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Study on Prevention System Construction of Coal Mine Gas Accident

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Abstract: The occurrence of coal mine gas accident seriously affects the coal mine safety production. It has important practical significance and value to carry out the study of gas accident prevention. Based on the analysis of the characteristics and causal theories of coal mine gas accidents, a coal mine gas accident causation model was studied and constructed. A coal mine gas accident prevention system was proposed, which focuses on four aspects: safety policy guidelines and current situation analysis, coal mine gas safety evaluation, formulation and implementation of preventive measures, and inspection and feedback of measure effectiveness. The research ideas and conclusions can provide reference and guidance for the prevention and control of coal mine gas accidents in China to a certain extent.

Keywords: Gas Accident; Theoretical Analysis; Causation Model; Prevention System; Safety Evaluation.

1. Introduction

Preventing coal mine gas accidents has become a major issue of concern for coal mine safety [1]. The occurrence of gas accidents involves many aspects of coal mine safety, and the influencing factors are numerous and variable [2-3]. At present, gas accident prevention mainly focuses on the construction of relevant laws and regulations, safety evaluation, and other aspects. The construction of laws and regulations related to coal mine safety in China started relatively late. The Coal Mine Safety Regulations issued by China in 2001, after continuous improvement and refinement, have now become the most authoritative basis and standard for coal mine production [4]. The prevention of coal mine accidents in foreign countries started earlier and has developed relatively well in various aspects. Moreover, foreign coal mine safety laws and regulations have dedicated regulatory systems to supervise and manage enterprises. In recent years, with the increasing attention paid to coal mine safety, research on safety evaluation has entered a new stage of development [5-6]. The application of modern mathematical theories, computer expert systems, decision support systems, and computer technology has opened up a broader prospect for security analysis and evaluation [7-10].

At present, there are common problems in the prevention system of coal mine gas accidents at home and abroad, such as one-sided accident analysis and single prevention mode. The effectiveness of the prevention system in practical application in coal mines is also not ideal [11]. Therefore, based on the analysis of the characteristics and causes of gas accidents, combined with the current situation of coal mine gas safety, it is of great practical significance to study and establish a systematic and comprehensive coal mine gas accident prevention system.

2. Analysis of Characteristics of Coal Mine Gas Accidents

2.1. Types of Coal Mine Gas Accidents

There are three main types of coal mine gas accidents, namely gas suffocation, gas explosion, and coal and gas outburst.

(1) Gas suffocation refers to a personnel suffocation accident caused by an increase in gas content, resulting in a decrease in air content in the underground space and insufficient oxygen content. When the gas concentration exceeds 57%, the oxygen concentration in the air will decrease to below 10%. If it enters tunnels, single headed alleys, etc. with undetected gas content, it can lead to hypoxia, suffocation, and even death of personnel.

(2) Gas explosion is a chain reaction, which is essentially a violent oxidation reaction produced by the action of a certain concentration of methane and oxygen. The chemical reaction equation can be written as:

$$CH_4 + 2O_2 = CO_2 + 2H_2O \quad (1)$$

The conditions for gas explosion are: a certain concentration of gas (5%~16%), a high-temperature fire source (650℃~750℃), and sufficient oxygen (over 12%). The harmful factors of coal mine gas explosions mainly include high temperature, shock waves, and harmful gases.

(3) Coal and gas outburst is a phenomenon that coal (rock) and gas are ejected into the mining space at an extremely fast speed in a very short time during the underground mining process of coal mines, under the combined effect of ground stress, gas and the physical and mechanical properties of coal. Ground stress and the physical and mechanical properties of coal are conditions for triggering outburst, while gas is a necessary condition for achieving outburst. Highlighting can not only destroy tunnel facilities, damage ventilation systems, and cause casualties, but in severe cases, it can also cause gas combustion or explosion, leading to the occurrence of fires and roof accidents [12-13].

