INNOVATIVE TECHNIQUES FOR DETECTION AND CONTROL OF UNDERGROUND SPONTANEOUS COMBUSTION OF COAL

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ABSTRACT: In recent years, the frequency and intensity of spontaneous combustion of coal in Australian underground coal mines has shown worrying signs of increasing. To enhance spontaneous combustion management capabilities in the Australian coal industry, a study was undertaken to investigate three innovative techniques that have been successfully used in China. These three are the radon detection technique, the infrared technique and the colloid injection technique. The radon detection technique is for remotely locating the areas of underground spontaneous combustion from a surface location. The infrared detection technique is for locating the spontaneous combustion within a short distance. The colloids injection technique is for controlling spontaneous combustion after it is located. This paper describes these techniques including their principles, operations, applications in China, and applicability in Australia.

INTRODUCTION

Spontaneous combustion (sponcom) is a significant hazard in coal mines worldwide, including Australia and China. If not detected at its early stage and appropriate controls are not employed, sponcom can lead to fires, explosions, asphyxiation, loss of life, equipment and resources.

In China, more than 90% of the fires in coal mines are the result of sponcom. 54.9% of the state-owned coal mines and 29.1% of the locally owned coal mines are classified as sponcom prone mines. Every year, there are about 300 sponcom-induced fires in coal mines in China. It is estimated that sponcom of coal in mines consumes 100 million tonnes of coal each year. To overcome the problem of sponcom, Chinese coal mines, in cooperation with research institutes and universities, have put substantial manpower and financial resources to undertake the fundamental research. Their aim is to develop techniques for preventing, detecting, locating and controlling the sponcom, and to implement these techniques in the Chinese coal industry. These efforts have led to an increased understanding of sponcom, the development of a number of innovative techniques, and a substantial reduction of sponcom-induced fire hazards.

In Australia, sponcom has been and continues to be a major hazard of underground coal mining. Over the last thirty years there have been over 250 reported or recorded incidents of sponcom in New South Wales and Queensland. The economic and social costs to the Australian coal mining industry in particular are very high. As evidenced over the last couple of years, the frequency and intensity of sponcom in Australian underground coal mines is showing the worrying sign of increasing. How to deal with sponcom is one of the major focuses of the Australian coal industry and the relevant governmental agencies.

In 2002 CSIRO and Yankuang Group Corporation in China agreed to undertake a study to investigate a number of innovative techniques developed and used in China for preventing, detecting, locating and controlling sponcom of coal (Xue and Cui, 2003). The applicability of these techniques in Australian coal mines were also investigated. The techniques selected for investigation include radon detection technique, infrared detection technique and colloid injection technique.

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RADON DETECTION TECHNIQUE

Principle

In radioactive processes, particles or electromagnetic radiation are emitted from the nucleus. The most common forms of radiation emitted have been traditionally classified as alpha (α), beta (β), and gamma (γ) radiation. The radioactive decay will change one nucleus to another if the product nucleus has a greater nuclear binding energy than the initial decaying nucleus. The difference in binding energy (comparing the before and after states) determines which decays are energetically possible and which are not. The excess binding energy appears as kinetic energy or rest mass energy of the decay-products. The energy emitted in the radioactive decay can be detected, measured and used as information to determine the concentration of the nucleus, its decay mode as well as its other properties. This is the principle of nuclear-based detection techniques.

U-238 is a common rare element in rock strata, as is its decay product Rn-222 (radon) and radon progeny. Radon has a strong diffusion ability. Activated carbon, silica gel, polyethylene and some other materials can easily adsorb radon and its progeny. This property enables radon and its progeny to be easily collected from the surface with a container coated with these adsorbents and analyzed. Experimental test data show that when the coal is heated up, the emanation rate of radon from overlying strata will increase. This relationship, combined with radon radioactive and its unique properties form the fundamental principle of radon-based detection techniques for coal sponcom.

Operation and Analysis Procedures

The operation and analyzing procedures with the radon detection technique are described below.

