Research on explosion suppression technology of low- concentration gas transmission pipeline

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Abstract：In order to effectively control the explosion accident disasters of low-concentration gas transmission pipelines and improve the safety of low-concentration gas transmission and utilization process, the paper has summarized and analyzed the current three types of low-concentration gas transmission pipeline explosion suppression technologies and devices used in the field, including powder suppression, inert gas suppression and fine water mist suppression, and put forward the problems of coal mine gas transmission pipeline explosion suppression technologies. It is of great practical significance to pipeline transmission and utilization of low-concentration gas.

1 Introduction

Gas is a kind of hydrocarbon gas associated with coal, and it is a high quality clean energy. The vast majority of coal mines in my country are gas mines, among which high gas mines and gas outburst mines account for about 44% of the total. The state attaches great importance to the development and utilization of coalbed methane and coal mine gas. The safety guarantee of the coal mine gas pipeline transmission and utilization system is of great significance to the safe production of coal mines and the efficient and reasonable allocation of resources.

Domestic and foreign institutions and scholars have conducted research on the mechanism of gas combustion and explosion, development and utilization, and explosion propagation characteristics. The American Gas Institute has optimized various parameters of the elementary reaction, and the research has formed the GRI-Mech3.0 mechanism, it contains 325 elementary reactions of 53 substances. Wang Qiuhong[1] and others used rectangular pipeline devices to conduct explosion experiments on gas with different volume fractions to study the pressure and temperature characteristics of gas explosion. Wang Lei[2] and Qiu Ruilai[3] studied the changes of characteristic parameters such as explosion pressure and flame velocity in pipelines with different concentrations of gas. Explosion suppression technology is one of the important measures to control gas explosion disasters in pipelines, and explosion suppression materials are a key factor affecting the performance of explosion suppression devices. Scholars at home and abroad have conducted many studies on the explosion suppression and fire extinguishing performance of powder fire extinguishing agent, inert gas, fine water mist and other materials. The effects and differences of parameters such as suppression of explosion pressure and pressure rise rate provide data support for the development and application of automatic explosion suppression devices.

The government has put forward the idea of "establishing the concept of safety development" and "safety first". In order to effectively control the explosion accident of low-concentration gas transmission pipelines and improve the safety of low-concentration gas transmission and utilization, the paper summarized and analyzed the current research status of domestic explosion-proof technology theories and devices, and pointed out the main problems existing in current research and practical applications. It provides a reference for the construction and development of low-concentration gas pipeline transmission and utilization systems.

2 Explosion risk analysis

Since the "Twelfth Five-Year Plan", the number of coal mines in China has fallen to more than 5,800 pairs, but the amount of underground coalbed methane gas extraction has increased to more than 18 billion cubic meters, and both the extraction volume and the utilization rate have steadily increased. At present, the utilization rate of underground gas extraction is still at a low level, and the technology for the utilization of low-concentration gas in coal mines is not mature enough. The safety problem in the process of low-concentration gas transmission is an important reason why the domestic gas utilization rate is low and the low-concentration gas cannot be effectively used.

The utilization rate of underground gas extraction in China is still at a low level. Most of the gas extraction is the gas extracted from the goaf or mining pressure relief area, and more than 70% of the gas extraction volume has

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a gas concentration of less than 30%[4], belonging to the range of low-concentration gas extraction, and a considerable part of the gas extraction concentration is lower than 20%. In the process of gas transmission, the gas concentration is not stable, and it is easy to mix with air during gas extraction. On the one hand, an oxygen-containing atmosphere is formed, and on the other hand, the gas concentration decreases. Low-concentration gas that is within the explosion limit or under special environmental conditions encounters electrostatic sparks、friction sparks and other ignition sources, which may cause explosion accidents in the conveying pipeline system.

Gas pipelines are special pipelines used for gas extraction、transmission and utilization in coal mines. Regardless of underground or ground extraction, they are long-distance from the extraction port to the emptying and utilization pumping station, and there is a danger of explosion. At present, non-metallic pipelines have been widely used in coal mine gas extraction and transmission systems. However, non-metallic pipelines have the problem that their antistatic performance does not meet the standard or gradually decreases during long-term use. It is easy to generate static electricity and detonate the gas in the pipeline.

