Numerical simulation study on influence of surface well location on gas distribution in Goaf

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Abstract. Surface well extraction is an important part of coalbed methane development in coal mine area. Taking the 1303 (lower) fully mechanized working face of Yuecheng coal mine as the research object, considering the characteristics of coal and rock accumulation in the three areas of goaf, this paper uses COMSOL numerical software to simulate and analyze the gas migration characteristics of the goaf where the surface wells are located along the strike and inclination of the working face. The results show that the gas concentration in goaf decreases gradually with the progress of drainage, and surface wells in different shaft location basically reach the balance in about 2000s. The shaft location of the surface well and the gas concentration in the upper corner are exponential function. In order to ensure the safety of coal production, the distance between the well distribution and the working face should be controlled within 240m, and close to the area near the return air lane. The research results provide a reference for the selection of surface well location.

1. Introduction

Gas is a kind of high-energy and clean resource associated with coal. Coal mine gas (coalbed methane) resources are very rich in China. According to the measured data of coal resource exploration results, the total amount of gas resources with coal gas content of more than 4 m³/t and buried depth of less than 2000 m is about 14.34×10¹² m³, which has great development and utilization potential. The practice shows that the surface well drainage technology is easier to develop high concentration gas resources than the underground drainage technology, which provides more convenience and choice for the subsequent gas utilization [1, 2]. The surface well drainage technology in coal mine area is more conducive to the efficient development and utilization of gas resources while relieving the pressure of mine gas disaster control and improving the level of coal mine safety production. The selection of the location of the surface well distribution in coal mine should consider the structural stability of the well body and the extraction effect [3-5]. Steven et al. [6] have carried out a lot of field tests on the effect and influencing factors of the surface well extraction. Qin and Zhang [7,8] have tested the application effect of surface wells, and put forward the coalbed methane development and governance mode of "joint development of ground and underground" in the experimental mining area. Zhou et al. [9] established the model of gas drainage amount of surface wells by using analytical method, and calculated
the gas drainage amount of practical application drilling in Wulan Coal Mine, and achieved good results. Li et al. [5, 10] analyzed the factors influencing the gas efficiency in the goaf of surface wells, and put forward some suggestions for improving the efficiency of surface well pumping. This paper intends to take the actual situation of Yuecheng coal mine as the research object, and use the numerical simulation method to analyze the gas migration law in goaf under different positions of surface well, which can provide reference for the selection of the shaft location of the surface wells.

2. Modeling

2.1. Background of the model

Taking 1303 (lower) fully mechanized working face of Yuecheng coal mine in Shanxi province, China as the simulation background. The strike length of the working face is 1226.1m, the inclined length of the working face is 158.1m. The total thickness of coal seam is 4.5~6.65m, the mining thickness is 2.8 ± 0.1m, the average dip angle of coal seam is 4°. The absolute gas emission of the working face is 3.71m³/min.

There are two bedding roadways in the working face, which are 1205(lower) lane and 1206(lower) lane. The two bedding roadways are arranged in parallel, and the excavation is carried out along the coal seam floor, which is perpendicular to the three main roadways in the east area. Among them, 1205(lower) lane is located in the west side of the working face, which is the air inlet lane and also serves as the belt transportation lane and equipment lane; 1206(lower) lane is located in the east side of the working face, which is the air return lane and also serves as the rail transportation lane. The working face roadway is designed as trapezoidal section, which is supported by metal shed and diamond net. The dimensions of main roadways are shown in Table 1.

| Roadway                     | Top size(m) | Bottom size(m) | Height(m) | Net sectional area(m²) |
|-----------------------------|-------------|----------------|-----------|------------------------|
| 1205/1206 (lower) lane      | 3.4         | 4.3            | 2.7       | 10.4                   |
| Open cut                    | 5.9         | 6.8            | 2.7       | 17.15                  |

The distribution of the three zones in the goaf: the caving zone is 16.48m; the fracture zone is 63.85m (including the caving zone); after the full mining of the bending subsidence zone, the bending subsidence zone must develop to the surface. If the mining is not enough, the bending subsidence zone may stop when it develops to a key layer of overburden. Surface well condition: the wellbore diameter is 224.42mm, the pumping negative pressure is non constant value, which can be taken as 20~40KPa.

2.2. Parameters of the model

The diameter of the drilling hole is 113mm, the negative pressure of pumping is 30KPa, the length of the screen pipe is 40m. Five different drilling positions are arranged respectively, which coordinates are shown in Figure 1 and Table 2.

