Research and application of gas overrun prevention technology by hydraulic reaming

Qiang Tang

1 China Coal Technology Engineering Group Chongqing Research Institute, Chongqing University, Chongqing, Chongqing, 400000, China.
tangqiang@cqccteg.com

Abstract. In order to solve the problem of gas overrun in hydraulic reaming of coal mine, this research has been put forward. Field tests show that, the overrun gas with hydraulic reaming mainly comes from the large amount of gas release caused by the occurrence change, and the sudden release of gas gathered due to the blockage of the drilling, etc. By adjusting the air supply of the area, improving the construction technology, controlling the slag rate, and adopting the blowout preventer, the gas overrun with hydraulic reaming can be effectively controlled.

1. Introduction

With the expansion of mining scale and the increase of mining depth, the pressure of gas control in coal mine has increased greatly. Gas has become the key problem of coal mining. In the mines with conditions, protective layer mining is the preferred method for regional outburst prevention. But in the mines without protective layer, drilling is the main measure to prevent coal and gas outburst, reduce gas emission and the times of gas overrun in working face [1-3].

Due to the characteristics of low permeability, broken and soft coal, it is difficult to increase gas drainage efficiently in some mines. In order to solve this problem, high pressure hydraulic reaming technology came into being [2-3]. The test coal seam has a series of limit conditions, such as large dip angle, broken and soft coal quality, local water content, thick coal seam and so on. In order to improve the gas drainage efficiency, the research of high pressure hydraulic reaming technology was carried out. Through the field test, the hydraulic reaming technology can greatly improve the drainage effect, but also leads to the problem of gas overrun, which seriously affects the construction safety. Aiming at the problem of gas overrun by hydraulic reaming, some mines have carried out a lot of experimental researches, but the research on a series of extreme conditions in this test mine is still insufficient.

In order to solve the problems of gas overrun with hydraulic reaming in the test mine, we carried out this research and finally controlled the times of gas overrun. We mainly adopt the following methods, such as the analysis of the reasons, the construction technology improvement, regional air supply regulation, slag discharge rate control, blowout prevention device and so on.

2. Overview of test area [4]

Test coal mine is located in Weixin County, Zhaotong City, which is a state-owned infrastructure mine. It adopts the construction mode of one mine and two wells, with a design production capacity of 2400k.
In this study, well 1 of test coal mine is selected. Its strike length is about 12.4km, and dip width is about 1.9-2.5km, and the area is about 30.1km². The inclined shaft development is adopted, which is divided into four levels of +800m, +500m, +250m, ±0m. The current infrastructure construction work is concentrated at the level of +800m. Most of the C1 coal seams in the mine field are minable, all of C₅ coal seams are minable. We arrange field test in the 106 gas drainage roadway.

### Table 1. Basic parameters of C₅ coal in test area

| Parameter name               | Dimension | Parameter value       |
|------------------------------|-----------|-----------------------|
| Thickness of coal seam       | m         | 2.6~4.8               |
| Coal seam dip                | °         | 34~39                 |
| Firmness coefficient         |           | 0.17                  |
| Damage type                  |           | III~IV                |
| Maximum gas pressure         | MPa       | 1.86 (indirect method)|
| Maximum gas content          | m³/t      | 12.95                 |
| Attenuation coefficient      | d⁻¹       | 0.59~1.1              |
| Air permeability coefficient | m²/MPa²·d | 0.607~2.67            |
| Initial release velocity     | mmHg      | 38                    |

### 3. Basic principle of hydraulic reaming [5-7]

High pressure hydraulic reaming is a kind of technology to improve the efficiency of drilling gas drainage. In the constructed drilling, the drilling machine is used to drive the high pressure drill pipe and bit, and the high pressure water is used to strike, cut or peel the coal wall. Through the drill pipe rotation, the drill hole diameter is continuously enlarged, the diameter of the drill hole is expanded, the exposed area and pressure relief range is also increased. With this technology, we can improve the permeability of the coal seam and the gas drainage effect, and further reduce the gas pressure of the coal seam.

