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Research Article

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Study on The Distribution Law of Airflow Field in Tunneling Roadway Under Different Ventilation Modes

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Abstract: With the increasing depth of coal mining, high temperature heat damage in deep mines has become an important bottleneck restricting the safe production of mines. According to statistics, more than 50 % of mine gas accidents are concentrated in the excavation operation section. In order to realize the scientific prevention and control of heat damage in the underground operation area, the core is to accurately grasp the distribution characteristics of the airflow field in the mining face. This paper expounds the ventilation mode of heading face, and on this basis, reveals the law of wind field under different ventilation modes. The research shows that when the distance from the air outlet to the heading face is within the effective range, the air flow field can be divided into jet zone, vortex zone, impact jet zone and reflux zone. When the effective range is exceeded, a sub-vortex zone is formed in front of the excavation work, and the existence of the sub-vortex zone is very unfavorable to the migration and diffusion of harmful gases such as dust and gas. It is of great significance to study the airflow field of heading face to prevent gas accumulation.

Keywords: Roadway excavation; the wind flow field; press-in ventilation; ventilation mode

1. Introduction

In recent years, China 's coal mining has gradually shifted to the deep, and more and more mines are facing a major problem: high temperature heat damage. In order to effectively control and prevent the high temperature heat damage of the underground mining face, it is necessary to first grasp the form of the airflow field and temperature field at the mining site, because the ventilation of the tunneling face directly affects the diffusion and migration of gas, dust and various harmful gases. Relevant data show that more than half of the mine gas accidents occur in the heading face. That is to say, it is necessary to clarify the distribution law of wind flow field and temperature field. In this way, effective heat damage prevention and control measures can be put forward according to the heat damage degree and ventilation air flow of working environment in different regions.

2. Ventilation Mode of Tunneling Roadway

There are four kinds of ventilation methods commonly used in heading face: total air pressure ventilation, diffusion ventilation, ejector ventilation and local fan ventilation. However, at present, one of the most commonly used ventilation methods in mine heading face is local fan ventilation. According to the working mode of the local fan, the ventilation of the local fan is divided into three types: forced ventilation, extraction ventilation and mixed ventilation.

(1) Press-in ventilation

The forced ventilation is to install the local fan and the starting device on the air inlet side 10 m away from the entrance of the driving roadway. The local fan presses the fresh air through the air duct to the driving face, and the dirty air is discharged along the roadway.

(2) Extraction ventilation

Exhaust ventilation is to install a local fan on the return air side 10 m away from the roadway entrance. The fresh air flows along the roadway, and the dirty air is discharged by the local fan through the air duct.

(3) Hybrid ventilation

The long extraction and short pressure ventilation is to install the local fan of the exhaust pipe on the return air side 10 m away from the roadway mouth. The arrangement of the local fan of the exhaust pipe is related to the position of the exhaust pipe, and the position of the local fan arrangement and the inlet of the exhaust pipe should be greater than 10 m.

3. Wind Field Law of Different Ventilation Modes

Press-in ventilation

Press-in ventilation refers to the installation of main fans at the entrance or in the lane of the special inlet shaft, which sends the fresh air flow pressure to the underground, so that all the air flow of the mine ventilation system is in a positive pressure state higher than the local atmospheric pressure.

The forced ventilation is simple and economical, but its fatal disadvantage is that the return air volume is small, so that the dirty air in the roadway cannot be quickly discharged to the ground through the return air shaft, and the underground air flow is disordered due to the interference of natural air flow. Due to the large wind speed at the air inlet of the roadway, the air flow moves forward, and at the same time, the surrounding air and the free dust in the roadway are continuously sucked, which makes the air in the jet gradually dirty. Due to the space limitation of the side wall of the excavation face of the mine roadway, after the ventilation jet advances for a period of time, part of the air in the jet fluid stops entrainment and begins to precipitate air continuously until it contacts the head-on end face of the working face. The continuity of the compressed air flow is impacted and then begins to rotate with the wall. The part of the rotating air flow is entrained in the jet zone, and eddy current is generated at the working face, while the other part of the air flow is continuously discharged from the roadway along the way.

In the process of forced ventilation, the degree of dust return air is reduced due to the eddy current generated in the process of air flow, and the dust concentration at the heading face is increased. Therefore, when the long-pressure and short-pumping hybrid ventilation mode is selected, when the distance from the air duct to the heading face is certain, the air duct should be arranged in front of the vortex zone as far as possible, so as to ensure that the dust at the heading face is sucked away by the air flow to the maximum extent.

Pressure-pumping mixed ventilation

The pressure-pumping hybrid ventilation refers to the ventilation mode in which the main fans are installed at the inlet and outlet of the intake and return air shaft or in the shaft, respectively, to send the fresh air flow to the underground and discharge the underground dirty air flow to the ground, so that all the air flow in the system is in partial positive pressure and partial negative pressure.

