The Selection and Application of Gas Drainage Methods under the Influence of the Coal Spontaneous Combustion in the Gob: A Case Study in the Dalong Coal Mine, China

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\textbf{Abstract}

Gas and spontaneous combustion of coal have seriously threatened the production safety and efficiency during the process of mining. Gas drainage can reduce the risk of gas while it may intensify the self-ignition of coal. In order to study the certain relationship between these two issues, the south 906 working face of Dalong coal mine was taken into research. The physical geometrical and mathematical model was established. Numerical investigation based on Fluent was conducted to identify the gas concentration distribution and air leakage field under four different gas drainage methods, such as high drill holes drainage (HDHE), buried pipe drainage (BPE), adjacent roadway drainage (ARE) and tail roadway drainage (TRE). The simulation results show that all these four gas drainage methods are able to control the gas concentration in the air return corner, so as not to exceed the certain limit (1%). However, these methods have also enlarged the area of spontaneous combustion zone with 1.11, 1.30, 1.61 and 2.10 times respectively. According to the comprehensive analysis on simulation results, HDHE has the minimal influence under the same gas drainage amount. This gas drainage method was then applied in the aforementioned working face. The follow-up monitoring data proved our research results, with CO concentration in the drainage pipes always keeping lower than 0.0024% and gas concentration in the air return corner maintaining no more than 0.70%. The study provides significant references for managing the gob where exists symbiosis disaster of gas explosion and spontaneous combustion of coal.

\textbf{Keywords}

Gas Disasters; Gas Drainage Method; Air Leakage Field; Spontaneous Combustion of Coal

\textbf{Introduction}

The strong dependence of Chinese economic development on energy has led to the increasing use of coal products \cite{1,2}, which accounts for 70\% of the nation’s total energy supply \cite{3}. As a result, the mining depth of coalbeds has increased annually by 10-50 m from shallow to deep deposits. With the increase of the mining depth, the coal seam gas pressure and ground stress increased. The result has been large numbers of gas outbursts and gas explosions, which have caused property losses and account for a significant share of the casualties associated with coal mining.
in China [4-6]. Known as a hazard to mining safety and a powerful greenhouse gas, coalbed methane is also a form of clean and efficient energy [7]. The CBM industry is well-developed in America, Canada, Australia, Poland [8-10] and also in China [11]. The mined-out areas known as gobs have high-permeability fractures that form open pathways for gas transport. And the amount of gas accumulates in these areas, which may come from the unmined roof or floor coal, or from an underlying coal seam [12]. For many years, mining engineers and researchers have developed a number of methods for underground gas drainage of gob, including high drill holes drainage (HDHE), buried pipe drainage (BPE), adjacent roadway drainage (ARE) and tail roadway drainage (TRE) [13-15]. However, gas drainage will accelerated the air leakage in gob and the residual coal of gob exposed to air undergoes oxidation reaction through a process of adsorption and chemisorption [16]. If the heat produced by the oxidation exothermic reaction is not dissipated as fast as it is accumulated, there will be an increase of temperature and a thermal runaway event can ensue [17, 18]. It has been well known that the self-heating and spontaneous combustion of coal in gobs may pose a difficult, persistent and costly problem for coal industries worldwide, usually causing significant economic losses, personal casualties, and environmental pollution [19, 20].

