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Experimental Study on Aerodynamic Stimulation Technology of Gas Surface Pumping Well

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ABSTRACT

The existing underground extraction methods have limitations and timeliness. The cost of mine outburst prevention and gas drainage is high, and the rate of gas drainage is low. The combination of gas surface extraction technology and underground gas extraction can effectively improve the effect of underground gas control. Aerodynamic surging technology is an important completion antireflection and outburst elimination technology for surface gas drainage wells. In Weijiadi Coal Mine, the application of aerodynamic oscillation cavitation technology to mine outburst prevention is one of the methods of cave completion. Through rapid gas pressure fluctuation, the reservoir produces stress damage, which leads to wellbore collapse, increases the exposed area of the reservoir, and destroys the coal seam blocked by the mud pollution channel around the wellbore. Through the suppression and discharge of high gas pressure, the blockage in the coal seam gap-coal ash can be poured into the wellbore, resulting in several self-supporting cracks extending in all directions, so as to realize the effective connection between the wellbore and the reservoir. Through the aerodynamic stimulation technology of the coal seam in the test well, the permeability of the plastic failure area is effectively increased, the efficient extraction of gas near the workload is realized, and the safety hazards of coal seam mining are eliminated in advance. It provides theoretical and practical support for the efficient development of coalbed methane and gas ground treatment, and has important engineering practical significance.

KEYWORDS

Aerodynamic Stimulation; Gas Control; Coal Seam Permeability Increase; Field Test.

1. INTRODUCTION

As an important unconventional natural gas and low-carbon energy, the efficient development of coalbed methane is of great significance to achieve the goal of ' carbon peak and carbon neutralization [1-3]. Coalbed methane is generally known as gas, and its main component is methane, which is the main factor causing gas explosion accidents [4]. Coalbed methane is associated with coal. Coal is formed and stored in coal seams and coal-bearing strata during the formation of coal. Its adsorbed and free states are gases [5]. The composition is similar to that of conventional natural gas, and the methane content accounts for more than 90 % of the total. China 's coalbed methane resources are abundant, but there is still a certain gap between production and large-scale application. At present,

China 's dependence on imported natural gas is relatively large, which seriously affects national economic development and energy security [6]. According to BP Energy, China 's external dependence on natural gas will exceed 55 % by 2035, posing a serious threat to the country 's strategic security of natural gas[7].

The aerodynamic surging technology injects high-pressure air into the wellbore through the air compressor unit, the pressurization device and the supporting ground-wellbore gas pipeline network, forming a high-pressure environment at the bottom of the well. The injected gas is divided into two action paths: one part acts directly on the exposed coal wall to produce mechanical effects, and the other part penetrates into the coal body and expands along the natural fracture network, resulting in stress concentration in the coal rock near the wellbore. Subsequently, the instantaneous pressure relief operation was carried out to quickly release the stress field of the coal reservoir and produce double effects. First, the structural damage of the coal body around the well occurred under the action of stress mutation, which was manifested as collapse, spalling and crushing. Secondly, the rapid expansion of high-pressure gas in the fracture carries out pulverized coal particles, which effectively dredges and expands the original fracture system. Subsequently, through the pressure air washing process, the broken coal cuttings are circulated back to the surface, thereby expanding the size of the borehole cave, increasing the exposed area of the coal wall, significantly improving the permeability of the coal seam near the well, and finally realizing the overall improvement of the reservoir conductivity. Since the 1980 s, this technology has been applied in the San Juan Basin of the United States, the Shouyang Block of Shanxi Province and the Shenbei Coalfield of China [8-10].

In Weijiadi Coal Mine, the aerodynamic oscillation technology is applied to surface drilling for the first time. The purpose is to use the principle of aerodynamics to discharge coal and gas in a certain range around the wellbore out of the well, minimize or eliminate the risk of underground coal and gas outburst, reduce the construction period, alleviate the mining replacement, and solve the problem that conventional downhole drilling may induce ' hole burst ' and drilling difficulties, which is of great significance to the safe and efficient production of the mine.