- Designing surface measurement grid. Firstly deciding the survey area underground and then selecting the surface area right above the underground area to be investigated. This is followed by design of surface measurement points. The measurement point spacing can be 5 m, 10 m, 15 m, or 20 m depending on requirements of site conditions.
- Placing test cups. An auger machine can be used to dig the holes. The hole is 30 cm in diameter and 30-40 cm in depth. Once the hole is dug, an alpha test cup (Figure 1) is placed in the hole upside down.
- Analyzing the cups. The cups are buried in the holes for at least 4 hours. The alpha cup is then recovered and inserted into a CD-1 radon detector for testing (Figure 1). The CD-1 radon detector shows counts per minute reflecting the concentration of radon and its progeny.
- Processing test data. A program is used to process the test data. It produces a 3D map of abnormal CPM values, and the location of "high-temperature" area(s) (Figure 2).

Characteristics

- It can remotely locate abnormal temperature areas. Its accuracy for locating the sponcom center is 90 %. Detection depth is up to 800 m.
- It is of high suitability, low cost and easy to operate.
- It has a high reliability and is largely unaffected by external factors.

Applications

The radon detection technique has been used in more than 25 underground coal mines in China with great success. For example, the coal seam in Caili mine is prone to sponcom. The mine had 40 cases of sponcom from 1967 to 1997. Efforts to control sponcom had been hampered by not knowing the exact location of sponcom. The radon technique has been used in LW2334, LW2349 and LW2313. An area of 66,000 m² was surveyed and locations of sponcom were detected with this technique.

Fig 1 - Alpha cup and CD-1 radon detector

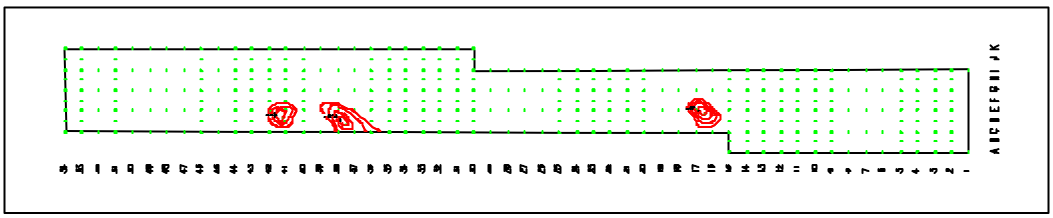

Fig 2- Hot spots detected with the radon technique

INFRARED DETECTION TECHNIQUE

Principle

All warm (warm defined as being above 0 Kelvin in temperature) objects' atoms, molecules, and electrons are always in motion, vibrating and radiating (emitting) infrared waves, forming in infrared radiation field. As the object's temperature increases, the intensity of the radiation increases. The radiation field can be characterized by its energy, momentum, direction and other information. Like any other objects, a coal seam is also emitting infrared waves. If there is a sponcom in the coal seam, this should be reflected in the characteristics of its infrared radiation field. The infrared radiation field can be used to determine the existence of the sponcom and its extent through establishing the relationship between the field and its source and monitoring the characteristic change of the field.

Operation and Analysis Procedures

The operation and analyzing procedures of the infrared detection technique are described below

- Layout of measurement points. Measurement stations are set along the gateroad to be surveyed. Each measurement station covers a number of adjacent measurement points in the ribs, roof and floor (Figure 3).
- Field Measurement. An infrared detector is used to measure the strength of the energy field of infrared radiation and surface temperatures of the measurement points. If a zone of abnormal strength is recorded, then repeated measurements in that zone are undertaken.
- Data Analyses. A program is used to process measurement data. The program has three main functions: (1) graphic outputs of strength profiles of infrared radiation, (2) identifying any abnormal strength of radiation caused by sponcom, and (3) determining the position and temperature of the

sponcom by the inverse calculation of heat conduction based on the heat conduction mechanism of coal strata.

