本科毕业设计（论文）

沿空留巷采煤工艺防灭火技术研究

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本文主要研究了沿空留巷采煤工艺防灭火技术，通过数值模拟、理论分析等方法，探讨了沿空留巷工作面自然发火的特点、规律、风险评价和综合防灭火方案。沿空留巷是指在采煤工作面后方沿采空区边缘维护原回采巷道，利用特定的方法对前一个区段的通道进行再次加固，以便下一个区段继续使用，是无煤柱开采技术中的一种方式，可以提高资源利用率和经济效益，避免煤体损失。但由于采空区内遗煤的氧化反应导致遗煤温度升高，沿空留巷也存在着自然发火的危险性，需要采取有效的防灭火措施。

本文的主要研究内容包括以下几个方面：

（1）基于数值模拟方法，建立沿空留巷工作面自然发火的数学模型，分析采空区内遗煤的温度场、氧浓度场、氧化反应速率场等参数的分布规律，探讨漏风量、地应力分布变化等因素对自然发火的影响。

（2）基于理论分析方法，建立沿空留巷工作面自然发火的风险评价模型，综合考虑煤层自燃倾向性、采空区遗煤量、漏风量、氧浓度、温度等因素，确定自然发火的危险性等级和预兆参数。

（3）基于综合防灭火技术方案，设计沿空留巷工作面回采期间的防灭火措施，包括漏风控制技术、注氮降温技术、注浆密闭技术、阻化剂喷洒技术、监测预警技术等，分析各种技术手段和措施的效果和优劣，确定最优化的防灭火方案。

沿空留巷自然发火的机理主要是由于采空区内遗煤的氧化反应和地应力分布的变化引起的。氧化反应会导致遗煤温度升高，地应力分布的变化会导致岩层移动或断裂，从而形成新鲜裂隙和漏风通道，加速氧化反应的进行。当遗煤温度达到自然发火点时，就会发生自然发火现象。

氧化反应是自然发火的主要原因，它受到遗煤的物理性质、化学性质、结构特征等因素的影响。遗煤的物理性质包括比表面积、孔隙率、含水量等，它们决定了遗煤与空气接触的程度和氧化反应的速率。遗煤的化学性质包括元素组成、灰分、挥发分等，它们决定了遗煤的可自然发火性和自然发火点。遗煤的结构特征包括粒度、形态、分布等，它们决定了遗煤的通风条件和氧化反应的范围。

地应力分布是自然发火的诱因之一，它受到开采方式、工作面进度、地质条件等因素的影响。地应力分布的变化会导致岩层移动或断裂，从而形成新鲜裂隙和漏风通道。新鲜裂隙会增加遗煤与空气接触的面积，提高氧化反应的速率。漏风通道会改变采空区内风流的方向和速度，提高氧浓度和温度。这些因素都会降低遗煤的自然发火点，增加自然发火的可能性。

沿空留巷自然发火受到多种因素的影响，主要包括以下几点：

煤层自燃倾向性：不同煤层的自燃倾向性不同，主要取决于煤层的化学组成、物理结构、含水量等因素。一般来说，挥发分高、灰分低、含水量低、比表面积大的煤层更容易自然发火。

