Analysis on the Influencing Factors and Prediction Sensitivity of the Initial Velocity of Gas Emission from Boreholes

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Abstract. The initial velocity of gas emission from boreholes is one of the main indicators for the prediction of the outburst hazard of the working face and the effect detection. Only by fully grasping the various factors affecting the initial velocity of gas emission from boreholes and continuously improving and perfecting the measurement method of the indicators can the test results be guaranteed, so that can accurately grasp the coal face outburst dangerous degree, thus improving the safety and reliability of prediction. In this paper, through the numerical analysis of the testing method of the initial velocity of gas emission from the borehole and the numerical analysis of the test results, various factors affecting the initial velocity of gas emission from the borehole are found, and the sensitivity of the prediction results of the initial velocity of gas emission from the borehole is further analyzed. Therefore, a technical way to improve the accuracy of the initial velocity of gas emission from the borehole was found. The analysis results show that the initial velocity of gas emission from boreholes is only suitable for coal seams or areas where the permeability of the coal seam is not small and changes little; when the gas pressure in the coal seam is small, the initial velocity of gas emission from boreholes is used to predict the geostress as the dominant factor The prominence of the prominence has poor prediction sensitivity; when measuring on site, the predicted borehole depth should enter the plastic deformation zone in the stress concentration zone, and high-quality and responsible test personnel should be assigned.

1. Introduction
At present, the initial velocity of gas emission from boreholes has been widely used in outburst mines at home and abroad, and has become one of the main indicators for predicting the risk of local outburst in mining face or testing the effect of outburst prevention measures. The 2019 edition of the "Detailed Rules for Prevention of Coal and Gas Outburst" provides detailed descriptions and regulations on the testing technology, measurement method and reference critical value of the initial velocity of gas emission from boreholes. When the initial speed is used for outstanding prediction or the effect of anti-outbreak measures, sometimes the application effect is very good, and sometimes the effect is not good. It is mainly reflected in two aspects[1]: On the one hand, the measured indicators generally exceed the critical value. After the anti-outbreak measures are taken, the inspection value is getting larger and larger, but the actual footage does not have any gas dynamic phenomenon; on the other
hand, it is predicted that the index is very small, but there are obvious dynamic phenomena in the mining process, and even prominent disaster accidents occur.

Therefore, it is necessary to study the influencing factors of the muzzle velocity of borehole gas emission, analyze the sensitivity of its prediction results, in order to find out some general rules, put forward the use conditions of this index and improve the test technology to better guide mine outburst prevention work improves safety production efficiency.

2. Testing method for initial velocity of gas emission from borehole

In order to find out the law of gas emission from the borehole after drilling, the researchers did a lot of experiments on the gas emission from the borehole over time. The research results show that in most cases, the gas emission rate function will have a maximum value within a certain period of time (0~2min) after the start of the measurement. The maximum value of the gas emission rate is called the drill hole. The relationship between the initial velocity of hole gushing, gas gushing velocity $q$ and time $t$ is shown in ‘figure 1’.

![Figure 1. The relationship between gas emission speed and time of borehole](image)

$t_0$—end time of drilling; $t_0$—start measurement time; $t_H$—time to reach the maximum initial velocity of gas emission

The test method for predicting the risk of coal seam outburst using the initial velocity of gas emission from the borehole is: Drill a number of holes with a depth of 8-10m and a diameter of 42mm in the coal seam during the mining work. The borehole should be arranged in the soft layer as much as possible, and the initial gas emission velocity of the borehole should be measured within 2min after the suspension of drilling from the 2m. The length of the measuring chamber is 1.0m.

According to the test method of the initial velocity of gas emission from the borehole, the gas flowing into the gas measurement chamber mainly comes from the plastic zone around the borehole. Under the conditions of a certain diameter of the gas measurement chamber and the borehole, the coal seam gas pressure, gas content, and surrounding area of the borehole. The larger the plastic zone radius $R_p$ and the air permeability $\lambda_0$ outside the plastic zone, the larger the initial gas emission velocity $q$ from the borehole, and vice versa. Under certain conditions of coal seam permeability coefficient and borehole diameter, the initial gas emission velocity $q$ from the borehole is directly proportional to the coal seam gas pressure, gas content, coal seam in-situ stress, and gas emission initial velocity, and inversely proportional to the strength of the coal body. The initial velocity of gas emission reflects the combined effect of coal seam gas, ground stress, and coal physical and mechanical properties in front of the work.