The symbiosis between coal gas and spontaneous combustion has become one of the important inducements to the serious accidents of coal mines [21]. Therefore, it is a problem urgent to be solved that how to harmonize the gas drainage with the spontaneous combustion of coal in gobs. Air leakage into the gob is one of the major causes of the spontaneous combustion of residual coal [22-24]. Therefore, studying the air leakage in gobs is important to control the spontaneous combustion of residual coal for security. The pressure difference between the upper and lower corners at the working face is the main force for air leakage into the gob, which is affected by air volume at the working face and gas drainage methods and negative pressure. Several studies have focused on the influence of gas drainage on spontaneous combustion of coal in the gob by using numerical simulations of air leakage flow fields. For example, Li ZX studied spontaneous combustion process of residual coal in gob [25] and the coupling relationship of methane drainage and spontaneous combustion [26]. Balusu, Wendt and Ren modelled the gas distribution using CFD technology under the condition of vertical shaft drainage and different cases of ventilation in working faces [27-29]. Liming Yuan conducted numerical study on spontaneous heating in the gob by use of custom model of heat release and oxidation in FLUENT software, on the basis of common mine ventilation systems [30]. Zhu et al. compared the influences of different air volumes on spontaneous combustion “three zones” and concluded that a higher air volume at the working face corresponds to deeper oxidation zones in the gob and the larger range of the oxidation zone [31]. Shao et al. simulated and analyzed the relationship of the air volume and air leakage volume in the gob and found that a higher air volume leads to higher air leakage volume in the gob [32]. Zhu and Liu simulated and analyzed qualitatively the influence of tail methane drainage pattern on easily spontaneous combustible region in gob [33].

But above researches have similar imperfections. Firstly, their research models were established under single gas drainage method. Furthermore, they only studied the gas migration state and percolation law of air leakage in gob theoretically. Besides, they did not make detailed analysis on these two issues. Therefore, it is necessary to conduct the research on effects of different gas drainage methods on spontaneous combustion of coal in gob. We took a working face with the coexistence disasters of gas explosion and spontaneous combustion of coal as research object and applied numerical simulation based on Fluent. Then, we got the gas concentration distribution and air leakage field under HDHE, BPE, ARE and TRE. The relatively reasonable control technology was found out and applied in production site. And its effects were analyzed as well. All these could be described in Figure 1.
Description of Da Long Coal Mine and Model Establishment

General Situation of Working Face

Dalong coal mine is located in the Midwest zone of Tiefa coalfield, Diaobingshan, Liaoning province, China. Scope of the mine field is 4.43 km from east to west and 2.58 km from south to north and the area is about 11.43 km². In 2014, the verified production capacity of the mine was 290 million tons per year and the service life is up to 20 years based on the exploitable reserves is 0.06266 billion tons. The direction of the south 906 working face is 50°3m long and 200m wide with working area of 113520 square meters. The coal seam exploited in the working face is 9# coal seam, which is a compound coal seam with better coal quality that the ash content is 28.65 wt.%, the moisture content is 8.40 wt.%, the volatile content is 36.50 wt.% and the calorific value is 20.15 mJ/Kg. The maximum thickness of coal seam is 7.30m and the minimum thickness is 3.90M with the average value of 5.10m. The dip angle of coal seam in the south 906 working face is 4.3°. The coal seam contains the multi-layer of stone, the maximum thickness is 1.0m and the average thickness is 0.40m. The layer spacing of overlying 7# coal seam is 25.5m and the south 706 working face has been mined. The roof of 9# coal seam is composed of false roof (mudstone, sandy mudstone), direct roof (siltstone, silty mudstone) and old roof (coarse sandstone). The direct floor is made up of silty sandstone and fine sandstone. The tight roof floor causes the gas which is difficult to be leaked out during the formation of the coal seam, and the gas accumulates in a certain pressure in the coal seam. The mining technology of the south 906 working face is blasting mining, using the “U” type ventilation and the design of face air distribution is 700m³/min. According to the drilling and the visual scene, there are volcanic intrusions in the air intake roadway, air return roadway and open cut off. So the coal seam is partly metamorphosed and thinned, the gas concentration in the working face may increase, which will have an effect on the recovery. On the basis of the measured gas basic parameters, it is concluded that the prediction result of relative gas emission quantity is 8.89m³/t and the absolute gas emission is 25m³/min. In the mining process of working face, abnormal gas emission caused the gas concentration in the air return corner exceeded the critical
value. In addition, 9# coal seam has the characteristics of oxidation at low temperature; belong to a spontaneous combustion coal seam with the spontaneous combustion period of 3 to 6 months. The coal dust explosion index is 44.06%.

