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Brief Communication

Normalizing Fire Prevention Technology and a Ground Fixed Station for Underground Mine Fires Using Liquid Nitrogen: A Case Study

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Abstract. Coal mine fires continuously attract the attention of researchers recently. Firefighting is the most important activities for protecting the mining safety and coal resources at the same time. Among them, liquid nitrogen is usually employed as emergency treatment for sudden fire accidents. However, it as a normalized fire prevention technology is still in the blank. Subsequently, a new system called ground fixed liquid nitrogen station has been developed for normalizing fire prevention. It took 5 months to build such total flooding fire extinguishing systems in JF colliery, with a maximum flow rate: 5000 Nm^3/h, pressure: 1.0 ± 0.05 MPa, high purity: $\geq 99.99\%$, and outlet temperature of CGN is 10°C lower than the atmospheric temperature. Field observations showed that it only took 3 days for the concentration of CO to decrease by 95.36%. The main fire extinguishing mechanism of the system is the nitrogen inertization, and the cooling effect is supplemented. By using the presented technique, there was no waste left behind. Thus, it is concluded that the newly developed firefighting system can be put into practice, especially its broad application prospects in large capacity collieries.

Keywords: Coal mine fires, Liquid nitrogen, Ground fixed fire extinguishing system, Inerting

1. Introduction

The majority of fires in coal mines are caused by the spontaneous combustion of coal. As one of the serious natural or artificial disasters in coal mine production (both underground and open pit), coal fires occur all around the world [1, 2].

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Numerous types of hazards are caused by coal's spontaneous combustion, such as safety, economic, environmental and ecological issues.

Firefighting is the most important activity for preventing underground fires and thus protecting mining safety, the environment and coal resources. Various techniques have been developed and widely applied in mines, including grouting, the spraying of chemical inhibitor, the injection of inert gases, gel, or foam, and so on [3]. Cryogenic grouting is also one of the most essential means of prevention. From the existing options, liquid nitrogen is selected as the research object of this paper. Liquid nitrogen is a potentially more efficient firefighting agent, and the vapour after vaporization is an unreactive gas [4, 5]. In view of previous applications [3, 6], liquid nitrogen for fire extinguishing has been entirely passive for emergency use. In other words, such a fire prevention system would delay the fire extinguishing time. Thus, normalizing fire prevention technology and a ground fixed station for underground mine fires using liquid nitrogen is presented in this paper. It can serve as both an emergency method and a normalizing fire control technology.

