Available online www.jsaer.com

***Journal of Scientific and Engineering Research*, 2024, 11(1):41-48**

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Theoretical Design and Engineering Application of High-Level Drilling

Yuan shuai

School of Safety Science and Engineering, Henan Polytechnic University, Jiaozuo Henan 454100, China
Email: 2235491483@qq.com

Abstract In order to solve the problems of gas accumulation in the airspace and over-limit of gas in the upper corner, Dangjiahe Coal Mine's 204 working face is taken as the background, and gas extraction and management of the airspace is carried out by using high-level directional drilling technology and interpolated multiple grouting and sealing technology. The results show that under the implementation of high-level drilling extraction, the amount of extracted gas accounts for 42.3%~50% of the total amount of extracted gas in the working face, and the concentration of gas in the return air of the 204 working face is maintained at about 0.5%, and the concentration of gas in the corner of the return air is less than 0.5%, which ensures the smooth progress of the return mining work, and it can provide references for the management of gas in mines with similar conditions.

Keywords roof directional drilling; gas extraction; hole sealing with grouting; drilling trajectory; fissure zone

1. Introduction

High-level drilling is currently an effective way to manage the gas in the airspace, which is widely used because it can well solve the problems of gas accumulation in the airspace and gas overlimit in the upper corner [1], and many scholars have carried out extensive research on the extraction of gas from the airspace by high level drilling.Guo Xinhong [2] used the isotope identification technique to determine the optimal layer position for gas extraction from high level drill holes, which effectively controlled the gas in this coal seam and adjacent seams.Yuanchun Li [3] investigated the method of determining the final hole location and spacing of the drill site for high level drill holes, which improved the gas extraction efficiency by about 55%.Sun Rongjun [4] presented the deficiencies of the existing drilling technology and introduced the composite directional drilling technology and development trend.Fu Shuai [5] proposed an optimization method based on the problems in the high level drilling technique, which increased the daily pure volume of gas extraction by three times.Zhao Jing [6] used high level drilling to reduce the volume fraction of gas in the upper corner and the volume fraction of gas in the return air at the working face to 1/3 of the original in Zhujiadian coal mine.Cai Wenpeng [7] effectively solved the problem of gas overlimit in the upper corner of the working face by utilizing high level drilling gas extraction technology, and improved the rate of workface recovery.Chen Lei [8] compared the buried pipe and high level drilling gas extraction technology in the air-mining zone, and proved the superiority of high level drilling gas extraction technology and the characteristics of low construction cost.Wu Shiyue [9] studied the gas extraction technology of large borehole high level drilling and came up with the layer with the best gas extraction effect, so that the pure volume of gas extraction from the drilling site was as high as $11.6m^3$/min.Liu Yunfeng [10] found that high level drill holes can replace the roof alley to manage the gas in the mining area and can be used as a slurry channel to manage the fire in the mining area.The above research results are enough to prove the important role of high level drilling in the gas management of the hollow area, but the theoretical design of high level drilling is a prerequisite to ensure that it gives full play to its role, and the author took the 204 working face hollow area of the Dangjiahe Coal Mine as a research object to carry out the research on the design and application of the trajectory design of the high level drilling.

2. Theoretical Basis of Drilling Design

2.1. The "three zones" of goaf

With the workface mining work, the original rock stress is damaged, the elastic-plastic energy accumulated in the overlying rock layer begins to release, resulting in the collapse of the direct top of the overlying rock layer, the basic top of the bending, sinking, articulation, and then the formation of the key layer below the occurrence of the rock layer with the rock layer of the transverse layer of the fissure and through the rock layer of the destruction of the vertical fracture fissure. The "three vertical zones" formed by the mining action of the overlying rock layer from bottom to top are the fall zone, fissure zone and bending and sinking zone respectively. Among them, the fallout zone is highly dispersed, with large porosity and high permeability; the fissure zone is located directly above the fallout zone, which produces different degrees of fissures and extends upward; above the fissure zone is the bending subsidence zone, where the strata are deformed or curved without major fracture. The roof fissure zone formed after the collapse of the overlying rock strata can be used as a gas flow channel, and the gas in the overlying rock strata, coal strata and corners of the working face can be extracted through high-level directional drilling, so as to change the distribution of the high concentration of gas in the mining area, which can effectively reduce the amount of gas flowing from the mining area and the neighboring strata to the return-air tunnels of the working face, and radically solve the problem of gas exceeding the limit in the corners of the working face and the return-air tunnels caused by a large amount of gas gushing out from the mining area or the neighboring strata. It can effectively reduce the flow of gas from the air mining area and neighboring layers to the return tunnels of the working face.