2. OVERVIEW OF REGIONAL GEOLOGICAL ENGINEERING

The structural position of Weijiadi mining area is located at the junction of the eastern end of the northern Qilian fold belt and the Ordos platform syncline in the Qilian geosyncline. Weijiadi mine field is located in the southeast wing of Baojishan syncline, which is actually a compound monoclinic structure. The stratum strikes N45° ~ 50°W, dips NE, and the dip angle is large in the shallow part, which is 20° ~ 30°, and the deep part becomes smaller, which is 5° ~ 10°. The working face is located in the lower part of the east mining area of Weijiadi Coal Mine. Well location coordinates: horizontal X: 4062543.38; y: 18493344.16; altitude H: 1657.0741 m. The strata of the working face from top to bottom are: Cenozoic Quaternary; lower Cretaceous Hekou Group of Mesozoic; upper Jurassic Kushuixia Formation, Middle Xinhe Formation and Yaojie Formation. The coal-bearing strata are the Yaojie Formation of the Jurassic Middle Series. The lithology is mainly gray, gray-white medium and coarse-grained sandstone and dark gray siltstone and sandstone mudstone interbedded, locally intercalated with carbonaceous mudstone, and the bottom is gray-white thick conglomerate and glutenite. The cycle structure is clear. There are four layers of coal (No.1,2,3 layers of coal from top to bottom), of which one layer of coal is the main minable coal seam widely distributed in the whole area. The thickness of the coal seam gradually becomes thinner from south to north along the strike. The total thickness of the coal seam is 5.71 m ~ 16.96 m, and the average total thickness is 11.2 m.

3. DRILLING EQUIPMENT

The main equipment in the drilling stage is: ZJ30 drilling rig; jJ170-32-K derrick; the hoisting system is JC-30B winch, TC-170A crane, YC-170A traveling pulley, DG-200 hook and SL-200 faucet. The

circulation system is 3NB-1000 drilling pump, CSQ200S desander and ZJ30 drilling fluid tank. The power system of the ordinary drilling rig is a PZ12V190PZL diesel engine and a PZ8V190B diesel engine. Drilling rig control system 2V-6.5 / 12 automatic pressure fan, SA-22A-10.5 electric pressure fan and DSF-35 auxiliary brake; the solid control system is S250-2 × 2 vibrating screen, NCS300-2F desander and LW450-842N centrifuge. Φ444.5 mm, Φ311.15 mm and Φ215.9 mm drill bits.

The main equipment in the stage of cavitation are: Φ700mm drill bit; cSH295A-T30D screw air compressor, a maximum displacement of 31m3 / min, rated exhaust pressure 2.4 / 3.0MPa; cSH295A-T31DB screw air compressor, a maximum displacement of 31m3 / min, rated exhaust pressure 2.5 / 3.1MPa; two SF-1.2 / 24-150-C type air compressors are introduced. The volume flow rate is 1.2 m3 / min, the suction pressure is 2.4 MPa, and the rated discharge pressure is 15 MPa.

4. WELL BORE CONFIGURATION

The well structure is shown in Fig.1.

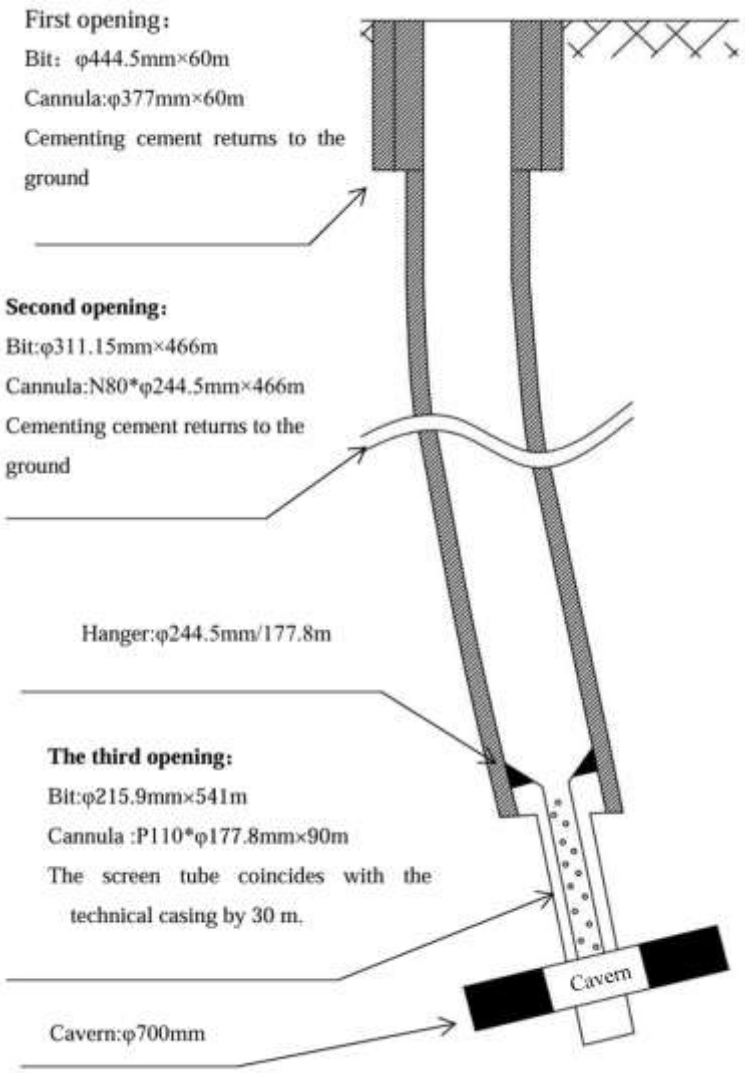

Figure 1. Well structure diagram

5. DRILLING ENGINEERING OPERATION PROCEDURE

① the Φ444.5 mm drill bit is used to drill to 58 m, and the Φ377.00 mm surface casing is run, and the G-class oil well cement is cemented, and the cement returns to the ground. After 48 hours of condensation, the test pressure was qualified.