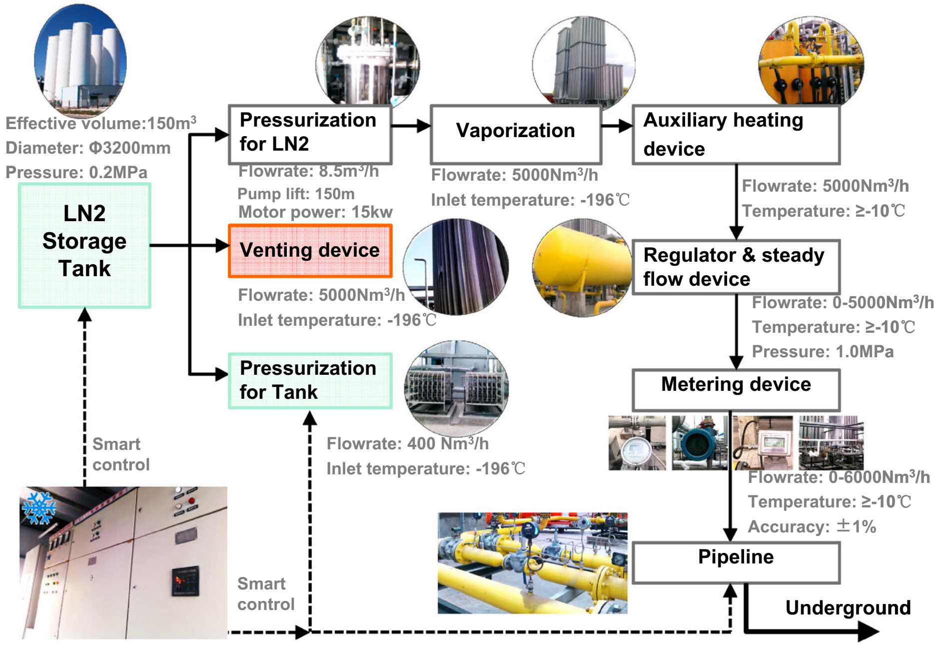

Figure 1. Schematic diagram of the ground fixed liquid nitrogen system for underground fire prevention (the main components of system include liquid nitrogen storage and booster device in green, delivery system in grey and safety assistance system in red) (Color figure online).

2. System Descriptions

The main structure of the device is composed of three parts: liquid nitrogen storage, a delivery system, and a safety assistance device (Fig. 1).

2.1. Liquid Nitrogen Storage and Booster Device

Liquid nitrogen storage is made of carbon structural steel (material: 06Cr19Ni10) with a yield point of 235 MPa. The effective volume of a single tank is 150 m^3. The inner diameter of the container is 3200 mm, and the outer diameter is 3700 mm. The total height of the tank is 23 m, and pearlite powder fills the mezzanine while the vacuum insulation is pumped simultaneously. The liquid nitrogen comes from the coal chemical plant, and the purity is greater than 99.99%.

When the storage tank is working, the pressure in it will decrease. To ensure the vaporization effect of liquid nitrogen, one set of pressurization for the tank is designed, with a flow rate of 400 N m^3/h. The principle of the booster device is to turn the liquid nitrogen into a gaseous state by heat exchange with air, and the gaseous nitrogen will be transferred to the top of the storage tank through the pipes, so that the pressure of the liquid nitrogen storage tank increases.

2.2. Delivery System

As seen in Fig. 1, the outlet of the liquid nitrogen tank is connected with the liquid conveying pipe and then is connected with the reciprocating cryogenic liquid pump, increasing the liquid nitrogen pressure to 1.5 MPa. Subsequently, liquid nitrogen, flowing through a vaporization device, will vaporize and form a cloud of vapour by air convection. If needed, the auxiliary heating device will work to further vaporize the liquid nitrogen or gas–liquid two-phase matter. Then, cryogenic gaseous nitrogen (CGN) will enter the regulator and steady device after the self-actuated regulator. The CGN pressure will remain stable at approximately 1.0 MPa in the horizontal buffer tank. CGN is exported to the metering device and transported underground through a pipeline. The fire will be rapidly extinguished by pouring CGN at a high flow rate into the fire region.

2.3. Safety Assistance System

The vaporized overpressure and excess amount of nitrogen through the venting device is discharged into the air atmosphere. Moreover, fully closed operation, intelligent infusion and a control system are employed in the station. Liquid nitrogen in the storage tank can be stored for a long time. When firefighting needs occur, liquid nitrogen can be readily available.

3. Case Demonstration

3.1. Field Site Description

JF Colliery is located at the east of the Ningxia Hui Autonomous Region, China, with a capacity of 4 Mt per year. Spontaneous combustion, the main disaster in this coal mine, was easily occurring in coal seams #12 and #18. The length of the 011802 fully mechanized mining face of JF Colliery is 2282 m, the inclination length is 260 m, and the thickness of the coal seam is 3.8 m with a dip angle of 6°. On the day of October 15, 2012, the concentration of CO in the goaf of the 011802 working face reached 3600 ppm, and the concentration of C_2H_4 was 78 ppm due to the spontaneous combustion of coal. The preliminary estimate of the volume of the goaf space where the fire is located was approximately 100,000 m^3. The prevention and control situation of the spontaneous combustion of coal is grim.

