Study on the Optimization of a Gas Drainage Borehole Drainage Horizon Based on the Evolution Characteristics of Mining Fracture

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Abstract: Gas disaster restricts the safety development of coal mine. The technology of high-level borehole gas drainage is an important means to reduce the gas concentration in goaf. In order to determine the best position of the end of gas drainage hole, in this paper, based on the geological conditions of Xinyuan coal mine 31009 working face, a series of numerical simulation is carried out; and through the field test, the dynamic change of gas concentration in different height of borehole is monitored. The results show that: When the working face advances to different distances, there are four characteristic distribution areas in the horizontal direction: the fracture area of the original rock stratum, fracture channel generation and development area, fracture channel mature area and fracture channel closure area. Although the drilling horizon is different, the change of gas concentration in drilling can be divided into four stages: gas stabilization stage, gas initial change stage, gas fluctuation stage and gas re-stabilization stage. The variation of borehole concentration can reflect the evolution characteristics of fracture area. The response time of gas change in different layers is also different. In the gas initial change stage and the gas re-stabilization stage, the low-level borehole first responds. The response of gas change in high-level drilling is a long process, so the effect of high-level drilling is better than that of low-level drilling. For 31009 working face, the best gas drainage layer is 32m, and the field gas drainage has achieved good practical results. This study can provide some guidance for the prevention and control of gas disaster in goaf.

Keywords: fracture channel; overburden strata; gas drainage; bundle tube; monitoring system

1. Introduction

With the development of coal mining methods, the comprehensive mechanization of coal mining has developed rapidly. However, due to the influence of large mining intensity, rapidly advancing speed, large areas of goafs, and the significant amount of coal left in goafs, the gas flow from goafs to working faces has increased rapidly. When the gas in the working face and return air roadway exceeds its predefined limits, gas combustion and other accidents will occur, which can pose a serious threat to the safety of the mine. Therefore, it is crucial to increase gas control in the working face, especially in the upper corner [1,2]. At present, there are many technologies in the coal mining industry that can be used to solve the problem of gas overrun in the upper corner. Due to its low cost, successful effects, convenient construction, and simple management, gas drainage by drilling through layers has been applied in many coal mines [3,4]. In order to ensure the effect of gas drainage by drilling, it is necessary to arrange drilling in an area with high permeability and gas accumulation.

However, in the process of coal mining, the degree of breakage and collapse of the overlying strata in a goaf can differ across time and space. Moreover, the permeability of the overlying strata in a goaf...
is dynamic [5–7]. Based on a theoretical analysis of stress and deformation, many researchers have studied the law of overburden collapse in goafs. Many theories have been developed, such as the “O” ring theory, the masonry beam theory, and the key layer theory of rock control [8–11]. In the application of theory to engineering practice, the mechanical properties of the rock in the horizontal and vertical direction of the goaf are studied, and the division mode and scope of the “vertical three zones” and “horizontal three zones” of the rock collapse and compaction in the goaf have been determined [5,12,13].

The fracture channel formed by the roof activity of the overburden caving in a goaf has an important influence on gas drainage by drilling. Therefore, the monitoring equipment and means of rock fracture development are particularly important. The method of numerical simulation is widely used in the study of the evolution law of rock fractures due to its economy and convenience [14,15]. With the application of advanced technology, precise monitoring equipment has been applied to monitor the development of overlying rock fractures and to analyze the dynamic characteristics of rock strata, such as automatic deep displacement monitor, electrical resistance inversion imaging, and distributed optical fiber detection [16–18]. To study the influence of fracture development on gas drainage and determine the gas accumulation area in the strata, some researchers have used numerical simulations to analyze the flow of gas in the goaf based on the gas migration law and the fracture evolution law [19–21].