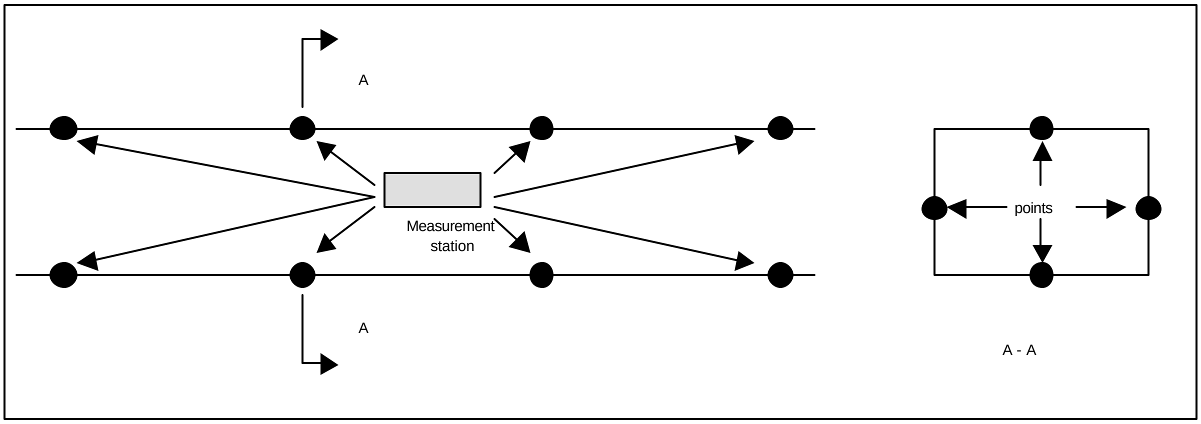

Fig 3 - Schematic layouts of measurement stations and points with the infrared technique

Characteristics

- It is remote and requires no direct contact to detect sponcom of coal.
- Maximum detection depth of 10 m in a coal pillar
- 90% accuracy for detecting the location of a sponcom
- It can detect a coal sponcom with temperature at 130º C and above
- Suitable for detecting "hot spots" in coal pillars and areas adjacent to roadways

Applications

The infrared technique has been successfully used in about a dozen underground coal mines in China for locating coal sponcom. For example the coal seam in Baodian mine is prone to sponcom. This technique was used to detect the suspected heating spots in the coal pillar and roof of two roadways in longwall #5308. A total of 1140 measurement points were selected along the 1900 m long roadway and two heating spots in the roof were successfully detected with this technique (Figure 4).