The hybrid ventilation mode has the advantages of both pressure-type and extraction-type. In the inlet and return air sections, the air flow is relatively concentrated, the dust discharge speed is faster, and it is less disturbed by natural air flow. It is a better ventilation mode to improve the efficiency of mine ventilation and dust removal. However, a major disadvantage of hybrid ventilation is that it requires more ventilation equipment and costs more. The common pressure pumping mixed ventilation methods are as follows:

(1) Pre-pressure and post-pumping hybrid ventilation

Pre-compression and post-extraction hybrid ventilation means that the position of the pressure air duct is arranged in front of the extraction duct, which is closer to the end face of the head. In the space of the overlapping part of the two air ducts and the space where the compressed air duct exceeds the exhaust duct, the air flow is mainly affected by the suction negative pressure of the exhaust air, supplemented by the positive pressure of the compressed air jet. Because the positive and negative pressures work together, the suction confluence is strengthened, so this area is called the effective area of suction. In the process of compressed air, as the air flow continuously entrains the surrounding air, the range of air flow jet gradually increases, but the wind speed gradually decreases. After exceeding the effective range, the airflow stops to entrain the surrounding air, and begins to continuously precipitate the air outward. A large amount of airflow reverses back, and a small part of the airflow that continues to move forward will reach the head-on end of the head-on working face, forming an impinging jet wall-attached area. This part of the airflow impacts the front wall to reflect, and then the airflow also begins to reverse flow. When the distance between the outlet of the compressed air duct and the heading face is far away, it is possible to produce local eddy current between the effective range and the end face of the head. Most of the return air flow disappears in the exhaust duct due to the entrainment of the exhaust air, and a very small amount of air flow is subjected to the pressure jet to form a small vortex zone between the jet and the reflux.

(2) Long-pressure and short-pumping hybrid ventilation

Long pressure short pumping refers to the distance from the air duct to the head face of the heading face is greater than the distance from the air duct to the head face of the heading face. Under the condition of safe wind speed that meets the requirements of ' Coal Mine Safety Regulations ', when the distance between the pressure air duct mouth and the end face of the head is within the effective range of the mine, the change of the specific distance between the pressure air duct mouth and the end face of the head is not very different from the flow field of the whole ventilation system, but the distance should not be too close. When the dust is too close, the dust is affected by the high-speed jet of the pressure air outlet, and it continues to spread outward and the pollution range continues to expand, which is not conducive to the dust reduction and dust control of the roadway.

4. Heading Face Airflow Distribution

When the distance from the air outlet to the tunneling face is within the effective range, the airflow field can be divided into jet zone, vortex zone, impinging jet zone and recirculation zone. When the effective range is exceeded, a sub-vortex zone is formed in front of the excavation work, and the existence of the sub-vortex zone is very unfavorable to the migration and diffusion of harmful gases such as dust and gas. It is of great significance to study the airflow field of heading face to prevent gas accumulation. When the distance from the tuyere to the heading face is within the effective range, the airflow field is mainly composed of jet zone, vortex zone, impinging jet zone and recirculation zone. The existence of the impinging jet zone indicates that the airflow can directly impact the heading face, thus ensuring the continuous migration and diffusion of gas and dust and various harmful gases at the heading face.

The cross-sectional area of the jet zone is continuously expanding from the tuyere to the heading face. The field observation found that the wind speed is decreasing from the outlet of the air duct to the heading face. The wind speed at the heading face is much lower than the outlet wind speed, which is unfavorable to the gas diffusion in the heading face. In fact, a considerable part of the ability is destroyed by the vortex zone in the process of the airflow moving forward. The so-called vortex zone is formed by the opposite flow direction of the jet and the backflow and the entrainment of the jet. Under the condition that the wind speed and other conditions remain unchanged, the size of the eddy current zone and its existence are determined by the distance from the tuyere to the tunneling face.

When the distance from the tuyere to the tunneling face exceeds the effective range, there are two eddy current zones on the horizontal plane of the test. The shape of the main eddy current zone is similar to an ellipse, which occupies a large place in the airflow range. When the flow velocity of the air flow is continuously reduced, and the air flow surface is continuously expanded, most of the air flow is refluxed, and a sub-vortex zone is formed in front of the excavation work. According to the analysis of the characteristics of the eddy current, the air flow is continuously circulating in a small area of the heading face. This is extremely unfavorable for the dilution, migration and diffusion of gas, dust and other harmful gases. Especially when the coal body has the tendency of gas outburst, the amount of gas emission increases sharply, which is easy to cause gas accumulation and should be paid special attention to.

5. Measures To Prevent the Accumulation of Harmful Substances Such as Gas

Timely forward air duct

The air duct is moved forward to make the outlet of the air duct within the effective range. The so-called effective range is the longest distance from the outlet of the air duct to the reverse of the jet, represented by Ls. The effective range is related to the size and shape of the excavation section, the diameter of the air duct, the position of the outlet, the outlet wind speed, the distance from the outlet of the air duct to the working face, and the wall roughness.