However, considering the complexity of overburden collapse during mining, the dynamic evolution of fractures also has a dynamic impact on gas drainage. At present, there is a lack of research on determining the best layer of gas drainage via the dynamic observation of gas drainage through layer drilling. In recent years, with the progress of science and technology, a relevant gas analysis system has been applied to coal mine monitoring of important gas changes [22–25]. In this paper, we use the Xinyuan coal mine as the engineering background and UDEC (Universal Distinct Element Code) numerical simulation software to simulate the caving characteristics of overburden in the goaf; we then summarize the law of the development of the overlying strata fracture. After that, an underground multi-component gas monitoring and analysis system is used to monitor the changes of gas concentration in different layers. The change of gas composition and concentration in the process of fracture development is observed, and then the best gas extraction horizon is obtained. These research results are significant as a guide for gas drainage in goafs through the drilling of adjacent strata and the prevention and control of gas emissions from the goaf to the working face.

2. Mining and Geological Conditions

The Xinyuan coal mine is located in Shouyang County, Shanxi Province. The working face of this test is 31009 working face, and the coal seam mined by 31009 working face is No. 3 coal seam. The average thickness of the coal seam is 2.95 m. The strike length of the 31,009 working face is 1200 m, the inclined length of the working face is 240 m, and the average mining speed is 5.7 m/d. Three roadways are arranged on the working face; these roadways include the intake airway, the auxiliary intake airway, and the return airway. The three roadways are arranged along the coal seam roof. The 31,009 working face adopts a “Y-type” ventilation system for air supply. The advantage of a “Y” ventilation system is to reduce the gas concentration in the working face and upper corner. If there is too much gas accumulation in the goaf to be discharged, there will be a risk that the gas from the goaf will flow into the working face. Therefore, in the 31,009 working face, the system of gas drainage through the strata and drilling holes is formed by drilling holes from the return air roadway to the overlying strata of the goaf. Through negative pressure suction, the gas that floats from the goaf to the overlying strata is removed by the gas drainage borehole. In this way, the gas concentration in the goaf can be reduced and excessive gas accumulation in the goaf can be prevented. The level of gas drainage layer has a great influence on the effect of gas drainage. Therefore, we have studied the best horizon of gas drainage borehole. The ventilation system is shown in Figure 1. The stratigraphic sequence is shown in Figure 2.
3. Numerical Simulation of the Mining Fracture Evolution of the Overlying Strata in the Goaf

UDEC is numerical analysis software based on the discrete element method [26,27]. This software can provide accurate analysis for geotechnical engineering problems using the explicit solution algorithm [26,28,29]. This software is especially suitable for simulating the responses of jointed rock systems or discontinuous block systems under static or dynamic load conditions [30]. In this section, we obtain the movement characteristics of the overlying strata in the goaf during the mining process of the 31,009 working face of the Xinyuan mine through numerical simulation and obtain the collapse law of the overlying strata.
3.1. Model Establishment

The model parameters are set according to the actual conditions of the Xinyuan mine. The model is 350 m long and 35 m high. The rock layer above the model is mainly sandstone, and the model is not added in the simulation, so the equivalent load method is used for processing. Horizontal displacement was restrained on the left and right boundaries, and vertical displacement was restrained on the bottom boundary. The upper part of the model is the load condition, and the self-weight stress of the rock is the boundary force.

3.2. Simulation Results and Analysis

1. The results of the UDEC simulation demonstrate the characteristics of overburden collapse in the goaf during the advancing process of the working face, as shown in Figure 3. The characteristics of the overburden collapse in the goaf are as follows:

   (a) 50 m  (b) 100 m  (c) 150 m  (d) 200m

**Figure 3.** Overburden strata movement with different advancing distances in the numerical simulation.

When the working face is excavated for 50 m, the direct roof above the goaf collapses in a trapezoid shape, the highest position of which is 12.21 m, and the rock strata above the direct roof does not collapse.