② The second section adopts Φ333mm drill bit to drill to 538m (No.4 / 5 coal seam roof).

③ logging (standard logging of the whole section of the second section, comprehensive logging of coal measures strata);

④ The Φ244.5mm * 10.03mm * Shandong Shundong casing was run, and the pressure test was carried out after waiting for 48 hours.

⑤ Φ215.9mm drill bit was used in the third section to drill through the target coal seam and drill to the coal seam floor 593 m to complete the drilling;

⑥ The Φ700mm reaming drill is used to mechanically expand the target coal seam, and the diameter of the cave is 700mm;

⑦ Installation of sealing device, and pressure test, pressure test 6MPa, pressure test qualified;

⑧ Change to use aerodynamic agitation technology to expand the hole in the target coal seam section until a stable cave is formed, and the well is washed to the bottom of the well.

6. DRILLING ASSEMBLY

① Centerless drilling in the first section: Φ444.5mmPDC × 0.50m + X / O × 0.52m + Φ167mmDC × 8.98m + Φ164mmDC × 8.58m + Φ165mmNMDC + Φ127mmHWDP.

② Centerless drilling in the second section: Φ333mm roller × 0.60m + Φ172mmUBHO * 0.61m + Φ165mmNMDC * 17.59m + Φ127mmDP.

③ The third section drilled through the target coal seam: Φ215.9mmPDC * 0.34m + Φ185mm screw * 8.10m + UBHO * 0.67m + Φ172mmNMDC * 9.17m + Φ127mmDP * 574.72m.

④ Mechanical reaming: φ700 mm reaming tool, φ120 mm drill collar 2, φ73 mm drill pipe, power head.

7. DRILLING FLUID PROPERTY

First open section: 0.00-58.00 m, section length 58.00 m. The drilling fluid system is a low solid polymer drilling fluid system. The first formation of this well is loess layer-estuary group. Mainly brick red coarse-grained sandstone.

Second section: 58.00m-573.00m, section length 515.00m. The drilling fluid system is a low solid polymer drilling fluid system. The second section of the well is from Hekou group to Yaojie group. It is dominated by purple sandy mudstone and gray-white medium-grained sandstone.

The third section: 535.00m-593.00, section length 58.00m. The drilling fluid system is a low-solid polymer drilling fluid system, and the third section of the well is the Yaojie Formation; mainly coal seam.

Avoid drilling cuttings dispersion pulping; reduce high temperature and high pressure water loss, appropriate control density, thereby inhibiting the collapse of the formation, improve the stability of the wellbore. There is no collapse phenomenon, and the wellbore is smooth, which ensures the smooth construction of electrical logging, casing running and cementing.

8. MECHANICAL REAMING OPERATION

(1) Location: 542.00-557.00 m.

(2) Technical parameters: drilling pressure 10 ~ 30kN, speed 37 ~ 54r / min, displacement 8 ~ 12L / s, pump pressure 4MPa.

(3) Drill bit: 700mm PDC drilling bit, blade length 350mm after expansion.

(4) Process: 1 Drill the cement plug (including floating hoop, floating shoe) to the depth of 542.00 m, clean the mud pool and replace the new drilling fluid to prepare for the third section drilling; 2 215.9 mm PDC bit sweeps cement plug, float collar and float shoe, and drills to 593 m depth. 3 Connect the drilling tool and mechanical reaming tool, open the mud pump, check the working condition of the mechanical reaming tool at the wellhead, and test the operation. After confirming that the mechanical reaming tool can be opened normally and can work normally, the drilling tool is put in. 4 Down into the Φ700mm reaming drill. The coal seam section is excavated, and the collapsed coal and cuttings are carried outside the well through the drilling fluid to form a columnar cave several times larger than the well diameter in the coal seam section, so as to realize the maximum connection between the coal seam and the wellbore, increase the effective radius of the wellbore, and maximize the adsorption gas desorption of the coal rock reservoir. Finally, about 6m3 of coal cuttings are returned, and the coal cuttings at the wellhead are shown in Fig.2.