**Physical Geometrical Model**

In order to achieve the purpose of this study, we made site inspection in the south 906 working face and collected basic geometrical parameters which can describe the shape of the gob. Simultaneously, we made several simplifications as follows:

1. The gob was treated as an isotropic porous medium region because that it consisted of stochastic caving gangue and residual coal.
2. As the dip angle of the south 906 working face was 4.3°, belonging to relatively gently inclined coal seam, we simplified it as flat seam.
3. For the modeling of the gob, the distribution of porosity and permeability has the characteristic of “O” style carving and compaction, and the porosity and permeability are the largest behind the working face and smallest at the middle of the gob [34]. We treated the working face, air intake roadway, air return roadway and gob as cuboids and divided the gob into five porous medium regions.
4. Four different gas drainage methods were simplified into corresponding single-hole drainage models. Figure 2 depicted the physical model of the gob.

The gob was divided into five porous medium regions which are all axisymmetric in the advancing direction. The viscous drag coefficient of each region was 0.48×10⁻⁶, 1×10⁻⁶, 1.5×10⁻⁶, 2.81×10⁻⁶ and 6.27×10⁻⁶, respectively, from outside to inside of the gob. The inertia drag coefficient of the whole gob was 2.2×10⁻⁵. Porosity is a parameter that features the loose degree of the fractured rock in the caving zone. The porosity of the presupposed five medium regions decreased gradually with the location in the gob deepening. Besides, the float coal in the gob released gas all the time. So, we set the gas emission rate in each region as shown in Figure 2. The unit of gas emission was ×10⁻⁶ kg/(m³-s). Single-hole drainage model simplified the whole drainage system as one negative pressure drainage.
hole. The location of the negative pressure point in HDHE was (10, 15, 22). Those simplified in the rest three models, BPE, ARE and TRE, were (15, 0.5, 3), (30, 1, 3) and (70, 1, 3) respectively.

Mathematical Model

The degrees of compaction of the residual coal and caving gangue in the gob are significantly different, thus, the speed and the airflow pattern vary at different places of the gob. The nonlinear seepage model proposed by Bachmat is popular in studying the air leakage flow field [35]. The control equation system should also add a continuous equation and diffuse seepage equation reflecting the change in gas regulation in the simulation process.

1) Gas Flow Equation

The stationary Navier-Stokes equations describe the air flow in the free-flow regions, such as the air intake roadway, air return roadway and the working face:

$$\nabla \cdot [-\eta(\nabla u + (\nabla u)^T) + pI] = -\rho(u \cdot \nabla)u$$

$$\nabla \cdot u = 0$$  \hspace{1cm} (1)

In the aforementioned five porous regions, use the Brinkman equations:

$$\nabla \cdot [-\frac{\eta}{\varepsilon_p}(\nabla u + (\nabla u)^T) + pI] = -\frac{\eta}{k}u$$

$$\nabla \cdot u = 0$$  \hspace{1cm} (2)

In the above equations, $\eta$ denotes the viscosity of the fluid (N-s/m²), $\varepsilon_p$ is the porosity (dimensionless), $u$ is the velocity (m/s), $\rho$ is the density (kg/m³), $p$ is the pressure (Pa), and $k$ is the permeability (m²).