As the working face advances to 100 m, the two strata at 16.81 m begin to collapse, forming a fracture in the strata. The strata above the immediate roof of the goaf maintain good strength, and the strata do not collapse completely, as only part of the weight is applied to the floor of the goaf.
When the working face is advanced to 150–200 m, the maximum caving height reaches 32.12 m, and the overburden of the upper rock layer in the middle of the goaf collapses continuously, producing pressure on the lower portion of the collapsed rock and causing the crack to begin to close. Due to the support of the masonry beam, the upper rock layer can maintain a portion of its strength after fracture displacement, thereby avoiding further extrusion and preserving the cracks in the rock layer.

2. According to the collapse patterns of the overburden at different distances for advancing the UDEC simulation working face, it can be seen that the fracture distribution in overburden has obvious characteristics in the horizontal and vertical directions, as shown in Figure 3d. Therefore, the development law of the overlying strata should be taken into account in the design of the gas drainage borehole. Horizontally, the overlying strata are divided into four areas:

- The fracture area of the original rock stratum: Beyond a certain distance in front of the work, the upper rock stratum is not affected by mining stress; the rock stratum has no fracture development and maintains a low permeability state.
- The fracture channel generation and development area: The overlying strata in this area gradually develops into a masonry beam structure bearing the upper strata’s pressure. The horizontal stress gradually decreases until it changes into tensile stress, and the rock fracture slowly increases.
- The fracture channel mature area: The overlying strata are completely broken and collapsed, and the strata relying on the upper masonry beam structure bear the vertical stress. The vertical stress borne by the strata here reaches its minimum state during the change of the overlying strata, and the fracture is the largest.
- The fracture channel closure area is located in the area where the goaf is recompacted. As the upper rock layer collapses further, the lower collapsed rock layer is gradually compacted. The vertical fractures in this area are gradually closed by vertical pressure. The subsidence of the overlying strata is the largest, the vertical stress of the strata is basically restored to the level before mining, and the fractures in the strata are close to the original level.

According to the results of numerical simulation, in the vertical direction of the floor of the goaf, there are three characteristics of collapse and subsidence of the overlying strata above the goaf: the caving zone, fracture zone, and bending subsidence zone. In the scope of the caving zone, the rock stratum at the top of the goaf directly collapses to the bottom, and the rock stratum is seriously broken with a large number of cracks. In the range of fracture zone, the strata here lose their support due to the direct roof falling, and generate separate fissures under tensile stress. The main body of the strata is basically intact but not completely collapsed. In the scope of the bending subsidence zone, the rock layer is kept intact, only small subsidence occurs, and the cracks in the rock layer are rarely produced.

4. Analysis on Continuous Sampling of Gas Drainage Borehole Through Strata

4.1. Continuous Sampling Analysis Technology

With the advance of the working face, the goaf is gradually formed and expanded. The existence of goaf provides a certain free space for the surrounding coal and rock strata, which leads to the fracture development and permeability increase of the surrounding rock mass [31]. Air and gas are accumulated in the goaf due to the air leakage from the working face. If the permeability of the rock layer where the gas extraction hole is located increases, the gas mixture in the goaf will be extracted by the extraction hole. The mixture gas in the goaf contains air and methane, so the concentration of methane will decrease. If the rock fracture under the gas extraction borehole is closed, the air content in the gas extracted from the gas extraction borehole will decrease, and the methane released from the surrounding coal body will be extracted because it floats up and accumulates in the upper rock stratum, and the methane concentration will increase [32]. If the borehole location is in the caving zone and the borehole collapses with the rock stratum, the methane concentration extracted is very small, and the borehole fails. If the location of the borehole is above the caving zone, and the borehole remains intact,
the variation of the methane concentration extracted from the borehole can reflect the variation law of the fracture in the lower stratum. Therefore, if the continuous sampling and analysis system is added to the gas drill hole through the layer to observe the change of methane concentration extracted from the drill hole, the development and collapse process of the rock fracture will be obtained, and then the best layer of methane extraction can be determined.

