

Gas drainage radius of single-seam and cross-seam boreholes

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Abstract. In high gas mine, gas needs to be pre-pumped through single-seam boreholes to prevent gas outburst in the working face. The effective drainage radius is an important parameter of borehole drilling and has a direct impact on the borehole design and pumping effect. In accordance with the coal seam gas flow theory, the relationship between the effective drainage radii of the cross- and single-seam boreholes is analyzed. A field test is conducted by using the pressure drop method. Experimental results are in line with the conclusions drawn from the theory. When accurate measurement is not required, the effective drainage radius of the cross-seam borehole is slightly equal to that of the single-seam borehole. Therefore, when the effective drainage radius of the single-seam borehole is difficult to determine, it can be replaced by the effective radius of the cross-seam borehole.

1. Introduction

At present, eliminating the outstanding danger in all high gas mines by gas drainage through cross- and single-seam boreholes is the most effective measure. The drilling parameters directly affect gas drainage. In the drilling parameters, the effective drainage radius is particularly important. Accurately measuring the effective drainage radius of boreholes can be reasonably arranged to achieve optimal design[1].

Numerous methods are available for determining the effective drainage radius, including numerical simulation, theoretical analysis, and field measurement[2-7]. The occurrence conditions of gas in the same coal seam may differ significantly due to the complex geological conditions of coal seams. Therefore, results of numerical simulations or theoretical calculations often deviate from the actual situation in the field. Most field testing is performed through the gas pressure and tracer gas methods. The tracer gas method can be used to determine the furthest distance affected by extraction at different pumping times. The regression analysis of the power function curve reveals the radius of extraction effect at a certain time; however, it cannot determine the effective drainage radius accurately[9-11].

Several scholars have used the gas pressure method to measure the effective drainage radius of gas drainage. A field experiment shows that using the gas pressure method in measuring the effective radius of the borehole produces good effect. However, when measuring the effective drainage radius of the borehole, numerous working faces do not have high porosity, the measured pressure is extremely small, excessive pressure is generated leading to the damage of the borehole, and the single-seam borehole is difficult to seal. The effective drainage radius is often difficult to determine accurately. Therefore, the relationship between the effective drainage radius of the cross- and single-seam boreholes should be analyzed to find a way to predict the effective drainage radius of the single-seam borehole.



2. Theoretical analysis based on gas flow field

In accordance with the theory of gas flow in coal seam, gas flow caused by the cross- and single-seam boreholes can be simplified into radial gas flow in coal seam. Ideally, the initial gushing strength of borehole gas can be expressed as follows:

$$q_0 = \frac{\lambda(p_0^2 - p_1^2)}{R_1 \ln \frac{R_0}{R_1}}, \quad (1)$$

where q_0 is the gas emission initial strength of the borehole (m/min), p_0 is original coal seam gas pressure (MPa), p_1 is the gas pressure inside the borehole (MPa), R_0 is the impact radius of the borehole flow field (m), R_1 is the radius of the borehole (m), and λ is the gas permeability coefficient ($\text{m}^2/(\text{MPa}^2 \cdot \text{d})$).

The gas emission intensity of the borehole at time t is expressed as follows:

$$q = q_0 e^{-at}, \quad (2)$$

where q is the gas emission intensity of the borehole at time t (m/min), a is the gas flow attenuation coefficient of the borehole (d^{-1}), t is time of gas flow in the borehole (d).

For the cross-seam borehole, the drilled-hole extraction Q can be calculated as

$$Q = 2\pi R_1 m \int_0^t q dt = \frac{2\pi m \lambda (p_0^2 - p_1^2)}{\alpha \ln \frac{R_0}{R_1}} (1 - e^{-at}), \quad (3)$$

where Q is the total amount of time t of the borehole gas drainage (m^3), and m is the seam thickness (m).

Assume that the length of the extraction area is a and the width is b . Then, the total amount of gas extraction in this area is

$$Q_1 = \eta Q_0 = \eta abm\gamma W, \quad (4)$$

where Q_1 is the total amount of gas extraction in this area (m^3), Q_0 is the total gas content of this area (m^3), γ is the coal density in this area (kg/m^3), and W is the gas content of coal in this area (m^3/kg).

The number of cross-seam boreholes that need to be drilled is expressed as follows:

$$N = \frac{ab}{4R_0^2}. \quad (5)$$

According to Eqs. 3–5, Eq. 6 is obtained:

$$\frac{2\pi m \lambda (p_0^2 - p_1^2)}{\alpha \ln \frac{R_0}{R_1}} (1 - e^{-at}) \frac{ab}{4R_0^2} = \eta abm\gamma W. \quad (6)$$

Eq. 7 is obtained by deforming Eq. 6:

$$R_0^2 = \frac{K}{\ln \frac{R_0}{R_1}}, \quad (7)$$

where $K = \frac{\pi \lambda (p_0^2 - p_1^2)(1 - e^{-at})}{2\eta \gamma \alpha W}$.

