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# Research and application of drainage parameters for gas accumulation zone in overlying strata of goaf area ☆

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ABSTRACT

While coal seam is being mined, an annular fissure circle with gas accumulation will be formed in the fissure zone as a result of desorption, dissipation and permeation of gas in the goaf area and overlying strata due to fissures from rock caving and mitigation in the roof. The methods for computation of spatial locations of the fissure circle are researched in this paper. Based on these methods, gas drainage technique for the fissure zone is optimized. By applying drill hole returning water method of variables, the height of caving zone that most affects the drainage effects of inclined high dip drill hole was measured on the site. Due to the consistency of the expected height with the computed height of caving lines at different positions, the correctness of the theoretical computation method is further validated. Meanwhile, the parameters of the inclined high dip drill hole at #3311 working face of Hexi Coal Mine are determined by a case study.



## 1. Introduction

Overlying strata in goaf area is also known as the strata adjoining the mined coal seam. As the coal of the mined seam is recovered, the rock strata on the roof undergo a cyclic process of stress release subsidence, breakage and caving along with advancing of the working face. While the roof is deformed, the gas in the goaf area and overlying strata will experience desorption, dissipation, permeation and accumulation. Eventually, a zone in the overlying strata of goaf area comes into being, where gas is relatively concentrated, gas concentration is considerably high and gas easily flows (Zhang et al., 2007). Study of the mitigation law of the overlying strata of goaf area and the permeation mechanism of the gas above the goaf area is of paramount guiding significance to control of gas emission in the goaf area, gas drainage in adjoining seam and assuring mine shaft safety, which attracts considerable concerns among the domestic and overseas scholars. By summarizing the research outcomes at home and abroad, it is found that the predecessors largely concentrated their research on the determination of vertical "three zones" positions (Liu and Yuan, 2004; Liu, 2009; Sun et al., 2011), the characteristics of gas emission in the goaf area and the optimization of gas drainage technique (Li et al., 2004; Gong, 2004; Wei et al., 2009; Wendt and Balusu, 2002), however, further research is needed for the theoretical computation method for determination of the drainage drill hole parameters by applying the spatial location parameters of annular fissure circle.

## 2. Formation of gas accumulation zone in the overlying strata of goaf area

### 2.1. Law of mitigation of the overlying strata of goaf area

According to the extent of the deformation damage, stress status and fissure scale of the overlying strata and differences of the sustaining status and re-compaction degree of the damaged strata, the overlying strata is vertically divided into "three zones": caving zone, fissure zone and bent deformation zone; and on the plane into longitudinal "three zones" and transverse "three zones": compression zone, separation zone and sustaining affect zone, as shown in Fig. 1.

Within the caving zone, the immediate roof undergoes deformation, separation, breakage and caving. The caved rock then undergoes sustaining by supports, loosely piling up, compression and compaction. As a result, there are a lot of pores among the rock

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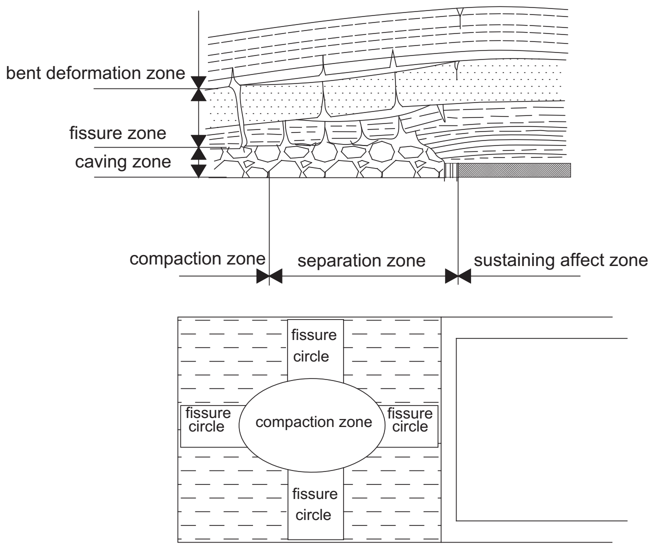


**Fig. 1.** Schematic of annular fissure circle in goaf area and overlying strata.

blocks in the caving zone (goaf area) that have good connectivity. They are the places where gas emits or concentrates. The maximal height of the caving zone is computed by the following formula:

$$a = \frac{h}{(K_p - 1)\cos\alpha} \tag{1}$$

where $a$ is the height of caving zone, m; $h$ the mining height of coal seam, m; $K_p$ the bulking coefficient of the caved rock; $\alpha$ the dip angle of coal seam, (°).