![Figure 1. Schematic diagram of surface well](image-url)
Table 2. The coordinates of boreholes

| Serial number | x-coordinate | y-coordinate | z-coordinate |
|---------------|-------------|-------------|-------------|
| 1#            | 50          | 0           | 20–60       |
| 2#            | 100         | 0           | 20–60       |
| 3#            | 250         | 0           | 20–60       |
| 4#            | 100         | -40         | 20–60       |
| 5#            | 100         | 40          | 20–60       |

According to the distribution law of fracture field, the goaf is divided into three areas: natural accumulation area, pressure crushing expansion area and compaction stability area. The porosity of goaf is as follows:

\[ n = n_x n'_y n'_z \]

\[ n_x = 0.2 \exp \left[ -0.0223 \left( \frac{D}{2} - \frac{|x|}{2} \right) \right] + 0.1 \]

\[ n'_y = \exp \left[ -0.15 \left( \frac{L}{2} - |y| \right) \right] + 1 \]

\[ n'_z = \begin{cases} 
\frac{(x - \frac{D}{2})^2}{a_x^2} + \frac{y^2}{b_y^2} \geq 1 \\
\frac{(x - \frac{D}{2})^2}{a_x^2} + \frac{y^2}{b_y^2} < 1 \\
\frac{(x - \frac{D}{2})^2}{a_x^2} + \frac{y^2}{b_y^2} \leq \frac{1}{4}
\end{cases} \]

Where, \( n_x \) is the porosity along the direction of \( x = 0 \) on the floor of the goaf, dimensionless; \( D \) is the depth of the goaf, m; \( x \) is the strike distance between a certain point in the goaf and the working face, m, the value range \( [0, D] \); \( n'_y \) is the variation coefficient of porosity along the \( y \)-axis, dimensionless; \( L \) is the length of working face, m; \( y \) is the coordinate value of a point in the goaf in the \( y \)-axis direction, m, and the value range \( [-\frac{L}{2}, \frac{L}{2}] \). \( n'_z \) is the variation coefficient of the porosity along the \( z \)-axis, dimensionless; \( A \) and \( B \) are undetermined coefficients, dimensionless, calculated from actual measurements and experimental results, where \( A \) is a real number slightly greater than 1, and the coefficient is \( A = 1.01, B = 0.007178 \); \( z \) is the height of a point in the goaf area based on the bottom plate, m, the value range is \([0, H] \); \( a_1, a_2, b_1, b_2 \) are the long and short axis of two ellipses in Figure 1, m, \( a_1 = 100, b_1 = 30; a_2 = 220, b_2 = 60 \).

The relationship equation between permeability and porosity in porous media in the goaf is:

\[ k = 0.01605 \mu n \]

Where, \( k \) is the permeability, m\(^2\); \( \mu \) is the dynamic viscosity coefficient of gas, \( 1.834 \times 10^{-5} \text{ Pa}\cdot\text{s} \) at room temperature; \( n \) is the porosity of goaf, dimensionless. The spatial distribution of three-dimensional permeability in goaf is as follows:

\[ k = \begin{cases} 
0.01605 \mu \left[ 0.2 \exp \left[ -0.0223 \left( \frac{D}{2} - \frac{|x|}{2} \right) \right] + 0.1 \right] \cdot \frac{\left( x - \frac{D}{2} \right)^2}{a_x^2} + \frac{y^2}{b_y^2} \geq 1 \\
0.01605 \mu \left[ 0.2 \exp \left[ -0.0223 \left( \frac{D}{2} - \frac{|x|}{2} \right) \right] + 0.1 \right] \cdot \frac{\left( x - \frac{D}{2} \right)^2}{a_x^2} + \frac{y^2}{b_y^2} < 1 \\
0.01605 \mu \left[ 0.2 \exp \left[ -0.0223 \left( \frac{D}{2} - \frac{|x|}{2} \right) \right] + 0.1 \right] \cdot \frac{\left( x - \frac{D}{2} \right)^2}{a_x^2} + \frac{y^2}{b_y^2} \leq \frac{1}{4}
\end{cases} \]
3. Law of gas migration in goaf during surface well drainage

3.1. Distribution law of gas concentration in goaf during drainage

Figure 2 shows the gas concentration distribution in the goaf during the process of 2 # surface well drainage. It can be seen from Figure 2 that the guiding effect of surface well on gas flow changes the gas concentration distribution. Due to the large drainage capacity, the gas near the working face is reduced to a low value in a very short time, and the maximum gas concentration in the goaf is reduced to 47.18% in 500s, and then the gas concentration reduction speed is gradually slowed down. Compared with the condition of no surface well drainage, the maximum gas concentration is reduced by 37.67%. Figure 3 is the gas concentration distribution map of the working face during the drainage of 2 # surface well. It can be concluded that the gas in the upper corner of the working face is relatively high, but it does not exceed the 1% limit.

