Paper No. 11

ISMS 2016

Methods of measuring the effective drainage radius of 3# coal seam in Huoerxinhe coal mine

Linchao Dai [a,b,]*, Kai Wang [a,b], Jie Cao [a,b], Bo Wang [a,b]

[a] State Key Laboratory of the Gas Disaster Detecting, Preventing and Emergency Controlling, Chongqing, China, 400037
[b] Chongqing Research Institute Co.,Ltd. of China Coal Technology and Engineering Group, Chongqing, China, 400037

ABSTRACT
At present, the radius of coal seam gas drainage can be determined using the theoretical calculation method, the in-situ test method, and the numerical simulation method. Determining a reasonable gas drainage radius parameter has important practical significance for improving drainage and for eliminating the danger of quick outburst. In order to determine the gas drainage parameters of Huoerxinhe 3# coal seam and to efficiently eliminate the prominent risks of mining, the current methods of determining the gas drainage radius are analyzed. Based on the gas and geological conditions of Huoerxinhe 3# coal seam, the theoretical calculations, laboratory parameters, and site measurement were used to investigate the effective drainage radius of Huoerxinhe 3# coal seam. The results show that the method of site measurement of gas drainage radius is more difficult to test and has worse precision, as well as other issues. However, the exact value of effective drainage radius can be obtained by combining the theoretical calculation method with the in-situ test method. By using this combined method, the effective drainage radius of Huoerxinhe 3# coal seam is found to be 1.6 m. This combined method provides a basis for gas drainage borehole design, increasing gas drainage efficiency, and ensures safe mining. Simultaneously, the method put forth in the present study can be used as a general method to determine effective drainage radius.
KEYWORDS: Huoerxinhe coal mine; gas drilling; effective drainage radius; theoretical calculation method

1. INTRODUCTION

Coal seam gas is the main measure to control coal and gas outburst, and the distance between holes is an important consideration in the design of mine boreholes. Whether it is reasonable or not is directly related to the effect and cost of controlling outburst. If the distance between holes is too small, the perforation phenomenon will occur, and it will increase the cost of controlling the outburst, reduce the effect of extraction, and exacerbate the mining shortage situation. If the distance between holes is too large, it will form the drainage blind, therefore the drainage effect will not reach the target, and will fail to eliminate the prominent risk on the mining face. However, the distance between holes is determined by the size of drainage radius. Therefore, it has important practical significance to determine reasonable gas drainage radius parameters for improving drainage effect and eliminating the danger of outburst. In order to determine the gas drainage parameters of Huoerxinhe 3# coal seam, and to eliminate the prominent risk of on the mining face, the effective drainage radius of Huoerxinhe 3# coal seam was determined based on the gas and geological conditions of the coal seam.

2. THE CALCULATION METHOD OF DRAINAGE RADIUS

In the pre-seam gas extraction, with the joint action of seam gas pressure and hole negative pressure, gas around the borehole is continuously pumped into the borehole. It then forms a similar circular hole centerline axis as the drainage effect. The influence circle radius is called the pumping influence radius. With the extension of the pumping time, the influence radius will gradually increase until the difference between the gas pressure in the coal seam and the negative pressure in the hole bottom is not enough to overcome the resistance of the deep coal seam gas migration to the borehole. In the borehole pumping influence circle, the coal body gas pressure will be reduced, and the gas emission quantity will be increased.

At present, theoretical calculation, field tests, and numerical simulations are generally used to determine the pumping radius. However, due to the complexity of coal seam occurrence and the rheological properties of coal containing gas, the numerical simulation method has a large error in determining the effective drainage radius. The present study focuses on the theoretical calculation method and the field test method.

*Corresponding author – email : dailinchao@126.com

2.1 The theoretical calculation method of drainage radius

Research has found that whatever the numerical simulation calculation, the measured data analysis, or approximate analytical solution, the relationship between the gas emission quantity of borehole surrounding rock and time is approximately consistent with the exponential function law with e as the bottom.

$$Q = Q_0 e^{-At} \quad (1)$$

In the formula, Q is the drilling gas flow at any time in m^3/min. Q_0 is the drilling initial gas flow in m^3/min. A is the drilling gas flow attenuation coefficient, d^{-1}. t is the borehole gas drainage time, d.

