Analysis and Drainage Technology Research of Downward Drilling in Aquiferous Coal and Rock Seam

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Abstract: A large amount of water and coal slag generally accumulates in the downward drilling of aquifer coal seam, and the effect of gas drainage boreholes is seriously affected. In this paper, the influence of simulated borehole water on coal desorption test and coal stability is analyzed. The test results show that the gas desorption capacity of the coalbed invaded by water accumulated in boreholes decreases by 70% on average, and the strength of coal and rock mass is reduced. The sedimentation, adhesion and cementation of suspended coal and rock particles in the borehole wall results in the sealing of coal cracks, which directly reduces or blocks the gas migration and production channels in the borehole. This paper studies and designs borehole drainage technology and equipment, and achieves the purpose of automatic circulation drainage in parallel with multi-holes. The field test results show that the process equipment can effectively discharge the Water-accumulated coal slag in the borehole. After drainage, the concentration and quantity of single-hole gas extraction are greatly increased, and the purity of single-hole gas extraction is stable at about 0.04m^3/min. The problem of water lock effect and coal slag blockage in coal body is effectively solved, and the smooth passage of borehole gas extraction is guaranteed, and the effect of borehole gas extraction is significantly improved.

1. Introduction

Hydraulic slag drainage drilling technology is widely used in coal mine, and influenced by the hydrogeological conditions of coal seam and other factors, a large amount of water and coal slag will be accumulated in downward drilling. Because the drilling hole is generally deep and the borehole diameter is small, it is difficult to effectively discharge the water slag accumulated in the drilling hole in the process of gas extraction. Therefore, how to effectively discharge the water and slag accumulated in the boreholes below the aquifer coal seam has become an urgent problem to be solved in the mine gas extraction work.

At present, downward boreholes in aquiferous coal and rock strata of coal mine mainly use static pressure air in roadway to drain and discharge slag through drill pipe pressure air, after sealing air and jet device. Sun Shouyi, et al[1]. developed a pressure air drainage device, which increased the maximum extraction purity by 1.34 times by using single hole. Zhang Zhenlong, etc[2]. used downhole pressure air timing to remove water and impurities at the bottom of the hole, and pressed the water in the hole into the slag discharger. Ren Zhongchang[3]. realized the application of automatic drilling drainage technology by controlling high-pressure air through time-controlled switches and solenoid valves. Zhai Cheng, et al[4]. proposed a multi-hole parallel pneumatic drainage technology, designed the downstream borehole sealing technology of "pneumatic drainage" and the multi-hole parallel drainage system. Li Dong, et al[5]. put forward the method of jet drainage and slag discharge, and designed and manufactured the device of jet deep hole drainage and slag discharge. In summary, above drilling and drainage technologies are based on the principle of pressure air drainage, which has limited effect and there are common problems of pressure air destabilizing the borehole wall which also affect the daily extraction of boreholes in the process of pumping and drainage.

2. Experimental Analysis of Gas Desorption from Coal by Drilling Water

Referring to the research experience of water injection development in the field of petroleum shale gas [6], coal belongs to a porous medium, and water is absorbed and flowed through the processes of surface wetting, microporous diffusion and seepage of coal seam fissures. Under normal temperature conditions, using gas desorption test device to simulate the influence of water intrusion in boreholes on coal gas desorption, and referring to the high pressure isothermal adsorption test of coal (GB/T19560-2008) and high pressure capacity test process, coal gas desorption test under water conditions and coal gas desorption test under anhydrous conditions were carried out. The influence of water accumulation in boreholes on coal gas desorption was investigated and analyzed through comparative experiments.

(1) Test conditions: At normal atmospheric temperature of 20 degrees, the salinity of water is 0 mg/L. The test coal samples are 2kg coal samples from a mine. The difference between the equilibrium pressure of gas adsorption and the ambient pressure is 0.5 MPa under different pressure conditions [7]. The solubility of gas in water with different test pressure conditions and ambient temperature of 20 degrees is shown in Table 1 and Table 2.