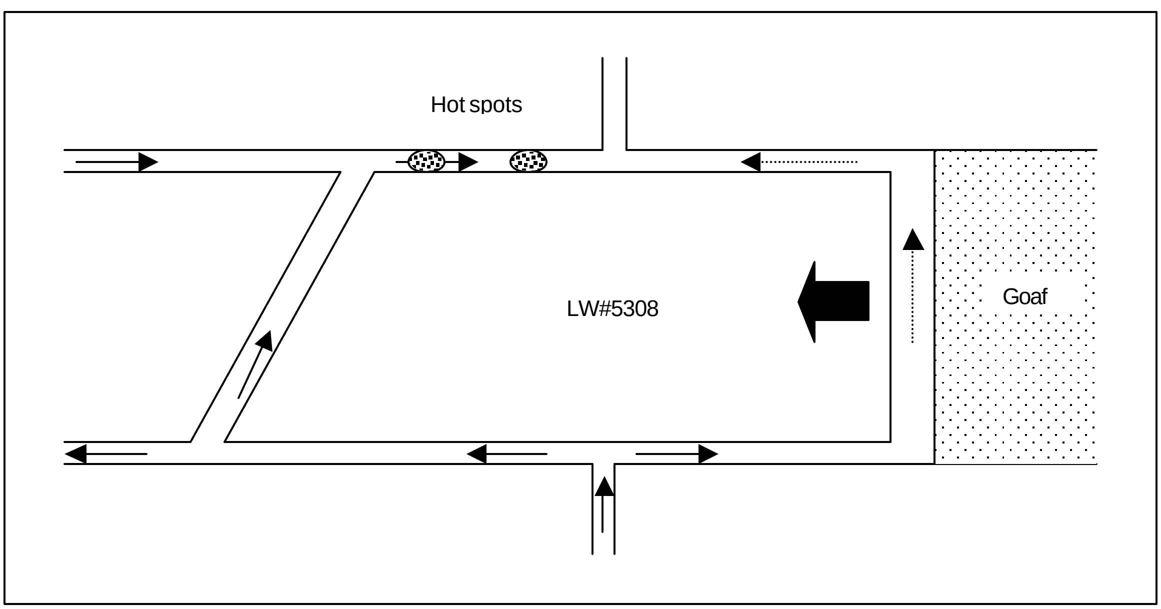

Fig 4 - Hot spots detected in LW#5308 of Baodian mine with the infrared technique

COLLOID INJECTION TECHNIQUE

Types and Characteristics of Colloids

Colloids developed for the control of sponcom can be broadly divided into three categories: gels, large-molecule colloids and compound colloids. The gels consist of a base material, an additive for fast gelatinization, and water. The large-molecule colloids are composed of large-molecule materials and water. Adding some additives for enhancing mechanical strength in the gels or large-molecule colloids makes compound colloids.

Operation systems

Two systems have been developed for the colloid injection technique for sponcom control: an underground-based system suitable for controlling small-scale sponcom and a surface-based method suitable for controlling large-scale sponcom. The main equipment used in the underground-based system includes a movable colloid mixer and pumping station. Required materials are fed into the station and mixed to make the colloid and then pumped into the area of sponcom via pipelines. Figure 5 shows the flow chart of the system.