Within the fissure zone, there exist fissure channels that connect the caving zone with deformation zone in the goaf area. The strata fissures in main roof also undergo a process of development, adequate development and compaction. Separation zone is the zone where fissure zone is most developed. Fissures increase strata permeability, produce channels for gas accumulation and emission, so the middle and lower part of the separation zone in fissure zone is the best position at which adjoining seam gas drainage drill hole are arranged to cut gas emission to the working face. When drill hole is arranged in tail roadway to drain the gas in adjoining seam, the best drainage results will be achieved at the very beginning of separation and fissure zone formation and before completion of subsidence and compaction. That is to say, the best drainage is achieved if drainage drill hole is made in a certain distance in front of or behind the working face.

Fissure zone height means the distance from the coal seam roof to the upper of fissure zone. Generally for mildly hard roof to the upper of fissure zone, the maximal height is computed by the following formula:

$$b = \frac{100h}{1.6h + 3.6} \pm 5.6 \tag{2}$$

$$\text{or} \quad b = 20\sqrt{h} + 10 \tag{3}$$

where $b$ is the maximal height of fissure zone, m; $h$ the mined height of coal seam, m.

Bent zone is also known as entire mitigation zone or bent subsidence zone. It refers to the strata ranging from the fissure zone top to the surface, generally exerting slight influence on the gas drainage in adjoining seam.

### *2.2. Formation of annular fissure circle with large concentration and fissure*

As the working face advances, and vertical "three zones", longitudinal "three zones" and transverse "three zones" intersect and mitigate in space, the caving zone rocks in the middle of goaf area and the separation fissures in fissure zone will be compacted once again due to overlying strata mitigation, and an annular fissure circle with high gas concentration is formed around the goaf area (Li, 2000; Liu and Yuan, 2004), which is indicated by the shadow area in Fig. 1.

While the working face is being advanced continuously, because of stress release and compaction, the pores and fissures in the overlying strata undergo a process of minimum to maximum and then relatively small sizes; longitudinal "three zones" keep alternate to mitigate forward, the width of re-compaction zone increases continually, while the width of separation zone basically keeps unchanged after circular weighting just like periodical weighting distance, and furthermore is related to periodical weighting distance. At the caving zone height, the sum of the line segment parallel to coal seam roof between caving line and stress release line and the periodical weighting distance is the lower width of fissure zone's separation zone, while at the fissure zone height, the sum of the line segment parallel to coal seam roof between caving line and stress release line and the periodical weighting distance is the upper width of fissure zone's separation zone. For the width of the horizontal "three zones", its value is steadily unchanged because the coal walls of the roadway on both sides of working face coal body are fixed. Relatively stable caving arc and stress release arc are formed, which goes upward along coal walls and inclines toward the direction of goaf area. The width of transverse and longitudinal separation zone in subhorizontal coal seam can be considered identical approximately. According to the above analysis and combining Figs. 1 and 2, the scope of each separation zone is determined as follows:

$$l_1 = \frac{a}{\tan\gamma} \tag{4}$$

$$c_1 = \frac{a}{\tan\beta} - \frac{a}{\tan\gamma} + l \tag{5}$$

$$l_2 = \frac{b}{\tan\gamma} \tag{6}$$

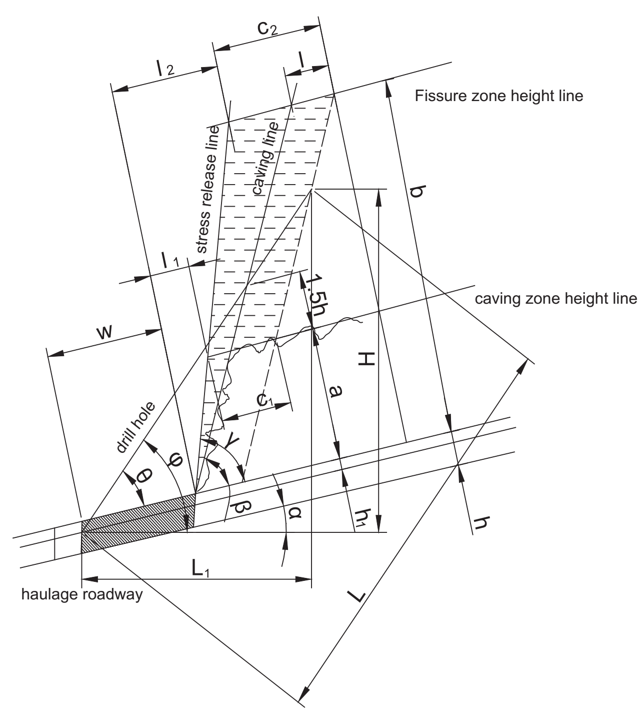


**Fig. 2.** Diagram of high dip drill hole arrangement principle and parameters computation.

$$c_2 = \frac{b}{\tan\beta} - \frac{b}{\tan\gamma} + l \quad (7)$$

where $l_1$ and $c_1$ represent the inclination distance and width of the lower part of separation zone at the maximal height of transverse or longitudinal caving zone respectively. The inclination distance of the lower part of separation zone is the distance from the intersection between caving height line and stress release line to the coal wall tip, perpendicular to coal seam inclination line, and the width of the lower part of separation zone is the width of the separation zone close to the coal wall point of the working face and away from the coal wall point, parallel to the coal seam inclination plane, m; $l_2$ and $c_2$ represent the inclination distance and width of the upper part of separation zone at the maximal height of transverse or longitudinal fissure zone respectively, m; $\beta$ is caving angle, (°); $\gamma$ is stress release angle, (°); $l$ is periodical weighting distance, m.

Within the annular fissure circle formed around goaf area after coal seam was mined, fissures and permeability not only increase twofold compared with original stratum, but are larger than compaction zone, so they provide channels and spaces for gas desorption, dissipation, permeation and accumulation in overlying strata, and meanwhile they are main regions where drill hole is arranged for gas drainage in adjoining seam. In particular, the fissure circle near the upper of the intersection of working face and return roadway is the main region for gas drainage in adjoining seam (gas drainage in fissure zone). Therefore, the parameters of gas drainage in adjoining seam will be determined according to the spatial location parameters of annular fissure circle in this paper.

## 3. Parameters of gas drainage drill hole in adjoining seam

Within the annular fissure circle, the gas especially at the upper corner fissure circle of working face – due to the pressure difference between the fissure channels and roadways, will release and dissipate to the working face, which increases gas emission there, and makes gas concentration at the upper corner exceed the limit. To drain the gas in the fissure circle of adjoining seam, main methods include inclined drill hole on the return roadway (inclined high dip drill hole), excavation of inclined roadway (inclined high dip roadway) parallel to the working face in the return roadway, and excavation of dedicated strike roadway (strike high dip roadway) within the upper fissure circle on the return roadway that is submerged into the fissure circle to drain the stress release gas in it. What Hexi Coal Mine adopts is inclined high dip drill hole to drain the gas in fissure zone. According to the location of gas fissure circle and gas seepage principle, in order to improve drainage effects and prevent drill hole being damaged or gas drainage failure or excessive air drainage due to improper drill hole arrangement, the design and arrangement of drainage drill hole shall be made according to the following principle:

(1) Reasonable drainage drill hole shall make the resistance met by the gas in the fissure circle of upper corner emitting to goaf area larger than that flowing to the drill hole, so as to cut off or diminish gas leakage in the fissure circle to the goaf area. Therefore, the position of drainage drill hole into separation zone shall not be too high, and shall be located on the middle or lower part of the fissure zone.