Table 1 Testing different pressure conditions

group	1	2	3
Gas Balance Pressure P_c/MPa	2.0	1.5	1.0
Environmental pressure P_z/MPa	1.5	1.0	0.5

Table 2 Gas solubility of water in different test pressure intervals

Gas Balance Pressure P_c/MPa	2.0	1.5	1.0	0.5
Solubility $m^3 \cdot m^{-3}$	0.510	0.470	0.430	0.215

(2) Formula for calculating coal gas desorption[8]:

$$\Delta m_{ti} = \frac{V_m \times V_f}{M \times R \times T}\left(\frac{P_{ti}}{Z_{ti}} - \frac{P_z}{Z_z}\right) \tag{1}$$

Formula: Δmti-gas desorbed per unit mass of coal, cm^3/g;Vm-Molar volume of methane, 22.4×10^3 cm^3/mol;Vf-free space volume of container,cm^3;M-quality of coal samples,g; R-gas constant, R=8.75;T-test temperature, K; Z_{ti},Z_z is compression factor of methane gas of P_{ti} and P_z.

(3) Test process

① Put coal sample and water into the corresponding container. First, vacuum degassing is carried out by vacuum pump. Volume V_f of free space in the corresponding container is measured. Then methane gas is injected into the container to make the gas adsorption of coal sample in the container reach equilibrium pressure P_c.

② The gas desorption amount of coal samples was measured under anhydrous condition, and the environmental pressure P_z and T_i values at different time points during the test were recorded. The gas desorption amount MTI at each time point was calculated according to the calculation formula of coal gas desorption.

③ Under the condition of water intrusion, the gas desorption amount of coal sample is measured. After the equilibrium pressure Pc is reached by re-injecting methane, the water is added to the coal sample, and then the environmental pressure P_z and T_i values at different times during the 12 h test are recorded. Then the gas desorption amount MTI at each time point is calculated according to the calculation formula of coal gas desorption.

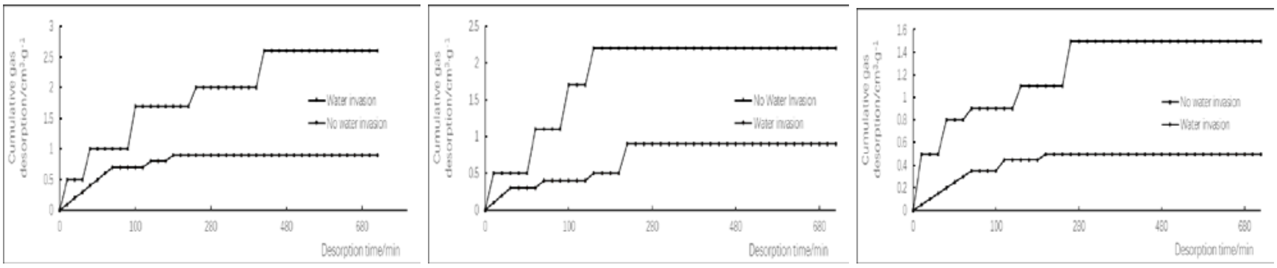

Fig. 1 Contrast Curve of Gas Desorption Amount at Different Pressure Levels

The test results show that the coal body can damage the gas desorption after water intrusion, as shown in Fig. 1, which can reduce the gas desorption amount by more than 70% on average. At the same time, there is an advance in the time of gas termination desorption, and capillary resistance occurs in the coal seam pore during water intrusion, which forms water lock effect, restricts and hinders the gas desorption and migration in the coal body pore, resulting in water lock damage, and then leads to borehole gas. The drastic decrease of pumping volume seriously affects the effect of pumping.

3 Stability of borehole water to borehole and plugging situation

In the boreholes of aquiferous coal seams, a large amount of water and coal slag are generally accumulated, and they exist in a mixed state, which is a solid-liquid two-phase flow state[9]. When the vertical depth of the borehole is greater than a certain value, it is difficult for the water-bearing coal and rock particles in the borehole to be discharged under the negative pressure of extraction.

3.1 Effect of drilling water on strength of drilling coal and rock mass

Drilling water mainly comes from residual water and fissure water in coal seam during construction, and eventually converges in the drilling hole. With the increase of water content, coal and rock undergo three stages with significant characteristics.

In the "lubrication" stage, when the water content of coal and rock mass is low or the water content of coal and rock mass begins to rise, the strength of coal and rock mass decreases.

In the "bonding" stage, with the increase of water content, the capillary plays a dominant role in coal and rock mass, and the influence of surface tension on strength is greater than that of friction, and the shear strength of soft coal increases.

In the "suspension" stage, the humidity of coal and rock mass reaches saturation state, the water fills between the particles of coal and rock mass, the shear strength begins to decrease, and the surface tension disappears.