9. AERODYNAMIC STIMULATION OPERATION

9.1. Aerodynamic stimulation operation process

① Static water level: The depth of static water level is 121.4 m.

② Pressure test: install and debug blowout preventer and ground equipment, and carry out ground manifold pressure test.

③ Exclusion of water and debris in the well: the Φ73 mm tubing is first put into the well to about 250 m below the depth of the static water level, and the actual depth is 374.96 m. First start the No.1 air compressor to inject gas and liquid until the wellbore fluid is no longer returned, and complete the first well washing. Continue to run the Φ73mm tubing to the top of the coal seam 543m, observe whether it is blocked, if not blocked, continue to run the tubing to the middle and upper position of the coal seam (design depth of 546m), start No.1 air compressor gas injection blowing liquid washing well, until all the liquid in the hole is blown out, and the washing well is completed. If the Φ73 mm tubing is blocked to 543 m at the top of the coal seam, the No.1 air compressor is started to inject gas and blow liquid to wash the well, and the tubing is gradually lowered until all the liquid in the hole is blown out and the well washing is completed.

④ Injecting air: Start two air compressors and boosters to inject high-pressure air into the well at the same time, and observe the pressure change after reaching 6-10MPa.

⑤ After the end of gas injection, the valve is closed to form a closed system, and the gas pressure change in the well is observed. If the pressure drop is too large, the gas is reinjected, and the closing time depends on the reservoir pressure and permeability.

⑥ Pressure release: Open the valve to release quickly, return water, gas, coal and so on at the wellhead, and complete a release process.

⑦ Washing operation: After the surge operation is completed, clean water is used to clean the pulverized coal in the cave of the target layer repeatedly until only clean water is returned in the well, or gas injection and blowout are carried out to clean the pulverized coal in the cave.

⑧ Data detection: After the well washing operation, the valve is closed to form a closed system, and the change of the pressure in the well is observed and recorded, and then the valve is opened to detect the flow of the produced gas.

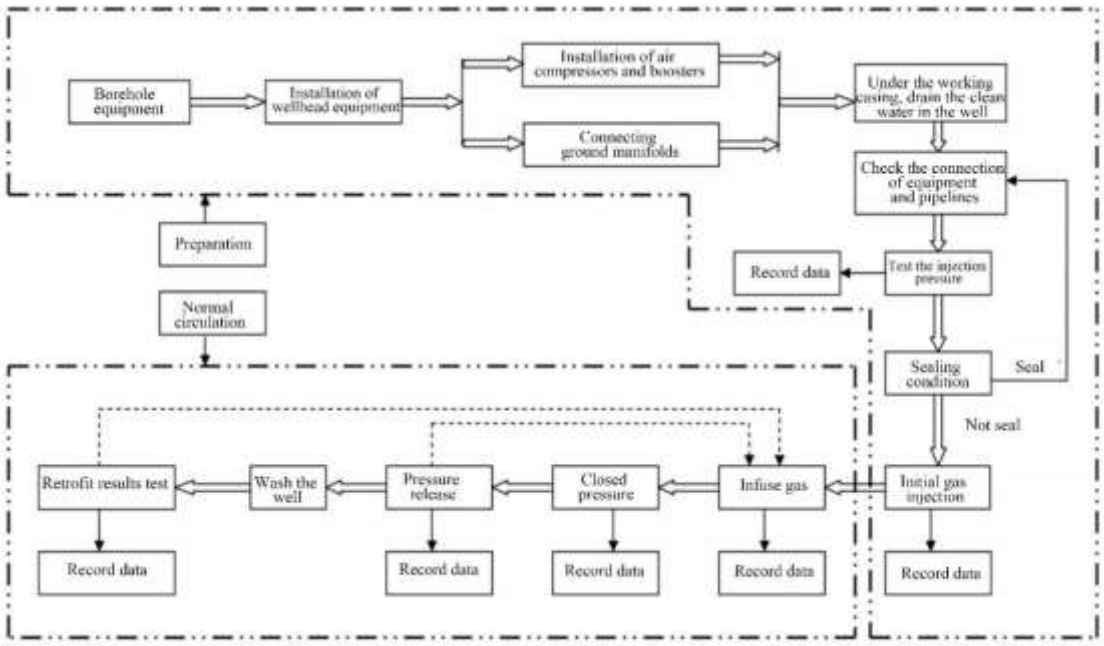

Figure 2. Construction process of aerodynamic stimulation technology

9.2. The specific construction situation and effect

A total of two rounds of aerodynamic stimulation operations were carried out in this experimental well, a total of 61 times. In two rounds of operation, different working conditions with holding pressure of 6MPa, 7MPa and 8MPa were tried respectively. Through the monitoring of pressure change, gas injection volume, holding pressure duration and blowout effect in the well, the following analysis results were obtained:

(1) Analysis of the first round of aerodynamic stimulation operation:

6MPa working condition: In the first round of 6MPa surge operation, the pressure holding time is 20-30 minutes, and the gas injection pressure remains basically stable, with only one pressure drop of 0.15MPa. According to fig 3.the curve of the relationship between the working time of the first round of air pressure holding pressure of 6MPa and the pressure in the well, it can be seen that the pressure curve remains stable during the pressure holding period, indicating that the coal seam can maintain good sealing under the pressure of 6MPa, and the pressure loss is small. After the blowout, a large amount of coal chips are returned from the wellhead, indicating that the coal seam cracks have been effectively expanded, and the coal structure has been damaged to a certain extent.

7MPa working condition: In the 7MPa surge operation, the pressure holding time is 40 minutes, and the pressure drops by 0.1-0.2MPa after the pressure holding. According to fig 4. the curve of the relationship between the first round of air pressure holding pressure of 7MPa and the pressure in the well, the pressure curve decreases slightly during the pressure holding period, indicating that the coal seam begins to have certain crack expansion and coal damage under the pressure of 7MPa. After the blowout, the amount of coal cuttings returned from the wellhead increased compared with the 6MPa working condition, indicating that the expansion range of coal seam cracks was larger.

8MPa working condition: In the 8MPa surge operation, the pressure holding time is 40 minutes, and the decrease of gas injection pressure increases with the increase of the number of surges, from 0.25MPa to 0.5MPa. According to fig 5, the first round of pressure holding pressure is the relationship

curve between the operation time and the pressure in the well (8MPa), the pressure curve decreases greatly during the pressure holding period, indicating that the fracture expansion and coal damage of the coal seam are more significant under the pressure of 8MPa. After the blowout, the amount of coal cuttings returned from the wellhead increased significantly, indicating that the expansion range of coal seam cracks was further expanded and the degree of coal damage was deepened.

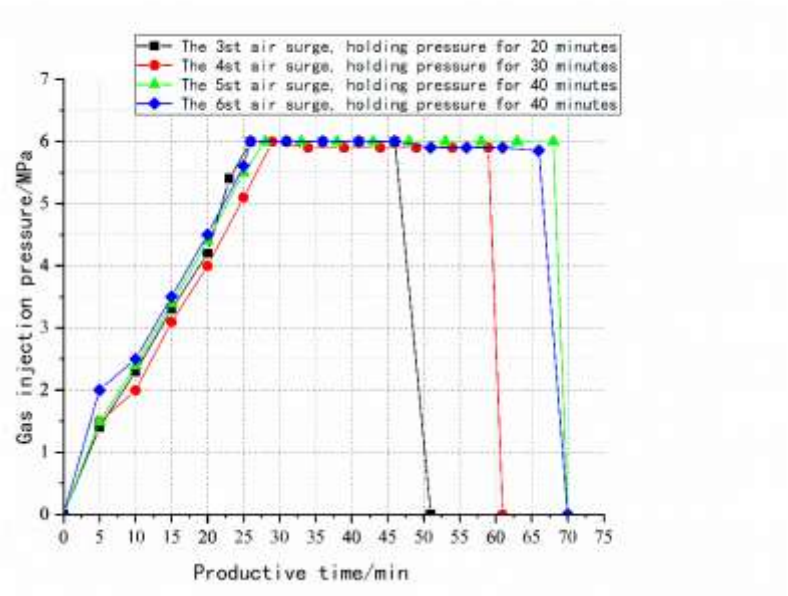

Figure 3. The first round of pressure holding pressure is 6MPa operation time and well pressure relationship curve