采空区遗煤量：采空区遗煤量越大，氧化反应的范围和强度越大，自然发火的可能性越高。采空区遗煤量受到开采方式、工作面进度、回采率等因素的影响。

采空区漏风量：采空区漏风量越大，氧浓度越高，氧化反应的速率和温度越快，自然发火的危险性越大。采空区漏风量受到通风系统、支护方式、地应力分布等因素的影响。

采空区温度：采空区温度越高，氧化反应的活化能越低，自然发火的临界条件越低。采空区温度受到地温、摩擦热、氧化热等因素的影响。

以上因素相互作用，共同决定了沿空留巷自然发火的特点和规律。

沿空留巷自然发火三带分布规律是指在采空区内，根据遗煤的温度、氧浓度、氧化反应速率等参数的变化，将采空区划分为散热带、氧化带和窒息带三个区域。散热带是指靠近工作面的区域，遗煤温度低于自然发火点，氧浓度高于 18%，氧化反应速率较快，但散热速度大于升温速度，遗煤不会自然发火。氧化带是指靠近采空区中心的区域，遗煤温度高于自然发火点，氧浓度在 8%到 18%之间，氧化反应速率较慢，但升温速度大于散热速度，遗煤有自然发火的危险。窒息带是指靠近采空区边缘的区域，遗煤温度低于自然发火点，氧浓度低于 8%，氧化反应速率极慢，遗煤不会自然发火。

沿空留巷自然发火三带分布规律对于防灭火技术的设计和实施具有重要的指导意义。通过确定三带的位置和范围，可以选择合适的防灭火措施和参数，如漏风控制、注氮降温、注浆密闭、阻化剂喷洒、监测预警等。一般来说，防灭火技术的目标是将氧化带转变为散热带或窒息带，从而抑制或消除自然发火现象。因此，在沿空留巷工作面回采过程中，需要根据工作面进度、地质条件、通风系统等因素动态调整防灭火技术方案。

沿空留巷自然发火三带分布规律还可以用于预测和评估自然发火的风险和危害。通过监测采空区内遗煤的温度、氧浓度、气体组成等参数，并结合数学模型和数值模拟方法，可以确定自然发火的临界条件和预警参数 。此外，还可以根据三带分布规律计算最小开采速度和最大停顿时间等指标，以防止或延缓自然发火现象的发生。

综上所述，沿空留巷自然发火三带分布规律是沿空留巷采煤工艺防灭火技术研究的基础和核心内容之一，对于保障沿空留巷工作面的安全生产具有重要意义。

计算流体力学（CFD）是一种利用数值方法和计算机模拟来分析和解决流体流动问题的技术。CFD 可以模拟复杂的流动现象，如湍流、多相流、化学反应等，为工程设计和优化提供有价值的信息。CFD 的基本原理是将流动区域离散化为有限数量的控制体积或网格单元，然后在每个单元上应用质量守恒、动量守恒和能量守恒等基本方程，求解出流场的压力、速度、温度等物理量。

本文采用了 Fluent 软件作为 CFD 求解器，利用有限体积法对沿空留巷工作面自然发火的温度场、氧浓度场、氧化反应速率场等参数进行了数值模拟。Fluent 软件是一种广泛应用于工程领域的通用 CFD 软件，具有强大的物理模型库、网格生成工具、后处理功能和用户自定义能力。

本文使用了 Fluent 软件中的标准 k-ε 湍流模型、稳态求解器、UDF 用户自定义函数等技术，对沿空留巷工作面自然发火的流动现象进行了模拟计算。

本课题以沿空留巷采煤工艺防灭火技术为研究对象，采用数值模拟、理论分析、监测预警等方法，研究了沿空留巷自然发火特点和规律，提出了综合防灭火技术方案，并在开滦矿区某沿空留巷工作面进行了验证和应用。主要得到以下结论：

（1）沿空留巷自然发火的机理主要是由于采空区内遗煤的氧化反应和地应力分布的变化引起的。氧化反应会导致遗煤温度升高，地应力分布的变化会导致岩层移动或断裂，从而形成新鲜裂隙和漏风通道，加速氧化反应的进行。当遗煤温度达到自然发火点时，就会发生自然发火现象。

（2）沿空留巷自然发火的规律主要表现在以下几个方面：一是自然发火的位置主要集中在采空区内部和巷旁充填墙后；二是自然发火的时间主要受到漏风量、氧浓度、温度等因素的影响；三是自然发火的范围主要受到地质条件、开采方式、防灭火措施等因素的影响。

