends to stabilise after 60min, and the pressure drops abruptly after 76min, indicating that the fracturing area of this borehole is through, and the fracturing fluid is discharged to the observation hole. Influenced by the difference of the coal body, the pressure drop of Y3# borehole fluctuates greatly after fracturing, and the initial fracture pressure is 24.5MPa. Typical pumping fracturing curve is shown in Fig. 4.



(a)Fracturing curve of Y1 # borehole (1st section)



(b)Fracturing curve of Y3 # borehole (2nd section)

Fig.4 Typical pump injection fracturing curve

4.2. Analysis of the scope of impact of hydraulic fracturing

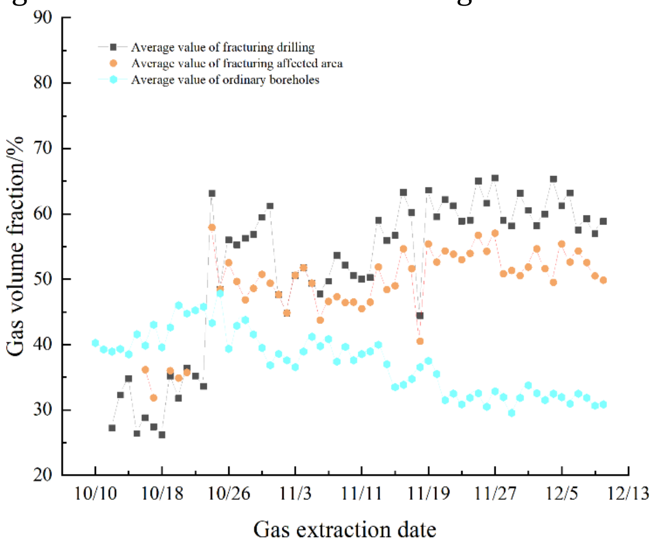
Most of the analysis of hydraulic fracturing influence range is carried out with the help of water seepage from neighbouring observation holes, and here, based on the downhole microseismic monitoring data combined with water seepage from neighbouring holes, we can make a comprehensive judgement. With the help of on-site video acquisition system, the water seepage condition of 1166 working face coal body was collected, and the change of water seepage and the location of seepage points can be further projected to get the influence area of fracturing fracture expansion. The water seepage situation shows that the projected distance of single-hole fracturing seepage range is between 19~31m, among which the projected distance of fracturing seepage in 6# drill hole is the farthest, up to 31m. downhole microseismic monitoring data show that during the fracturing operation, the rupture is extended and developed along the front, back and both sides of the tool string, and the range of fracture expansion in a single drill hole is about 17~26m. Considering that the microseismic signal is the fracture of the seam tip of the coal body, which does not fully reflect the development of the fracture network of the coal body, the actual fracturing influence area should be larger than this interval, and finally it can be determined that the actual fracturing influence range of a single hole is in the range of 17-31m.

4.3. Examination of the effectiveness of hydraulic fracturing and extraction

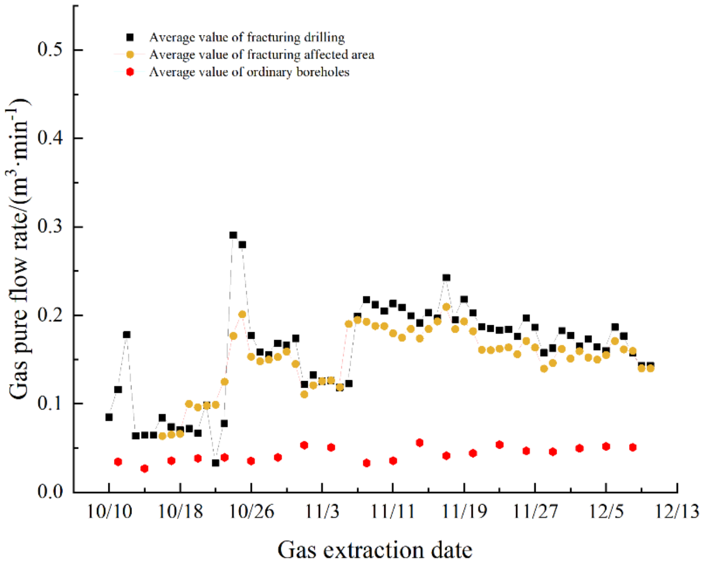
1)Analysis of fracture hole extraction effects

The fracturing operation of 1166 working face started in the morning shift on 8 October 2022, and the fracturing of Y1#~Y22# took a total of 25 days. After the completion of the fracturing of individual drill holes, we immediately carried out extraction, recorded the data of drilling and extracting from 10 October to 10 December, and compared the data of drilling and extracting from the area of the unfractured area of the transport roadway, in order to analyse the effect of its hydraulic fracturing.

After the completion of fracturing, due to the influence of fracturing fluid residue, the volume fraction of gas extraction in the initial stage was slightly lower than that of the unfractured boreholes in the transport lane. When the water in the fractured area is gradually discharged, the extraction effect is significantly improved, and the average value of the extraction volume fraction of direct fracturing holes basically stays at 55%~65%, with an average of 60%, while the volume fraction of gas extraction of ordinary drill holes is 32%~49%, with an average of 37%, which is an increase of about 0.63 times of the extraction volume fraction after the fracturing. At the same time, the overall permeability of the area was increased after the fracturing operation, and the internal stress balance of the coal body was changed, which contributed to the desorption of coal seam gas, and the volume fraction of gas extracted from the boreholes in the area affected by the fracturing was maintained at 45%~57%, with an average of 52%. The extraction data in the past 2 months showed that the pure volume of extraction was significantly increased after the fracturing operation. Compared with the unfractured boreholes, the pure volume of gas extraction in the effective influence area was increased to 2~4.5 times after the fracturing operation, with an average increase of about 3 times, of which the pure volume of extraction from the directly fractured boreholes was in the range of 0.07~0.3m^3/min, with an average of 0.21m^3/min. The gas extraction purity of unfractured borehole is low, maintaining 0.03~0.05m^3/min, with an average value of 0.042m^3/min. Fracturing extraction data are shown in Figure 5.