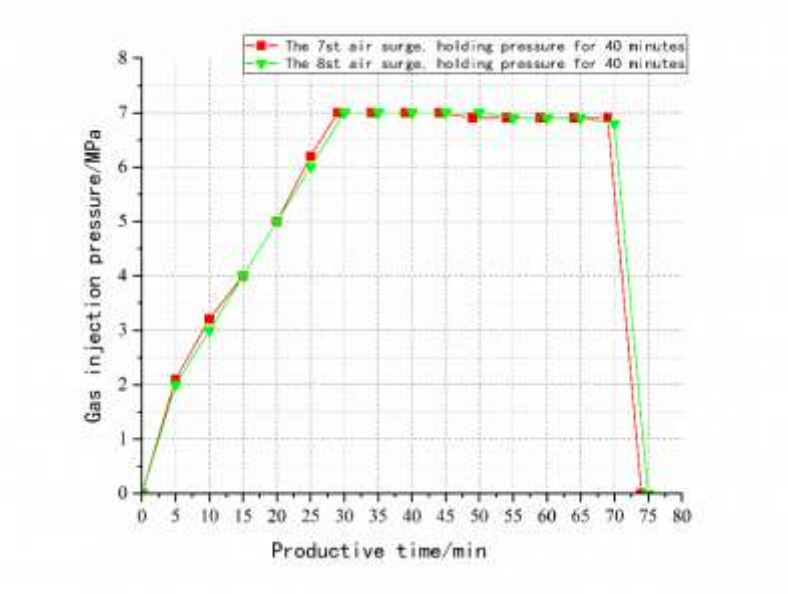

Figure 4. The first round of pressure holding pressure is 7MPa operation time and well pressure relationship curve

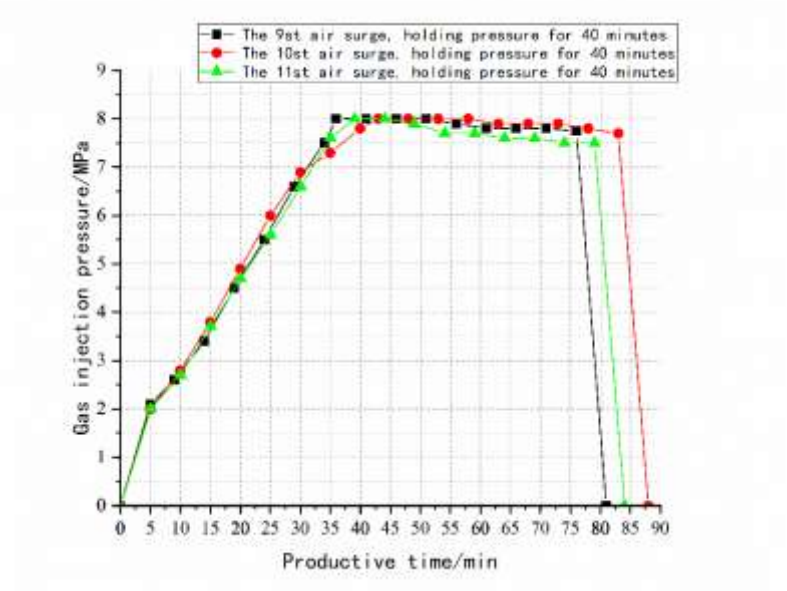

Figure 5. The first round of pressure holding pressure is 8MPa operation time and well pressure relationship curve

(2) Analysis of the second round of aerodynamic stimulation operation:

6MPa working condition: in the second round of 6MPa surge operation, the pressure holding time is 30-40 minutes, and the decrease of gas injection pressure decreases with the increase of surge times, from 0.5MPa to 0.1MPa. According to fig 6. the curve of the relationship between the working time of the second round of air pressure holding pressure of 6MPa and the pressure in the well, the pressure curve gradually stabilized during the pressure holding period, indicating that the fracture system of the coal seam gradually stabilized after multiple excitations, and the pressure loss decreased. After the blowout, the amount of coal cuttings returned from the wellhead is reduced compared with the first round, indicating that the expansion of coal seam cracks tends to be stable.

7MPa working condition: in the 7MPa surge operation, the pressure holding time is 30-60 minutes, the decrease of gas injection pressure is maintained at 0.2-0.25MPa, and does not increase with the increase of pressure holding time. According to fig 7.the curve between the second round pressure holding pressure of 7MPa and the pressure in the well, the pressure curve remains relatively stable during the pressure holding period, indicating that the fracture expansion and coal failure of the coal seam tend to be balanced under the pressure of 7MPa. After the blowout, the amount of coal cuttings returned from the wellhead increased compared with the first round, indicating that the expansion range of coal seam cracks was further expanded.

8MPa working condition: In the 8MPa surge operation, the pressure holding time is 30-60 minutes, and the decrease of gas injection pressure increases with the increase of the number of surges. It can be seen from the relationship curve between the working time and the pressure in the well when the second round of pressure holding pressure is 8MPa in Fig.8 that the pressure curve decreases greatly during the pressure holding period, indicating that the crack propagation and coal body damage of the coal seam are more significant under the pressure of 8MPa. After the blowout, the amount of coal cuttings returned from the wellhead increased significantly, indicating that the expansion range of coal seam cracks was further expanded and the degree of coal damage was deepened.