（3）沿空留巷综合防灭火技术方案主要包括以下几个方面：

一是漏风控制技术，通过加固沿空留巷墙体、设置堵塞墙、改变通风系统等方式，减少漏风量，降低氧浓度，抑制遗煤氧化反应；

二是注氮技术，通过在采空区内设置注氮点或注氮管道等方式，在遗煤表面形成一层低氧环境，抑制遗煤自然发火；

三是注浆技术，通过在采空区内设置注浆点或注浆管道等方式，在遗煤表面形成一层隔离层或填充裂隙等方式，阻断漏风通道和遗煤接触；

四是阻化剂喷洒技术，通过在采空区内设置喷洒点或喷洒管道等方式，在遗煤表面喷洒一定浓度的阻化剂液体或粉体等方式，改变遗煤的物理化学性质，降低其可自然发火性；

五是监测预警技术，通过在采空区内设置温度传感器、气体传感器、红外摄像机等设备，在实时监测采空区内温度、气体、图像等参数，并进行数据分析和预警判断等方式，及时发现并处理自然发火现象。

This paper mainly studies the fire prevention and extinguishing technology of gob-side entry retaining coal mining process, and discusses the characteristics, laws, risk assessment and comprehensive fire prevention and extinguishing scheme of natural fire in gob-side entry retaining working face through numerical simulation and theoretical analysis. Gobside entry retention refers to maintaining the original mining roadway along the edge of the goaf behind the coal mining face, and using a specific method to re-reinforce the passage in the previous section so that the next section can continue to be used. It is mining without coal pillars A way in technology can improve resource utilization and economic benefits and avoid coal loss. However, due to the oxidation reaction of the remaining coal in the goaf, the temperature of the remaining coal will rise, and there is also a risk of spontaneous fire in the goaf retention roadway, so effective fire prevention measures need to be taken.

The main research content of this paper includes the following aspects:

(1) Based on the numerical simulation method, establish a mathematical model of spontaneous combustion in the goaf retaining face, analyze the distribution laws of the temperature field, oxygen concentration field, oxidation reaction rate field and other parameters of the remaining coal in the goaf, and discuss the air leakage, Influence of factors such as changes in ground stress distribution on spontaneous combustion.

(2) Based on the theoretical analysis method, establish a risk assessment model for spontaneous combustion in gob-side entry retaining working face, comprehensively consider the spontaneous combustion tendency of coal seam, the amount of coal left in goaf, air leakage, oxygen concentration, temperature and other factors, and determine the risk of spontaneous combustion Hazard levels and warning parameters.

(3) Based on the comprehensive fire prevention technology plan, design fire prevention measures during the mining of gobside entry retaining face, including air leakage control technology, nitrogen injection cooling technology, grouting sealing technology, inhibitor spraying technology, monitoring and early warning technology, etc. Analyze the effects and advantages and disadvantages of various technical means and measures, and determine the optimal fire prevention plan.

The mechanism of spontaneous combustion in gob-side entry retention is mainly caused by the oxidation reaction of residual coal in the goaf and the change of ground stress distribution. The oxidation reaction will cause the temperature of the remaining coal to rise, and the change in the distribution of ground stress will cause the rock formation to move or break, thereby forming fresh cracks and air leakage channels, and accelerating the oxidation reaction. Spontaneous ignition occurs when the temperature of the remaining coal reaches the spontaneous ignition point.

Oxidation reaction is the main cause of spontaneous combustion, which is affected by the physical properties, chemical properties, structural characteristics and other factors of coal residues. The physical properties of coal residue include specific surface area, porosity, water content, etc., which determine the degree of contact between coal residue and air and the rate of oxidation reaction. The chemical properties of residual coal include element composition, ash content, volatile matter, etc., which determine the spontaneous ignition and spontaneous ignition point of residual coal. The structural characteristics of residual coal include particle size, shape, distribution, etc., which determine the ventilation conditions and oxidation reaction range of residual coal.