(2) In order to avoid high dip drill hole being damaged due to excessive strata deformation or caving, the position of the high dip drill hole shall not be too low. According to numerous practices, generally the intersection point between high dip drill hole and caving line shall be located 1.5 times the mining height above the caving zone height line. If this condition is met, then according to Fig. 2, the included angle between inclined high dip drill hole and the level shall be:

$$\theta = \arctan\frac{1.5h + a + h_1}{w + (1.5h + a)\cot\beta + h_1\tan\alpha} \quad (8)$$

$$\varphi = \theta \pm \alpha = \arctan\frac{1.5h + a + h_1}{w + (1.5h + a)\cot\beta + h_1\tan\alpha} \pm \alpha \quad (9)$$

where $\varphi$ is the inclined angle of high dip drill hole, (°); $\theta$ the included angle between the drill hole and coal seam tendency, (°); $w$ the width of coal pillar along inclination face, m; $h_1$ the height of drill hole opening to the coal seam roof, m. The other symbols are same as above.

(3) In order to drain more gas, after the drill hole exits caving line, it shall at least enter into the boundary between the separation zone and compaction zone of fissure zone or the center of separation zone. Then, the minimal drill hole length is:

$$L = \frac{(1.5h + a + h_1)(w + l - h_1\cot\beta + h_1\tan\alpha)}{(w - h_1\cot\beta + h_1\tan\alpha)\sin\theta} \quad (10)$$

where $L$ minimal drill hole length, m. The other symbols are same as above.

(4) The vertical height and horizontal distance between drill hole stoppage and opening are as follows:

$$H = L\sin\varphi \quad (11)$$

$$L_1 = L\cos\varphi \quad (12)$$

where $H$ is the vertical height between drill hole stoppage and opening, m; $L_1$ is the horizontal distance between drill hole stoppage and opening, m. The other symbols are same as above.

## 4. Comparison between caving zone and fissure zone in site measurement

In May–July 2009, site measurement was conducted in Hexi Coal Mine for the caving zone height, which most affects the drainage results of inclined high dip drill hole, by applying drill hole returning water method of variables.

According to the above requirements, when coal seam thickness (mining height), coal seam dip angle, drill hole opening height, drill hole dip angle, strata caving angle and coal pillar width are known, the following computation formulas for the included angle between drill hole and coal seam slope, the height of the upper contour point of caving zone (expected height $a$), the length of drill hole entering goaf area (expected length $L$) and the inclination length of drill hole entering goaf area can be derived according to formulas (8)–(10):

$$\theta = \varphi - \alpha \quad (13)$$

$$a = \arctan\frac{w\tan\theta + h_1\tan\alpha\tan\theta - h_1}{1 - \cot\beta\tan\theta} \quad (14)$$

$$L = \frac{a + h_1}{\sin\theta} \quad (15)$$

$$L' = L\cos\theta - w \quad (16)$$

where $L'$ is the length of drill hole entering mining area and along the inclination direction of coal seam, m. The other symbols are same as above.

The observation site of caving zone is #3309 goaf area. The construction site of drill hole is located on the tail roadway of #3309 working face. Prior to construction of observation drill hole, #3309 working face parameters are theoretically analyzed at first. The, according to formulas (13)–(16), the construction parameters of drill hole are determined. Expected height and length of drill hole are computed at caving angle 45°, average dip angle of coal

**Table 1**
Construction and design of observation drill hole at caving zone height.

| Hole no. | Azimuth (°) | Opening height $h \sim h_1$ (m) | Drill hole dip angle $\varphi$ (°) | Expected $a$ (m) | Expected $L$ (m) | Measured $L$ (m) | Actual $a'$ (m) | Inclination length $L'$ (m) | Water return |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Perpendicular to coal wall | 1.2 | 5.5 | 0.01 | 30.09 | 31.5 | 0.04 | 1.49 | Water stopped |
| 2 | Perpendicular to coal wall | 1.2 | 7 | 0.84 | 30.98 | 30 | 0.79 | −0.04 | Water stopped |
| 3 | Perpendicular to coal wall | 1.2 | 8 | 1.42 | 31.61 | 33 | 1.52 | 2.92 | Water stopped |
| 4 | Perpendicular to coal wall | 1.2 | 12 | 4.02 | 34.53 | 35 | 4.09 | 4.66 | Water stopped |
| 5 | Perpendicular to coal wall | 1.2 | 15 | 6.32 | 37.21 | 36.5 | 6.18 | 5.83 | Water reduction |
| 6 | Perpendicular to coal wall | 1.2 | 23 | 14.73 | 47.67 | 37 | 11.26 | 4.99 | Water reduction |