The minimum ignition energy of gas is determined by the gas concentration in the air, the initial pressure, the energy of the fire source and its release intensity and time of action. Extraction pipelines often accumulate coal powder, the friction between coal powder and the inner wall of the pipeline will generate static electricity. When the gas concentration in the pipeline is within the explosion limit, the static electricity generated by friction may cause the gas in the pipeline to burn and explode. On the ground, the low-concentration gas venting nozzle will cause a lightning strike or other fire sources to cause a gas explosion at the venting nozzle, and the explosion will enter the venting pipe, causing the explosion to spread, then destroying the ground pumping station and the extraction system. The internal combustion engine generator set of low-concentration gas power generation device may generate backfire, enter the intake pipe, cause an explosion, It will spread along the transmission pipelines, putting the entire system in a dangerous state.

3 Explosion suppression technology of low- concentration gas transmission pipeline

3.1 Explosion suppression mechanism analysis

Explosion suppression media can be divided into powder, inert gas and fine water mist according to the existence form and suppression effect. The suppression effect can be divided into physical suppression and chemical suppression. The suppression effect is better when the concentration of the medium increases. ABC dry powder fire extinguishing agent is a colorless and transparent tetragonal crystal. It is prone to multi-step decomposition reaction under high temperature conditions. Each step of decomposition reaction is endothermic reaction[5]; inert gas exists in liquid state in the tank of the explosion suppression device and vaporizes quickly after spraying; the fine water mist rapidly vaporizes at high temperature to form water. These changes have a good cooling effect, which can reduce the ambient temperature of the combustion zone [6] and reduce the reaction rate.

No matter what kind of explosion suppression medium, after decomposition or gasification, it will generate a large amount of inert gases such as ammonia, carbon dioxide, water vapor, etc., which can dilute the concentration of combustible gas and oxygen in the combustion system and have a suffocating effect. In addition, the inert gas can block the contact of methane and oxygen, and play a role of isolation and blocking.

The free ammonia generated by the decomposition of ABC powder can be combined with OH, O and other free radicals in the methane explosion process to reduce the number of active free radicals. The addition of CO_2 or other inert gases reduces the concentration of active free radicals such as H, O, OH and CH_3, which can inhibit the dissociation of free radicals and reduce the concentration of active centers in the reaction. When the inert gas or intermediate products generated by the decomposition and conversion of the explosion suppression medium are sufficient, the consumption rate of the reaction radicals is greater than the generation rate, the chain reaction is terminated, and the explosion is completely suppressed.

3.2 Automatic powder spraying explosion suppression technology and device

The automatic explosion suppression technology relies on the advanced detection of the combustion or explosion information of the gas pipeline, and automatically ejects the explosion suppression medium to extinguish the flames propagated by the combustion or explosion, which controls the explosion disaster to a minimum. The automatic explosion suppression device for mine gas pipeline is composed of ultraviolet principle flame sensor, controller, pipeline explosion suppressor and adaptable electric source. The explosion suppression powder used in the automatic powder spraying explosion suppression device is mainly ABC and BC dry powder fire extinguishing agent or its modified materials, and its main components are $NH_4H_2PO_4$ and $NaHCO_3$.

The working principle of automatic powder spraying explosion suppression device is shown in Figure 1. The overall response time of the automatic powder spraying explosion suppression device is less than 35ms, and the spraying of the explosion suppression medium can be completed within 150ms [7]. When the fire source of the gas transmission pipeline causes a combustion and explosion, the sensor converts the combustion or explosion flame into an electrical signal and transmits it to the controller. The controller sends an instruction to trigger the detonator action, and a large amount of gas is generated in the detonator to drive the detonator at an instant. The anti-explosion agent is sprayed from the spraying mechanism to quickly form a high-concentration anti-explosion barrier, fully contact with the flame surface, absorb the energy

of the flame, terminate the combustion chain, and extinguish the flame, so as to stop the spread of the flame surface in the pipeline.