In-situ stress distribution is one of the causes of spontaneous combustion, which is affected by mining methods, working face progress, geological conditions and other factors. Changes in the distribution of ground stress can cause rock formations to move or fracture, creating fresh cracks and air leakage channels. Fresh fractures will increase the contact area of the remaining coal with the air and increase the rate of the oxidation reaction. The air leakage channel will change the direction and speed of the air flow in the goaf, and increase the oxygen concentration and temperature. All these factors will reduce the spontaneous ignition point of residual coal and increase the possibility of spontaneous ignition.

Spontaneous fire in gob-side alleys is affected by many factors, mainly including the following:

Spontaneous combustion tendency of coal seam: The spontaneous combustion tendency of different coal seams is different, mainly depending on the chemical composition, physical structure, water content and other factors of the coal seam. Generally speaking, coal seams with high volatile content, low ash content, low water content and large specific surface area are more likely to spontaneously ignite.

Amount of residual coal in the goaf: the larger the amount of residual coal in the goaf, the greater the scope and intensity of the oxidation reaction, and the higher the possibility of spontaneous combustion. The amount of coal remaining in the goaf is affected by factors such as the mining method, the progress of the working face, and the recovery rate.

Air leakage in gobs: The greater the air leakage in gobs, the higher the oxygen concentration, the faster the oxidation reaction rate and temperature, and the greater the risk of spontaneous combustion. The amount of air leakage in the goaf is affected by factors such as the ventilation system, support methods, and ground stress distribution.

Gob temperature: The higher the gob temperature, the lower the activation energy of oxidation reaction and the lower the critical condition of spontaneous combustion. The gob temperature is affected by factors such as ground temperature, friction heat, and oxidation heat.

The above factors interact together to determine the characteristics and laws of spontaneous fires in gob-side retaining lanes.

The distribution law of three zones of spontaneous combustion in gob-side retaining means that in the goaf, according to the changes in parameters such as temperature, oxygen concentration and oxidation reaction rate of the remaining coal, the gob is divided into three zones: heat dissipation zone, oxidation zone and suffocation zone. area. The heat dissipation zone refers to the area near the working face, where the temperature of residual coal is lower than the spontaneous ignition point, the oxygen concentration is higher than 18%, and the oxidation reaction rate is fast, but the heat dissipation rate is greater than the heating rate, and the residual coal will not spontaneously ignite. Oxidation zone refers to the area near the center of the goaf, where the temperature of the remaining coal is higher than the spontaneous ignition point, the oxygen concentration is between 8% and 18%, the oxidation reaction rate is slow, but the temperature rise rate is greater than the heat dissipation rate, and the residual coal has spontaneous ignition danger. The suffocation zone refers to the area near the edge of the goaf, where the temperature of the remaining coal is lower than the spontaneous ignition point, the oxygen concentration is lower than 8%, the oxidation reaction rate is extremely slow, and the remaining coal will not spontaneously ignite.

The distribution law of spontaneous fire in gob-side entry retention in three zones has important guiding significance for the design and implementation of fire prevention technology. By determining the location and range of the three zones, appropriate fire prevention measures and parameters can be selected, such as air leakage control, nitrogen injection for cooling, grouting sealing, inhibitor spraying, monitoring and early warning, etc. Generally speaking, the goal of anti-fire suppression technology is to transform the oxidation zone into a heat dissipation zone or a suffocation zone, thereby suppressing or eliminating the spontaneous combustion phenomenon. Therefore, during the mining process of the gobside entry retaining working face, it is necessary to dynamically adjust the fire prevention and extinguishing technical scheme according to the progress of the working face, geological conditions, ventilation system and other factors.

The three-zone distribution law of spontaneous combustion in gob-side retaining can also be used to predict and evaluate the risks and hazards of spontaneous combustion. By monitoring the temperature, oxygen concentration, gas composition and other parameters of the remaining coal in the mined-out area, combined with mathematical models and numerical simulation methods, the critical conditions and early warning parameters of spontaneous combustion can be determined. In addition, indicators such as minimum mining speed and maximum pause time can also be calculated according to the three-zone distribution law to prevent or delay the occurrence of spontaneous combustion.