3.2. Injecting Liquid Nitrogen in a Large Quantity from the Surface to the Goaf

It took 5 months to build the ground fixed liquid nitrogen station (as shown in Fig. 2). The injection of liquid N_2 through the ground fixed station and surface borehole was adopted in this field trial test. The diameter of the main pipeline for liquid nitrogen was 245 mm, the total length was 2230 m, and the main pipeline was placed in a return air well. The total length of the bypass pipe was 5230 m, and it was laid in the goaf of a different working face. Open fire extinguishing

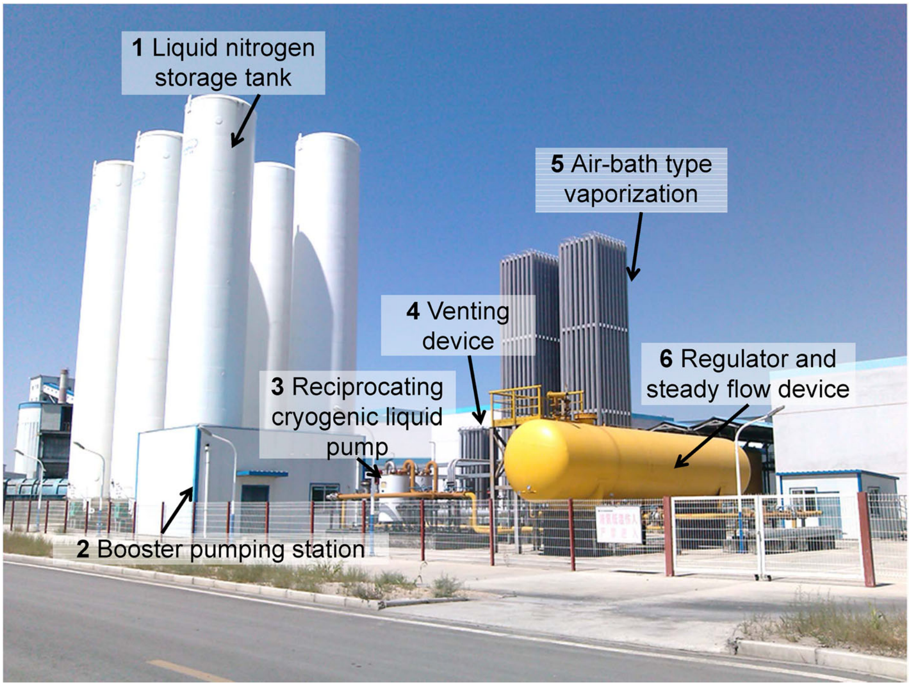

Figure 2. Layout of the ground fixed liquid nitrogen system in JF coal mine.

technology with CGN was adopted, which meant that there was no impact on continued exploitation of the mine.

The maximum allowable nitrogen injection flowrate was calculated according to the Eq. (1).

$$QC_1 - QC_2 = Q_{\max} C_2 \tag{1}$$

where Q_{max} was the maximum allowable nitrogen injection flow rate in m^3/h; Q was the supply air volume at the working face in 65,100 m^3/h; C_1 was the initial oxygen concentration in 20.5%; $C_2=19\%$ was the allowable oxygen concentration at working face. Thus, the maximum allowable nitrogen injection flowrate was 5140 m^3/h. The CGN at a pressure of 1.0 MPa was delivered to the pipeline underground through the regulator and steady flow device and metering device.

4. Results and Discussion

4.1. Analysis of the Results

As shown in Fig. 3, on October 16, 3.0×10^4 m^3 of CGN was injected into the goaf immediately, the CO concentration of the upper corner of the working face decreased to 1746 ppm, and the concentration of C_2H_4 was reduced to 46 ppm. After three consecutive days of CGN injection, a total of 9.8×10^4 m^3 of nitrogen was injected into the goaf, and the CO concentration was less than 20 ppm without the C_2H_2, C_2H_4 and C_2H_6. Moreover, the above gas was in a stable state, indicating that it eliminated the fire hazards of the goaf of the 011802 working