According to the theoretical analysis and empirical formula of the rock properties of the roadway roof, the theoretical calculation value of the height of the fissure zone and the height of the fallout zone can be initially calculated. 204 working face roof rock properties are sandy mudstone, and after the theoretical analysis and selecting the appropriate empirical formula, the height of the fallout zone and the height of the fissure zone for the mining height of 1.8m can be calculated and predicted as follows:

Height of the fallout zone (m):

$$H_1 = \frac{100\sum M}{4.7\sum M + 19} \pm 2.2 = 6.6 \pm 2.2$$

Fissure zone height (m):

$$H_{21} = \frac{100\sum M}{3.1\sum M + 5.0} \pm 4.0 = 17 \pm 4.0$$

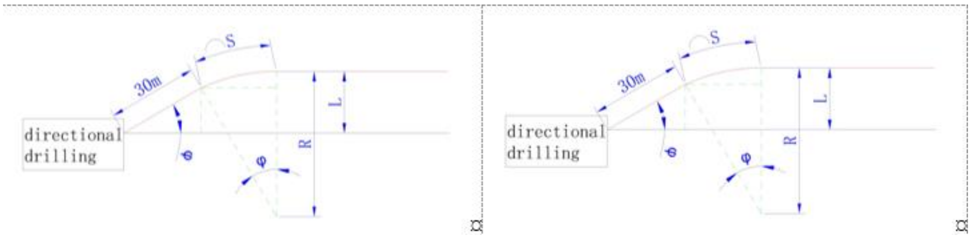
$$H_{22} = 10\sqrt{\sum M} + 15 \approx 28$$

Note: $\sum M$---- cumulative mining thickness, single layer thickness of 1-3m, the cumulative thickness of not more than 15m, ± No. item is the median error.

2.2. Principles of high level drilling design

Dangjiahe Coal Mine uses ZDY15000LD high power directional drilling rig, which consists of main machine, operation desk, pump station, explosion-proof computer, rotator, feeding device, gripper, hydraulic system, flowmeter, directional drilling head, screw motor, through the cable drilling rod, crawler and stabilizing device, etc., which are connected with each other by communication cables, high-pressure hoses and bolts, etc. The pump station provides high-pressure water flow and sends it to the drill head through the through cable drilling rod according to the pre-designed parameters. The high pressure water flow is provided by the pump station and sent to the directional drilling head through the through-cable drilling rod, and the drilling head is driven by the main engine to break through the rock according to the pre-designed parameters. At the same time, drilling parameters such as drilling inclination and azimuth are transmitted to the computer by the signal transmission device to form the actual drilling trajectory and display. The construction personnel can compare the design parameters and drilling parameters and adjust the drilling direction of the screw motor in real time, so as to achieve the purpose of directional drilling.

The length of each supporting drill rod of the directional drilling rig is 3m, and the overall maximum change angle is 0.75°when adjusting the direction with the screw motor. In order to avoid jamming and broken rods during the construction process, the maximum change angle of each drill rod is designed to be 0.5°. The first 30m of the designed drilling hole is the sealing section, the drilling angle is the same as the opening angle, and after 30m of drilling, the angle of each drilling rod changes to 0.5°; when the main hole of the designed drilling hole reaches the predetermined position, the horizontal direction is parallel to the roadway gangs, and the plumb direction is parallel to the top plate of the coal seam; the drilling continues to be carried out until the length of the hole is in accordance with the requirements of the designed length. The drilling design principle is shown in Figure 1.



