Mining Influence Law’s Application in Coal Bed Gas Extraction Engineering

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Abstract. Aimed at further improve the efficiency of coal bed gas extraction, the coal bed gas extraction technology and temporal & spatial law of mining influence are elaborated in this paper. The characteristics of ground movement and deformation, the failure zones in overburden strata, the heights of caving zone and fracture zone in overburden strata, and failure scope in underlying strata are analyzed. According to coal bed gas extraction technology, the requirements of ground movement, deformation, and failure degree are ensured. Based on the laws of coal mining influence and failure in surrounding rock, the principle of coal bed gas extraction engineering design is put forward. It has certain reference value.

Keywords: Mining influence; Caving zone; Fracture zone; Temporal and spatial law; Overburden strata; Coal bed gas extraction; Surface drill well; High roadway; Protective seam mining.

1. Overview

1.1. Coal Bed Gas Extraction Technology
First of all, coal bed gas extraction can eliminate major gas accidents and ensures the safe production in coal mines, and turns high gas and high dangerous outburst coal seam to low gas and low dangerous outburst coal seam; secondly, it solves the difficult problem only by mine ventilation, and reduces the ventilation cost in mine, so that the work surface wind flow (intake wind, return wind, upper angle, tail roadway) gas concentration is not limited; finally, it is the use of valuable coal bed gas as an efficient clean energy source.

Based on the succession of coal development, the coal mine area is divided into three areas: planning area, preparation area and production area. Planning areas generally refer to areas where mining activities can only be involved after 6 years or more, which have no coal mining influence at all, where coal bed gas in situ are pre-pumped by method of ground development. Preparation area refers to areas that will be excavated within 3 to 6 years, in which there are no mining faces but there is roadway excavation, and the mining influence is very small, where coal bed gas extraction is taken by the ground method or ground combined underground method. Production area refers to areas that will be mining within 3 years, which is greatly affected by mining. It is the key area to carry out the coordinated development of the coal and coal bed gas. Coal bed gas extraction is taken by the ground method, the ground method, and their combined method.

The coal bed gas extraction in production area is researched mainly in this paper. At present, in the production area, the main technologies of coal bed gas extraction are: ground vertical drilling...
technology, underground high-pumping roadway technology, underground crossing drilling hole technology, bedding drilling hole technology, and protection layer mining technology \cite{1-3}.

1.2. Relationship between Coal Bed Gas Extraction and Coal Mining Influence

On the one hand, the permeability of coal reservoir stratum in China is generally low. When direct extraction of coal bed gas in situ, it is often necessary to use hydraulic fracturing and other increased permeability technologies to improve output of coal bed gas extraction. In coal and coal bed gas co-mining, after coal seam mining, strata movement forms stress filed and crack field, even if the coal seam with very low permeability, its permeability will increase by dozens to hundreds of times, which creates conditions for coal bed gas to unload pressure, transfer, and mining.

On the other hand, production area involves the area with strong mining influence and the goaf area with basically stability after mining. The strata movement will destroy ground vertical drilling well and underground high-pumping roadways. Therefore, we should consider not only the permeability effect of the caved and fracture zone on coal bed gas extraction, but also the damage of strata movement and separation layer effect to the structure of the ground well. Therefore, it is necessary to analyze the relationship between the law of coal mining and coal bed gas extraction, in order to guide the coordinated development of coal and coal bed gas.

2. Ground Movement and Deformation Law

2.1. Definition of Ground Subsidence Basin

Ground subsidence basin refers to the range of ground movement above the goaf caused by coal mining, commonly referred to as the ground collapse basin. The range is generally defined at the boundary angle or by 10mm subsidence points. The final ground movement deformation value, which reaches stability after coal mining, is called the static ground movement deformation value. Ground movement deformation mainly includes: subsidence, horizontal movement, tilt deformation, horizontal deformation, and curvature deformation.

Ground movement deformation is related to mining thickness, mining depth, structure and properties of overburden strata \cite{4-5}. The curves of subsidence and horizontal deformation when sufficient mining is shown in Figure 1. The outer edge of the inflection point in surface subsidence basin is the stretch deformation area, and the inner edge of inflection point in the surface subsidence basin is the compression deformation area. The inflection point is zero horizontal deformation point, and the middle part of the basin is free-deformation zone. There are three zero horizontal deformation points (zones) in the entire section.