2.2. Characteristics of Coal Mine Gas Accidents

Through statistical analysis of coal mine gas accidents that have occurred in China over the years, it is summarized that coal mine gas accidents in China have the following characteristics [2,12,14-16]:

(1) Coal mine gas accidents pose significant hazards. The

consequences of coal mine gas accidents are severe, with huge economic losses and heavy casualties. With the increasing attention paid to gas accidents, the number of deaths from gas accidents each year gradually decreases, but still accounts for about 25% of all deaths.

(2) Coal mine gas accidents occur frequently. Statistical analysis of the number of major coal mine accidents in the past two decades shows that gas accidents account for 65% of all major accidents, equivalent to four times the number of coal mine roof accidents, and are the greatest threat to coal mine safety production.

(3) There are significant differences among coal mining enterprises of different natures. The mortality rate of gas accidents per million tons in state-owned key coal mines is 1/3 and 1/8 of that in state-owned local coal mines and township individual coal mines, respectively. The root cause lies in the inadequate management and weak safety awareness of local township coal mines compared to state-owned key coal mines.

(4) There are significant regional differences. The regional differences in gas occurrence have led to significant regional differences in coal mine gas accidents in China. Statistical analysis of gas accidents in recent years shows that Guizhou has the highest number of gas accidents in China, followed by Hunan, Yunnan, Sichuan, Chongqing, and Shanxi.

(5) Highly influenced by management factors. Management errors are a prominent cause of coal mine gas accidents. Investigation and analysis have found that state-owned and large coal mines have a lower probability of gas accidents compared to township and small coal mines. Many human errors, material defects, and environmental degradation that lead to coal mine gas accidents ultimately stem from significant deficiencies in the safety production management of coal mining enterprises.

3. Theoretical Analysis of the Causes of Gas Accidents in Coal Mines

3.1. The Proposal of the Cause Theory of Coal Mine Gas Accidents

To prevent accidents from occurring, describing the essence of accidents through theories and models is called accident causation theory. This theory reflects the laws of accidents and can provide quantitative and qualitative analysis of accidents. While learning from experience and lessons, it also provides a basis for safety evaluation of similar accidents in the future. Representative accident causation theories include: human error theory, management error theory, accident causality theory, trajectory intersection theory, energy transfer theory, etc. [17].

The early theories on the causes of coal mine gas in China were limited by the level of technology and the times, and failed to deeply understand the essential reasons for accidents. With the deepening of research on coal mine accidents, especially the development and application of system safety theory, a comprehensive analysis method for the causes of coal mine gas accidents has been proposed. This method analyzes the causes of accidents from the perspectives of human, machine, environment, and management at a deep and multiple levels.

Through the analysis of numerous coal mine gas accident cases, the following conclusions can be drawn: (1) The direct causes of gas accidents are generally composed of three factors: unsafe human behavior, unsafe state of objects, and unsafe environment. Two or three factors among them jointly contributed to the occurrence of the accident. (2) The main indirect causes of gas accidents are defects in people, objects, environment, and information. The existence of defects leads to unsafe behaviors, states, and environments. (3) The indirect causes of accidents are not out of thin air, and defects in people, objects, environment, and information are also caused by certain reasons. Management defects are the fundamental cause of coal mine gas accidents.

In summary, the causal theory of coal mine gas accidents in China can be summarized as follows: the occurrence of coal mine gas accidents is fundamentally due to the emergence of management defects, which bring about defects in various aspects such as people, objects, environment, and information. These defects blend and affect each other, leading to unsafe human behavior, unsafe state of objects, and unsafe environment. These three factors combine in a certain time and space, ultimately leading to the occurrence of coal mine gas accidents.