2) Convection-diffusion Equation

In the porous regions, there was methane gas sending out continuously. At the same time, oxygen can be consumed when it touches the float coal in the gob. In the intake air flow, there was almost no methane. Instead, there existed a high methane concentration in the drainage pipes and a obvious existence evidence in the air return roadway. So, the convection-diffusion equation in the gob is:

$$\nabla \cdot (-D_i\nabla c_i + c_i u) = R_i$$  \hspace{1cm} (3)

In this equation, $c_i$ denotes the concentration (mol/m³), $D_i$ is the diffusivity (m²/s), and $R_i$ is the reaction rate for oxygen or methane (mol/(m³·s)). Because the change of concentration takes place in the porous regions only, the reaction term is zero in the free-flow regions. Besides, the gas emission in gob accounted for the $R_i$ of methane:

$$R_m = R_e / M_m$$  \hspace{1cm} (4)

where $R_m$ and $R_e$ denote the reaction rate (emission rate) of methane in the point of mole and mass
respectively (mol/(m$^3$·s) and kg/(m$^3$·s)), and $M_w$ is 16 kg/mol.

3) Boundary Conditions

A constant velocity profile and oxygen concentration is assumed at the inlet boundaries. At the outlet, assume that convection dominates the mass transport:

$$n \cdot (-D_D \nabla c_i + c_i u) = n \cdot c_i u$$

(5)

Besides, the boundary condition for the Navier-Stokes equations at the outlet reads

$$t \cdot u = 0$$

$$p = 0$$

(6)

Finally, at all other boundaries, insulating conditions apply:

$$n \cdot (-D_D \nabla c_i + c_i u) = 0$$

(7)

Based on all above mathematical model, we used the CFD module of the program FLUENT (version 6.3) to solve model the air flow. FLUENT is a general finite-volume code that can be used to model a wide range of fluid flow problems. The control-volume-based technique was used to solve aforementioned equations (1)-(7).

Simulation Results and Analysis

Simulation Results and Analysis of Gas Concentration Distribution

Firstly, we got the gas concentration distribution in gob without gas drainage (Figure 3(a)-(d)). In order to intuitively analyze stereo distribution conditions, we made stereo scan from the middle of working face into deep of gob, shown as the direction marked in Figure 3(a). Besides, in order to compare gas concentration distribution before starting gas drainage with that after applying certain method, we made another scan on the YZ-plane under four different drainage methods. The specific positions in X-axis direction of HDHE, BPE, ARE and TRE were 10 meters, 15 meters, 30 meters and 70 meters respectively, just right consistent with those locations of simplified drilling holes.

The simulation results without drainage show that the gas concentration increases with the depth of gob rising and keeps stable after arriving the certain depth. The change of gas concentration can be divided into three stages. Firstly, from the working face to 60 meters inside the gob, the concentration not only slowly increases, but also keeps usually small, being generally smaller than 5%. Then, during the period of 60 meters to 160 meters away from the working face, the speed of increase obviously accelerates, transferring to 85% quickly. At last, when the distance extending into the gob reaches beyond 160 meters, the gas concentration changes slightly and keeps stable finally. The deep area of gob was basically in the compaction sate because of the subsidence of caving rock, where gas accumulated easily and the highest concentration was higher than 90%.

In Y-axis direction, Figure 3(a)-(d) show that gas concentration gradually increases from the air intake side to the return side. When the distance is no more than 150 meters from the air intake side, gas concentration is quite small and shows unobvious increasing trend, fluctuating below 0.1% basically. However, the increasing range becomes remarkable when close to the air return side, with the gas concentration reaches about 6% in air return corner. This
phenomenon can be explained as follows: Near the working face, the rocks exist in natural state and accumulate loosely, with no compaction and high porosity. Then air leakage makes a great influence on the gas concentration distribution as it leads gas moves with wind from the air intake side to the return side. As a result, the gas concentration gradually increases in the direction of air flow and gas obviously accumulates in the return side. In addition, the concentration change existing in the return side of deep gob is very slight, because the air leakage in deep gob becomes quite weak.