The relationship between the amount of gas drilling cumulative emission and the time is obtained by the formula (1) integral.

$$Q_t = \int_0^t 24 \times 60 \times Q_0 e^{-At} dt = \frac{1440 Q_0}{A}(1-e^{-At}) = Q_{max}(1-e^{-At}) \quad (2)$$

In the formula, Q_t is the drilling cumulative gas drainage in m^3. Q_{max} is the drilling limit pumping gas quantity in m^3.

The effective drainage radius of gas drainage borehole is defined so that in the specified time, the gas pressure or gas content in the radius is reduced to the safe allowable value.

When the impact between the two holes is not considered, according to formula (2) and mass balance principle, then the formula (3) and (4) can be obtained.

$$\int_{r_1}^{r} 2\pi r L \times M \times \eta dr = Q_{max}(1-e^{-At}) \quad (3)$$

$$r(t)^2 - r_1^2 = \frac{Q_{max}(1-e^{-At})}{\pi L M \eta} \quad (4)$$

Due to $r >> r_1$, so

$$r = \sqrt{\frac{Q_{max}}{\pi L M \eta}} \times \sqrt{1-e^{-At}} \quad (5)$$

$$\eta = \frac{M_c}{M} \times 100\% \quad (6)$$

$$t = -\frac{\ln(1 - \frac{\pi r^2 L M \eta}{Q_{max}})}{A} \quad (7)$$

In the formula, η is the coal seam gas extraction rate when coal seam gas content is at the safe concentration in %. M_c is the coal seam residual gas content after drainage in m^3/t. M is the coal seam original gas content in m^3/t. The remaining symbols are as previously listed.

In order to meet the requirements of coal and gas outburst prevention, "coal and gas outburst prevention rules" and "coal mine safety regulations" stipulate the coal seam gas extraction rate (η =25% or 30%).

2.2 Field test method for pumping radius

The method of site measurement of gas drainage radius leads to greater difficulties in testing, worse precision, and other issues. It cannot determine the gas drainage radius with consideration to the change in gas geological conditions. The pressure reducing method and flow method are most commonly used in the coal mine. The pressure reducing method involves the set up of more pressure measuring boreholes, and the gas pressure measurement is influenced by many factors. It can be difficult to measure the gas pressure, as the pressure is sometimes too large, and the hole leakage pressure often decreases rapidly.

Coal and gas outburst prevention rules determine the method of measurement for the effective discharge radius. Firstly, gas flow measuring parallel drillings (diameter of 42 mm) are placed in the work face layer with variable spacing. Then a parallel discharge hole is placed to one side of the measuring hole, and the variation in gas emission quantity in the holes by time is observed. If within two hours the amount of gas emission in the hole is increased by 10%, the distance between the hole and the discharge hole is called the effective radius.

3. THEORETICAL CALCULATION OF HUOERXINHE PUMPING RADIUS

Shanxi Huoerxinhe Coal Industry Co. Ltd. is located in Zhangzi County, Changzhi City. The mine area is 71.3947 km^2, and the 3# coal seam is located in the lower part of the Shanxi formation. The coal seam dip angle is about 5 degrees, and the coal thickness is 4.49-7.17 m with an average of 5.65 m. The 3# coal seam gas content is 8-10 m^3/t。.

According to "the 3# coal seam coal and gas outburst hazard identification", the maximum gas pressure of 3# coal seam is 0.52 MPa, the maximum initial velocity of gas emission is 23.1, the minimum coal firmness coefficient is 1.27, and the damage type of coal is II. The 3# coal seam in the identification range above +430 m level is without outburst danger.

In the Huoerxinhe 3301 return air trough, measurements of the attenuation coefficient of gas flow and borehole flow in one hundred meters were conducted by field test. Four measuring points were arranged, with a pore diameter of 94 mm, a hole depth 100 m, a drilling angle of 0 degrees horizontal, a vertical angle degree of 1, and a hole distance 10 m. The following four holes are as shown in Figure 1.