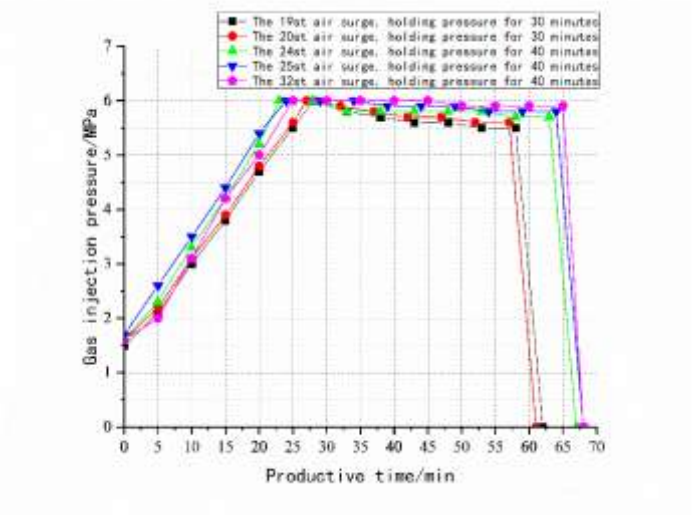

Figure 6. The second round of pressure holding pressure is 6MPa operation time and well pressure relationship curve

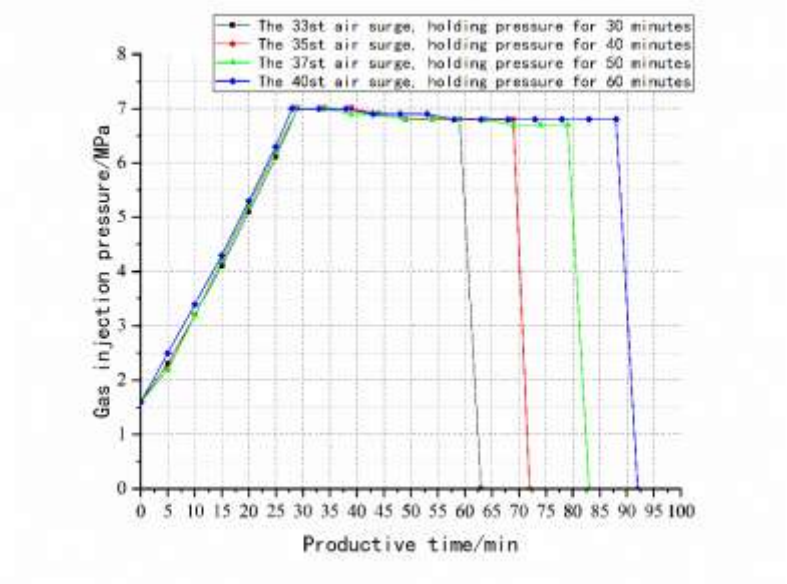

Figure 7. The second round of pressure holding pressure is 7MPa operation time and well pressure relationship curve

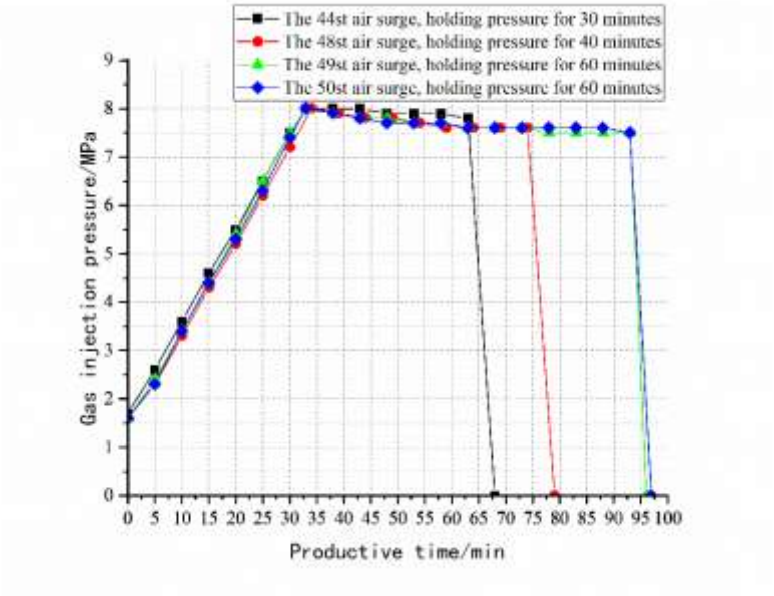

Figure 8. The second round of pressure holding pressure is 8MPa operation time and well pressure relationship curve

(3) Analysis of the third round of aerodynamic stimulation operation

7MPa working condition: In the third round of 7MPa surge operation (51st to 61th), the pressure holding time is 30-50 minutes. The decrease of gas injection pressure gradually stabilized, from 0.5 MPa to 0.3 MPa. It can be seen from the curve of the relationship between the air surge operation time and the pressure in the well when the third round of pressure holding pressure is 7MPa in Fig.9 that the pressure curve gradually tends to be stable during the pressure holding period, indicating that the fracture system of the coal seam is gradually stable after multiple surges, and the pressure loss is reduced. After the blowout, the amount of coal cuttings returned from the wellhead is reduced compared with the previous two rounds, indicating that the expansion of coal seam cracks tends to be stable, and the degree of coal damage gradually tends to be balanced.