Infrared and laser detection technology can measure a variety of gases [33,34]. This technology has the advantages of a large measurement range, fast response, no poisoning, high measurement accuracy, good stability, reliability, and the ability to realize the on-line detection of gas. Compared to the electrochemical sensors and catalytic sensors of traditional monitoring systems, an optical gas analyzer can improve the accuracy and reliability of gas analysis greatly and can realize multiple groups of rapid analysis after one injection. An underground multi-component gas monitoring and analysis system based on laser gas analysis is adopted in this test. This system can automatically and continuously sample and analyze various gas concentrations (CO, O₂, CO₂, CH₄, C₂H₄, and C₂H₂). This system is used to place the gas monitoring substation in the mine and collect gas from many places throughout the mine over 24 h in real time through the built-in air pump placed in the mine monitoring substation. After filtering dust and water, the extracted gas is sent to the monitoring substation through the bundle tube for real-time analysis. Through this monitoring station, underground personnel can determine the gas composition status of the monitoring point in real time. This monitoring substation also uploads its analysis results to the ground control center station through the communication line and uses information processing tools, such as a computer and a database, for sampling data statistics, analyses, fire predictions and early warnings, storage, displays, reports, printing, and other functions, to avoid the errors caused by an extraction pipeline that is too long and to improve the real-time accuracy of the monitoring. The system’s composition is shown in Figure 4.

![Underground multi-component gas monitoring and analysis system.](image)

**Figure 4.** Underground multi-component gas monitoring and analysis system.

4.2. Test Drainage Boreholes Design

This field test is divided into two groups: group A and group B, with a spacing of 15 m. The drilling layout is shown in Figure 5, and the drilling construction parameters are shown in Table 1. Group A consists of three boreholes: No. 1, No. 2, and No. 3. The heights of the end of the boreholes from the coal seam floor are 15 m, 19 m, and 32 m. Group B consists of three boreholes: No. 4, No. 5, and No. 6.
The heights of the end of the boreholes from the coal seam floor are 15 m, 19 m, and 23 m. The No. 1, No. 2, No. 4, and No. 5 holes need to be drilled from the 31009 auxiliary air intake roadway along the top of the roadway to the strata above the coal seam, while the No. 3 and No. 6 holes need to be drilled in the return air roadway. After the completion of drilling construction, the bound pipe will be connected to the borehole, and the borehole will be sealed. Then, the change of the various gas concentrations in the borehole will be monitored in real time.

Figure 4. Underground multi-component gas monitoring and analysis system.

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Figure 5. Layout of gas drainage boreholes.

Table 1. Drilling parameters of gas drainage.

<table>
<thead>
<tr>
<th>Number</th>
<th>Group Number</th>
<th>Drilling Depth/m</th>
<th>Borehole Elevation Angle/°</th>
<th>Horizontal Angle of Borehole/°</th>
<th>Vertical Height of Drilling End/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
<td>26.1</td>
<td>35</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>2</td>
<td>A</td>
<td>26.9</td>
<td>45</td>
<td>0</td>
<td>19</td>
</tr>
<tr>
<td>3</td>
<td>A</td>
<td>60.0</td>
<td>37.8</td>
<td>0</td>
<td>32</td>
</tr>
<tr>
<td>4</td>
<td>B</td>
<td>26.1</td>
<td>35</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>5</td>
<td>B</td>
<td>26.9</td>
<td>45</td>
<td>0</td>
<td>19</td>
</tr>
<tr>
<td>6</td>
<td>B</td>
<td>60.0</td>
<td>32.5</td>
<td>0</td>
<td>23</td>
</tr>
</tbody>
</table>
4.3. Results and Analysis