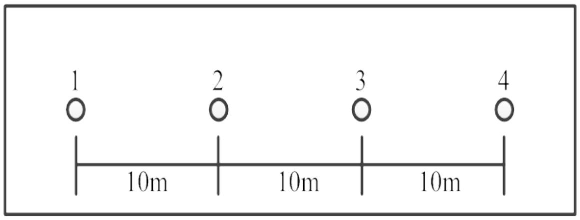


Figure 1: Drilling layout.

After the end of sealing, the gas meter was connected and observed every day for 30 min. Through the data acquisition, it is found that the four holes had zero flow in the three days.

The data were recorded for the first two day's 30 min (as shown in Tables 1 and 2). In order to get the hole attenuation law, the data were fitted and the results were as shown in Figures 2 and 3.

Table 1: Instantaneous flow on the first day.

Time/min	1#	2#	3#	4#
1	2.6	3.2	2.8	2
2	2.4	3.4	3	2
3	2.4	3.4	2.8	2.2
4	2.6	3.6	2.8	1.8
5	2.4	3.4	2.6	1.8
6	2.6	3.4	2.6	1.8
7	2.4	3.4	2.8	2
8	2.6	3.2	2.6	2
9	2.4	3.2	2.4	2
10	2.6	3.2	2.8	2
11	2.4	3.4	2.8	2
12	2.6	3.2	2.6	1.8
13	2.4	3.2	2.8	1.8
14	2.6	3	3	1.8
15	2.4	3	2.6	1.8
16	2.6	3.2	2.8	1.8
17	2.4	3	2.6	1.8
18	2.4	3	2.4	1.6
19	2.2	2.8	2.4	1.6
20	2.2	2.8	2.6	1.6
21	2.2	2.8	2.8	1.6
22	2.4	2.6	2.6	1.6
23	2.2	2.6	2.6	1.8
24	2.2	2.8	2.8	1.6
25	2	2.6	2.6	1.6
26	2	2.4	2.6	1.8
27	2	2.4	2.4	1.8
28	2	2.4	2.4	1.6
29	2	2.4	2.6	1.6
30	2	2.2	2.4	1.6

Table 2: Instantaneous flow on the second day.

Time/min	1#	2#	3#	4#
1	1	1.2	1.2	1
2	1	1.2	1	1
3	0.8	1.2	1	0.8
4	0.8	1	1	0.8
5	0.8	0.8	1	0.8
6	0.8	0.8	1	0.8
7	0.8	1	1.2	0.8
8	0.8	1.2	1.2	0.8
9	0.6	0.8	1	0.8
10	0.6	0.8	1	0.8
11	0.6	1	0.8	0.8
12	0.6	1	1	0.8
13	0.6	1	0.8	0.8
14	0.6	1	0.8	0.6
15	0.6	1	1	0.6
16	0.6	1	1	0.6
17	0.6	1	1	0.6
18	0.6	1	1	0.6
19	0.4	0.8	1	0.6
20	0.6	0.8	1	0.6
21	0.6	0.8	1	0.6
22	0.6	0.8	0.8	0.6
23	0.6	0.8	0.8	0.6
24	0.6	0.8	0.6	0.6
25	0.6	0.8	0.6	0.6
26	0.6	0.8	0.6	0.6
27	0.6	0.6	0.6	0.6
28	0.6	0.6	0.6	0.6
29	0.6	0.6	0.4	0.4
30	0.6	0.6	0.4	0.4