3.2 Plugging of coal and rock particles

The generation of coal and rock particles is the result of comprehensive action of many factors. The nature of coal and rock itself is the basis of coal powder production. Mechanical damage during drilling construction, i.e. instability damage of drilling tool cutting coal and rock mass and borehole wall, is the main source.

Coal and rock particles precipitation, attachment and cementation in the borehole wall cause crack plugging in the borehole wall, thus forming a compact coal slurry plugging column. In addition, the water-bearing coal and rock strata are immersed in water for a long time, which results in the decrease of the strength of coal and rock around the borehole, aggravates the instability damage of the borehole wall, further causes borehole plugging, and increases the difficulty of gas extraction, or even increases the difficulty of gas extraction. It leads to the failure of drilling and extraction.

4. Study on Drainage Technology

4.1 Drainage Technology Scheme Design

4.1.1 Technical principle

In view of the drainage characteristics of downward boreholes in aquiferous coal and rock strata, this paper designs a multi-hole parallel automatic drainage scheme. The pneumatic drainage pump is controlled by the PLC control box and the electric valve to drain downward boreholes. The drainage system is mainly composed of PLC control box, electric valve, drainage pump and drainage pipeline, as shown in Fig. 2.

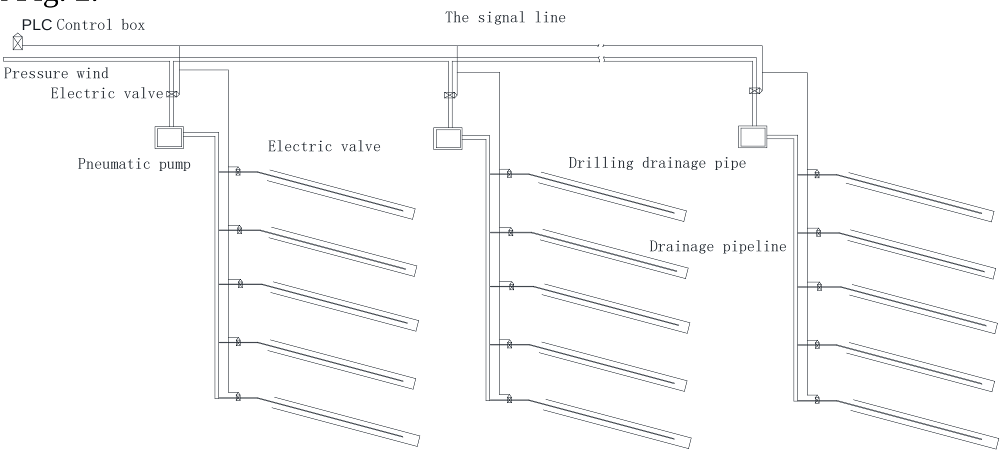

Fig. 2 Drainage process chart of downward borehole in aquifer coal seam

4.1.2 Technological process

A drainage pipe is added to the pumping pipeline, as shown in Fig. 3. The purpose of automatically discharging coal slag from the borehole is realized by using the pumping pump through the control system. The specific technological process is as follows:

① When there is no drainage operation, the PLC control box controls the electric valves of the borehole drainage pipeline and the compressed air pipeline to close, the compressed air pipeline to close, and the gas in the borehole enters the drainage system by itself from the drainage pipeline.

② When opening drainage operation: PLC control box works, electric valves for controlling borehole drainage pipeline and pneumatic drainage pipeline are opened, and pneumatic drainage pump, drilling hole, drainage pipe and water cinder drainage drilling hole are opened. At this time, gas in borehole enters the drainage system by itself from the drainage pipeline, and the drainage work does not affect the normal daily gas drainage work. After a period of pumping and draining, PLC controls the electric valves of borehole drainage pipeline and air pressure pipeline to close and the pumping and drainage pumps to stop working.