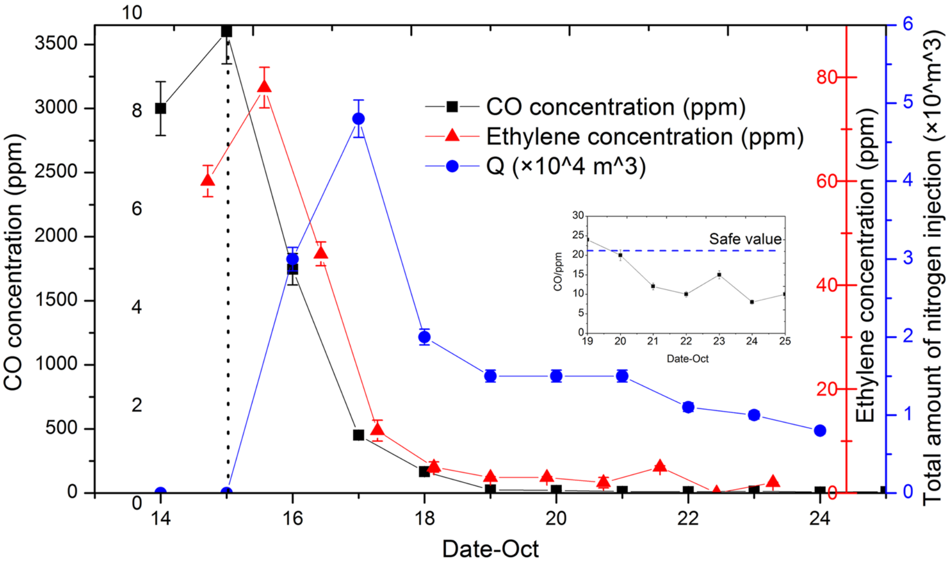

Figure 3. Fire extinguishing effect by the total flooding fire extinguishing systems in JF colliery.

face. It only took 3 days for the concentration of CO to decrease by 95.36%. During this period, the temperature in the mined-out area continued to be 1–2°C lower than the ambient temperature underground. It could be concluded that liquid nitrogen had the prominent effects of total flooding and fire extinguishment.

4.2. Discussion

(1) This is the first time the ground fixed liquid nitrogen system was used to prevent coal mine fires. Compared with the conventional nitrogen injection, this technology has the following advantages:

1. Safe: Full closed-type operation was employed in the entire process with simple, safe and reliable operation features.
2. Fast and convenient: Liquid nitrogen was sourced from the coal chemical company's by-products, transportation is convenient, and the liquid nitrogen source is sufficient. Liquid nitrogen can be stored in the tank for a long period of time. When firefighting needs occur, liquid nitrogen can be readily available.
3. High efficiency: The temperature of CGN was lower than the ambient temperature. Liquid nitrogen stored in a 900-m^3 tank could generate 0.58 million m^3 of CGN. The CGN flow rate could be as high as 5000 m^3/h, which is higher than that of other nitrogen generators. Moreover, the outlet temperature of CGN is 10°C lower than the atmospheric temperature.
4. Economical: Compared with the conventional nitrogen generator, the maintenance cost is low. Liquid nitrogen is directly vaporized with air, which greatly reduces the power consumption.

(2) Due to the large heat capacity of coal and rock underground, it seems that the cooling effect is not so obvious in the short term, but the inertization effect is obvious.

(3) The lesson learned from the engineering application is that the CGN injection flow rate should be higher first so that it can significantly inhibit the development of spontaneous combustion. Then, the flow rate of CGN should be reduced for economic reasons to further make inert the fire zone until the spontaneous combustion is completely controlled.

(4) Shortcomings still exist. The monitoring measurements, effect evaluation and emergency mechanism of underground nitrogen leakage need to be further improved.

5. Conclusions

To completely reverse the passive situation of fire prevention, a new technique called a ground fixed liquid nitrogen station has been developed for normalizing fire prevention for underground coal mine fires. The effectiveness of this clean and cryogenic agent for total flooding fire extinguishing systems in a full-scale underground mine was assessed. Field observations showed that it only took 3 days for the concentration of CO to decrease by 95.36%. During this period, the temperature in the mined-out area continued to be 1–2°C lower than the ambient temperature underground. The main fire extinguishing mechanism of the system is the nitrogen inertization, and the cooling is supplemented. By using this system, it has become possible to evaporate a large quantity of liquid nitrogen in a short amount of time without any additional heat source near the fire area. The entire system is feasible for coal mine fires.

Acknowledgements

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