(a) Floor plan (b) Profiles

Figure 1: Drilling design principle

Equations (1), (2), (3), and (4) are established from Figure 1(a)

$$R = RCos\varphi + L - Sin\varphi \tag{1}$$

$$S = \frac{\pi R\varphi}{180} \tag{2}$$

$$S = \frac{3\varphi}{0.5} \tag{3}$$

$$\theta = 184.16 - \varphi \tag{4}$$

Where R is the radius of the arc at the turn of the drill pipe, m; φ is the angle between the drill pipe and the roadside gang at the time of opening, °; θ is the design magnetic azimuth; L is the distance between the main section of the drill hole and the roadside gang; and S is the length of the arc at the turn of the drill pipe, m. The design is based on the following criteria.

Equations (5), (6), and (7) are established according to Figure 1(b)

$$R = RCos(\alpha + \beta) + H - 30Sin(\alpha + \beta) \tag{5}$$

$$S = \frac{\pi R(\alpha + \beta)}{180} \tag{6}$$

$$S = \frac{3(\alpha + \beta)}{0.5} \tag{7}$$

In the formula, R is the radius of the arc at the turn of the drill pipe, m; α is the inclination angle of drilling, °; β is the inclination angle of the coal seam, °; H is the design height of the main hole of the borehole; S is the length of the arc at the turn of the drill pipe, m.

2.3. Design parameters for high level drilling

Based on the above drill hole design principle, 6 high level extraction drill holes are designed above the coal seam roof of IV# drill field in 204 working face, and the specific parameters are shown in Table 1.

Table 1: Design parameters of high level extraction drill holes in drillfield IV# at Workface 204

drill site	aperture number (e.g. on a cell phone)	Design distance between main hole and roadway gang/m	Design main hole height/m	Design magnetic azimuth θ/°	Design inclination angle α/°	Height of opening position from drill floor/m	Distance between opening position and roadway gang/m	Design hole depth/m
IV# Drill site	IV-1	3	12.2	182.05	11	2.5	1.5	402
	IV-2	8	15.5	177.55	12.7	2.3	2.0	
	IV-3	13	16	174.35	12.9	2.5	2.5	
	IV-4	18	16.5	171.65	13.3	2.3	3.0	
	IV-5	23	17	169.35	13.4	2.5	3.5	
	IV-6	28	17.5	161.9	11	2.3	4.0	