![Figure 2. Cloud chart of concentration distribution of goaf at different time](image)

![Figure 3. Cloud chart of gas concentration distribution in working face](image)

3.2. The influence of different shaft location on gas migration in goaf

(1) Different well location along strike

Figure 4 shows the gas distribution law of goaf drainage by surface wells in different strike positions. It can be seen that when the local surface wells are arranged within 100m strike, the concentration distribution in goaf is greatly affected. Due to the effect of drainage, the gas concentration in the goaf near the working face is low, and the difference of concentration gradient along the dip and vertical direction is small. The gas concentration in the deep goaf behind the surface well presents a symmetrical distribution of "V" shape. When the layout of local surface wells is 250m, the influence on the concentration distribution law of goaf is small, and the concentration distribution characteristics are consistent with those under the condition of only return air, but the overall concentration decreases. At
the same time, the gas concentration in the goaf gradually decreases with the drainage, and the surface wells at different well layout positions basically reach the balance in about 2000s, as shown in Table 3. It can be concluded that the surface well near the working face has better drainage effect at the initial stage, but with the passage of time, the gas concentration in the goaf is the lowest after 3 # surface well drainage. This is because 3 # surface well is located in the deeper part of the goaf, the concentration is relatively high, and the effective radius of the surface well drainage is fully covered in the goaf, and the effective range of 1 # and 2 # wells near the working face is small.

![Figure 4](image)

**Figure 4.** Cloud chart of gas distribution in goaf of surface well drainage in different strike positions

| Time   | 0s   | 50s  | 500s | 2000s | 5000s | 10000s |
|--------|------|------|------|-------|-------|--------|
| 1#     | 98.5%| 88.79%| 52.85%| 47.79%| 47.88%| 47.79% |
| 2#     | 98.05%| 86.23%| 47.18%| 44.27%| 44.35%| 44.25% |
| 3#     | 99.31%| 93.88%| 52.05%| 36.89%| 37.37%| 37%    |

The maximum gas concentration of working face in the initial stage of 1 #, 2 #, 3 # surface well drainage is 0.84%, 0.87%, 10.72% respectively, which indicates that the closer the surface well is to the working face, the greater the influence of gas concentration on the working face. Over time, the gas concentration in the upper corner decreased to 0.34%, 0.22% and 0.95% respectively. Therefore, it can be concluded that the relationship between the location of the surface well strike and the gas concentration in the upper corner is basically an exponential function, as shown in Figure 5. In order to ensure the safety of coal mine production, the gas concentration in the upper corner should be controlled within 0.8%, and the surface well spacing should be controlled within 240m.

![Figure 5](image)

**Figure 5.** Relationship between gas concentration in upper corner and location of surface wells

(2) Different well location along dip

Figure 6 shows the gas distribution law of the goaf of the surface well in different dip positions. Due to the pumping action, the gas concentration in the goaf near the working face is lower, and the gradient of concentration along the direction of inclination and vertical direction is less. With the development of the goaf, the gas concentration gradually decreases, and the surface wells in different distribution positions are basically balanced in 2000s, as shown in Table 4. The influence of different positions along the inclined direction of the surface wells on the highest concentration of goaf is small. After the surface...
wells are pumped in different inclined positions, the highest gas concentration in the goaf is about 42% - 45%. The highest gas concentration of the working face in the initial stage of the surface well extraction is 1.2%, 0.87% and 0.72%, respectively. It indicates that the greater the influence of the surface well extraction near the return air lane on the gas concentration of the working face is, the surface well should be arranged near the return air lane. Over time, the gas concentration in the upper corner decreased to 0.23%, 0.22% and 0.18%, which were all within the control range of safety production.

![Figure 6. Cloud chart of gas distribution in goaf of surface well drainage in different dip positions](image)

| Time | 0s     | 50s    | 500s   | 2000s  | 5000s  | 10000s |
|------|--------|--------|--------|--------|--------|--------|
| 4#   | 98.7%  | 89.69% | 46.12% | 42.26% | 42.34% | 42.24% |
| 2#   | 98.05% | 86.23% | 47.18% | 44.27% | 44.35% | 44.25% |
| 5#   | 97.87% | 84.79% | 44.4%  | 42.26% | 42.36% | 42.26% |

4. Conclusions

In this paper, the 1303 (lower) fully mechanized working face of Yuecheng mine is taken as the research object, considering the characteristics of coal and rock accumulation in the three areas of goaf, the numerical analysis model of gas migration in goaf is constructed by using COMSOL numerical simulation software, and the gas migration characteristics of goaf with surface wells located at different positions along the strike and inclination of working face are obtained. With the development of the goaf, the gas concentration gradually decreases, and the balance of the surface wells in different distribution positions is about 2000s. From the horizontal direction, the contour map of gas concentration in the deep part of goaf is distributed symmetrically in the form of "V". The distribution position of the surface well and the gas concentration in the upper corner are basically exponential function. In order to ensure the safety of coal production, the distance between the well distribution on the ground should be controlled within 240m. After the surface wells in different inclined positions are pumped, the highest gas concentration in the goaf is about 42% - 45%. The greater the influence of the surface well extraction near the return air lane on the gas concentration of the working face is, the surface wells should be arranged near the return air roadway. The research results provide a reference for the selection of well distribution location.

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