Study on gas permeability coefficient measurement of coal seam by radial flow method

ZHANG Shuchuan¹,²

1. College of Energy and Safety, Anhui University of Science and Technology, Huainan, Anhui 232001, China;
2. Key Laboratory of Mine Safety and High Efficient Mining Jointly Built by Province and Education Ministry, Anhui University of Science and Technology, Huainan, Anhui 232001, China

Email: sczhangaus@163.com

Abstract: For the accurate measurement of the coal seam permeability coefficient, the application range of the coal seam permeability coefficient was studied under various gas flow conditions with the guidance of the coal seam gas flow theory. Adopting the radial flow method, the measurement and calculation of the permeability coefficient of the coal seam C13-1 in Xinji No. 1 Coal Mine shows that the permeability coefficient of the original coal seam C13-1 is less than 0.1, and the coal seam is difficult to extract.

1. Introduction
Most coal seams in our country have the characteristics of low permeability, compaction and easy flow, and the permeability coefficient of coal seams is only 10^-3~10^-2 (MPa·d) [1]. The permeability coefficient of coal seam refers to the amount of daily gas flow through the 1m² face in both sides of the 1m³ coal when the pressure square difference is 0.01MPa². It is one of the indexes to measure the complexity in coal mining. When the permeability coefficient of the original coal seam is greater than 10, it is easy to work on the coal seam. When it is between 10 and 0.1, coal seam can be mined. When it is less than 0.1, it is difficult to extract from the coal seam [2,3]. The accurate determination of permeability coefficient of coal seam has some guiding significance for the development and utilization of coalbed methane in china.

2. Test method
According to the spatial direction of the gas flow field, the gas flow in the coal seam has unidirectional flow, radial flow and spherical flow, as shown in figure 1. In the actual gas flow in coal mine, the unidirectional flow refers to the situation that the coal thickness is less than the level height and the whole tunnel is open for excavation when excavating the level tunnel along the coal seam; the radial flow is for ross drift, vertical shaft and borehole running vertically through the coal seam; the spherical flow is for the borehole or cross drift just entering the mining working face of the coal seam or thick coal seam.

Different coal seam gas flow determines the adoption of different test methods for coal seam permeability coefficient; our methods to measure the coal seam permeability coefficient of the borehole gas flow include the unidirectional flow method, the radial flow method and the spherical flow method etc. The specific choice of the test method is generally based on the test location of the
coal seam, that is, the different disturbance range of the test location determines different choice of the methods. The unidirectional flow method is suitable for the coal seam with fractures, higher hardness and strength; the radial flow method is used when the permeability of the coal seam is reflected with smaller fractures; the spherical flow method will be chosen when some dynamic phenomena, such as spray orifice, are more likely to occur with the comprehensive effect of crustal stress and gas pressure.

For most high gas mining areas in China, the permeability of coal seams is smaller. The determination of permeability coefficient of coal seams is mainly carried out with the radial flow method. The method is applied when the gas flow of the coal seam through the borehole is radial and unsteady. The permeability coefficient of the coal seam is calculated by measuring the radial unstable flow of the coal seam gas and other related parameters. The test location of this method should meet the needs of the coal seam with stable occurrence, and no faults and folds. The test-hole depth should generally be greater than 15m, and there is no gas drainage borehole within the scope of 20m around the test hole. The depth of the sealing hole should be up to 5~8m; the sealing hole should be tight; the borehole runs vertically through the coal seam with the deflection angle not more than 30 degree, and the spray orifice and its number in the borehole shall be recorded in detail to correct the result of calculation[3,4]. The test of gas pressure and gas flow should be accurate. The diameter of the piezometer tube should not be too small so as to avoid large gas flow and great pressure loss of the pipeline. When the diameter of the piezometer tube is too small, it is necessary to correct it in accordance with the relevant formula. The small gas flow can be measured with wet flow meters, gas meters and other instruments, the big gas flow with small orifice plate flow meters.