For the single-seam borehole, the drilled hole extraction Q can be calculated as follows:

$$Q = 2\pi R_1 d \int_0^t q dt = \frac{2\pi d \lambda (p_0^2 - p_1^2)}{\alpha \ln \frac{R_0}{R_1}} (1 - e^{-\alpha t}), \quad (8)$$

where d is the length of the single-seam borehole.

For the same extraction area of length a and width b , assuming that the thickness of coal seam $m = 2R_0$, the total amount of gas drainage in this area is calculated as follows:

$$Q_1 = \eta Q_0 = 2\eta ab R_0 \gamma W. \quad (9)$$

When $d = b$, the number of single-seam boreholes is expressed as N , as shown as Eq. 10:

$$N = \frac{a}{2R_0}. \quad (10)$$

According to Eqs. 8–10, Eq. 11 is obtained:

$$\frac{2\pi b \lambda (p_0^2 - p_1^2)}{\alpha \ln \frac{R_0}{R_1}} (1 - e^{-\alpha t}) \frac{a}{2R_0} = 2\eta ab R_0 \gamma W. \quad (11)$$

Eq. 12 is obtained by deforming Eq. 11.

$$R_0^2 = \frac{K}{\ln \frac{R_0}{R_1}}, \quad (12)$$

where $K = \frac{\pi \lambda (p_0^2 - p_1^2)(1 - e^{-\alpha t})}{2\eta \gamma \alpha W}.$

When the ideal state is satisfied, the effective drainage radius of the single-seam borehole calculated by using the simplified mathematical model is the same as that of the cross-seam borehole.

3. Field experiment

In accordance with the specific conditions of the 13-1 coal seam in the pilot mine, the adjacent sites are selected to conduct the experiment.

3.1 Effective drainage radius design

Scholars have arranged several pressure-measuring boreholes on both sides of a drainage borehole to test the effective drainage radius. This method possesses the following problems: only one drainage borehole is available; the test is easily affected by external factors; and the pressure-measuring borehole is extremely close, thereby leading to the inter-drilling cracks between boreholes. These problems will cause disagreements with the test results and the actual situation. Therefore, the present work aims to optimize the design of the borehole layout, as shown in Fig. 1. The specific layout is as follows. A set of boreholes is arranged at intervals of 10 m. Each group of boreholes consists of a pressure-measuring borehole and a drainage borehole. Among these boreholes, 1#–3# are single-seam boreholes and 4#–6# are cross-seam boreholes. Table 1 shows the parameter design of boreholes.

Pressure-measuring boreholes are constructed and pressure monitoring is performed every 8 hours. After the pressure of the pressure-measuring boreholes is stabilized, the drainage boreholes are constructed, then, these drainage boreholes are sealed and connected to the extraction pipe for extraction with a negative pressure of 18 KPa, and the pressure data are recorded every 8 hours.

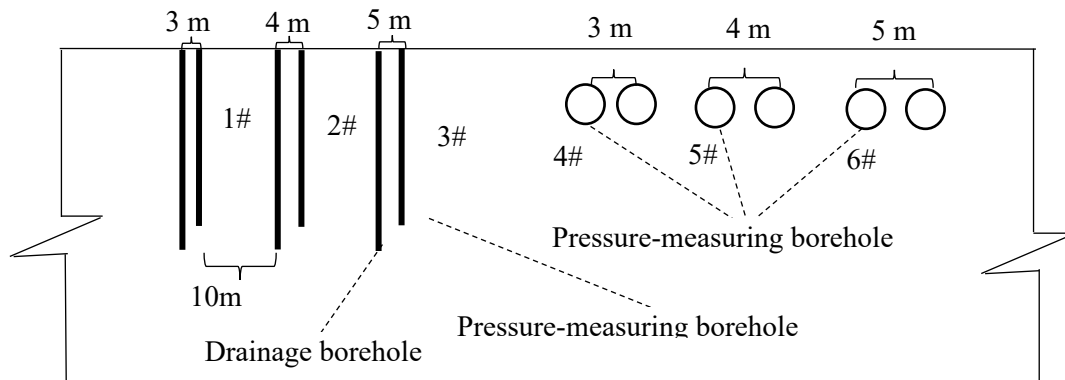


Fig. 1. Borehole layout diagram.

Table 1. Borehole design parameters.

Type	Diameter/ mm	Declination/ n/°	Elevation/ /°	Drilling depth/m	Sealing depth/m
Pressure-measuring single-seam borehole	75	90	-1	40	35
Drainage single-seam borehole	113	90	-1	50	20
Pressure-measuring cross-seam borehole	75	90	70	30	28
Drainage single-seam borehole	113	90	70	30	20

3.2 Result analysis

The field experiment shows that the pressure in the single-seam borehole. Eleven pressure-measuring boreholes are constructed; however, only four exhibit pressure, whereas the remaining seven do not. For the construction drainage boreholes, the pressure suddenly disappears in one pressure-measuring borehole; thus, only three sets of pressure data are finally obtained.

In accordance with the recorded data, the gas pressure curve is developed, as shown in Fig. 2.

