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Research Article

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Study on the Application of Negative Pressure Coupling Method in the Process of Extraction Radius Investigation

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Abstract In order to verify the reliability of the extraction radius investigation results, the reliability of the extraction radius investigation results was examined using the negative pressure coupling method. The test at Daping coal mine showed that the degree of negative pressure coupling in the extraction drill hole and the radius of negative pressure coupling in the drill hole increased as the negative extraction pressure increased. When the extraction negative pressure is 26kPa, the negative pressure coupling radius of extraction drill hole is 17.77m, which is much higher than the effective extraction radius of 5.2m at the same period when the hydraulic punching unloading coal volume is 2t/m. Thus, it can be considered that the results of the investigation of the effective extraction radius of gas at the hydraulic punching unloading coal volume of 2t/m are reliable.

Keywords hydraulic perforation; extraction radius; pressure drop method; negative pressure coupling method; reliability check

1. Introduction

Gas extraction is one of the important tools to prevent major safety accidents in mines. Hydraulic punching technology is an important tool to improve the efficiency of gas extraction in mines [1]. The use of perforated boreholes for pre-smoking coal seam gas can lead to blind extraction areas if the borehole spacing is set too high, and increase production costs if the borehole spacing is set too low [2]. Reasonable spacing of extraction boreholes can effectively improve the efficiency of coal seam gas extraction, enhance the mine production efficiency and reduce the mine gas management cost.

The extraction radius is one of the important bases for controlling the spacing of drill holes, and a reasonable extraction radius can effectively improve the efficiency of coal seam gas extraction and reduce the construction volume of drill holes and mine production costs. At present, there are several methods for investigating the extraction radius, such as theoretical calculation, numerical simulation, direct determination and comprehensive determination [3], among which, direct determination methods such as gas pressure drop method [4] and flow rate method [3] are widely used because they have the characteristics of simple operation, direct investigation process and can truly reflect the on-site gas extraction situation. Due to the influence of geological conditions and other factors, Daping coal mine can only use the method of pre-pumping coal seam gas to carry out regional anti-surge, therefore, the investigation result of extraction radius has an extremely important guiding role for coal seam gas control in the mine.

Nowadays, mines usually use a combination of several methods to verify the extraction radius, but this practice leads to higher construction costs and longer verification time, which affects the mine construction efficiency.

The gas pressure drop method has the advantages of simple operation and intuitive results when investigating the extraction radius, and considering the test conditions and other factors, it is proposed to use the pressure drop method to investigate the extraction radius. In order to verify the reliability of the investigation results, after the effective extraction radius investigation, according to the current situation of mine production, a scheme compatible with mine production is selected, and the negative pressure coupling method is used to test the reliability of the investigation results.

2. Methods for investigating the effective extraction radius of large flat coal holes and reliability test methods

The gas pressure reduction method is mainly used to determine the size of the extraction radius by examining the degree of reduction of gas pressure at the adjacent location of the extraction borehole. As shown in Equation 1, according to the relationship between the pre-pumping rate and the participating gas pressure and residual gas content, it can be determined that when the gas pressure is reduced to 51% of the original gas pressure, the pre-pumping rate is 30%, and the distance between this observation hole and the extraction hole is the effective extraction radius at this time.

$$\eta = 1 - \frac{W_c}{W} = 1 - \frac{\alpha\sqrt{P_c}}{\alpha\sqrt{P}} = 1 - \frac{\sqrt{P_c}}{\sqrt{P}} \quad (1)$$

where: η is the gas pre-pumping rate, %;

P_c is the residual gas pressure, MPa;

P is the original gas pressure, MPa;

W_c is the residual gas content, m^3/t;

W is the original gas content, m^3/t;

α is the coal seam gas content factor, $m^3/(t•MPa^{1/2})$.

After using the pressure drop method to determine the size of the extraction radius, the reliability of the extraction radius investigation results was checked using the negative pressure coupling method, which can effectively reduce the amount of mine borehole construction because the negative pressure coupling method is based on the original extraction borehole investigation. When using penetration borehole for coal seam gas extraction, as shown in Fig. 1, as the extraction process continues, the influence area of single borehole gradually expands and the pore fissure in coal further develops, and the influence area of single borehole gradually expands under the influence of various factors such as extraction negative pressure and pore fissure development, and gradually superimposes on each other with the influence area of adjacent borehole, and finally affects the adjacent borehole, and has a coupled superposition with the adjacent borehole The coupling and superposition effect is produced with the pumping effect of the adjacent borehole.