3. Calculation formulas
The measurement of the coal seam permeability coefficient with the radial flow method is applied on the basis of the radial flow theory of the coal seam gas. The basic assumption is that the coal seam is homogeneous and anisotropic within the flow scope of the drilling gas; the vertical hole drilling (deflection angle not more than 30 degree) goes through the coal seam, and the seam thickness with the gas flow remains unchanged. The gas flow inside the thick coal seam roof unchanged; airtight and not containing gas; the roof of the coal seam is airtight and gas free; before opening the borehole, the gas pressure within the borehole is the original; after open it, it is always the atmospheric pressure of the roadway; the gas flow in the coal seam is an isothermal process and conforms to Darcy's law.

The flow number and time number are similar dimensionless number of the radial flow of coal seam gas. The two are respectively expressed as follows:

$$Y = \frac{qr_0}{\lambda \left( p_0^2 - p_1^2 \right)}$$

$$F_0 = \frac{4\lambda p_0^{1.5} t}{\alpha R_1^2}$$

In the formula, $p_0$ is the original absolute pressure of the coal seam, MPa; $p_1$ is the gas pressure
in the borehole gas drainage, usually 0.1MPa; \( r_1 \) is the radius of the borehole, m; \( \lambda \) refers to the coal seam permeability coefficient, \( m^2/(MPa^2\cdot d) \); \( q \) is the gas flow of a unit area on the drilling wall when the gas drainage is \( t \), \( m^3/m^2 \cdot d \); \( L \) is the coal hole length, m; \( t \) refers to the time interval from the beginning of the gas drainage to the measurement of gas flow, d; \( \alpha \) is the gas content coefficient of the coal seam, \( m^3/m^3 \cdot MPa^{0.5} \); in \[ \alpha = X / \sqrt{p_0} \] \( X \) represents the gas content of the coal seam, \( m^3/m^3 \).

To make \[ A = \frac{q r_0^2}{p_0^2 - p_1^2}, \quad B = \frac{4 p_0^{1.5} \cdot t}{a r_0^2} \] \[ Y = \frac{A}{\lambda} \] \[ F_0 = B \alpha \] \[ (3) \]

The relation of the time number and the flow number is as follows:

\[ Y = a F_0^b \] \[ (4) \]

The time number ranges corresponding to different regression coefficients, and the corresponding calculation formula of the coal seam permeability differs. The measurement of the coal seam permeability coefficient parameters (flow number, time number, regression coefficient etc.) with the radial flow method and calculation formula are shown in table 1[2-8]. The formulas in table 1 are used for the calculation of the coal seam permeability coefficient. It is usually done by using any formula first, and when the value of \( \lambda \) is obtained, it will be verified in formula (4). If the time number \( F_0 \) is in the original formula range, it shows the calculation result is correct; if not in the formula range, it should be calculated in another formula until \( F_0 \) is in the original formula range.

4. Field applications

The permeability coefficient of the main coal seam \( C_{13-1} \) from Xinji No.1 Coal Mine in Huainan is measured with the radial flow method. The measurement field is shown in Figure 2; figure 3 is the gas flow variation curve in the borehole; table 2 shows the corresponding parameters of \( C_{13-1} \) permeability coefficient measurement.

| flow number \( Y \) | time number \( F_0 \) | coefficient a | coefficient b | gas permeability coefficient of coal seam \( \lambda \) |
|---------------------|-----------------|---------------|---------------|----------------------------------|
| 10^{2-1}            | 1               | -0.38         |                | \( \lambda = A^{1.61}B^{0.61} \) |
| 1\~10               | 1               | -0.28         |                | \( \lambda = A^{1.39}B^{0.39} \) |
| 10^{1-10^2}         | 0.93            | -0.20         |                | \( \lambda = 1.1A^{1.25}B^{0.25} \) |
| 10^{2-10^3}         | 0.588           | -0.12         |                | \( \lambda = 1.83A^{1.14}B^{0.14} \) |
| 10^{3-10^5}         | 0.512           | -0.10         |                | \( \lambda = 2.1A^{1.11}B^{0.11} \) |
| 10^{5-10^7}         | 0.344           | -0.065        |                | \( \lambda = 3.14A^{1.07}B^{0.07} \) |
Table 2 Datum of the gas permeability coefficient test of C_{13-1}