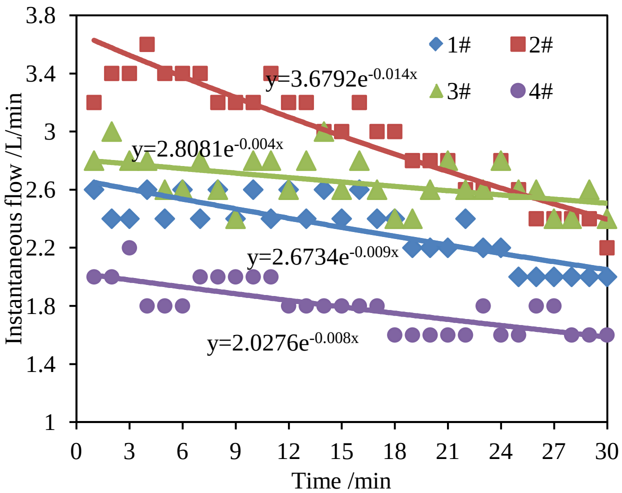


Figure 2: 1, 2, 3, 4 hole flow chart within the first day 30 min.

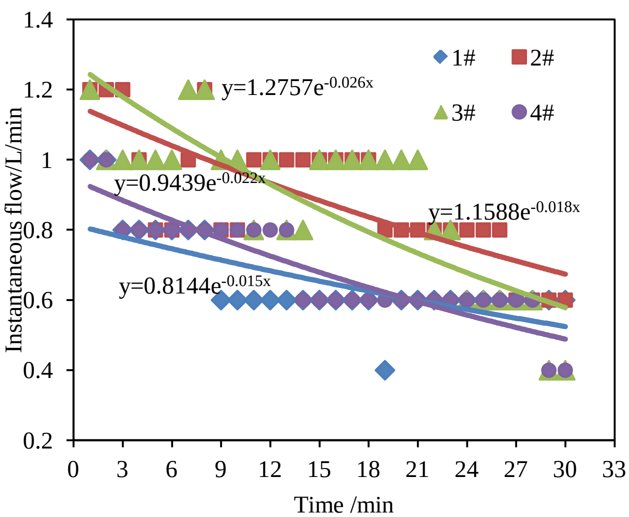


Figure 3: 1, 2, 3, 4 hole flow chart within the second day 30 min.

According to the formula of the hole flow attenuation fitting of four holes, gas flow attenuation coefficient A and the initial speed of 100 m drilling Q_0 can be obtained by the corresponding formula (1).

The theoretical pumping radius r of four holes can be calculated by coal seam gas extraction rate 30% and A, Q0 into the formula (5),. The specific parameters are shown in Table 3.

Table 3: Theoretical pumping radius calculation results.

Time	Hole	A(min^{-1})	Q_0(m^3/min)	r(m)
first day	1	0.009	2.6734	2.006479
	2	0.014	3.6792	2.272102
	3	0.004	2.8081	2.132388
	4	0.008	2.0276	1.76
second day	1	0.015	0.8144	1.061569
	2	0.018	1.1588	1.240409
	3	0.026	1.2757	1.233736
	4	0.022	0.9439	1.089657

From the Table 3, the effective pumping radius of Huoerxinhe is 2.043 m on the first day, and the average is 1.156 m on the second day. Therefore, the total average is 1.6 m.

4. FIELD TEST OF HUOERXINHE PUMPING RADIUS

4.1 Measurement point arrangement and method

The field test of gas drainage radius was tested in Huoerxinhe 3203 singh transport trough. Five measuring points were arranged, as shown in Figure 4. Among them, drilling holes 1-4 are the test holes, and drilling hole 5 is the pre drainage hole.

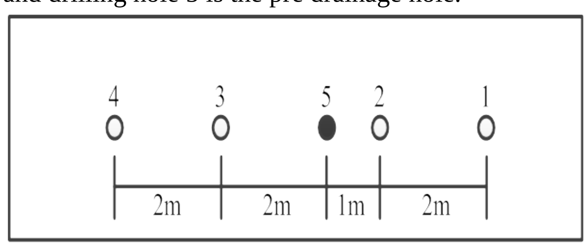


Figure 4: Drilling layout.

The steps of the determination method are as follows:

(1) Four parallel test holes were arranged along the soft stratification seam with a pore diameter of 94 mm, hole depth 100 m, a drilling angle of 0 degrees horizontal angle and a vertical angle of degree 1, with hole distances as shown in Figure 4.