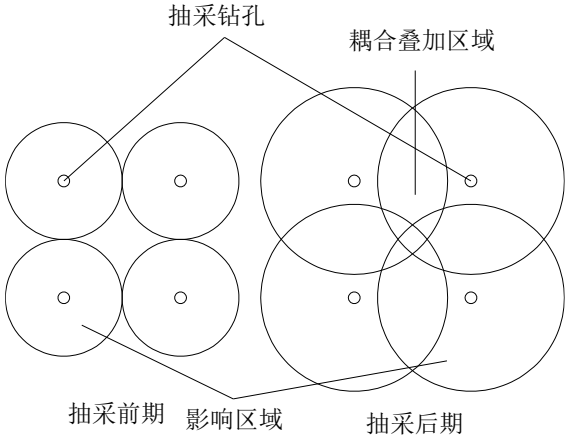

Figure 1: Schematic diagram of coupled superposition of drainage borehole influence range

The negative pressure coupling method focuses on examining the extent of this coupling overlay and thus judging the reliability of the effective extraction radius. When a seam penetration borehole is used for coal seam gas extraction, the borehole is connected to the extraction system by extraction pipes, and a pressure gradient is generated between the interior of the borehole and the coal seam. The gas in the coal seam flows along the pressure gradient, resulting in the adsorption-desorption equilibrium of the coal to the gas being disrupted and the adsorbed gas in the coal being further desorbed. As the pumping process continues, the influence of this adsorption-desorption equilibrium gradually expands, and eventually the influence reaches the adjacent borehole, producing a negative pressure coupling superposition effect with the adjacent borehole.

When using the negative pressure coupling method to examine the results of the effective extraction radius, it is necessary to observe the changes of the negative pressure in each borehole under the natural decay state, at this time, since all the boreholes are closed and there is no interference from external factors, the decay of the negative pressure in each borehole is in the natural decay state, and the changes of each parameter such as the decay rate and the relative stability value of the negative pressure in the borehole only depend on the internal coal seam The decay rate and relative stability of the negative pressure in the borehole depend only on the desorption rate of the coal seam. After determining the change of negative pressure in each borehole under the natural decay state, only the test borehole is kept as the normal extraction borehole under the normal extraction state of each borehole, and the size of the negative pressure in this borehole is adjusted through the orifice valve, and then the other boreholes except the test borehole are closed with the orifice valve, and the change of negative pressure in the other boreholes is observed under the normal extraction of the test borehole. When the change of negative pressure in other boreholes is higher than the decay value of negative pressure in each borehole in the natural decay state and higher than 13kPa, it is determined that the coupling of negative pressure is superimposed between the test borehole and the nearby boreholes, and the distance between the borehole with the farthest negative pressure coupling superimposed from the normal extraction borehole is the negative pressure coupling radius of the extraction borehole. The radius is considered reliable.

3. Results of extraction radius inspection and reliability test

(1) Investigation of extraction radius

The extraction radius investigation was mainly carried out in 13131 East bottom extraction lane, and the drill holes were drilled using hydraulic punching measures for enhanced extraction, and the amount of coal unloaded by hydraulic punching was 2t/m. The results of the extraction radius investigation are shown in Figure 2.

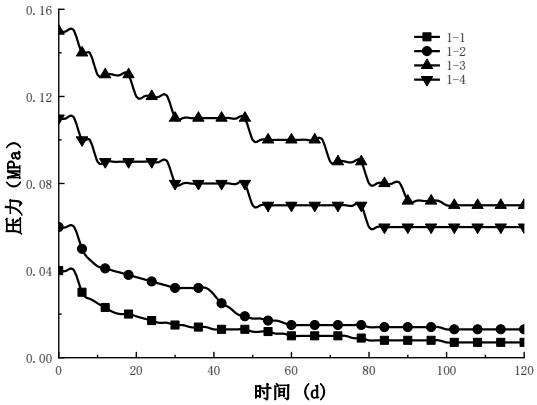

Figure 2: Graph of gas pressure change in pressure measurement borehole

The observed gas pressure data can be substituted into equation 1 to obtain the effective extraction radius under different hydraulic punching coal discharge volume, and the relationship between extraction radius and time can be obtained by fitting the results of extraction radius examination, as shown in equation 2:

$r = 3.2971\ln(t) - 8.2992$ （$1t/m$ （煤孔段））

$R^2 = 0.9924$ （1t/m（煤孔段））

(1)

The size of the extraction radius corresponding to different prepumping times can be calculated by bringing the prepumping time into Equation 2, as shown in Table 1.