3. Numerical analysis of initial gas velocity in borehole

According to the law of coal seam gas flow obtained by Professor Zhou Shining’s experiments and analysis, under general assumptions, using Darcy’s law of coal seam gas flow and the energy conservation equation, the differential equation of gas emission around the borehole can be derived as [3]:

$$\frac{d^2 q}{dt^2} + \frac{d}{dt} \left( \frac{d q}{dt} \right) + \frac{q}{\rho C_v} = 0$$
\[
\left[ F + \frac{Kab}{(1 + u^2)} \right] \frac{\partial u}{\partial t} = \frac{2\sqrt{u}}{r} \times \frac{\partial (\lambda \frac{\partial u}{\partial r})}{\partial r}
\]  

(1)

Where: \( F \), Porosity, \%; \( K \), Coal moisture and ash correction coefficient; \( a \), \( b \), Gas adsorption constant; \( u \), The square of gas pressure, MPa\(^2\); \( r \), The distance from the borehole center, m; \( \lambda \), Coefficient of coal seam permeability, \( \text{m}^2/\text{MPa.d} \).

The conditions for the solution are: when \( t=0 \), \( u = p^2 \); when \( r=r_0 \), \( u = p^2 \); when \( t=T \) (for a sufficiently large time), \( \frac{\partial u}{\partial t} = 0 \). Among them: \( r_0 \), The original gas pressure of the coal seam, MPa; \( p_0 \), Drilling radius, m; \( p_1 \), Atmospheric pressure, generally 0.1MPa.

In actual coal, because the permeability coefficient of the coal in a heterogeneous coal is different due to the difference in space and time, the gas flow in the coal is very complicated, but it still obeys the law of conservation of mass, so there are [4]:

\[
q = -4\pi \rho^2 \frac{\partial P}{\partial r}
\]

The coal permeability distribution around the borehole is approximately as follows:

\[
\lambda = \lambda_0 e^{-n(\sigma_0 - \sigma_t)}
\]

Among them: \( \lambda_0 \), the original permeability coefficient of the coal seam when the borehole tangential stress is \( \sigma_t \), \( \text{m}^2/\text{MPa.d} \); \( \sigma_t \), Drilling tangential stress, MPa; \( \sigma_0 \), The original stress of the coal seam, MPa; \( n \), The compression coefficient of coal seam permeability, which is determined by analyzing the test data is \( n = 0.0247 / f^{1.3} \); \( f \), Coal firmness coefficient.

Since there is no analytical solution to the above-mentioned nonlinear partial differential equations, the numerical solution of gas pressure can be obtained by the finite difference method, and the expression of the initial velocity of gas emission from the borehole can be calculated using Darcy’s law. Because the in-situ stress, gas pressure and coal seam permeability coefficient at different distances from the coal wall before drilling change, from the 2m section to the 10m section of the borehole, the ground stress, gas pressure and coal seam in front of the working face of each meter section are changed. The average value of the air permeability coefficient is used as the original ground stress \( \sigma_0 \), original gas pressure \( p_0 \), and original coal seam permeability coefficient acting on the borehole in the meter section \( \lambda_0 \). According to the analysis results of the gas radial flow in the heterogeneous coal seam, the initial gas emission velocity from the borehole can be obtained as follows Approximate relationship:

\[
q = 2.8348 f^{-0.1615} \sigma_0^{0.2106} \lambda_0^{0.6174} p_0^{1.4575}
\]  

(2)

It can be seen from equation (2) , that the initial gas emission velocity from the borehole is mainly related to the coal seam firmness coefficient \( f \), the original ground stress in the coal seam \( \sigma_0 \), the original gas pressure in the coal seam \( p_0 \), and the original air permeability coefficient in the coal seam \( \lambda_0 \). The smaller the coal seam firmness coefficient \( f \), the greater the original in-situ stress in the coal seam \( \sigma_0 \), the greater the original permeability coefficient in the coal seam \( \lambda_0 \), and the greater the original gas pressure in the coal seam \( p_0 \), the greater the initial gas emission velocity from the borehole, especially in the coal seam. The \( \lambda_0 \) and \( p_0 \) have the greatest influence. The small change of \( p_0 \) and \( \lambda_0 \) may be compared with \( f \) and \( \sigma_0 \), the big changes cancel out.
4. Influencing factors of measuring result of initial gas emission velocity from borehole