3.2. Establishment of Causal Model for Coal Mine Gas Accidents

By analyzing the cause theory of coal mine gas accidents, a corresponding coal mine gas accident cause model is established as shown in Figure 1. The first layer of the model is the fundamental cause of accidents - management reasons, the second layer is the indirect cause of the accident - defects in people, objects, environment, and information, and the third layer is the direct cause of accidents - unsafe human behavior, unsafe state of objects, and unsafe environment. The combination of the unsafe state of objects and the unsafe environment among these three forms a hidden danger. Once the hidden danger is triggered by human unsafe behavior, it can lead to accidents. From the model, it can be seen that management factors not only affect people and information, but also, in turn, influence the decisions of managers. In addition, information defects are often fatal. They can not only induce managers to make mistakes in management, but also directly lead to unsafe behavior of people, unsafe state of things, and unsafe environment.

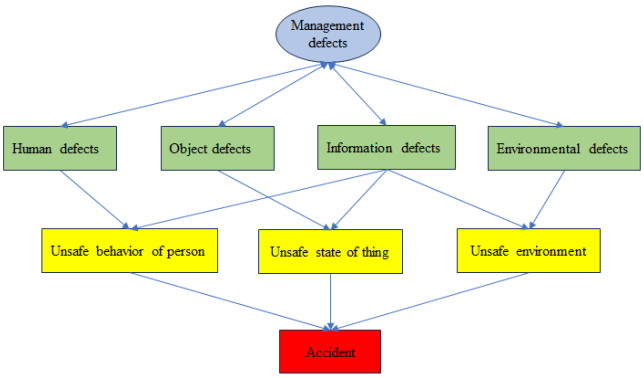

Figure 1. Causal model of coal mine gas accidents

3.3. Analysis of Causal Model for Coal Mine Gas Accidents

Based on the analysis of the direct causes of gas accidents, it can be concluded that human unsafe behavior refers to the "three violations" that affect the occurrence of gas accidents, namely illegal command, illegal operation, and violation of labor discipline [18]. These behaviors are the direct causes of coal mine gas accidents. The unsafe state of objects refers to the lack of necessary equipment and facilities related to coal

mine gas safety, or the improper operation of these equipment settings. Coal mine gas accidents are largely caused by these safety facilities and equipment being in an unsafe state. Unsafe environment generally refers to the natural and operational conditions that directly cause coal mine accidents. In coal mine gas accidents, unsafe environment mainly refers to the accumulation and outburst of gas.

Based on the analysis of the indirect causes of gas accidents, it can be concluded that human defects refer to the shortcomings and shortcomings of coal mine employees themselves, mainly in terms of human habits, psychological states, and other aspects. Human defects prompt people to engage in unsafe behavior, which in turn leads to accidents. The defects of materials mainly refer to insufficient investment in safety, incomplete facilities, and non-standard protective devices in coal mining enterprises, which reduce the resistance of coal mines to gas accidents. The defects in information mainly include information defects in the production process, information defects of internal managers, and external information defects of the enterprise. Information defects induce managers to make mistakes in decision-making. Environmental defects refer to the adverse natural conditions and working environment that may lead to accidents. The numerous gas mines, complex geological conditions, and high incidence of natural disasters in China, coupled with unreasonable ventilation design and mining replacement, further pose higher challenges to the safety production of coal mines in China.

Based on the analysis of the fundamental causes of gas accidents, it can be concluded that the deficiencies in coal mine management include two aspects: internal management deficiencies within the enterprise and external management deficiencies within the enterprise. The internal safety management of enterprises should be responsible for the entire safety production process, which is the core and key to coal mine safety production. It mainly includes safety management rules and regulations, production responsibilities, management institutions, safety investment, and training and education. External management deficiencies of enterprises refer to the supervision and management of coal mines by the government and coal mine safety supervision departments outside the enterprise. Through safety inspections, safety hazards in coal mines can be identified in a timely manner, and they can be urged to rectify them to prevent coal mine accidents from occurring.

4. Coal Mine Gas Accident Prevention System

Coal mine gas accidents are caused by multiple factors working together. To fundamentally reduce the occurrence of gas accidents, it is necessary to establish and improve a reliable and effective coal mine gas accident prevention system, and control the risk factors of coal mine gas accidents.