(2) Polyurethane was used to seal holes 1-4. The gas flow of the boreholes was determined immediately after the end of sealing. Meanwhile, each hole was tested every 1 min with each test hole measurement time being at least 30 min.

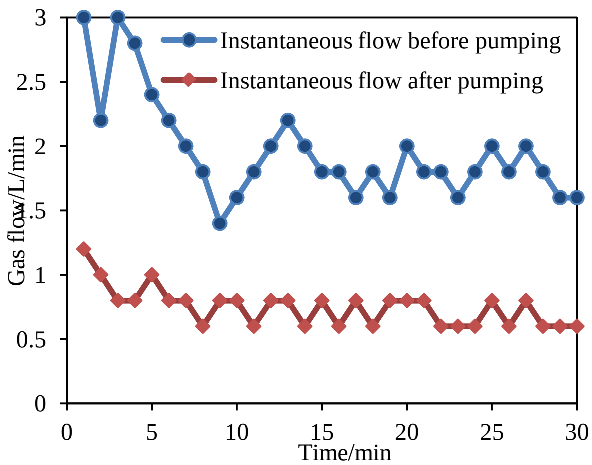
(3) The pre-pumping hole was arranged in parallel between holes 2 and 3. After the construction of the pre pumping hole, polyurethane was used to seal the hole immediately. Sealing length was at least 8m.

(4) After the end of the sealing, networking drainage was implemented immediately. Holes 1-4 were then tested every 1 min with each test hole measurement time being at least 30 min.

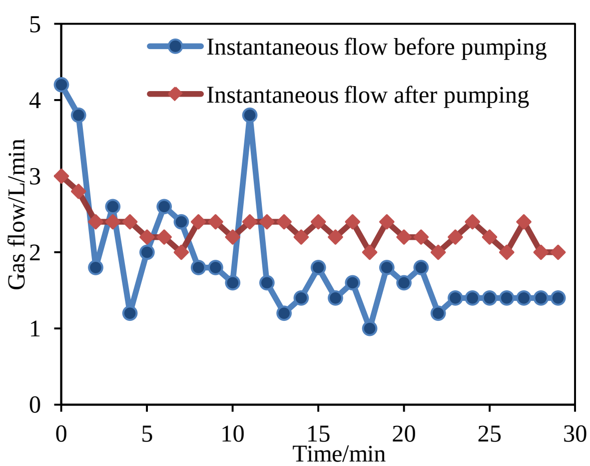
(5) After completing the pre drilling within 2 h, the gas flow rate of each test hole was determined and plotted. If the test hole gas flow rate is increased by 10% compared with that of the pre drilling hole for 3 continuous measurement times, it then follows that the test hole is in the effective radius of the hole drilling. The most distant in accordance with the above test hole distance is the effective radius of the pre-drilling hole.

4.2 Determination of gas drainage radius

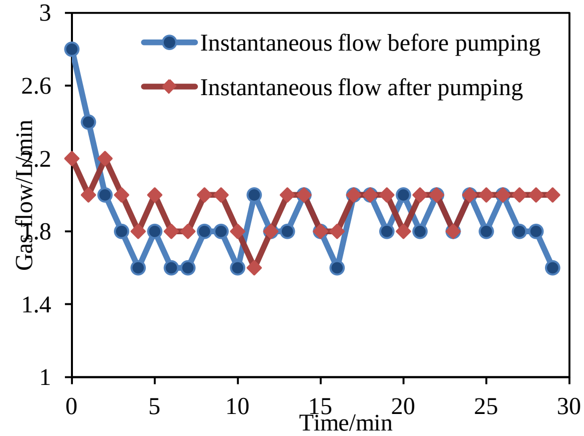
With time as the horizontal coordinates and gas flow as the longitudinal coordinates, the gas flow observation data was used to draw the hole gas flow curve, as shown in Figure 5 and Table 4.