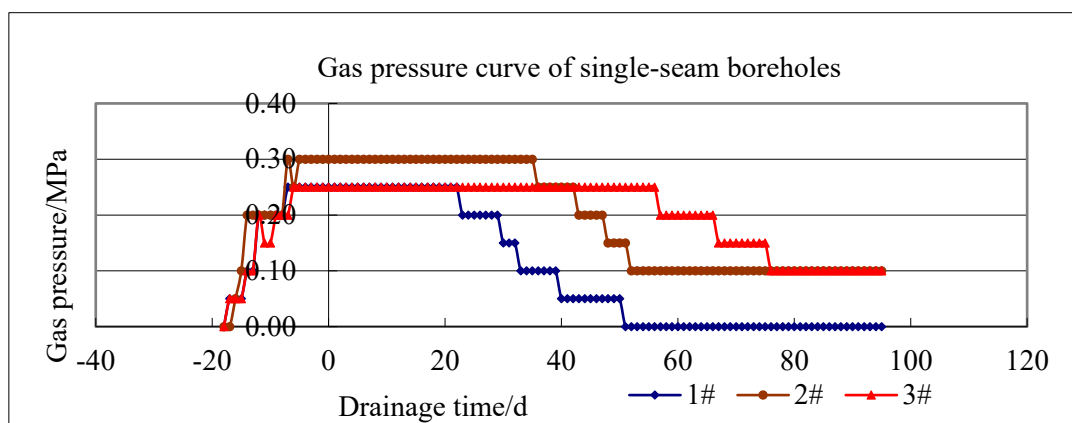


Fig. 2. Gas pressure curve of single-seam boreholes.

Measuring the pressure for cross-seam boreholes is easier than that for single-seam boreholes. Fig. 3 presents the gas pressure curve of cross-seam boreholes.

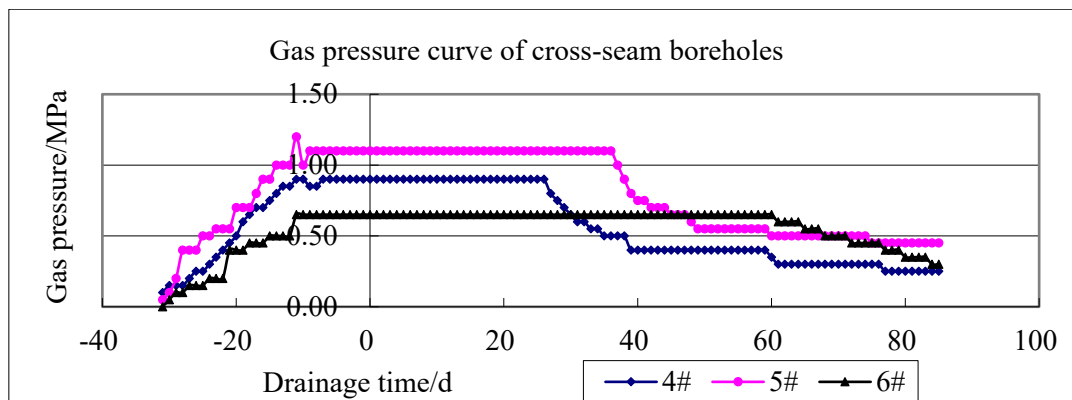


Fig. 3. Gas pressure curve of cross-seam boreholes.

From Figs. 2 and 3, (1) the pressure of boreholes initially shows a gradually increasing trend and then stabilizes. This phenomenon is consistent with the trend of the original coal seam gas pressure. (2) The pressure of cross-seam boreholes is larger than that of single-seam boreholes. By contrast, the pressure of cross-seam boreholes is closer to the original gas pressure than that of single-seam boreholes. (3) After 33 days of drainage, the gas pressure in 1# decreases from 0.25 MPa to 0.10 MPa. After 52 days of drainage, the pressure in 2# decreases from 0.3 MPa to 0.10 MPa. After 76 days of drainage, the pressure in 3# decreases from 0.25 MPa to 0.10 MPa. These pressures are less than 49% of the original gas pressure. (4) After 40 days of drainage, the gas pressure in 4# decreases from 0.9 MPa to 0.4 MPa. After 60 days of drainage, the pressure in 5# decreases from 1.1 MPa to 0.50 MPa. After 84 days of drainage, the pressure in 6# decreases from 0.65 MPa to 0.30 MPa. These pressures are less than 49% of the original gas pressure.

4 Conclusion

Based on theoretical analysis and field practice, this study draws the following conclusions:

(1) From the simplified model of gas flow field, when the ideal state is achieved, the effective drainage radius of the single-seam borehole is the same as that of the cross-seam borehole.

(2) When the effective drainage radius is 3 m, the drainage times of the single- and cross-seam boreholes are 33 and 39 days, respectively. When the effective drainage radius is 4 m, the drainage times of the single- and cross-seam boreholes are 52 and 60 days, respectively. When the effective drainage radius is 5 m, the drainage times of the single- and cross-seam boreholes are 76 and 84 days, respectively.

(3) To reach the same effective drainage radius, the time required to drill through the cross-seam borehole is slightly longer than that through the single-seam borehole; however, the difference is small. On the basis of the combination of the theoretical analysis and actual measurement, the effective drainage radius of the single-seam borehole can be replaced by that of the cross-seam borehole.

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