![Figure 1. Section of surface subsidence and horizontal deformation.](image)

2.2. Surface Fore Affect Range

After critical mining, toward the main section of trend direction, the angle near pillar, between the connection line from the surface subsidence 10mm point before working face to the position of the mining work and horizontal line, is fore affect angle. The horizontal distance between the surface
subsidence 10 mm point and the position of the mining work face is called the fore affect distance. The fore affect distance of longwall mining depends on such factors as the thickness, the structure and strength of the overburden strata.

2.3. Surface Movement Duration
The surface movement process can be divided into three periods: initial, active and recession. The period, from the cumulative subsidence 10mm at surface maximum subsidence point to the surface subsidence speed of up to 50mm per month, is called the initial period; the period, in which the sinking speed is more than 50mm per month, is called the active period; the period from the end of the active period to the less than 30mm subsidence within continuous 6 months of observation, is called the recession period. It has the most severe damage to overburden strata and surface during surface active period. Generally, the recession period lasts for a long time but it has no much increasement of the damage to the overburden and surface[6]. The duration of surface movement can be calculated according to the following formula:

\[ T = 2.5h_0 \quad \text{when } h_0 < 400 \text{m} \]  \hspace{1cm} (1)
\[ T = 1000 \exp\left(1 - \frac{400}{h_0}\right) \quad \text{when } h_0 > 400 \text{m} \]  \hspace{1cm} (2)

Where \( T \) is surface movement duration, unit as m.

3. Law of Movement and Failure within Surrounding Rock

3.1. Partition of Movement and Failure in Overburden Strata
The mining influence degree in overburden strata mainly refers to the degree of the failure zone development. A lot of practical and theoretical research on the distribution of overburden strata damage in china were made by Liu Tianquan Academician, and the theory of "upper three zones" was put forward, such as: caving zone, fracture zone\textsuperscript{[7-8]}, and overall movement zone in Figure 2.

![Figure 2. Movement and failure partition in overburden strata after longwall mining.](image)

After working face of longwall coal mining with caving method advances from the cut, the direct roof collapses, and then forms a caving zone; when the working face continues to advance, the overburden strata above caving zone begins to breck and crack, and then forms a fracture zone. Strata in the fracture zone is divided by fracture degree into serious fracture, medium fracture and slightly fracture. Slightly fracture strata generally does not break up, with poor connectivity. The upper point of slightly fracture strata is the top of fracture zone.

After finishing mining, the caving zone, the fracture zone and the overall movement zone still exist above the goaf. The damage to the strata in the caving zone is serious. In fracture zone, the strata near caving zone are severely fractured and the strata far away from caving zone are slightly fractured. The overall movement zone refers to the curved and sinking zone in overburden strata from the top boundary of the fracture zone to the surface.
3.2. Range of Movement and Failure in Overburden Strata

According to the field observed data, the final fracture zone range in overburden strata in gently inclined coal seam is similar to the saddle shape: the failure height above the boundary of mining area is higher than the central of mining area, and the highest point is within or without a few meters from the mining area boundary.

The failure height is closely related to the rock mechanical character and structure of overburden strata[9]. The failure height of hard strata is high, generally 18 to 28 times of mining height, the failure height of weak plastic strata is small, generally 9 to 12 times of mining height, and the failure height of the medium-hard strata is generally between hard strata and weak strata. The relationship between the failure height of strata and mining height is the fractional function, which increases with the increase of mining height.

According to guidelines for coal pillar design and mining under buildings, water bodies, railways and main shaft and road way, the calculation formula for caving height and fracture height of single mining in medium-thick coal seam and slicing mining in thick coal seam is shown in Table 1; the calculation formula for caving height and fracture height of in top coal caving mining in thick coal seam is shown in Table 2[10].

Table 1. Calculation formula for caving height and fracture height of single mining in medium-thick coal seam and slicing mining in thick coal seam.

| Strata       | Caving zone height (m) | Fracture zone height (m) |
|--------------|------------------------|--------------------------|
| Hard.        | \( H_k = \frac{100 \sum M}{2.1 \sum M + 16} \pm 2.5 \) | \( H_h = \frac{100 \sum M}{1.2 \sum M + 2.0} \pm 8.9 \) |
| Medium-hard  | \( H_k = \frac{100 \sum M}{4.7 \sum M + 19} \pm 2.2 \) | \( H_h = \frac{100 \sum M}{1.6 \sum M + 3.6} \pm 5.6 \) |
| Weak.        | \( H_k = \frac{100 \sum M}{6.2 \sum M + 32} \pm 1.5 \) | \( H_h = \frac{100 \sum M}{3.1 \sum M + 5.0} \pm 4.0 \) |
| Very weak.   | \( H_k = \frac{100 \sum M}{7.0 \sum M + 63} \pm 1.2 \) | \( H_h = \frac{100 \sum M}{5.0 \sum M + 8.0} \pm 3.0 \) |