High pressure hydraulic reaming destroys coal and rock mass by jet, the main functions are as shown below: jet impact, water wedge, stress wave produced by jet, cavitation. Jet impact force and stress wave play an important role in the whole process of reaming, while water wedge and cavitation promote the expansion and accelerated failure.

### 4. Research plan

Under the different conditions of hydraulic reaming, such as adjusting regional air supply, improving construction technology, controlling slag discharge rate and adopting blowout preventer, each test group is designed with 5 rows of drillings, each row is designed with 6 drillings.

Gas monitoring sensor T1 and T2 are respectively arranged within the scope of 3 ~ 5m and 50 ~ 100m on the return air side of the reaming operation point. Count the frequency and amplitude of gas monitoring sensor (T1, T2) exceeding the limit (≥1%), and then analyze the causes of gas overrun and the corresponding prevention measures.

![Figure 1. Design of ordinary and enlarging drilling test](image-url)
5. Cause analysis of gas overrun with conventional hydraulic reaming operation

5.1. Gas overrun of conventional hydraulic reaming operation

Combined with the field observation, the frequency and amplitude of gas overrun in conventional hydraulic reaming operation (without taking preventive measures) were counted. The calculation and analysis showed that, the average drilling reaming slag was about 0.82t/m. During the conventional drilling, there was less gas overrun. During the reaming operation, the T1 sensor exceeded the limit 92 times and the T2 sensor exceeded the limit 73 times in total.

Table 2. Statistics of exceeding gas by ordinary hydraulic reaming technology

| Number | Overrun range | T1 overrun frequency | T2 overrun frequency | Description of site conditions |
|--------|---------------|----------------------|----------------------|--------------------------------|
| 1      | 1% ≤ X < 3%   | 63                   | 48                   | Slight orifice                 |
| 2      | 3% ≤ X < 5%   | 16                   | 17                   | General orifice                |
| 3      | 5% ≤ X < 10%  | 9                    | 6                    | The slag discharge rate is not stable, and the hole is sprayed violently, accompanied by wind noise |
| 4      | 10% ≤ X       | 4                    | 2                    | After the hole is blocked, the hole is suddenly sprayed, lasting for 5 min at most |
| Total  | 92            | 73                   |                      |                                |
| Average single hole overrun frequency | 3.07 | 2.43 | |

5.2. Cause analysis of gas overrun

High pressure hydraulic reaming not only increases the exposed area of coal seam and radial pressure relief range of drilling, but also greatly improves the permeability of coal seam. Combined with the actual observation on site, the following conclusions can be preliminarily summarized by statistical analysis of gas probe monitoring data.

1) The gas exceeding the limit of 10% often occurs when the drilling is blocked and suddenly sprayed. This kind of overrun is mostly the sudden emission of pressurized gas with long duration, large amount of coal ejected, large amount of gas released, accompanied by severe wind blowing, which seriously threatens the safety of drilling expanding operation, and belongs to the gas overrun that can be greatly weakened [4].
There are many reasons for drillings plugging. Such as the following reasons. ① Severe collapse in coal section, limited slag discharge channel, and a large number of collapsed coal blocks the coal rock joint. ② The gas is emitted violently, pushing a large number of broken coal into the limited drilling hole to block the coal rock joint. ③ Smooth drill pipe reaming operation is used to crush the soft coal, which is easy to form paste when encountering water and block the drilling.

2) The gas exceeding the limit of 5% ~ 10% often occurs under the conditions of fast and slow slag discharge rate, hole collapse in coal section but not blocked, severe spray hole and so on. This kind of overrun coal emission is large, but relatively stable, accompanied by violent wind noise, which seriously affects the safety of reaming operation, and belongs to the gas overrun that can be weakened but difficult to eliminate.

3) The gas exceeding the limit of 3% ~ 5% often occurs under the conditions of relatively stable slag discharge rate, slight hole collapse in the hole and general spray drilling. This kind of overrun coal emission is limited, continuous and stable gas release is large, often accompanied by slight wind noise, which greatly restricts the efficient development of reaming operation, and belongs to the gas overrun that can be effectively controlled.