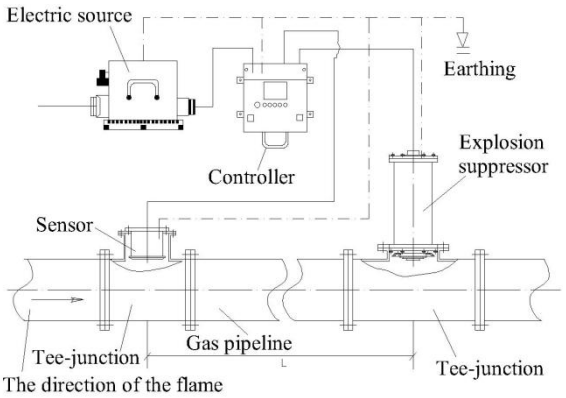

Fig.1 Working principle of automatic powder spraying explosion suppression device

Fig.2 Automatic powder spraying explosion suppression device

3.3 Automatic inert gas explosion suppression technology and device

The explosion suppression medium of the automatic inert gas explosion suppression device mainly includes carbon dioxide、heptafluoropropane, etc., its composition structure is the same as that of the automatic powder spraying explosion suppression device, as shown in Figure 3. The inert gas is stored in a liquid state under high pressure. The explosion suppression device adopts the principle of pressure storage. The working pressure is generally 7~9MP. The pressure in the gas cylinder is monitored by the pressure gauge in real time. The explosion suppression device based on the pressure storage principle eliminates the process of gas production and pressurization, and the spraying lag time is short, which can suppress gas explosion accidents more quickly. The spraying lag time of the inert gas explosion suppression device is less than 5ms, the spraying duration is greater than 1000ms, and the spraying efficiency is greater than 99%.

Fig.3 Automatic inert gas explosion suppression device

The quick opening mechanism is one of the key components of the rapid action of the pressure storage explosion suppression device. The opening pressure can be calibrated, the action response speed is fast, and the pressure is high. In the initial stage of the explosion, the quick-opening mechanism of the explosion suppressor opens rapidly, and the liquid inert explosion-suppressing medium is quickly vaporized and sprayed out of the tank to form an effective explosion-proof barrier. Compared with powder media, inert gas has high stability, it can be stored and used for a long time, and it has the characteristics of cleanliness and environmental protection.

3.4 Automatic fine water mist explosion suppression technology and device

Fine water mist refers to a water mist with a droplet diameter of less than 400 μ m and a volume that accounts for more than 50% of the total water mist droplet volume. The specific heat capacity of water is high, and the specific surface area of the fine water mist is large, it is easy to evaporate to form water vapor. It has the characteristics of high-efficiency cooling and extinguishing, safety and pollution-free. The automatic fine water mist explosion suppression device generates fine water mist at equal distances on the gas pipeline transmission path through the circulating water pump and the water mist generator, and forms a multi-level explosion prevention and control measure with the wet fire and explosion venting device and the flame arrester. Its safe transmission process is described in the industry standard AQ1078-2009.

The explosion suppression effect of fine water mist is mainly reflected in physical suppression. In order to improve the explosion suppression performance, in recent years, scholars at home and abroad have changed the physical and chemical properties of fine water mist, such as adding additives, charged fine water mist and other measures[8], so that it has a chemical suppression effect, the suppression effect of parameters such as explosion pressure and pressure rise rate is better and prominent. As water freezes at low temperatures, it loses its gas explosion suppression effect, and the application of the safety protection system for gas pipeline transmission in the north is obviously limited.

4 Problems

(1) There are still many problems to be solved in the domestic research on explosion propagation dynamics in low-concentration gas transmission pipelines. With the improvement of experimental conditions and experimental test methods, theories of explosion propagation characteristics and mechanism of action need to be further studied to ensure gas pipelines transmission safety and improve the utilization rate of low-concentration gas.

(2) At present, due to the improvement of gas extraction technology and pipeline transmission capacity, the scale of gas transmission pipeline generally reaches 1000mm in diameter and above. However, there is a lack of systematic research on gas explosion propagation characteristics and explosion suppression technology in large-scale pipelines, and there is a lack of direct experimental data and theoretical support.

(3) Due to the lack of data support for the propagation characteristics of the characteristic parameters of gas explosion propagation under large-scale and long-distance conditions, there is no national or industry technical standard for large-scale explosion suppression equipment, there is no inspection specifications for performance verification, which Severely restricts the development and application of gas pipeline explosion prevention and control devices for large-scale conditions.

5 Conclusions

(1) Analyze the current explosion suppression technologies and devices of low-concentration gas transmission pipeline, including powder spraying explosion suppression, inert gas explosion suppression and fine water mist explosion suppression. The automatic powder spraying explosion suppression device can complete the spraying within 150ms, and the spraying duration of the automatic inert gas explosion suppression device is more than 1000ms.

(2) Due to the limitation of realization conditions, gas explosion propagation dynamics, pipeline explosion suppression technology and prevention equipment under large-scale pipeline conditions are restricted, and further research and solutions are urgently needed.

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