(a)Gas volume fraction



(b)Gas pure flow rate

Fig.5 Fracturing extraction data

2)Analysis of total extraction volume

In order to further analyse the extraction effect of the segmental hydraulic fracturing technology in this seam, the total amount of gas extraction at different stages of the technology application in this working face in the past 2 months since the implementation of the fracturing measures can be divided into four stages: the initial stage, the transitional stage, the full extraction stage and the stabilisation stage. At the initial stage of extraction, the fracturing operation was just completed, and the gas extraction was not significantly increased due to the influence of fracturing fluid residue; during the transition period, the fracturing fluid residue in the fracturing drill holes was gradually discharged, and additional extraction drill holes were drilled between the fracturing drill holes, so that the overall gas extraction from the working face began to rise; after all the drill holes in the area of fracturing influence were completed, the total amount of gas extraction rose exponentially, and the amount of gas extracted from extraction pipes could be up to 2-3 times of the amount of gas extracted prior to the construction of the technology. After a period of time, the extraction rate stabilises and enters a period of stable extraction.

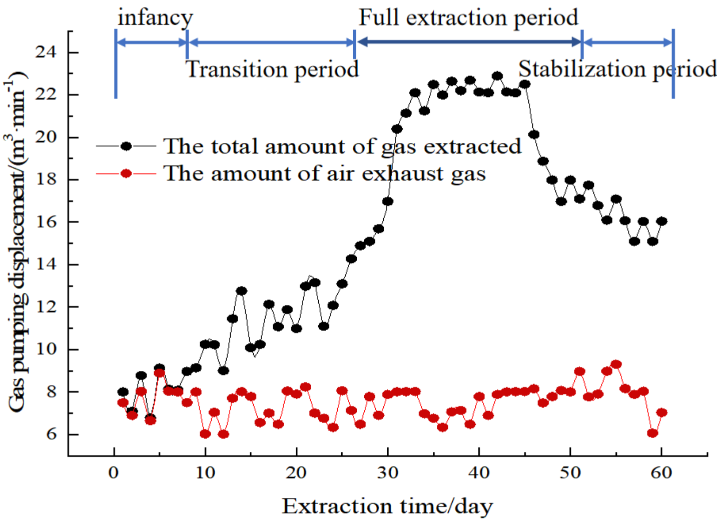


Fig.6 Gas extraction at different stages

In addition to drilling extraction, the ventilation of the working face is an extremely important part of gas control, and the effect of gas control at the working face can be further analysed by analysing the proportion of the gas content of the air discharge in the total amount of gas extracted from the working face at different stages. Before the hydraulic pre-cracking drill holes were constructed, the permeability of the coal body was not good, and the amount of gas extracted from the ordinary drill holes was limited, so the proportion of the gas content of the wind discharge in the total amount of gas extracted from the face at this stage was large, basically between 48% and 59%. since the hydraulic fracturing operation was carried out in the No.16 seam, the proportion has been continuously decreasing, and the proportion of the gas content was at least 28% after entering the period of full extraction, and the proportion of the gas content of the wind discharge was about 30% of the total amount of gas extracted from the face after the extraction stabilised. After the extraction is stable, the gas content of the air discharge accounts for about 30%~36% of the total amount of extraction from the working face.

4.4. Analysis of direct benefits

The implementation of this technology can increase the overall permeability of the working face of the 16# coal seam, improve the gas extraction rate, reduce the time for the working face to reach the standard of gas extraction, thus shortening the succession time of the quasi-mining work, and shortening the time required for extracting the equivalent amount of gas to 52.5% of the original. Hydraulic pre-cracking and permeability enhancement of the coal body of the 1166 working face was carried out with large-area and long-drilled holes, which led to the desorption of gas in the coal seam and objectively increased the radius of the coal body's drilled holes, and the drilling spacing was increased from 3.6m before the pre-cracking and permeability enhancement to 6.4m under the same time for the same extraction, and the efficiency was improved by 43.7%.

5. Conclusion

Due to the slow progress of gas extraction in the primary protective layer at Siji chun Coal Mine, as well as time and space constraints for gas treatment, enhancements have been made to the existing gas treatment measures in the protective layer area of the first mining. Additionally, with the utilization of our independently developed complete set of hydraulic fracturing technology equipment, a directional drilling and backward stage fracturing process has been established along the protective layer.

2) The hydraulic fracturing test was carried out on the working face of 1166, and the cumulative fracturing operation was 60 stages. The single stage fracturing displacement was 26.81-33.95m^3/h, the single stage fracturing time was 62-87min, and the cumulative water injected was 2522m^3. The water seepage and underground microseismic monitoring data showed that the fracturing influence range of a single borehole was 17-31m.

3) After the fracturing operation, the extraction volume fraction of the direct fracturing holes was maintained at 55%~65%, and the volume fraction of the gas extraction from the drilled holes in the fracturing influence area was maintained at 45%~57%, with remarkable effect of improving the pure flow rate of extraction, and the pure volume of the gas extraction in the effective influence area was increased by about three times on average, and the percentage of gas content in the wind discharge of the working face was maintained at 30%~36% after the extraction was stabilised. Under the same extraction time, the distance between drill holes has increased from 3.6m to 6.4m, and the drilling efficiency has been improved by 43.7%, which has greatly alleviated the problem of tense extraction succession.

Acknowledgments

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