4.1. Construction of Coal Mine Gas Accident Prevention System

The establishment of a coal mine gas accident prevention system should first fully analyze the evolution process of coal mine gas accidents. On the basis of analyzing the causal model of coal mine gas accidents, the evolution process of the accident is vividly represented, and the evolution model of gas accidents is shown in Figure 2. The danger incubation period, development period, and outbreak period in Figure 2 correspond to three different coal mine gas safety states: safety, danger, and accident. In a safe state, the possibility of gas accidents is extremely low, and defects in people, objects, environment, etc. are in the latent period. In a dangerous state, the probability of coal mine gas accidents increases, and unsafe behaviors, states, and environments caused by defects are in a dangerous development period. Dangerous factors interact and influence each other within a certain time and space, and are stimulated by certain factors, ultimately leading to the occurrence of gas accidents. Therefore, only by controlling defects in people, objects, environment, information, and other aspects within the danger incubation period can the occurrence of gas accidents be fundamentally reduced.

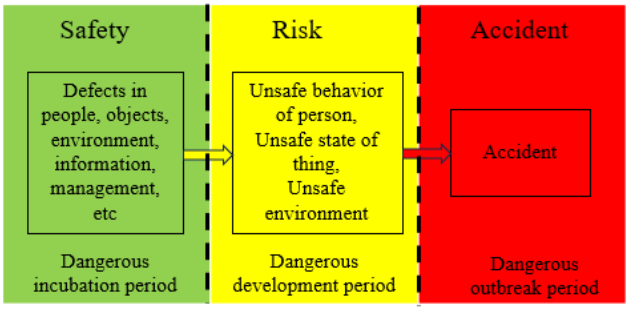

Figure 2. Evolution model of gas accidents

The current coal mine gas accident prevention system in China has problems such as one-sided accident analysis and single prevention modes. Based on the analysis of the characteristics and causes of coal mine gas accidents, combined with the current situation of coal mine gas safety, a systematic, comprehensive, and practical coal mine gas accident prevention system has been established, as shown in Figure 3.

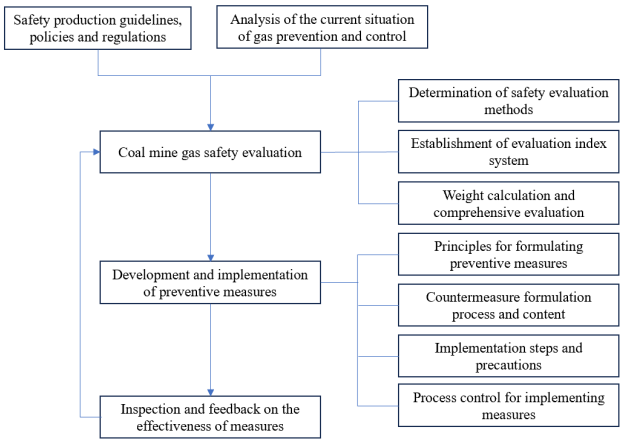

Figure 3. Coal mine gas accident prevention system

Starting from the analysis of the causes of coal mine gas accidents, the prevention system organizes and statistically analyzes a large amount of accident case data to determine the causes of gas accidents, thereby making the prevention of coal mine gas accidents rational and systematic. The coal mine gas accident prevention system includes four parts: analysis of safety policy guidelines and gas prevention and control status, coal mine gas safety evaluation, formulation and implementation of preventive measures, and inspection and feedback of measures effectiveness. These four aspects are closely connected to form a scientifically reasonable prevention system.