4) The gas exceeding the limit of 1% ~ 3% often occurs under the conditions of stable slag discharge rate, no hole collapse in the hole and slight spray hole. The duration of this kind of overrun is relatively short, the amount of coal ejected and gas released is limited, and the wind noise is slight or even not, which restricts the efficient development of reaming operation, and belongs to the gas overrun that can be effectively prevented.

6. Prevention and control of gas overrun by hydraulic reaming

6.1. Air volume control
When the gas exceeds the limit slightly in local area of coal mine, the air supply volume of the area can be increased to dilute the gas, so as to control the gas overrun. The regional air supply is regulated through the following two aspects.① the daily air supply of the roadway is about 300 m³ / min ~ 400 m³ / min, and the air volume is adjusted to 500 m³ / min ~ 700 m³ / min during the hydraulic reaming operation. ② the diversion wind barrier is set to increase the air supply at the top of the roadway and other gas prone areas.

The frequency of gas exceeding the limit (1% ~ 3%) can be greatly reduced by adjusting the regional air supply volume, but the effect is not obvious for the high concentration gas overrun.

Table 3: Statistics of exceeding gas by hydraulic reaming technology with air volume control

| Number | Overrun range | T₁ overrun frequency | T₂ overrun frequency | Remarks |
|--------|---------------|----------------------|----------------------|---------|
|        | Convention    | Air supply regulation | Convention          | Air supply regulation |          |
| 1      | 1%≤X<3%       | 63                   | 48                   | 20      |
| 2      | 3%≤X<5%       | 16                   | 17                   | 9       |
| 3      | 5%≤X<10%      | 9                    | 6                    | 3       |
| 4      | 10%≤X         | 4                    | 2                    | 1       |
| Total  |               | 92                   | 73                   | 33      |
| Average single hole overrun frequency | 3.07 | 1.6 | 2.43 | 1.1 |

6.2. Improvement of construction technology
Based on the analysis of the causes of gas overrun, the construction technology was improved from the following aspects.① hydraulic reaming was carried out immediately after the completion of a single drilling, and then reamed one by one after the completion of 6 drillings.② the conventional smooth drill pipe was replaced by spiral groove drill pipe to enhance the slag discharge capacity. ③ the original shallow to deep forward reaming was changed to deep to shallow return reaming. ④
The original fixed water pressure reaming was changed to variable pressure reaming according to slag discharge.

Through the above process improvement, the probability of drilling plugging is effectively reduced. The gas overrun with an amplitude of more than 5% is reduced, but the effect is not obvious for the gas overrun range of 1% ~ 5%.

### Table 4. Statistics of exceeding gas by improved hydraulic reaming technology

| Overrun range | T₁ overrun frequency | T₂ overrun frequency | Remark        |
|---------------|----------------------|----------------------|---------------|
|               | Convention           | Improve construction technology | Convention | Improve construction technology |
| 1 1%≤X<3%     | 63                   | 49                   | 48            | 37            |
| 2 3%≤X<5%     | 16                   | 13                   | 17            | 11            |
| 3 5%≤X<10%    | 9                    | 3                    | 6             | 1             |
| 4 10%≤X       | 4                    | 0                    | 2             | 0             |
| Total         | 92                   | 65                   | 73            | 49            |
| Average single hole overrun frequency | 3.07 | 2.2 | 2.43 | 1.6 |

#### 6.3. Slag rate control

In high pressure hydraulic reaming operation, by controlling the water pressure and advancing speed, the slag rate can be effectively controlled, and the coal spalling and exposed area can be also controlled, so as to slowing down the gas release and reducing the probability of drilling plugging. Through field research, it is found that there is an obvious positive correlation between gas release and slag rate under the slag discharge rate of 0.01t/min ~ 0.16t/min. When the slag rate is greater than 0.16t/min, there is an obvious spray hole phenomenon. In order to control gas overrun, the slag rate was controlled in the range of 0.08 t/min ~ 0.13 t/min in this comparative test.

By controlling the slag rate, the drilling plugging situation is effectively reduced, and the frequency of high concentration gas exceeding the limit (more than 5%) is reduced. However, for the gas with the range of 1% ~ 5%, the reduction is limited.