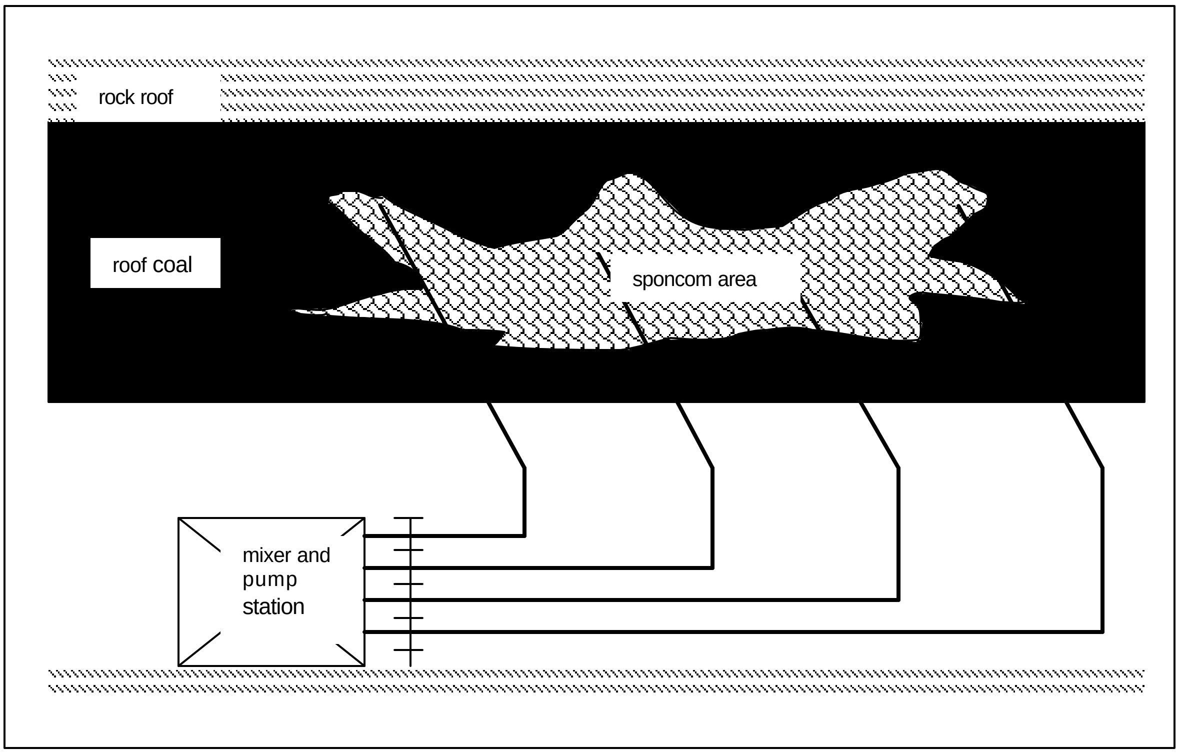

Fig 5 - An underground-based system for colloid injection

To control large-scale sponcom, a surface-based system should be used. A surface-based mixer blends base materials with water. A pipeline is then used to deliver colloids from surface to underground, the pipeline is connected to a number of borehole drilled from underground workings into the area(s) of sponcom. A small mixer and pumping station located underground is used to mix water with the additive for fast gelatinisation and pump the mix into the pipeline. Figure 6 shows the flow chart of the system. The system is capable of delivering 30-100 m^3/h of colloids into sponcom spots.