The distance from the outlet of the air duct to the heading face has a great influence on the distribution of the airflow field. Limited by the construction and space of the working face, the air duct after blasting in the heading face is generally not in the effective range, and the dilution of gas and other harmful substances is limited. Therefore, it is necessary to move the air duct in time after the completion of each construction process to ensure that the air flow can effectively impact the gas and other harmful substances in front of the heading face.

Appropriately increase the air volume

It is proved to be effective to appropriately increase the air volume, that is, to increase the wind speed, within the scope specified in the ' Coal Mine Safety Regulations '. Under the condition that the size and shape of the roadway section, the diameter of the air duct, the position of the air outlet, the distance from the air duct outlet to the working face, and the wall roughness are determined, the effective range of the ventilation jet is determined by the air volume at the outlet. However, the effective power of the general fan is certain, that is, the air volume can only be increased within a certain range. And the increase of air flow will further cause dust production, which will bring harm to the construction of tunneling face.

Export or extract gas

Combined with the gas source of the roadway, in order to fundamentally avoid gas accidents, the most direct method is to cut off the gas source. The gas source of the tunneling face is mainly the coal wall around the tunneling face and the roadway. When the gas content of the coal seam is large, especially the permeability of the coal seam is poor, the damage caused by the tunneling will produce a large amount of gas in an instant. Through the action of airflow, the harmful products such as gas are diluted, and the gas concentration needs a long time or even cannot be reduced to below the safe working range.

Therefore, by arranging extraction boreholes on both sides of the coal body and the excavation roadway in the excavation face, the gas in the coal body is extracted. Due to the influence of the excavation construction, a pressure relief ring and a loose ring are generated in front of and around the excavation, thereby increasing the permeability of the coal body, making the gas more conducive to drainage, and reducing the amount of gas emission from the excavation face.

6. Conclusion and Prospect

Main conclusions

Reasonable selection of ventilation mode, optimization of air flow field structure, dynamic adjustment of ventilation parameters and supplemented by gas drainage measures can effectively control gas accumulation in heading face. The research shows that:

(1) The selection of ventilation mode in tunneling roadway affects the distribution of airflow field. Press-in, pull-out and hybrid ventilation have their own advantages and disadvantages. Among them, hybrid ventilation (such as long-pressure short-pumping, pre-pressure and post-pumping) combines the advantages of press-in and pull-out, which can effectively improve the efficiency of dust removal and gas emission, but the equipment investment is large.

(2) The structure of air flow field determines the migration effect of gas and dust.

In the effective range, the airflow field can be divided into jet zones, vortex zones, impinging jet zones and recirculation zones. The impinging jet zone is helpful to the diffusion of gas and dust. When the effective range is exceeded, the formation of the secondary vortex zone will lead to the accumulation of gas and dust, which will increase the potential safety hazard.

(3) Optimizing ventilation parameters can improve the effect of gas control.

The air duct should be moved forward in time to ensure that the air duct outlet is within the effective range, so as to enhance the direct impact of air flow on the working face. In the safe wind speed range, the air volume should be appropriately increased to improve the effective range, but the relationship between the air volume and the dust generation should be balanced.

(4) Comprehensive measures can effectively reduce the risk of gas accumulation.

The extraction borehole is used to release the coal seam gas in advance to reduce the gas emission during tunneling. Combined with hybrid ventilation (such as long pressure short pumping) to optimize the air flow field, improve the efficiency of pumping, and reduce the adverse effects of vortex zone on gas and dust.

Outlook

(1) With the increase of coal mining depth, the traditional ventilation method is difficult to accurately deal with the distribution of gas and dust under complex geological conditions. In the future, an intelligent ventilation system can be constructed by combining the Internet of Things (IoT), artificial intelligence (AI) and digital twin technology to monitor the airflow field, gas concentration and dust distribution in the tunneling face in real time, and dynamically adjust the fan parameters and air duct layout. For example, machine learning is used to predict the gas emission law at different tunneling stages, automatically optimize the air volume ratio of pressure-drainage hybrid ventilation, reduce the lag of human regulation, and achieve efficient and adaptive ventilation management.

(2) The current research mostly focuses on the single relationship between air flow field and gas migration, while the coupling effect of heat damage, stress field and gas seepage in deep mining has not been fully revealed. In the future, multi-scale numerical simulation (such as CFD-DEM coupling) and physical experiments should be carried out to explore the linkage mechanism of thick and hard roof fracture-crack evolution-gas adsorption / desorption-thermodynamic effect. On this basis, the integrated technology of ' ventilation-cooling-pressure relief-extraction ' is developed. For example, ultra-high pressure hydraulic fracturing is used to actively control the roof cracks, and the problems of heat damage and gas overrun are solved simultaneously by combining directional drilling and low temperature airflow injection.

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