According to the advance of the working face, the data for various gas concentration changes monitored by the continuous monitoring system of the bundle pipe from 23:00 July 13 2018 to 16:00 July 23 2018 are analyzed. At 12:19 on July 13, the working face was mined at the vertical face of the group A boreholes. At 16:30 on July 16, the working face was mined at the vertical face of the group B boreholes. The methane concentration in the monitoring data reflects the change in the methane extraction amount, and the change of oxygen concentration reflects the fracture development degree in the process of fracture development. According to Figures 6–9, the variation of methane concentration and oxygen concentration in six boreholes can be divided into four stages:

- In the gas stabilization stage, before the working face is mined to the drilling section, the oxygen concentration shown in the drilling hole is basically unchanged, the cracks under the drilling hole are not connected, and the gas extracted from the drilling hole is the gas originally stored in the rock stratum (mainly methane and nitrogen).
- The gas initial change stage occurs due to the initial conduction of the fracture between the drilling hole and the goaf, and the air in the goaf flows into the upper stratum through the fracture, resulting in a sudden change in the concentration of oxygen and gas in the drilling hole.
- In the gas fluctuation stage, the gas concentration in the borehole will fluctuate due to the collapse and compaction of the rock under the borehole and the continuous generation of new cracks.
- In the gas re-stabilization stage, due to the basic end of rock activity and the completion of fracture development, the concentration of gas extracted by drilling is basically stable, and the air and methane in the goaf flow to the fractures of the upper rock stratum through drilling suction. Due to the different degrees of fracture development, the methane accumulation in different locations is different, resulting in different concentrations of gas extracted by drilling. After the completion of fracture development, the gas drainage capacity of the low-level boreholes (No. 1, No. 2, No. 4, and No. 5) is invalid, and the gas concentration is reduced to zero. The gas concentration is still very high in the high-level drilling holes (No.3 and No.6).

Figure 6. $O_2$ concentration of the group A boreholes.
In the gas re-stabilization stage, due to the basic end of rock activity and the completion of fracture development, the concentration of gas extracted by drilling is basically stable, and the air and methane in the goaf flow to the fractures of the upper rock stratum through drilling suction. Due to the different degrees of fracture development, the methane accumulation in different locations is different, resulting in different concentrations of gas extracted by drilling. After the completion of fracture development, the gas drainage capacity of the low-level boreholes (No. 1, No. 2, No. 4, and No. 5) is invalid, and the gas concentration is reduced to zero. The gas concentration is still very high in the high-level drilling holes (No. 3 and No. 6).

Figure 6. O$_2$ concentration of the group A boreholes.

Figure 7. CH$_4$ concentration of group A boreholes.

Table 2 shows the time points when gas changes are detected in each borehole after the working face is mined through the borehole section. It can be seen that the monitoring gas change time will be different due to the location of the end of the borehole in different layers. The initial fracture conduction time of the No. 3 and No. 6 drilling holes in the high layer is later than that of the No. 1, No. 2, No. 4, and No. 5 drilling holes. The oxygen concentration monitored by the No. 1, No. 2, No. 4, and No. 5 boreholes soon reached their maximum values. This occurred because the borehole with a vertical height of 15 m and 19 m is located in the caving zone, and the rapid collapse of the rock stratum causes the borehole fracture to develop too fully, resulting in air leaking into the borehole, so the air in the borehole includes more than just methane. After 216.53 h and 145.32 h, respectively, the oxygen concentration in the No. 3 and No. 6 boreholes reached a stable state. This occurred because the No. 3 and No. 6 drilling holes are located in the fracture zone, and the strata below are continuously collapsed and compacted, which ultimately formed a complete gas channel with the

Figure 8. O$_2$ concentration of group B boreholes.