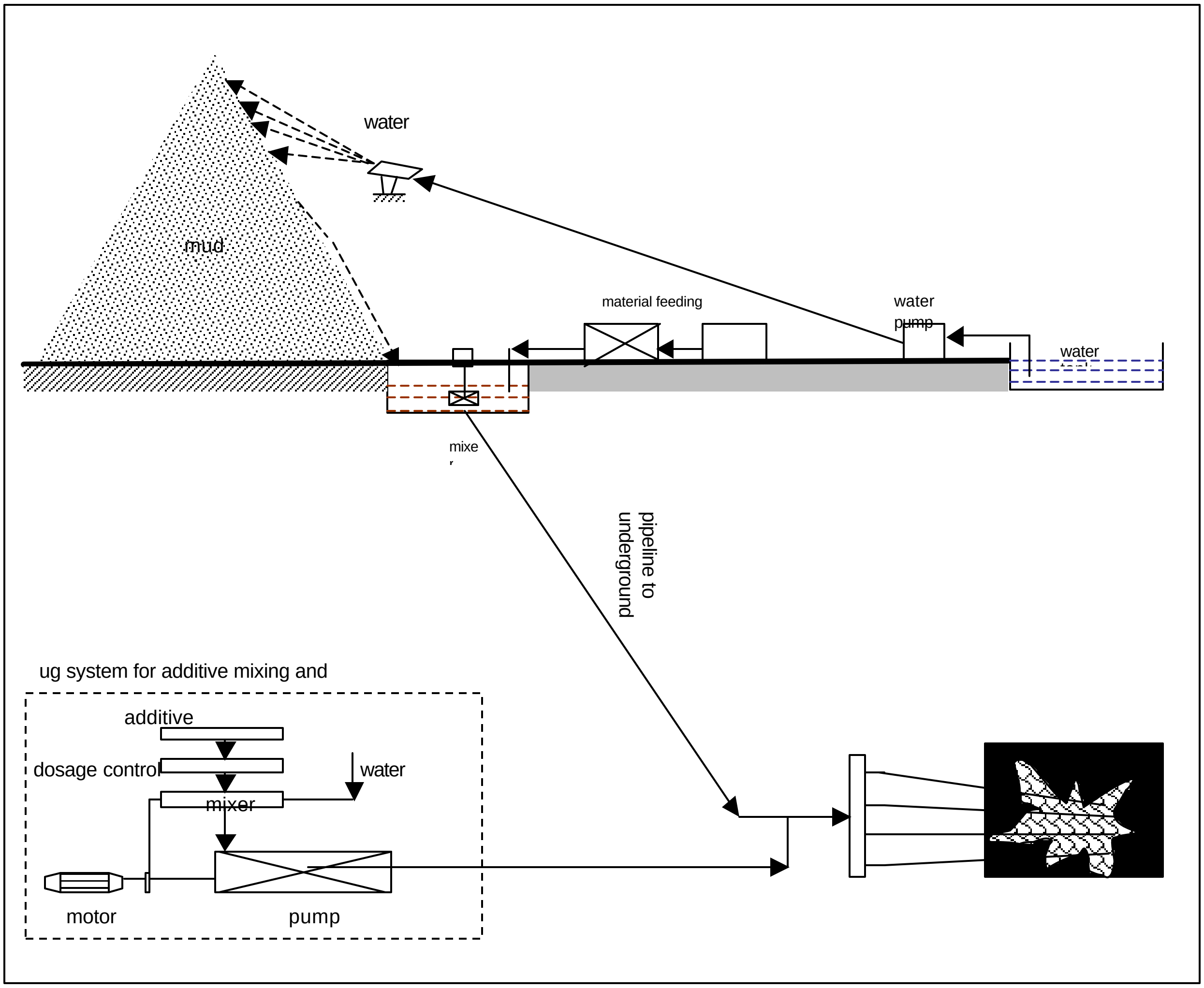

Fig 6 - A surface-based system for colloid injection

Characteristics

- Speedy control of sponcom. For a small-scale sponcom in a coal pillar it may take only a few hours to control, even for a large-scale sponcom in goaf it may take a couple of days at maximum.
- Colloid can be solidified in fragmented coal, resulting in the blockage of leakage passes and hence stopping poisonous gases flowing out from the passes. At high temperatures a colloid gives off a very small amount of water steam (unlike water injection technique) and therefore there is no possibility of explosion of water gas and no risk of injuries resulted from high temperature water steam.
- To date there has been is no reoccurrence of sponcom in an area treated with colloid.

Applications

The colloid injection technique has been successfully applied to control about 100 cases of coal sponcom in Chinese coal mines. For example, in March 1993, sponcom occurred in longwall face #11501 of Wangcun mine. Sponcom occurred in a large goaf area immediately behind chock #9 to chock #13. Several control techniques including ventilation pressure balancing, water injection and slurry injection were used with no success. As a last attempt to avoid sealing of the face the colloid injection technique was applied. The area was injected with 100 m³ gel, and sponcom was controlled.

APPLICABILITY IN AUSTRALIA

The Radon detection technique is operated from the surface. There are no specific requirements for its operation condition. Since there is no competing technique available in Australia, this makes the technique quite attractive. Its limitations include that targeted surface areas have to be accessible by operators and if sponcom occurs in multiple seams the technique needs to be used with other techniques for accurately locating the sponcom.

The Infrared detection technique is operated from underground openings. For pillar heatings, the infrared technique may be more sensitive than gas detection. However it cannot detect sponcom below 130º C or if sponcom occurs more than 10 m inside a coal pillar.

There is no specific operation requirement with the colloid injection technique. However for the large-scale surface system it requires some surface infrastructures such as a water tank, mixer and pipeline. It should be noted that the area of sponcom has to be relatively close to an underground opening so that injection boreholes can be drilled into the area.

These three techniques are technically and operationally feasible to apply in Australian coal mines, and should be included in the current collection of approaches available for prevention, detection, locating and controlling sponcom of coal in Australian coal mines.

CONCLUSIONS

The three techniques investigated in this study offer the Australian coal industry the potential to enhance its capacity to deal with the issues of preventing, detecting, locating and controlling sponcom of coal. This study has identified the following advantages of these techniques over existing technique associated with sponcom:

- These techniques enable an integrated approach from detection to controlling.
- Radon technique provides the only solution for remotely locating underground sponcom from surface
- Infrared technique offers an alternative for detecting sponcom, particularly in coal pillars
- Colloid injection technique can be used in conjunction with other inertisation techniques to control sponcom.

REFERENCES

Xue S and Cui H Y, 2003. Study of detection and control techniques of spontaneous combustion of coal seams, CSIRO Exploration and Mining, Rpt No 1106F