### Table 5. Statistics of exceeding gas by slag rate control

| Overrun range | T₁ overrun frequency | T₁ overrun frequency | Remark |
|---------------|----------------------|----------------------|--------|
|               | Convention           | Control slag rate    | Convention | Control slag rate |
| 1 1%≤X<3%     | 63                   | 52                   | 48     | 41            |
| 2 3%≤X<5%     | 16                   | 9                    | 17     | 6             |
| 3 5%≤X<10%    | 9                    | 2                    | 6      | 1             |
| 4 10%≤X       | 4                    | 1                    | 2      | 0             |
| Total         | 92                   | 64                   | 73     | 48            |
| Average single hole overrun frequency | 3.07 | 2.1 | 2.43 | 1.6 |

#### 6.4. Application of blowout preventer

The high pressure hydraulic reaming operation expands the diameter of the drilling, increases the exposed area of the coal seam and the pressure relief range of the drilling. In a short period of time, a large amount of gas emission will inevitably form a spray drilling, which will lead to gas overrun [9]. In order to reduce the over limit frequency of spray drilling, the blowout preventer is used. Through the large diameter blowout prevention hole sleeve and connecting pipe, the slag enters the steam coal water separation device. Then the gas is directly introduced into the drainage pipeline. At the same
time, a drainage pipe is set on the blowout prevention hole sleeve, which is directly connected with the drainage pipeline, so as to timely extract the gas from the spray hole.

Through the use of blowout preventer, the gas emitted from the hole is directly introduced into the drainage system, which greatly reduces the frequency of gas overrun. However, the control effect of high concentration overrun caused by sudden emission of pressurized gas after drilling blockage is limited.

| Number | Overrun range | T1 overrun frequency use of blowout preventer | T1 overrun frequency use of blowout preventer | Remark |
|--------|---------------|---------------------------------------------|---------------------------------------------|--------|
|        | Convention    |                                             |                                             |        |
| 1      | 1%≤X<3%       | 63                                          | 19                                          |        |
| 2      | 3%≤X<5%       | 16                                          | 6                                           |        |
| 3      | 5%≤X<10%      | 9                                           | 3                                           |        |
| 4      | 10%≤X         | 4                                           | 1                                           |        |
| Total  |               | 92                                          | 29                                          |        |
| Average single hole overrun frequency | 3.07 | 1 | 2.43 | 0.6 |

6.5. **Comprehensive application**

To sum up, the improvement of construction technology, slag rate control and other methods can effectively reduce the high concentration gas overrun. The methods of air supply regulation and blowout preventer are effective in reducing low concentration gas overrun. In order to further reduce the frequency of gas overrun during reaming, the above methods are used for comprehensive application test.

Statistical analysis shows that, after the comprehensive application of the above methods, we can put an end to high concentration gas overrun (more than 5%), gas overrun (1% ~ 5%) are greatly reduced.

| Number | Overrun range | T1 overrun frequency use of blowout preventer | T1 overrun frequency use of blowout preventer | Remark |
|--------|---------------|---------------------------------------------|---------------------------------------------|--------|
|        | Convention    | Comprehensive application                  | Comprehensive application                  |        |
| 1      | 1%≤X<3%       | 63                                          | 9                                           |        |
| 2      | 3%≤X<5%       | 16                                          | 2                                           |        |
| 3      | 5%≤X<10%      | 9                                           | 0                                           |        |
7. Conclusion
1) In the high pressure hydraulic reaming operation, the out of limit gas mainly comes from the gas release caused by the occurrence change and the sudden release of the gas accumulated in the drilling blockage.

2) The improvement of construction technology and slag rate control can effectively reduce the high concentration gas overrun; the air supply regulation and the use of blowout preventer have remarkable effect in reducing the low concentration gas overrun.

3) The comprehensive application of above methods can effectively prevent high concentration gas overrun, and greatly reduce the frequency of low concentration gas overrun.

4) High pressure hydraulic reaming increases the diameter and pressure relief range of drilling, increases the exposed area of coal seam. A large amount of gas emission is inevitable. How to control and even eliminate the gas overrun will be a scientific and sustainable research topic.

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