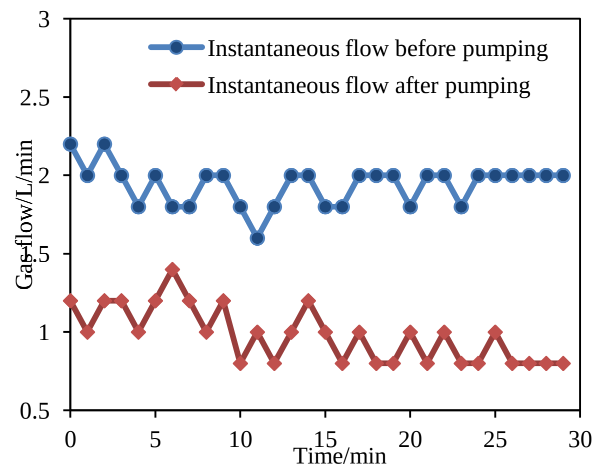
(a) No. 1 test hole



(b) No. 2 test hole



(c) No. 3 test hole



(d) No. 4 test hole

Figure 5: The test hole gas flow before and after the pre pumping.

Table 4: Average flow before and after the pre pumping.

Hole	Average flow (L/min)	
	Before pumping	After pumping
1	1.96	0.75
2	1.86	2.29
3	1.87	1.94
4	1.94	0.98

From Figure 5 and Table 4, it can be seen that the gas flow rate of test hole 2 is increased by more than 10% after the pre pumping. The gas flow rate for hole 2 is increased by 23%, 3% for hole 3, and the gas flow for holes 1 and 4 are decreased.

According to the principle of the gas drainage radius, the Huoerxinhe 3# coal mine gas drainage radius is 1-2 m. It can be seen that the site measurement of gas drainage radius leads to greater difficulty in testing, worse precision, as well as other issues.

5. CONCLUSION

(1) When taking the pumping rate of 30% above the standard as the condition, the effective pumping radius of Huoerxinhe 3# coal mine is 1.6 m as found through the theoretical analysis and calculation.

(2) Using the field test method to measure the effective extraction radius is feasible, and the effective drainage radius of Huoerxinhe 3# coal mine as measured by the field test method is 1-2 m.

(3) Through a combination of the field measurement and the theoretical calculation, the effective extraction radius of Huoerxinhe 3# coal mine is 1.6 m.

6. ACKNOWLEDGEMENT

This study was financially supported by Special Foundation of Par-Eu Scholars Program, National Natural Science Foundation of China (51374236, 51574280), The Science and Technology Innovation Fund of China Coal Technology & Engineering Group (2014QN007, 2015ZDXM14).

7. REFERENCES

Cai C.G., Zhou G.Z. (2004). Gas drainage in seam with large auto variable diameter bore holes. Coal Science and Technology, Volume 32, No. 12, pp.39-41

Cao X.Q., Xin H.H., Xu L.H. (2009). Determination of effective drainage radius of gas drainage borehole, Coal Engineering, No. 9, pp.88-90

Hao F.C., Liu M.J., Sun L.J. (2012).Study on comparison of methods to determine gas drainage radius and existed problems. Coal Science and Technology, Volume 40, No. 12, pp.55-58

Li Z.W., Lin B.Q., Guo M.G.(2014). Determination on effective influence radius of gas drainage through borehole based on one-dimensional radial flow. Coal Science and Technology, Volume 42, No. 12, pp.62-64

Liu S.J., Ma G., Lu J. (2011).Relative pressure determination technology for effective radius found on gas content. Journal of China Coal Society, Volume 36, No. 10, pp.1715-1719

Wang Z.F., Zhou S.H., Li Z.Q. (2011). Numerical calculation method of effective drainage radius for gas drainage borehole. Coal Engineering, No. 6, pp.82-84

Xu S.M.(1996).Discussion on the method to determine the effective gas drainage radius. Coal Engineer, No. 3, pp.43-45

Yu, B.F. (2000).Prevention of coal-mine gas hazards and utilization manual. Coal Industry Press, China

Yu T., Lu P., Sun J.H. (2012). Measurement of effective drainage radius based on gas flow and pressure of boreholes. Journal of Mining & Safety Engineering, Volume 29, No. 4, pp.596-600