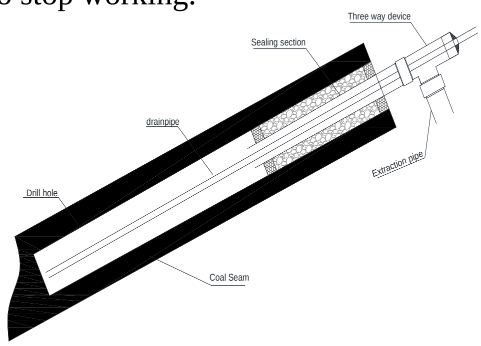

Fig. 3 Drainage Pipeline and Connection Diagram in Borehole

4.2 Test Effect Analysis

4.2.1 Test site

The cutting hole of 3307 working face in a coal mine is selected as the test site as shown in Fig. 4. There are eight boreholes, inclination angle of boreholes is -15°, depth of boreholes is 100 meters, borehole spacing is 2.5 m, and borehole diameter is 113 mm. When the coal mine production scale is 3.00Mt/a, the normal water inflow in the mining area is 5900m^3/d and the maximum water inflow is 7200m^3/d. Water accumulation and hole collapse are common in the test boreholes. The net gas flow rate of the extraction branch pipe decreases from 6.105 m^3/min to 0.386m^3/min, and the gas extraction concentration decreases from 31.57% to 8.97%.

4.2.2 Drainage equipment and pipeline layout

The drainage pipeline is arranged in multi-hole parallel mode. The electric ball valve is arranged in the drainage pipeline in each drilling hole. The gas-water separation is realized by connecting the water collecting pipeline with the pneumatic pumping and drainage pump and the drilling water slag with the steam-water separator. The water slag is discharged through the water discharger and the mixed tile is produced. The gas-water separator is used for pumping pipeline.

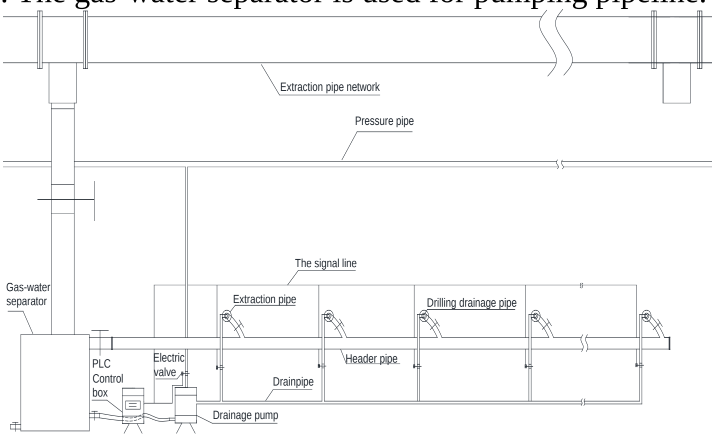

Fig. 4 Drainage System Pipeline Layout Scheme

4.2.3 Data analysis before and after drainage of test boreholes

The drainage effect of downward boreholes in aquifer coal and rock strata was investigated by comparing the changes of gas concentration and gas flow rate before and after drilling. A group of test boreholes with 8 downward boreholes were designed. The daily data of drilling before test and the data of drilling during test were measured by statistics, and the recorded data were analyzed by statistics.

The variation trend of drainage concentration and pure gas flow rate before and after drainage was shown in Fig. 5. It can be seen from the figure that after drainage by test boreholes, the purity of single-hole pumping is stable at about 0.04 m^3/min, and the high concentration of pumping is maintained. It has been proved by application that the water-bearing coal and rock downward boreholes can effectively discharge the water-bearing coal slag in boreholes, relieve the water lock effect and coal slag blockage in coal bodies, ensure the smooth passage of gas drainage in boreholes, effectively improve the gas drainage volume in boreholes, solve the problem of water accumulation in downward boreholes and not easy to discharge, and significantly improve the drainage effect of boreholes.