Table 1: Effective extraction radius examination results

Results of site visits		Fitting calculation results	
Effective extraction radius /m	**Pre-draw time /d**	**Pre-draw time /d**	**Effective extraction radius /m**
3	20	30	4.13
5	40	45	5.21
7	90	60	5.97
—	—	90	7.05

2) Reliability check

The boreholes for effective extraction radius inspection results verification using the negative pressure coupling method are shown in Figure 3.

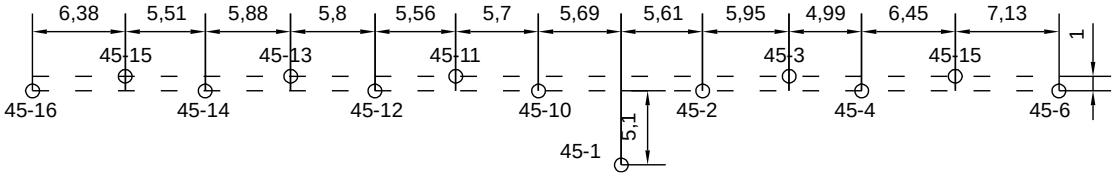

Figure 3: Schematic diagram of borehole layout for testing by negative pressure coupling method

During the test, boreholes 45-16 were selected as the test boreholes for the negative pressure coupling method, and the rest of the boreholes were used as observation holes for the observation of the negative pressure decay state. After eliminating the boreholes that are far away and have less influence on the test results, the decay diagram of the negative pressure in each borehole with time under different negative pressure states of the test boreholes is drawn based on the test results, as shown in Figure 4-figure supplement 9.