To sum up, the distribution law of three zones of natural fire in gob-side entry is one of the foundations and core contents of the research on fire prevention and extinguishing technology of gob-side entry coal mining process, and it is of great significance to ensure the safe production of gob-side entry entry working face.

Computational fluid dynamics (CFD) is a technique that uses numerical methods and computer simulations to analyze and solve fluid flow problems. CFD can simulate complex flow phenomena, such as turbulent flow, multiphase flow, chemical reaction, etc., and provide valuable information for engineering design and optimization. The basic principle of CFD is to discretize the flow area into a finite number of control volumes or grid cells, and then apply basic equations such as mass conservation, momentum conservation, and energy conservation to each cell to solve the pressure, velocity, and temperature of the flow field. and other physical quantities.

In this paper, Fluent software is used as the CFD solver, and the numerical simulation is carried out on the temperature field, oxygen concentration field, oxidation reaction rate field and other parameters of spontaneous combustion in the gobside entry retaining working face by using the finite volume method. Fluent software is a general-purpose CFD software widely used in the engineering field. It has a powerful physical model library, mesh generation tools, post-processing functions and user-defined capabilities.

In this paper, the standard k-ε turbulence model, steady-state solver, UDF user-defined function and other technologies in Fluent software are used to simulate and calculate the flow phenomenon of spontaneous combustion in gob-side entry retaining face.

This subject takes the fire prevention and extinguishing technology of gob-side entry retaining coal mining technology as the research object, adopts methods such as numerical simulation, theoretical analysis, monitoring and early warning, etc., to study the characteristics and laws of natural fire in gob-side entry retaining, and proposes a comprehensive fire prevention and extinguishing technical plan, and It has been verified and applied in a gobside entry retaining face in Kailuan mining area. The main conclusions are as follows:

(1) The mechanism of spontaneous combustion in gob-side entry retention is mainly caused by the oxidation reaction of residual coal in the goaf and the change of in-situ stress distribution. The oxidation reaction will cause the temperature of the remaining coal to rise, and the change in the distribution of ground stress will cause the rock formation to move or break, thereby forming fresh cracks and air leakage channels, and accelerating the oxidation reaction. Spontaneous ignition occurs when the temperature of the remaining coal reaches the spontaneous ignition point.

(2) The law of spontaneous combustion in gob-side entry retention is mainly manifested in the following aspects: First, the location of spontaneous combustion is mainly concentrated inside the gob and behind the filling wall beside the roadway; second, the time of spontaneous combustion is

mainly affected by the amount of air leakage, Oxygen concentration, temperature and other factors; third, the scope of spontaneous combustion is mainly affected by geological conditions, mining methods, fire prevention measures and other factors.

(3) The technical scheme of comprehensive fire prevention and extinguishing for gob-side entry retention mainly includes the following aspects:

The first is air leakage control technology, which reduces air leakage, reduces oxygen concentration, and inhibits the oxidation reaction of residual coal by strengthening the walls of gob-side entry retaining, setting up blocking walls, and changing the ventilation system;

The second is nitrogen injection technology. By setting nitrogen injection points or nitrogen injection pipelines in the goaf, a layer of low-oxygen environment is formed on the surface of the remaining coal to inhibit the spontaneous combustion of the remaining coal;

The third is grouting technology. By setting grouting points or grouting pipes in the goaf, an isolation layer is formed on the surface of the remaining coal or cracks are filled to block the contact between the air leakage channel and the remaining coal;

The fourth is the inhibitor spraying technology. By setting spraying points or spraying pipes in the goaf, a certain concentration of inhibitor liquid or powder is sprayed on the surface of the remaining coal to change the physical and chemical properties of the remaining coal and reduce the its pyrophoric properties;

The fifth is the monitoring and early warning technology. By setting up temperature sensors, gas sensors, infrared cameras and other equipment in the goaf, the temperature, gas, image and other parameters in the goaf are monitored in real time, and data analysis and early warning judgments are carried out. Detect and manage spontaneous pyrotechnics.