4.1 Influence of permeability coefficient of coal seam on $q$ measurement result

It can be seen from formula (2) that the air permeability has a great influence on the measurement result of the initial velocity $q$ of gas emission from the borehole. When the permeability coefficient changes by an order of magnitude, the initial velocity index of gas emission from the borehole changes by more than 4 times. Under normal circumstances, the permeability of non-outburst coal seams is greater than that of outburst coal seams. According to the data from the Institute of Comprehensive Development of Mineral Resources of the former Soviet Academy of Sciences, the permeability of non-outburst coal seams is 3-10 times greater than that of outburst coal seams. However, for different coal fields and different mines outburst coal seam, even for different sections of the same outburst coal seam, the air permeability coefficient sometimes differs by several orders of magnitude. Therefore, the air permeability cannot well reflect the danger of coal seam outburst. When the air permeability of the coal seam is very small, even if the gas pressure and ground stress in the coal seam are large, the coal seam's firmness coefficient is very small, and the measured initial velocity index of gas emission from the borehole is still very small.

4.2 The influence of coal seam gas pressure on the result of $q$ measurement

Under different original gas pressures, the gas emission rate from the borehole changes with time, and has a certain relationship with the original gas pressure, that is, the greater the original gas pressure, the greater the gas emission rate from the borehole. According to Darcy's law, in the adiabatic process, the amount of gas entering the borehole from the coal seam per unit time is proportional to the gas pressure difference between the borehole and the coal seam. The initial gas emission velocity of the borehole is the embodiment of the gas emission power in the coal near the borehole and the concentrated reflection of the gas pressure gradient. It embodies the original gas pressure inside the coal, the level of gas content and the redistribution of ground stress situation. It can be seen from formula (2) that when other parameters are the same, $q$ increases by 2.8 times when the gas pressure changes from 0.5 MPa to 1 MPa.

Coal seam gas pressure is an extremely important factor that causes coal and gas outburst. The greater the gas pressure, the greater the risk of outburst. But sometimes the gas pressure is relatively high, but the measured $q$ is very small. The reason is that the air permeability of the coal seam is too poor. Therefore, $q$ cannot truly reflect the change of coal seam gas pressure. For coal seams with high gas pressure, low air permeability, and high degree of damage, even if the measured $q$ is small, the outburst risk is very high. When the coal seam gas pressure is very small and the ground stress is very high, even if the measured $q$ index is small, the coal seam may be extruded by ground stress or dumped by gravity [5].

4.3 The influence of drilling depth on the result of $q$ measurement

Affected by the excavation work, in front of the work, the square has become a pressure relief zone, a stress concentration zone and an original stress zone, as shown in ‘figure 2’. Because the gas flowing into the measurement chamber mainly comes from the plastic zone around the borehole, the differences in coal seam permeability, ground stress, gas pressure, and gas content in these three areas result in different changes in the initial velocity of gas emission from the borehole.
In front of the mining work, the initial velocity of gas emission from the borehole is related to the stress distribution of the coal seam. In the pressure relief zone, although the coal seam has high permeability, due to the influence of the working face, coal seam gas is discharged in advance. Gas pressure and gas content are reduced, so the initial velocity of gas emission from boreholes is generally small, which cannot reflect the real outburst risk of coal seams. In the stress concentration area, the coal body is less affected by the working face, the gas pressure is restored to the original gas pressure, the ground stress is higher than the original ground stress of the coal seam, and the plastic zone around the borehole is the largest. The initial velocity of gas emission from the borehole has a peak in this area, which represents the actual outburst hazard of the coal seam in front of the mining work [6].

4.4 The influence of test process and device on the result of q determination
Drilling operation, sealing quality (including the tightness of the hole sealing device, the sealing performance between the measuring rod joints, etc.), the flow resistance inside the measuring rod, and the working performance of the measuring instrument will directly affect the drilling gas measurement result of the initial velocity of gushing affects the sensitivity of index prediction. The speed of drilling operation will directly affect the release of coal gas around the drilling; the stability of drilling will affect the quality of the drilling and the size of the drilling, and the quality of the drilling and the size of the drilling will affect the drilling The air permeability of the surrounding coal and the quality of the sealing hole, that is to say, the stability of drilling will also affect the initial velocity of gas emission from the borehole [7]. The working performance of the measuring instrument will cause the measurement error of the initial velocity of gas emission from the borehole.