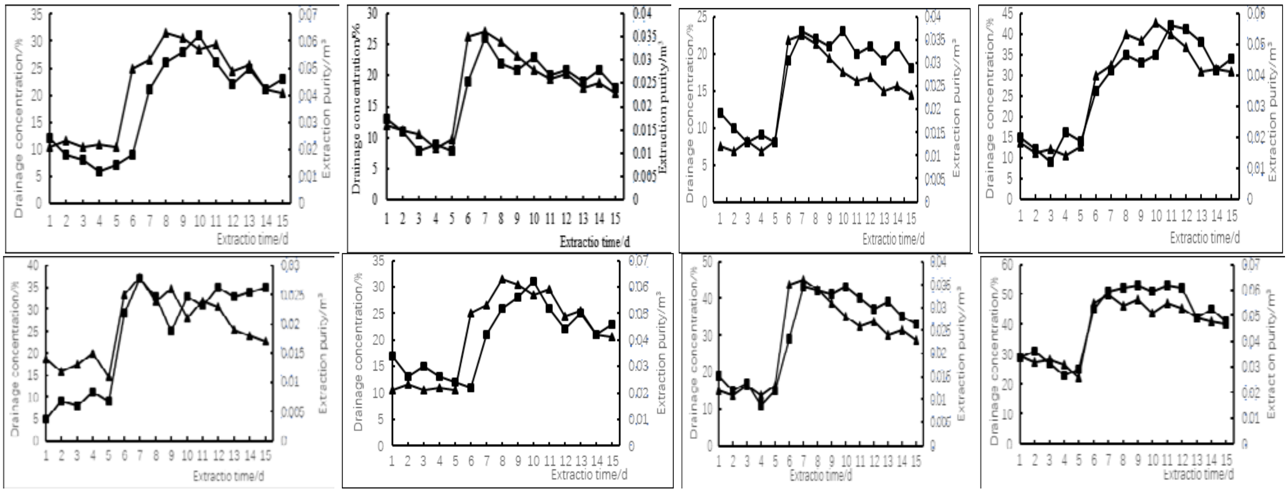

Fig. 5 Variation Trend of Drainage Concentration and Purity before and after Drainage of Test Borehole

5. Summary

This paper studies and designs the drilling and drainage technology and equipment through the analysis of the influence of drilling water on gas desorption, stability of coal and rock mass along the borehole wall and coal slag plugging, and draws the following conclusions:

(1) By simulating the effect of water accumulation in boreholes on coal desorption test and coal stability analysis, the test results show that the gas desorption of borehole coal decreases by more than 70% on average after water accumulation and foaming.

(2) It is found that the sedimentation, adhesion and cementation of micro-particles in suspended coal and rock mass on the borehole wall result in the blockage of coal cracks, which directly reduces or blocks the gas migration and production channels in boreholes, and the effect of gas extraction is seriously affected.

(3) In view of the characteristics of water-bearing coal and slag in downward boreholes in aquiferous coal and rock strata, the drainage technology and equipment developed and designed can greatly increase the concentration and quantity of gas extraction in single borehole after drainage, and the purity of single borehole extraction is stable at about $0.04m^3$/min. The effect of drilling gas extraction is remarkably improved.

(4) Engineering application shows that the drainage system process device realizes multi-hole parallel drainage operation, improves the efficiency, intensive and automatic drainage degree of boreholes, fundamentally solves the problem of low gas drainage caused by water accumulation in downward boreholes of aquiferous coal and rock strata.

Acknowledgments

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References

[1] Sun Shouyi,Huang Liang,Li Xijian,et al.Application of water draining equipment in the down hole to improve gas drainage in Fa`er Coal Mine[J], Journal of Safety,2016,42(2):98-100.

[2] Zhang Zhenlong, Zhang Tingyong, Cai Yong . Test of automatic water discharge technology for downward gas drainage holes and development of discharge device[J] . Mining Safety and Environmental Protection,2013,40(2):43-45.

[3] Ren Zhongjiu. Research and application of automatic water drainage technology in downward gas drainage borehole[J]. China Energy and Environment Protection, 2018,40(1),31-35.

[4] Zhai Cheng,Xu Yanming,Li Quangui, et al.Study on Parallel Multi-hole Technology for Water Removing by Compressed Air and Its Application in Gas Drainage[J].Ming safety & environmental protection,2014,41(4):50-58.

[5] Li Dong,Lu Yiyu,Wang Jie, et al.Method and Experimental Study on Draining Water and Cinder by Jet in Gas Drainage Hole[J].Journal of Mining & Safety Engineering,2012,29(2), 283-288.

[6]Liao Ruiquan,Xu Yonggao,Hu Xuebin.Hibiting and Removing Methods[J].Natur.Gas Ind.v.22(6):87-89.

[7] Nie Baisheng,Liu Xianfeng,Guo Jianhua,et al. Effect of moisture on gas desorption and diffusion in coal mass[J]. Journal of China University of Mining & Technology, 2015,44(5), 781-787.

[8] Zhang Guohua,Liang Bing,Hou Fengcai,et al.Experiments on the invasion impact of pentrant solution with different concentrations on gas desorption[J].2013,36(5):107-112.

[9] Han Ying,Zhang Feiyan,Yang Zhilong.Analysis of stability of coalbed borehole wall[J].China Safety Science Journal,2014,24(6):80-85.

[10] Wang Liangjin,Liu Xiao.Research on Increasing Production of Depression Angle Drilling with Water[J].Coal Technology, 2014,33(6):108-110.