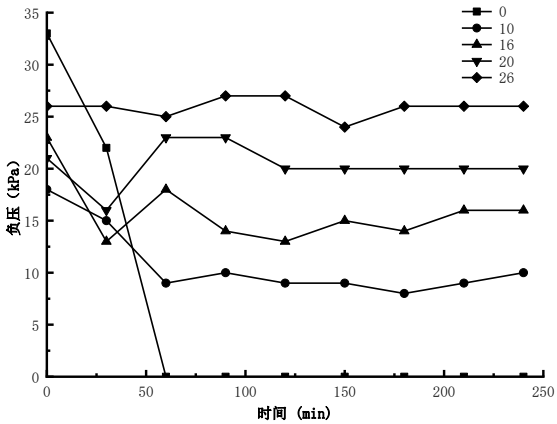

Figure 4: Changes of negative pressure in borehole 45-16

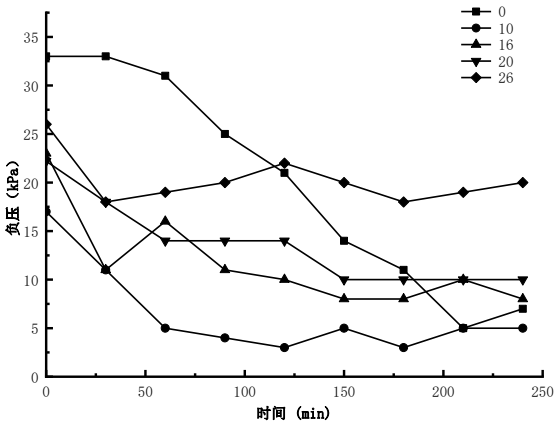

Figure 5: Change diagram of negative pressure in borehole No. 45-15

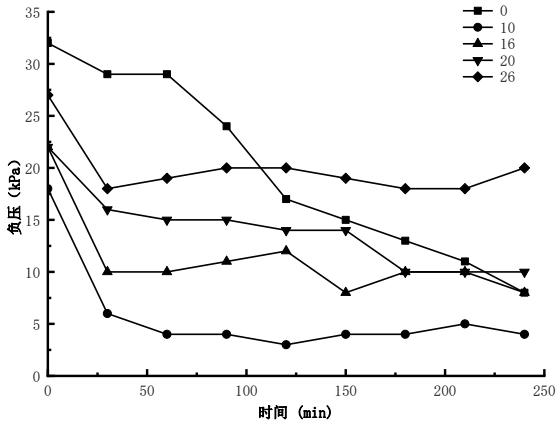

Figure 6: Negative pressure change chart of No. 45-14 borehole negative pressure

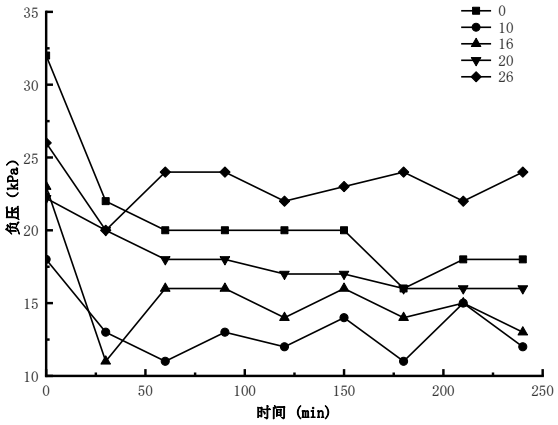

Figure 7: Change diagram of negative pressure in borehole No. 45-13

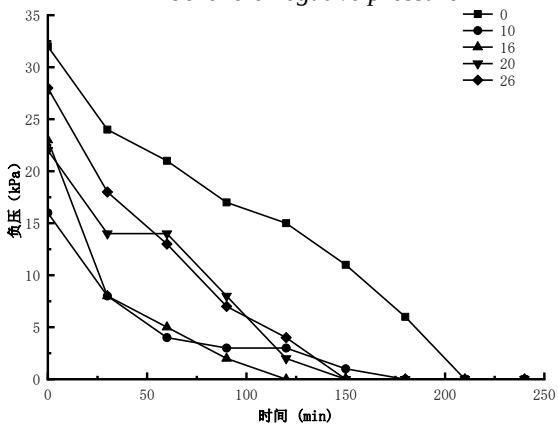

Figure 8: Negative pressure change diagram of borehole No. 45-12

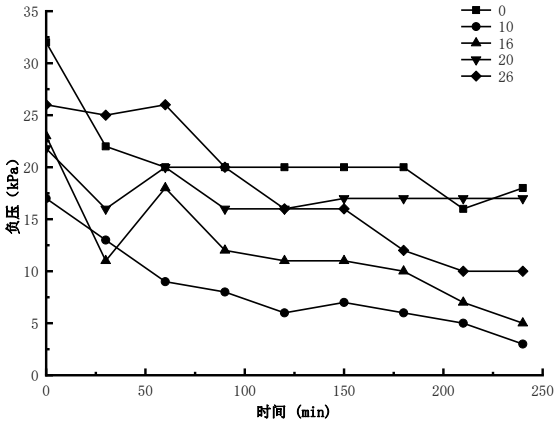

Figure 9: Negative pressure changes in borehole No. 45-11

From Figure 4-figure supplement 9, the radius of the coupling superposition effect on the adjacent borehole under different negative pressure states of the test borehole is shown in Table 2.

Table 2: Coupling radius of test borehole under different negative pressure conditions

Extraction of negative pressure	Drill hole number					
	45-16	45-15	45-14	45-13	45-12	45-11
0	—	—	—	—	—	—
10	—	无	无	无	无	无
16	—	6.38	无	无	无	无
20	—	6.38	11.89	无	无	无
26	—	6.38	11.89	17.77	无	无

4. Conclusion

- According to the test, it is known that the effective extraction radius at 30d, 45d, 60d and 90d are 4.13m, 5.21m, 5.97m and 7m respectively when the coal unloading volume of the borehole hydraulic punching is 2t/m.
- According to the results of the negative pressure coupling method examination, the higher the negative pressure of the drill hole extraction, the larger the negative pressure coupling radius.
- The reliability of the investigation results of effective extraction radius at 2t/m of coal unloading by hydraulic punching was checked by the negative pressure coupling method, and the results showed that

the investigation results of effective extraction radius at 2t/m of coal unloading by hydraulic punching were valid.

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