Table 2. Calculation formula for caving height and fracture height of in top coal caving mining in thick coal seam.

| Strata       | Caving zone height (m) | Fracture zone height (m) |
|--------------|------------------------|--------------------------|
| Hard.        | \( H_k = 7M + 5 \)       | \( H_h = \frac{100M}{0.15M + 3.12} \pm 11.18 \) |
| Medium-hard  | \( H_k = 6M + 5 \)       | \( H_h = \frac{100M}{0.23M + 6.10} \pm 10.42 \) |
| Weak.        | \( H_k = 5M + 5 \)       | \( H_h = \frac{100M}{0.31M + 8.81} \pm 8.21 \) |

3.3. Time of Movement and Failure within Overburden Strata

The movement and damage of overburden strata caused by underground mining has obvious time property. When the coal-mining working face advances a certain distance, the strata movement begins at its roof and develops upwards, and then the strata movement range expands and rises, spreading to the surface and gradually expanding. After underground mining space reaches stability for some time after the end of mining, mining influence in overburden strata and surface tends to be stable.

The failure height in overburden strata varies over time. The development of fracture zone measured at the working face of one mine in Wanbei Mine was shown in Figure 3. It goes through the time process of fracture zone that generation O-A, upward development A-B, reaching the maximum C, compression decreases C-D, final stability D. The height of fracture zone increases over time before
the maximum value is reached, and after reaching the maximum, the height of fracture zone decreases over time.

![Figure 3. Height change in fracture zone in one mine over time.](image)

### 3.4. Support Pressure Partition and Floor Damage Depth

In the horizontal direction of coal seam floor, the support pressure change from the coal pillar to the center of mining area after mining is divided into the compression area with stress increase, the discharge expansion area with stress reduction, and the compaction area with stress recovery. The severe area of stress and displacement changes, in general, is a few tens of meters before and after working face. The maximum peak of the front support pressure is generally at 2 to 10m into coal body, and the influence range can reach 90 to 100m in front of working face. In the vertical direction of coal seam floor, it is prone to shearing and expansion damage in the compression area and expansion area and forming damage zone from the coal seam floor to the destruction bottom. There are 2 main indexes. One index is mining damage depth and the other is pressure relief angle.

Within the range of mining damage depth, fissures are rich in surrounding rock. The field observation results of china coal mines show that the degree of floor damage caused by mining mainly depends on the geological mining conditions of the working face and the resistance ability of the floor strata. Considering mining depth, inclination, and working face length, statistical formula can be obtained. The mining damage depth ($h_1$) is generally from 6 to 35m\(^4\).

$$h_1 = 0.0085H + 0.1665\alpha + 0.1079L - 4.3579$$  \hspace{1cm} (3)

Where $h_1$ is floor damage depth, unit as m; $H$ is mining depth, unit as m; $\alpha$ is coal seam inclination, unit as; $L$ is working face length, unit as m.

Within the range of pressure relief angle, the stress of surrounding rock is released. The permeability of surrounding rock increases, which is conducive to coalbed gas extraction. The pressure relief angle ($\delta$) is generally from 65° to 75°.

### 4. Coal Bed Gas Extraction Engineering Application

#### 4.1. Ground Drilling Well Extraction Engineering

Ground drilling well is one of the most effective methods of coal bed gas extraction. In Jincheng mining area, HuaiBei mining area and Huainan mining area, it has been mostly applied. However, strata movement caused ground drilling well wall to break, dislocate, and closed severely. In Xieqiao, Zhangji, Guqiao, Dingji and other mines of Huainan mining area, most all of ground drilling well is not successful. All drilling wells no longer produce gas after working face goes through the drilling wells for 150 m. Through a number of well video recording, we found the main reason of non-gas production is that the well pipe is broken in many places, drilling wells in some places are blocked, water level rises. At the same time, due to the break of well wall and gas pipe, the water from quaternary strata or bedrock into the extraction well, which will cause mines a great threat of water damage.