The next step was to bring gas drainage into the existing geometrical model. After conducting virtual gas drainage, another simulation results are shown as Figure 3(e)-(h). Comparing Figure 3(e)-(h) with Figure 3(a)-(d), it is obvious that the second scan planes become colorful under the same scan positions, instead of low concentration color basically. That means gas concentrations around the simplified drilling holes have increased after starting gas drainage. In the air return corner (marked as the red circle in Figure 3(a)), the gas concentration has changed dramatically under all these drainage methods, turning into 0.7%, 0.50%, 0.60% and 0.74% respectively. Therefore, in the opinion of gas control, all four methods can effectively solve the problem of gas concentration exceeding the certain limit.

To make concrete analysis on the change of gas concentration in gob, Figure 3(a) and Figure 3(e) were then picked out as an example. The results of comparing are shown as follows. In X-axis direction, high concentration gas in gob accesses to the high drilling hole whose simplified location in X-axis was 10 meters. Besides, in the Y-axis direction in YZ-plane at the drilling hole, gas concentration increases firstly and drops then, with the maximum appearing at the surrounding area of drilling hole which is 15 meters away from the air return roadway. In addition, high concentration gas in the air return corner has transported towards the certain YZ-plane, 10 meters extending into the gob. This change results in significant concentration decrease in the air return corner, solving gas problem efficaciously. Analogical contrastive analysis can be also carried out with remaining figures and similar conclusions will be drawn.

Simulation Results and Analysis of ‘Three Zones’ of Spontaneous Combustion

After making investigation on gas concentration distribution, numerical simulation method was continually used to study the distribution of ‘three zones’ of spontaneous combustion in gob under different gas drainage methods. Current researches have provided three indicators for dividing the ‘three zones’ of spontaneous combustion in gob, that is, speed of air leakage, oxygen concentration and the temperature [36, 37]. This paper divided the ‘three
zones’ according to the speed of air leakage, shown in Table 1.

**TABLE 1 DIVIDING STANDARD FOR 'THREE ZONES' OF SPONTANEOUS COMBUSTION**

<table>
<thead>
<tr>
<th>Zone name</th>
<th>Speed of air leakage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling zone</td>
<td>$v &gt; 0.004 \text{m/s}$</td>
</tr>
<tr>
<td>Combustion zone</td>
<td>$0.0016 \text{m/s} \leq v \leq 0.004 \text{m/s}$</td>
</tr>
<tr>
<td>Asphyxia zone</td>
<td>$v &lt; 0.0016 \text{m/s}$</td>
</tr>
</tbody>
</table>

The first step of this simulation period was making a contrast sample which was set before applying any gas drainage method. The simulation result is shown in Figure 4(a).

In Figure 4(a), it can be seen that the air return side of gob earlier enters combustion zone than the intake side. Besides, the width of combustion zone along the return side is slightly wider than that of intake side. The aforesaid phenomenon accords with the law of air leakage in gob that existing in ‘a source and a sink’ working face. In other words, the air leakage in the air intake side is more serious than the one of return side in gob.

Then, the following step was to forecast the ‘three zones’ of spontaneous combustion with applying different drainage methods. The results are showed in Figure 4(b)-(e). Comparing Figure 4(b)-(e) with Figure 4(a), it can be seen that the four different drainage methods all expand the area of combustion zone in gob and lead it to extend into the deep of gob. The main reason was that air in gob flowed toward the drainage holes, certainly raising the sphere of influence of air leakage. The zone expansion took place obviously when we used BPE (Figure 4(c)), ARE (Figure 4(d)) and TRE (Figure 4(e)) while HDHE (Figure 4(b)) caused a relatively smaller influence as the drainage holes drilled in the former three methods were deeper in gob than that of HDHE. Specific changes are shown in Table 2.