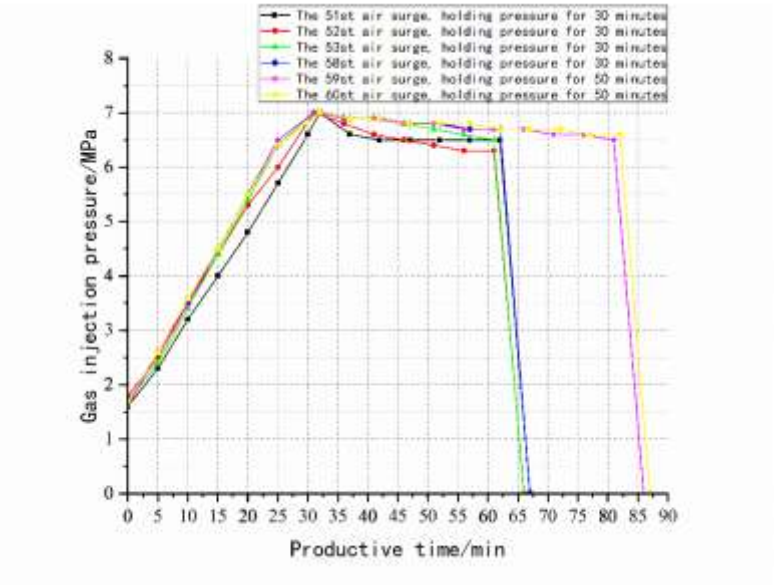

Figure 9. The third round of pressure holding pressure is 8MPa operation time and well pressure relationship curve

The total amount of gas released during the blowout is 146,785 m^3, and the average gas concentration at the orifice is 56%. The amount of gas discharged through the blowout operation is about 82,200 m3, and the coal debris carried to the rock powder pool through the well washing is about 40 m^3.

During the negative pressure extraction, the total amount of gas extraction is about 30240m3. The initial gas concentration of the outburst elimination well is about 3 %, which gradually increases to 5% and then decreases to 0, and the total amount of gas extraction is 1512m3.

Table 1. working face ground gas drainage data table

Date	Gas content (%)	Mixing quantity (m3/min)	Scalar (m3)	Daily gas production (m3)
2024.5.5	3	4.8	0.14	207
2024.5.6	4	4.77	0.19	275
2024.5.7	5	4.77	0.24	343
2024.5.8	5	4.77	0.24	344
2024.5.9	5	4.77	0.24	343
2024.5.10	0	0	0	0
footing				1512

After the implementation of ground air agitation high pressure displacement + negative pressure drainage, a total of 83,700 square meters of gas was drained. The gas content of the coal seam in the area decreased from 2.85 m3 / t-5.45 m3 / t to the lowest 1.0 m3 / t, and the gas pressure of the coal seam decreased from the highest 0.82 MPa to the lowest 0.15 MPa.

The gas geological reserves in the radius of drilling design outburst elimination (the control area is ellipse, the long half axis is 50m, the short half axis is 25m, and the enclosed area is about 392m2) are:

Gi=0.01AhDCad

Gi-gas geological reserves A-coal seam gas-bearing area, km2; h - net thickness of coal seam, m; d-coal seam apparent density, t/m3; air dry basis gas content of Cad-coal m3/t;

10. CONCLUSION

(1) The coal and water in the well are released along the anti-nozzle sink during the blowout prevention of aerodynamic surge operation. However, due to the excessive pressure, the blocking effect of the anti-blowout pool is not ideal, and the coal and water are accompanied by the air rising, which causes environmental pollution to the working surface. In the future construction, it is necessary to do a good job of pulverized coal capture equipment to reduce environmental pollution.

(2) Compared with other completion technologies, the aerodynamic agitation technology has the advantages of rapid gas recovery without fracturing and other auxiliary measures in the whole process of drilling, completion, drainage and gas recovery, which reduces the cost of completion. At the same time, because the cave completion has the advantages of improving the permeability of coal seam, the productivity and development benefit of coalbed methane are improved. However, the gas output of this well is very small due to the coal seam structure, which is not ideal as a drainage well.

(3) In the blowout prevention stage, continuous gas injection should be maintained, otherwise coal slime and coal ash will enter the gas injection pipe, resulting in blockage of the gas injection pipe and affecting the subsequent construction.

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