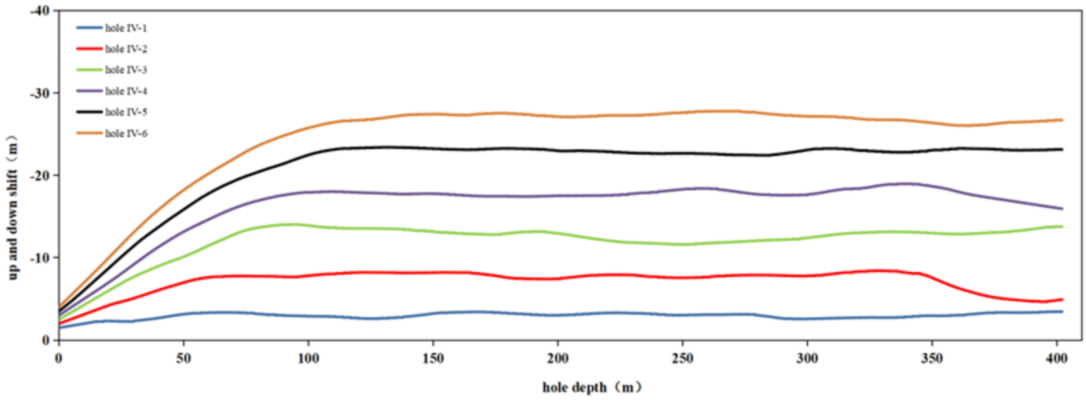
3. Engineering tests

3.1. Overview of the project

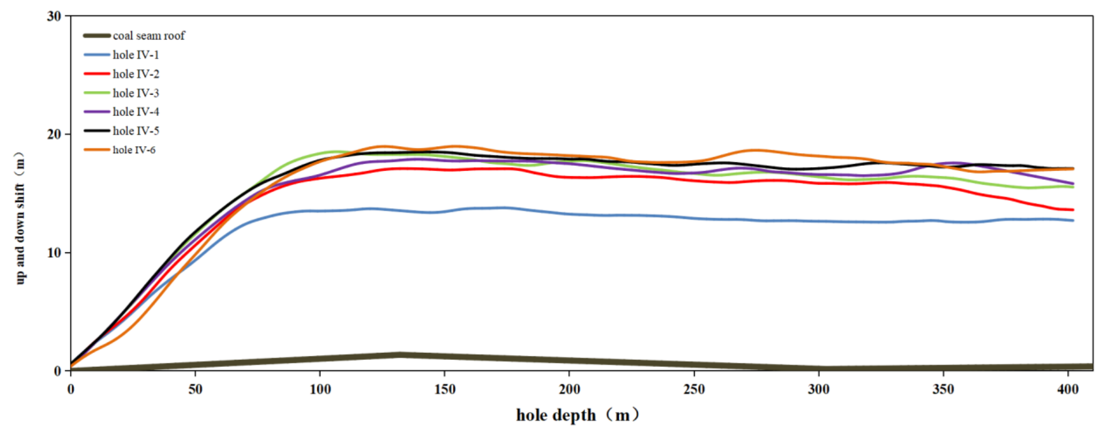
The Dangjiahe Coal Mine is located in Fuxian County, Shaanxi Province, and its shaft field belongs to the Huangling Mining Area of the Huanglong Jurassic Coal Field in Shaanxi Province, bounded on the north and west by the Lucun Survey Area, on the south by the Huangling No. 2 Coal Mine, and on the east by the Huangling No. 1 Coal Mine. The Dangjiahe Coal Mine contains three coal seams in the well field, numbered from top to bottom as I# coal seam, II# coal seam and III# coal seam, of which II# coal seam is the only mineable coal seam at present. The geological structure of the mine is relatively simple, the average coal thickness of II# coal seam is 1.8m, and the coal seam is nearly horizontally developed. There is obvious difference in physical properties between the coal seam and the surrounding rocks, the bottom plate is mostly mudstone or sandy mudstone, the pseudo-top of the coal seam is mostly mudstone, and the direct top is fine-grained sandstone and siltstone. The upper rock layer of the coal seam is basically fine sandstone and siltstone interbedded. The strength of the coal seam is relatively small and Poisson's ratio is large, which is a weak rock layer.

3.2. High level drilling construction

Since Dangjiahe coal mine 204 working face cutting along the lower trench to the north 1153.8m IV# drilling field, drilling field design 6 high level drilling, using ZDY15000LD type high power directional drilling rig in strict accordance with the design parameters of the construction, drilling trajectory of the actual drilling is shown in Figure 2.



(a) Floor plan

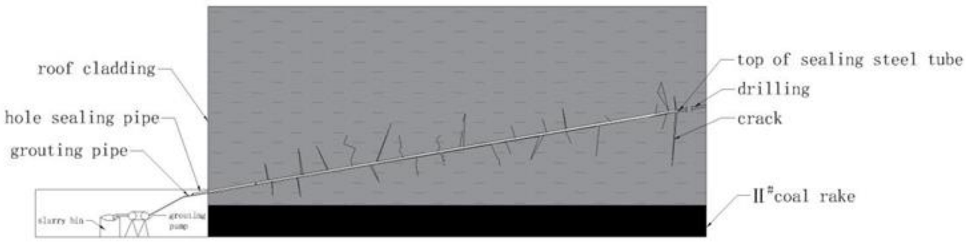


(b) Profiles

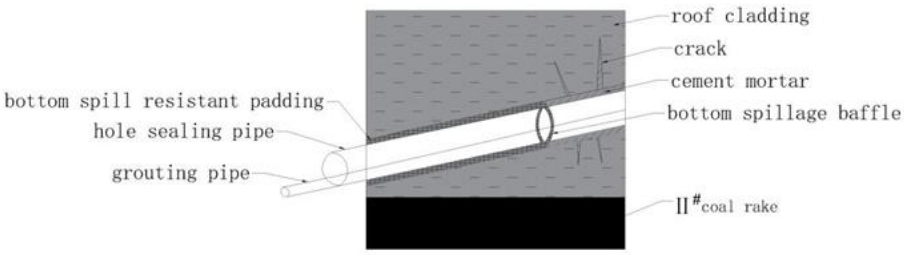
Figure 2: Drilling trajectory of the actual drill hole