4.2. Coal Mine Gas Safety Evaluation

Coal mine gas safety evaluation refers to analyzing the various factors of coal mine gas accidents based on the current situation of coal mine gas, identifying the existing problems, and presenting them in qualitative and quantitative forms to formulate corresponding preventive measures. The existing safety evaluation methods include comprehensive analysis method, fuzzy comprehensive evaluation method, analytic hierarchy process, accident tree analysis method, safety checklist method, etc. Based on the actual situation of coal mine gas accidents, the comprehensive safety evaluation method is a suitable method for coal mine gas safety evaluation, which is in line with the purpose of coal mine gas safety evaluation.

By combining the causal model of coal mine gas accidents and extracting typical cases of gas accidents in China for analysis, it can be concluded that the corresponding primary indicators affecting coal mine gas safety are safety management factors, personnel quality factors, equipment and facility guarantee factors, environmental factors, and information factors. These five factors work together to affect the safety of coal mine gas. Conduct statistical analysis on the main influencing factors under each primary indicator, for example, safety management factors include seven aspects: safety regulations and systems, technical management, safety management institutions, safety inspections, safety investment, emergency rescue system, and external supervision. The analysis of the main influencing factors under other primary indicators will be extended accordingly, and will not be further elaborated here.

4.3. Development and Implementation of Preventive Measures

The prevention system should not only identify the defects and hidden dangers in coal mine gas safety, but also eliminate them to ensure the safe production of coal mines. Therefore, it is necessary to develop and implement coal mine gas accident prevention measures. The formulation of accident prevention measures must follow the principles of pertinence, rationality, and economic optimization. The process of formulating coal mine gas accident prevention measures is shown in Figure 4. For the implementation of prevention measures for coal mine gas accidents, the first step should be to allocate relevant responsibilities and work based on the formulated prevention measures, clarify the work content of each person, and formulate corresponding job responsibilities accordingly. Secondly, a detailed implementation plan should be developed to ensure the implementation of countermeasures from the perspectives of responsible persons, methods, costs, time, etc.

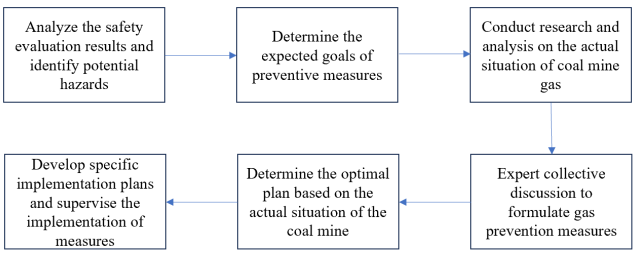

Figure 4. Flow chart of formulating prevention measures for coal mine gas accidents

4.4. Inspection and Feedback on the Effectiveness of Measures

The inspection of the implementation effect of preventive measures requires that the implementation effect inspection must be carried out during and after the implementation of the measures. The implementation effect inspection can be divided into two types: one is a separate effect analysis applied during the implementation process, which refers to the analysis of the implementation effect after the preventive measures have been implemented to a certain stage. This effect analysis is combined with the implementation and review of the countermeasures, and is a part of the implementation of the countermeasures. Another type is overall effect analysis, which refers to the analysis of the overall effect after the implementation of countermeasures. After the conclusion is drawn through the implementation effect test, if the hidden dangers have been eliminated and the prevention purpose has been achieved, the entire prevention process will be organized and archived as a reference for future accident prevention. If the hidden danger of the accident still exists, it is necessary to summarize the reasons and lessons of the ineffective measures, and formulate more effective preventive measures according to the prevention system, in order to achieve feedback on the effectiveness of the measures.

5. Conclusion

A study was conducted on the construction of a coal mine gas accident prevention system. Based on the analysis of the characteristics and causal theory of coal mine gas accidents, a causal model suitable for coal mine gas accidents was established. Finally, a coal mine gas accident prevention system was proposed, which includes four aspects: safety policy guidelines and current situation analysis, coal mine gas safety evaluation, formulation and implementation of preventive measures, and inspection and feedback of measure effects. This provides reference and basis for coal mine gas governance and prevention work.

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