Figure 9. CH$_4$ concentration of the group B boreholes.
Table 2 shows the time points when gas changes are detected in each borehole after the working face is mined through the borehole section. It can be seen that the monitoring gas change time will be different due to the location of the end of the borehole in different layers. The initial fracture conduction time of the No. 3 and No. 6 drilling holes in the high layer is later than that of the No. 1, No. 2, No. 4, and No. 5 drilling holes. The oxygen concentration monitored by the No. 1, No. 2, No. 4, and No. 5 boreholes soon reached their maximum values. This occurred because the borehole with a vertical height of 15 m and 19 m is located in the caving zone, and the rapid collapse of the rock stratum causes the borehole fracture to develop too fully, resulting in air leaking into the borehole, so the air in the borehole includes more than just methane. After 216.53 h and 145.32 h, respectively, the oxygen concentration in the No. 3 and No. 6 boreholes reached a stable state. This occurred because the No. 3 and No. 6 drilling holes are located in the fracture zone, and the strata below are continuously collapsed and compacted, which ultimately formed a complete gas channel with the goaf below. The time from the working face mining to the lower part of the borehole to the change of the gas concentration in the borehole to the stable state is the time when the rock fissures under each borehole are fully developed. The time for the complete development of the fractures in the lower strata of the No. 1, No. 2, No. 6, and No. 3 boreholes at different drilling positions is 43.47 h, 85.68 h, 145.32 h, and 216.53 h, respectively. The higher the drilling horizon, the longer the fracture development time, as shown in Figure 10.

Table 2. Key time points of the borehole monitoring data.

<table>
<thead>
<tr>
<th>Number</th>
<th>Mining Time</th>
<th>Starting Time of Change</th>
<th>Duration of Initial Change/h</th>
<th>Duration of the Whole Process/h</th>
<th>Average Gas Concentration after Stabilization</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7/13 12:19</td>
<td>7/14 5:59</td>
<td>17.67</td>
<td>43.47</td>
<td>0.96%</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>7/14 7:54</td>
<td>19.58</td>
<td>85.68</td>
<td>1.57%</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>7/14 22:24</td>
<td>34.08</td>
<td>216.53</td>
<td>20.03%</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>7/16 20:33</td>
<td>4.05</td>
<td>8.25</td>
<td>0.24%</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>7/17 2:09</td>
<td>9.65</td>
<td>49.13</td>
<td>0.49%</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>7/17 15:28</td>
<td>22.97</td>
<td>145.32</td>
<td>17.96%</td>
</tr>
</tbody>
</table>
As shown in Table 2, compared to the low-level drilling, the methane concentration extracted from the high-level drilling at No. 3 and No. 6 is higher, and the effective time of extraction is longer. As the molecular weight of methane is lighter than that of air, it more easily floats up and gathers in the upper strata. There are two factors related to the gas concentration in the gas drainage borehole. There are also two factors related to the concentration of gas extracted from the gas extraction borehole. The first is the accumulation degree of methane in the rock stratum, and the second is the fracture connection between the gas extraction borehole and the methane accumulation rock stratum. As shown in Figures 6–9, in the early stage of the fracture development of overlying strata, the methane concentration of a low-level borehole will be higher than that of a high-level borehole. This is because a low-level borehole first forms a gas channel with the goaf. As mining activity on the working face causes methane accumulation in the goaf, and the low-level borehole first extracts the methane in the goaf, the methane concentration will suddenly increase. With mining of the working face, the overlying strata of the goaf continues to collapse, so the gas drainage capacity of the low-level drilling hole decreases because of the collapse of the strata. However, the rock stratum where the high-level gas drainage borehole is located will not collapse seriously but will instead form a gas channel with the goaf, so the gas in the goaf floats up to the layer of the high-level borehole and accumulates there. The gas extraction concentration of the high-level borehole can be kept at 17.96%–20.03%, which has a good effect on reducing gas accumulation in the goaf. The gas extraction concentration of the No. 3 borehole is 11.5% higher than that of the No. 6 borehole, so it is more favorable to arrange the terminal of the gas extraction borehole at a vertical height of 32 m.