3.3. Hole Sealing

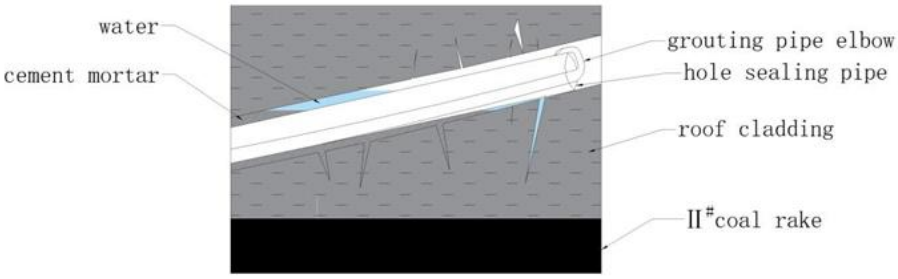
The initial hole diameter is Φ120mm, and the hole diameter is Φ153mm after reaming. After the drilling, the hole is sealed by Φ108mm seamless steel pipe, cement mortar sealing material, and interpolated multiple grouting sealing process, and the length of the hole is 30m, and the hole is connected to the negative-pressure extraction system for gas extraction after the completion of the sealing, and the principle of the interpolated multiple grouting sealing process is shown in Fig. 4. The principle of inserted multiple grouting sealing process is to use the grouting pipe with elbow to hang on the wall of the steel pipe from the inside of the sealing pipe, so that the cement mortar flows to the bottom of the drilling wall and the sealing pipe at the overflow baffle, and gradually upward accumulation of the filling to the cement mortar from the inside of the sealing steel pipe back to slurry so long as the cement mortar to be left to stand for 24h-48h after the cement precipitation and solidification of cement separation from the water, and then grouting again, and repeat until the sealing length of 30m to meet the design requirements. Repeat the operation until the length of hole sealing meets the design requirements, and the grouting pipe can be disassembled and reused.The structure of the device is shown in Figure 3.



(a)



(b)



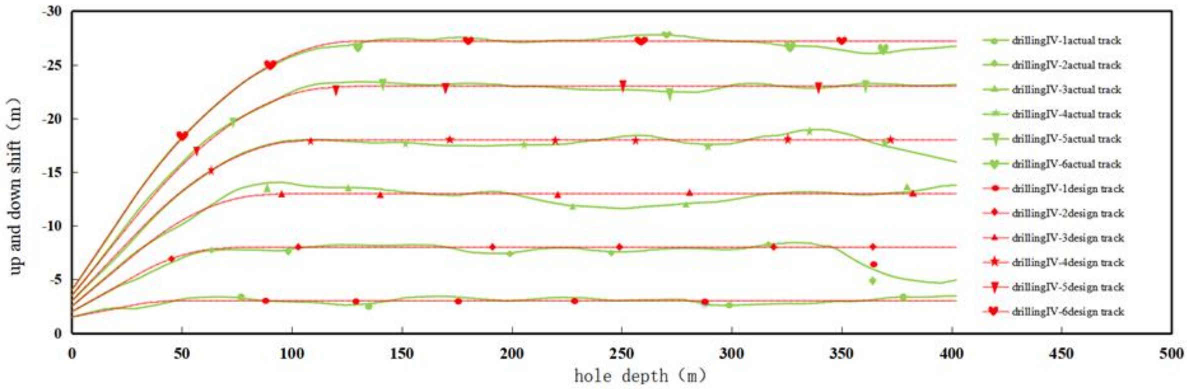
(c)