**TABLE 2 CHANGE OF AREA OF COMBUSTION ZONE AFTER APPLYING DIFFERENT GAS DRAINAGE METHODS**

<table>
<thead>
<tr>
<th>Gas drainage state</th>
<th>Area of combustion zone /m²</th>
<th>Change rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without gas drainage</td>
<td>10752</td>
<td>----</td>
</tr>
<tr>
<td>Applying certain gas drainage method</td>
<td>HDHE 11905</td>
<td>1.11</td>
</tr>
<tr>
<td></td>
<td>BPE 13967</td>
<td>1.30</td>
</tr>
<tr>
<td></td>
<td>ARE 17294</td>
<td>1.61</td>
</tr>
<tr>
<td></td>
<td>TRE 22483</td>
<td>2.10</td>
</tr>
</tbody>
</table>
When carrying out TRE, the air leakage flowed through the whole gob, making the influence of air leakage more serious and enlarging the area of combustion zone significantly. In contrast, HDHE located drilling holes in the fractured zone of gob, away from the floor of working face. Then the impacts of drainage negative pressure focused on the surrounding areas of fractured zone. Therefore, it was concluded that the method of HDHE had a relatively smaller influence on the air leakage in the bottom of gob which would be beneficial for preventing spontaneous combustion.

**Application and Effects**

According to the above analytical results of simulation, we decided to apply HDHE in the actual the south 906 working face and made a check on the simulation results. The detailed design and drainage effects are described as follows.

**Design of High Drill Holes Drainage**

Five high level drilling fields were built along the air return roadway of the south 906 working face. The central pumping station was used to extract the gob and the coal seam gas, and the distance between drilling field was 50m~70m. The layout plan of drilling fields was shown in Figure 5. The 1# drilling field was at a distance of 75 meters from the open-off cut, the spacing between 1#, 2#, 3#, 4# drilling fields was 70 meters. The last drilling field, 5# drilling fields, was 50 meters away from 4# and 70 meters to the stopping line.

As shown in Figure 6, 6 high position boreholes are arranged like a fan in each high drilling field, amounting to forty. Besides the control area of the later drilling field covered the former one, overlapping 30 meters. The area with horizontal distance of 30m from the air return roadway can be extracted by the boreholes. The distance between the end of boreholes and the roof of coal seam is 15~30m, the diameter of drilling hole is 113mm and the total amount of drilling is 3000m. The parameters of gas drainage borehole layout include aperture, azimuth, inclination and length. The selection of drilling parameters is mainly based on the gas source, gas distribution in the gob, the position of the fracture zone of the roof of the gob, the pressure of the stope and the condition of the roof. The construction parameters of boreholes in 1# and 2# drilling fields are shown in Table 3. Two domestic drilling rigs (SGZ-type A) with drilling technology were applied to the engineering. The drill diameter 94mm and reaming diameter is phi 133mm. The drill pipe diameter 50mm and each pipe length is 2m.
Table 3 Parameters of drilling holes in #1 drilling field

<table>
<thead>
<tr>
<th>Drilling field</th>
<th>Drilling hole</th>
<th>Azimuth angle (°)</th>
<th>Dip angle (°)</th>
<th>Hole depth (m)</th>
<th>Projection in working face (m)</th>
<th>Vertical height (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1#</td>
<td>18</td>
<td>19.6</td>
<td>70</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>2#</td>
<td>27</td>
<td>18.9</td>
<td>73</td>
<td>30</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>3#</td>
<td>40</td>
<td>16.8</td>
<td>83</td>
<td>50</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>4#</td>
<td>50</td>
<td>14.5</td>
<td>97</td>
<td>70</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>5#</td>
<td>56</td>
<td>12.6</td>
<td>112</td>
<td>90</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>6#</td>
<td>59</td>
<td>11.8</td>
<td>120</td>
<td>100</td>
<td>25</td>
</tr>
<tr>
<td>2</td>
<td>1#</td>
<td>21</td>
<td>13.0</td>
<td>109</td>
<td>35</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>2#</td>
<td>28</td>
<td>12.3</td>
<td>115</td>
<td>50</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>3#</td>
<td>33</td>
<td>11.6</td>
<td>122</td>
<td>60</td>
<td>25</td>
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<tr>
<td></td>
<td>4#</td>
<td>42</td>
<td>11.0</td>
<td>130</td>
<td>80</td>
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<td></td>
<td>5#</td>
<td>49</td>
<td>10.0</td>
<td>144</td>
<td>100</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>6#</td>
<td>55</td>
<td>9.0</td>
<td>158</td>
<td>120</td>
<td>25</td>
</tr>
</tbody>
</table>