**Table 2**
Parameters of annular fissure circle's position.

| Caving zone height (m) | Fissure zone height (m) | Inclination distance of separation zone lower part (m) | Inclination width of separation zone lower part (m) | Inclination distance of separation zone upper part (m) | Inclination width of separation zone upper part (m) |
|---|---|---|---|---|---|
| 5.06 | 18.36 | 0.99 | 16.35 | 18.58 | 29.79 |

**Table 3**
Optimal process parameters of inclined high dip drill hole.

| Drill hole dip angle (m) | Drill hole length (m) | Height of drill hole stoppage (m) | Horizontal length (m) | Drill hole spacing (m) |
|---|---|---|---|---|
| 16.80 | 60.21 | 18.64 | 57.64 | 15 |

seam 4°, average mining height 1.98 m and coal pillar thickness 30 m, used to guide drill hole construction and observation. And then, construction is made according to the opening height and dip angle of drill hole to observe water return. The designed drill hole construction parameters and actual drill hole length when reduction or stopping of drill hole water returning is observed are shown in Table 1.

It can be seen from Table 1 that, the expected height of caving line at different positions is in full agreement with the measured and computed height. This proves the correctness of the theoretical computation method.

## 5. Case studies

### 5.1. Parameters of the annular fissure circle on #3 coal seam roof of Hexi Coal Mine

Take Hexi Coal Mine for example. The coal seam mined in this working face is #3 combined coal seam. The values for #3 coal seam of Hexi Coal Mine are: coal seam thickness 1.98 m, seam dip angle 4°, caving angle 67°, stress release angle 79°, periodical weighting distance 15 m, coal pillar width 30 m, and the height from drill hole opening to coal seam floor 1.2 m. The parameters of the annular fissure circle in the overlying strata of #3 + 4 coal seam, calculated according to formulas (1)–(7), are listed in Table 2. And the caving zone height and fissure zone height are the average value computed according to each formula.

### 5.2. Parameters of inclined high dip drill hole in Hexi Coal Mine

Through simulation computation according to Table 2 and formulas (8)–(12), the optimal process parameters of the inclined high dip drill hole for the tail roadway of #3311 working face are shown in Table 3.

According to the above analysis, the fissures within the fissure circle before and after working face weighting undergo a process of development, full development and compaction. Therefore, the fissures within the annular circle in two periodical distances before and after two weightings are the largest. Hence, the maximal drill hole distance can be considered as periodical weighting distance. Generally the distance shall be slightly smaller than periodical weighting distance. Even before the previous drill hole fails, the next drill hole can begin to drain gas, so as to control gas emission to goaf area.

## 6. Conclusions

According to the investigations on the actual construction parameters of high dip drill hole in #3311 working face tail roadway of Hexi Coal Mine and the actual drainage effects of inclined high dip drill hole, and through simulation computation, the following conclusions are reached:

i. While the drill hole angle is guaranteed, we shall manage to increase drill hole length and stoppage height and decrease hole spacing so as to drain the gas in a larger stratum in addition to fissure circle.
ii. When coal seam thickness (mining height) is definite, the intersection point between high dip drill hole and caving line is located 1.5 times mining height above the caving zone height line, if the caving angle is changed, the minimal drill hole length and minimal stoppage height change slightly with the caving angle, but when the caving zone height changes, drill hole parameters change obviously.
iii. Drill hole dip angle, caving zone height and periodical weighting distance are three major factors that affect the drainage effects of inclined high dip drill hole. Excessively large dip angle will deviate from fissure zone and lead to small drainage amount, or even fails to drain gas. Too small angle will lead to drill hole being or even penetrating across goaf area, and too low gas concentration, as a result of which drainage fails. Therefore, during drilling, the drill hole dip angle shall be strictly controlled. When coal seam dip angle changes, the drill hole dip angle shall be adjusted in a timely manner. According to the above formulas, the drill hole dip angle is mainly determined by the caving zone height.

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