Figure 3: Inserted multiple grouting sealing process

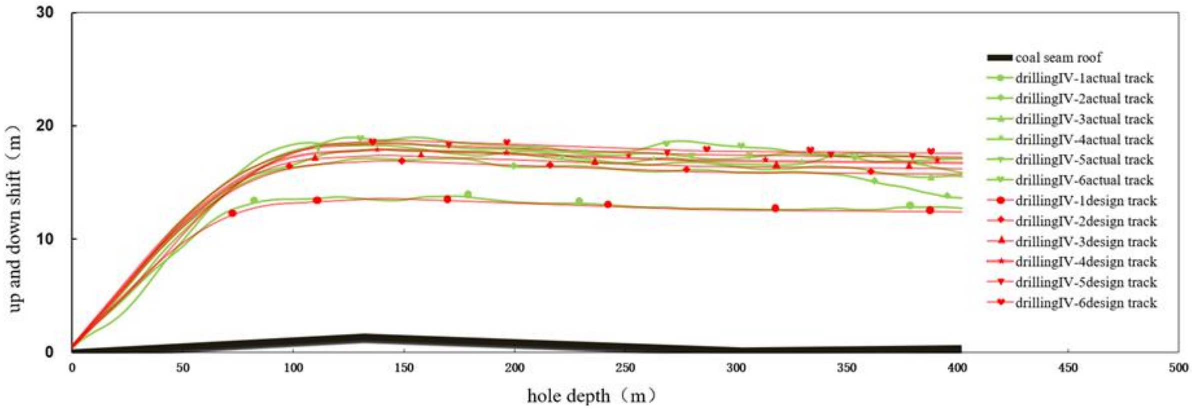
4. Engineering effect analysis

4.1. Analysis of drilling construction effect

According to the proposed high level drilling design, 1# high level drilling, 2# high level drilling, 3# high level drilling, 4# high level drilling, 5# high level drilling and 6# high level drilling were constructed in the IV# drilling field of 204 upper trench, the construction effect of the high level drilling directly affects the effect of gas extraction, and thus influences the validation of the correctness of the conclusion of the above study. Therefore, analyzing the construction effect of high level drill holes is a key step to ensure the scientific and rigorous validation results. According to the real-time drilling data fed back to the computer from the data transmission system of ZDY15000LD high-power directional drilling rig during the construction process, the data within the 0-400m distance of the high level drilling footage are selected to draw the actual drilling trajectory of the high level drilling holes and analyze it in combination with the design trajectory, see Figure 4.



(a) Floor plan



(b) Profiles

Figure 4: Comparison between the actual drilling trajectory and the design trajectory of the high level directional drill hole

As can be seen from the figure, in the left-right displacement direction, the trajectory of 2# high-level drill hole in the hole depth of 350-400m range of large fluctuations, deviation from the original design trajectory of more than 3m, 3# high-level drill hole trajectory in the turn flat and the middle stage of the slight fluctuation, but the degree of deviation is not large, the rest of the drilling trajectory basically close to the original design; in the up and down displacement direction, the trajectory of 2# high-level drill hole in the hole depth of 350-400m range of height is lower than the design of more than 3m. In the direction of upward and downward displacement, 2# high level drill hole trajectories in the range of 350-400m are lower than the design height by more than 3m, 6 high level drill holes in the range of 260-300m are slightly higher than the design height, and the rest of the drill holes construction trajectories are in line with the design requirements.

4.2. Analysis of gas extraction effect

For analysis IV# gas extraction at the drill site, a scatter plot of the extraction parameters for this drill site was plotted and is shown in Figure 4.

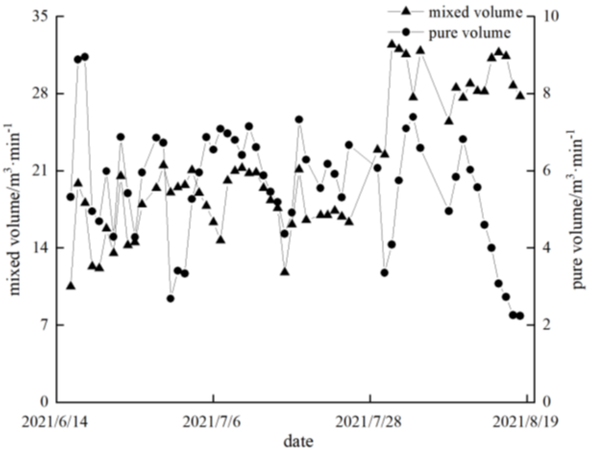


Figure 5: 204 working face IV #Scatter plot of drilling field extraction parameters

General IV# The pure volume of gas extracted from the drilling site is 5.5-7.5m^3 /min, and the maximum pure volume of gas extracted is 8.95m^3 /min (June 18th). Taking July 30 as the cut-off date IV# drillfield extraction gas mix can be divided into two stages before and after, the pre-extraction gas mix is 10-20 m^3 /min, and the post-extraction gas mix is 25-32 m^3 /min, then the average value of the pre-extraction and post-extraction gas concentration is 43% and 22.8%, respectively; among them, the extraction gas concentration on June 17th and June 18th is 44.8% and 49.4%, respectively. Although IV # the total extracted gas concentration and gas mixing volume of the drilling site show two stages before and after, but the pure extracted gas volume is basically stable, and the overall volatility is smaller than the volatility of a single hole, indicating that the extraction effect is relatively stable.