Note: (1) Azimuth angle is the counterclockwise direction angle between drilling hole and air return roadway; (2) Vertical height is refers to the projection distance from the end of the borehole to the coal seam floor.

Analysis of Drainage Effects

In order to analyze the gas drainage effects, we selected the daily monitoring data of #1 drilling field from April, 2013, the change trend of gas concentration and amount of drainage were showed in Figure 7.

In Figure 7, it can be seen that gas concentration and amount of drainage fluctuate with time, with the average mixing flow running up to 29.44 m³/min, the concentration reaching 19.48% and pure gas flow increasing significantly to 5.77m³/min. The accumulated data indicated that the pure gas flow of #1 drilling field in April was 240839 m³, occupying near 38.48% of gas emission. During this period, the gas concentration in the air return corner had never exceeded 0.70%, achieving the expectant targets of gas drainage, as shown in Figure 8.

In addition, as the index-gas of the spontaneous combustion of coal (Juha et al., 2012; Lu et al., 2004), CO is an important reference that is significant for the early prediction of spontaneous combustion of coal in gob. And the specific data of CO concentration of #1, #2, #3, #4, #5 and #6 drainage holes are showed in Figure 9.
FIG. 7 CHANGE TREND OF GAS CONCENTRATION AND AMOUNT OF DRAINAGE

FIG. 8 GAS CONCENTRATION IN THE AIR RETURN CORNER

FIG. 9 CHANGES OF CO CONCENTRATION WITH TIME IN 1#, 2#, 3#, 4#, 5# AND 6# DRAINAGE HOLES
Besides, Figure 9 shows that during the period of 1#-6# drilling, the CO concentration has been stable below 24ppm, and the average values are 16.57ppm, 17.75ppm, 14.43ppm, 13.19ppm, 13.26ppm, 12.96ppm, and there is no sign of coal spontaneous combustion in gob. Thus, all these monitoring data agree with our simulation results as mentioned earlier in this paper.

Conclusions

The schematic of control technology for the coexistence was proposed. The physical geometrical model was established according to the actual parameters after simplifying from the south 906 working face of Dalong Coal mine. The mathematical model was deduced on the Navier-Stokes equations and Brinkman equations.

Comparing the simulation results without gas drainage and those after applying different drainage methods (HDHE, BPE, ARE and TRE), we can draw conclusions in two aspects as follows. In one aspect, all these four methods can effectively solve the problem of gas concentration exceeding the certain limit. Gas concentration in the air return corner has changed dramatically, turning from 6% into 0.7%, 0.50%, 0.60% and 0.74% respectively. In another aspect, all these four methods expanded the area of combustion zone in gob, with 1.11, 1.30, 1.61 and 2.10 times respectively. HDHE has the minimal influence under the same gas drainage volume.

In order to confirm the simulation results, five high level drilling fields were built along the air return roadway of the south 906 working face, designing according to HDHE. Monitoring data in the drainage pipes illustrated that average mixing flow ran up to 29.44 m³/min, the gas concentration reached 19.48% and pure gas flow increased significantly to 5.77 m³/min, with CO concentration always keeping lower than 0.0024%. The gas drained out occupied near 38.48% of total gas emission. During the whole drainage period, gas concentration in the air return corner had never exceeded the certain limit, maintaining no more than 0.70%. All these accorded with the simulation results.

The study provides significant references for managing the gob where exists symbiosis disaster of gas explosion and spontaneous combustion of coal.

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