The length of drilling and sealing time has a great influence on the initial velocity of gas emission from drilling. According to field tests and previous studies, it is believed that under normal circumstances, the time from the withdrawal of the drill pipe to the beginning of the measurement of the initial velocity of gas emission from the borehole should be completed within 2 minutes as much as possible. Due to the limitation of the measurement site, the test must be repeatedly connected and unloaded when the upper and lower drill pipes or measuring rods are used to delay the measurement time, or the drilling cannot be arranged in the soft layer of the coal seam as required; and the proficiency and operation coordination of the measurement personnel The inconsistency caused the measurement to be unable to start the measurement within 2 minutes after stopping the drilling, etc. These problems encountered in the special measurement site directly affected the measurement results of the initial velocity of gas emission from the borehole.

5. Sensitivity analysis of outburst prediction for initial velocity of gas emission from borehole
Coal seam permeability coefficient and gas pressure are the main factors that affect the sensitivity of outburst prediction by the initial velocity q of gas emission from boreholes. However, the coal seam permeability coefficient is a parameter that is difficult to accurately determine. On the one hand, it is
caused by the unevenness of the permeability coefficient of the coal seam, and on the other hand, it is caused by measurement errors. The air permeability coefficient of the vertical coal seam layer is much smaller than the air permeability coefficient of the parallel bedding surface. Different structures affect the air permeability coefficient of the belt, and the air permeability coefficients measured by different measurement methods and different measuring points are not the same. Because the initial velocity $q$ of gas emission from boreholes is more sensitive to coal seam permeability coefficient and gas pressure than to coal seam firmness coefficient and ground stress. Therefore, for coal seams or areas with relatively large changes in air permeability coefficient, the initial velocity of gas emission from boreholes is less sensitive to outburst prediction. When the coal seam gas pressure is very small, the prediction of the initial velocity of gas emission from the borehole is less sensitive to the outburst hazard prediction with ground stress as the dominant factor.

Predicting the construction depth of the borehole is an important factor affecting the sensitivity of the initial gas emission rate $q$ index to predict the outburst. In order to obtain a stable and representative initial gas emission velocity reflecting the coal seam gas dynamic state, the borehole must pass through the coal seam pressure relief zone and enter the plastic deformation zone in the stress concentration zone. The gas measurement chamber is best located at the peak of the stress concentration, so that the measured initial gas emission velocity from the borehole can truly reflect the combined effect of the in-situ stress, gas pressure, and the physical and mechanical properties of the coal before the work. The measured value can represent the actual outburst of the coal seam. Dangerous. The size of the pressure relief zone and the plastic limit stress zone of the coal seam in the mining face is related to the technical conditions and geological conditions of the coal seam. For the coal seam under specific conditions, the pressure relief zone and the plastic limit stress zone of the coal seam must be measured. In order to accurately determine the test depth of the initial velocity of gas emission from the borehole.

Measurement error is a key factor that affects the sensitivity of predicting the outburst of the initial gas emission velocity $q$ from the borehole. Among them, including the quality of the tester, proficiency, work attitude, etc., the reliability of the instrument, the quality and stability of the hole prediction drilling and the quality of the sealing, etc. The experimental investigation believes that when $q<3$L/min.m, the measurement error has a great influence on the index, and the reliability of the measured $q$ is low. In actual operation, it is obvious that various errors exist objectively, but the operation is required to be standardized as much as possible to reduce the measurement error in order to ensure the true and reliable test results to the greatest extent.

6. Conclusion
The initial velocity of gas emission from boreholes is only applicable to coal seams or areas where the permeability of the coal seam is not small and changes little. Critical values should be determined separately for coal seams or areas where the permeability coefficient of coal seams changes more than one order of magnitude. Otherwise, the sensitivity of predicting outbursts is poor. In the outburst coal seam with relatively large air permeability, when the $q$ index is used to predict the outburst risk, it is recommended to use $q$ and $C_q$ (the borehole gas emission attenuation index $C_q=q_5/q_m$, that is, $C_q$ is the borehole gas at the 5th minute after the start of measurement. The ratio of flow rate to maximum flow rate) comprehensively predicts the outburst risk of coal seams.

When the gas pressure in the coal seam is small, the outburst prediction sensitivity of outburst with ground stress as the dominant factor is poorer when the initial gas emission velocity of the borehole is used. It is predicted that the depth of the borehole should pass through the coal seam pressure relief zone of the mining face and enter the plastic deformation zone in the stress concentration zone.

When the initial velocity of gas emission from boreholes is used as a predictive index for the outburst hazard of coal seams, high-quality and responsible testers should be assigned, and the air tightness and reliability of the instrument must be strictly checked before testing. The drilling and testing process should be stable to ensure the stability of the hole formation and the quality of the hole sealing, and reduce the measurement error to a minimum, thereby improving the reliability of the
prediction index.

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