Production practice shows that the gas extraction effect of IV# drilling field is good, which meets the target requirement of gas prevention and control in 204 working face. During the production period, the volume of air-discharged gas in the 204 working face was generally 7.5 m3/min, and the volume of extracted gas accounted for 42.3% to 50% of the total volume of extracted gas, and the volume of extracted gas accounted for 54.4% of the total volume of extracted gas when the volume of extracted gas was at its maximum, and the concentration of the gas in the return wind of the working face was kept at 0.5%, and that in the return-wind corners was less than 0.5%.

5. Conclusion

1) According to the mechanism of high directional drilling for gas extraction in the roof fissure zone, the vertical height of high directional drilling is determined to be 12.2~17.5m for the geological conditions of the 204 working face of Dangjiahe Coal Mine.

2) The high level directional extraction drill holes constructed according to the design program have good gas extraction effect. At the maximum time, the amount of extracted gas accounted for 54.4% of the total amount of extracted gas, and the concentration of gas in the return air of the working face was kept at 0.5%, and the concentration of gas in the corner of the return air was less than 0.5%, which could ensure the safety of the subsequent production work of the working face.

References

[1]. Cheng Yuanping, Yu Qixiang. Development of Regional Gas Control Technology for Chinese Coalmines [J]. Journal of Mining ＆ Safety Engineering, 2007, (04):383-390.

[2]. Guo Xinhong, Ren Zhongjiu. Research on optimization of gas drainage height with high-level boreholes under multiple coal seam conditions [J]. Safety in Coal Mines,2021,52(06):194-198.

[3]. Li Chunyuan，Zhang Yong，Li Jia，Zhang Guojun. Highly-located boreholes drainage technology of gas macroscopic flow channel in goaf [J]. Journal of Mining & Safety Engineering,2017,34(02):391-397.

[4]. Sun Rongjun，Li Quanxin，Fang Jun，Xu Chao. Construction technology and development tendency of high level borehole for gas drainage in goaf [J]. Coal Science and Technology, 2017, 45(01): 94-99+213.

[5]. Fu Shuai，Lv Pingyang，Wang Jiajian，Li Jinquan，Mao Guoli. Study on gas drainage technology with high level borehole in contiguous soft coal seams group [J]. Coal Science and Technology, 2016, 44(11):78-81.

[6]. Zhao Jing，Pi Xiyu，Wang Shuanlin，Zhang Zhirong，Lian Zhenshan，Liu Guifeng. Gas drainage technology with high level borehole at coal mining face in gassy thin seam [J]. Coal Science and Technology, 2015, 43(11):78-82.

[7]. Cai Wenpeng，Liu Jian，Sun Dongsheng，Jiang Erlong. Research and application of gas drainage technique with high-located drilling method along roof strike [J]. Journal of Safety Science and Technology, 2013, 9(12):35-38.

[8]. Chen Lei，Yuan Heyong，Xue Weiyi，Yan Jinpeng. Comparative study on gas drainage technology of high level borehole and mined-out area buried pipe [J]. Journal of Safety Science and Technology, 2013, 9(10):98-102.

[9]. Wu Shiyue，Liu Yang，Li Jinpeng. Gas Drainage Technology of Large Diameter Fan and High Level Boreholes Based on Overburden Movement Law [J]. Safety in Coal Mines, 2013, 44(07):63-65.

[10]. Liu Yunfeng，Zhang Jufeng，Xie Yadong，Zhao Zhiming，Feng Qingqi，Dang Jun，Yang Weitai. Integrated Application of High Level Borehole Gas Drainage and Grout Spraying Fire Prevention and Control in Goaf [J]. Coal Science and Technology, 2013, 41(04):53-56.