| coal seam number | borehole number | gas pressure of coal seam $p_0$ (MPa) | pressure of drain hole $p_1$ (MPa) | gas content coefficient $\alpha$ (m$^3$/m$^3$·MPa$^{0.5}$) | drilling radius $r$ (m) | time $t$ (d) | flow $q$ of time $t$ (m$^3$/d) | length of coal borehole $L$ (m) |
|------------------|-----------------|---------------------------------------|-----------------------------------|---------------------------------|------------------------|---------|---------------------------|-------------------------|
| C_{13-1}         | #               | 3.0                                   | 0.1                               | 9.6054                          | 0.0465                 | 4       | 3.36                       | 12.4                    |

(1) The Solvation of $q$:

$$q = \frac{Q}{2\pi r L} = 0.927 \left( m^3 / m^2 \cdot d \right)$$

(2) The Evaluation of A and B:

$$A = \frac{qr}{p_0^2 - p_1^2} = 0.0048$$

$$B = \frac{4p_0^{1.5}t}{\alpha r^2} = 1000.74$$

(3) The Coefficient of Permeability

Since the test time is 4 days, the formula of time number range $F_0 = 1 \sim 10$ is adopted to calculate the permeability coefficient of the coal seam (Table 1) and it is $\lambda = A^{1.39} B^{0.256} = 0.008886$ m$^2$/ (MPa$^2$·d).

(4) The Verification of $\lambda$

As shown in formula: $F_0 = B\lambda = 8.89$, $F_0$ is within the range from 1 to 10. It proves that the formula chosen is suitable and the calculation result is right.

The original coal seam permeability coefficient of Xinji No.1 Coal Mine C_{13-1} is 0.008886, less than 0.1, the coal seam is difficult to extract.

5. Conclusions

As the permeability coefficient of the coal seams is small for most coal mining areas in China, the radial flow method is adopted to measure the permeability coefficient of the original coal seam C_{13-1} in Xinji NO.1 Coal Mine. With the formula chosen suitable and the calculation correct, the permeability coefficient of C_{13-1} is 0.008886, less than 0.1, and the coal seam is difficult to extract.
References:

[1] CHENG Yuanping, YU Qixiang, ZHOU Hongxing, et al. Practice and effectiveness of draining gas before coal mining to prevent gas from bursting [J]. Journal of Mining & Safety Engineering, 2006, 04: 389-392+410.

[2] ZHOU Shining, LIN Boquan. Gas occurrence and flow theory of coal seam. Beijing: China Coal Industry Publishing House, 1999.

[3] YU Bufan. Handbook of coal mine gas disaster prevention and utilization [M]. Beijing: China Coal Industry Publishing House, 2000.

[4] Ma Yaolong LinBaiqua. The determination add analysis of permeability coefficient in coal seam [J]. Journal of Liaoning Technical University (natural science), 1998, 03: 240-243.

[5] LIU Mingju, HE Xueqi. Optimistic calculation method of gas seepage coefficient [J]. Journal of China Coal Society, 2004, 29(1): 74-77.

[6] WANG Zhiliang, YANG Renshu. Optimization study on calculation method on coal seam gas permeability coefficient in locale measurement [J]. China Safety Science Journal, 2011, 21(3): 23-28.

[7] SUN Jinglai, MA Piliang, CHEN Jinyu. The problems of coal seam permeability coefficient calculation formula and the solving method [J]. Safety in coal mines, 2008, 08: 89-90+96.

[8] GAO Guangfa, CHEN Jian, SHI Biming, et al. An optimized algorithm and a simplified algorithm for solving gas seepage coefficient of coal seam [J]. China Safety Science Journal, 2012, 11: 113-118.