Based on the temporal and spatial law, principle of ground drilling design is:

1. In the plane location design of surface drilling wellhead, according to ground movement law, we should avoid placing wellhead in the area of severe pull deformation and choose the area with zero or
small horizontal deformation, i.e. near the inflection point and the middle position of subsidence basin, such as Figure 4. Drill wells are arranged in zero static horizontal deformation position around the inflection point, such as drill wells 1-6, supplemented drill wells at the center of working face, such as drill well 7-8. In this way, drilling well damage caused by strata movement can be reduced. In the practice of ground drill well construction in Huainan and Huaibei mining areas, in space, drill wells are arranged in 1/3 of long wall face length away from the return roadway, the well spacing 200–400m; Coupled with the reinforced drilling well wall structure, ground drilling extraction effect is good.

Figure 4. Application of mining influence law in ground drilling extraction engineering.

(2) In the location design of drilling well bottom, based on the damage characteristics of overburden strata, the height of caving zone, and compaction zone condition, drilling well bottom locations are designed within caving zone, so as to capture the coal bed gas in fracture area and gas-enrichment area, meanwhile, they are designed into the gas O-ring crack channel around working face, so as to have enough channels and extract the coal bed gas of working surface smoothly. (3) In time, construction period of ground drill well should avoid active period of surface movement as possible.

4.2. Underground High Roadway Extraction Engineering
The underground high roadway is such a roadway above coal seam used to extract coal bed gas from below coal seam. The roadway is connected to mining area. High concentration gas in underground high roadway is pumped out by pre-positioned pipes. The section of high roadway is generally about 7.0m², three closed walls are built in the proper position along high roadway, and pump pipes, water pipes and observation holes are installed.

When designing underground high roadway, it is necessary to make the roadway position be within the crack and fracture channels, but also to control it without serious caving, so as to maintain its efficiency of transporting coal bed gas. Therefore, in strike section, its advance direction is alone strike direction of coal seam working face; in dip section, high roadway is set the center of working face or near the side of return roadway; in vertical direction, high roadway is arranged within the fracture zone of overburden strata, from which drill holes are constructed into caving zone. And then, drill holes connect the high roadway and the coal mining area, as shown in Figure 5.
4.3. Underground Upper Protection Seam Mining Engineering

Design principle of protective layer is that the protected coal seam should be located in the mining influence range after the protection layer is mined. Through mining of the protection layer, the protected coal seam and surrounding rock are forced to move and deform as to increase their permeability, increase the effective pressure relief spacing, and improve the extraction rate of pressure-relief coal bed gas.

Take Qinan coal mine as an example. No.61 coal is non-outburst coal seam. No.7 coal is outburst coal seam. Their average interlayer spacing is 34m. In No.7 coal, gas pressure is 1.81Mpa. Gas content is 94m³/t. The average mining depth is 550m, coal seam inclination is 20°, working face length is 195m. as shown in Figure 6.

According to the calculation, mining damage dept h is 25m. Measured pressure relief angle of coal mine is 75°.

Before upper protection seam mining, laying out gas extraction floor roadways under protected seam, drilling holes through protected seam. At the same time as upper protection seam mining, timely extract discharge-pressure gas from protected seam. The floor roadways are arranged under the protected seam, 20m distance from its seam bottom. The bottom spacing of cross drilling hole within protection area of upper protective seam is 20m*20m. The diameter of cross drilling hole is 113mm.

By floor roadway and cross drilling holes of 6125 working face, coal bed gas extracted from protected seam (No.7) is accumulated 1.928 million m³, coal bed gas extracted by buried pipe from No.61 goaf is 0.2027 million m³, coal bed gas extracted by wind is 0.6471 million m³. The bottom cross-extraction gas is accounted for 90.8%, with extraction rate at 76.7% for the working face.

After implementing a series of technical measures for upper protective seam mining, during mining of protective seam 7225 working face, the use of old pond buried pipe and high-level drilling extraction, gas extraction from high-level drilling is average 4.6m³/min, gas extraction from buried pipe is average 0.6m³/min. Measured coal seam drilling chip amount Δh₂ maximum is 80pa. The working face is equipped with air volume of 1500m³/min, and the return gas concentration remains below 0.3%, ensuring safe and efficient mining.
5. Conclusion
(1) Coal bed gas extraction technologies are elaborated. Ground drilling well, high roadway, and upper protective seam are main coal bed gas extraction technologies in China.
(2) Temporal & spatial law of mining influence is analyzed. The height calculation of the caving zone and the fracture zone in overburden strata, and the depth calculation of mining damage in the underlie strata are described.
(3) Through studying relationships between these technologies and strata deformation & destruction, paper makes it clear the requirement of coal bed gas extraction to ground movement, deformation, and failure degree.
(4) The principles of the ground drilling well design, the arrangement of high-roadway, and the selection design of the protective seam are put forward, which can be used for reference of coal bed gas extraction in coal mines.

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