5. Discussion

1. Distribution of the gas accumulation area formed by fracture evolution.

   According to the analysis of numerical simulations and field test results, it can be seen that there are dynamic changes in the horizontal and vertical directions of the fractures in the overlying strata of the goaf. As the distribution of rock fractures will affect gas accumulation, according to the distribution law of the overlying rock fracture in the goaf, gas accumulation in the goaf is divided into three areas: a gas turbulence area, a gas accumulation area, and a gas seepage area, as shown in Figure 11. For the
gas turbulence area, the overburden in the caving zone is broken to a large extent and is accumulated in the goaf, where the cracks in the broken rock are the most significant, and the gas channel is mainly formed from large cracks. Due to the air leakage from the working face to the goaf, the gas migration state is mainly turbulent, so it is difficult for gas to accumulate. The gas accumulation area is located in the fracture zone. The overburden in this area is relatively intact. In the process of separating the strata, primarily tensile cracks are formed, and the permeability of the strata is significantly increased. Furthermore, a large amount of gas floating in this area is accumulated. The gas seepage area is mainly located in the bending subsidence zone, and the overburden in this area is slightly subsided as a whole, with only a small number of fractures, and the permeability of the rock layer is only slightly increased compared to that of the original state. The gas migration in this area is mainly seepage, and the amount of gas is very small. The research results of fracture development of overlying strata in the goaf are consistent with those of Liu [16]. This paper further analyzes the gas accumulation area, due to the influence of gas seepage and fracture distribution characteristics.

![Schematic diagram of the gas distribution in the overlying strata.](image)

Figure 11. Schematic diagram of the gas distribution in the overlying strata.

2. Optimization of gas drainage borehole layout.

In general, only effective fracture and effective influence radius are considered in the optimization of the gas drainage borehole layout [35]. There are two factors to be considered in the layout of gas drainage holes. On the one hand, the stability of rock strata in the drilling area must be considered; on the other hand, the area of drainage is the area of gas accumulation. In the horizontal direction, the fractures of the overlying strata in the goaf range from small to large and then reduce; in the vertical direction, along the floor and upward, the fractures are distributed from large to small. In the gas turbulence area, the rock strata in the caving zone fall in a large range, with a large development of fissures. The gas drainage holes arranged here are vulnerable to damage, resulting in hole collapse. Moreover, the gas concentration here is greatly affected by air leakage in the working face, resulting in more air being extracted from the holes and less methane extraction. In the gas seepage area, the permeability of rock is small, so it is difficult to achieve an effective drainage effect. If the gas drainage borehole is arranged in the gas accumulation area, the entire rock stratum is intact, and the fracture channel is mature. The gas floats upward in this area to form an accumulation, so the gas can be extracted from the drainage borehole for a long period of time after the fracture is formed.
6. Conclusions

In order to determine the best position at the end of a gas drainage hole, a new research method was put forward—that is, connecting the gas monitoring system in the drainage hole to study the development process of the rock fracture. First of all, UDEC software was used to simulate the collapse characteristics of overburden above a goaf. The simulation results show that when the working face advances to different distances, the fracture development process of the overlying strata in the horizontal direction of the goaf has four characteristics: the fracture area of the original rock stratum, the fracture channel generation and development area, the fracture channel mature area, and the fracture channel closure area. In the vertical direction of the goaf floor, there are three characteristics of overburden: caving zone, fracture zone, and bending subsidence zone. Through the field test, it is found that there are four stages in the change of gas concentration in the borehole: the stable stage of drilling gas, the initial change stage of drilling gas, gas fluctuation stage, and the re-stabilization stage of drilling gas. The results of the field test show that the data law of gas drilling in different layers is consistent with that of numerical simulation. The response time of gas change in different layers is also different. The development time of high drilling fracture is long, the gas extraction concentration is high, and the extraction time is long. The gas drainage efficiency of the 32m gas drilling hole is 11.5% higher than that of the 23 m gas drilling hole, which can be used as the best drainage layer of the coal seam. Therefore, the efficiency of gas drainage can be improved by combining the overburden caving law in the design of gas drainage holes.

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