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Review of Current Practice of Early Detection of Spontaneous Combustion at Longwall Panels

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Abstract. There are many, incidents where the spontaneous combustion of coal in underground longwall panels has resulted in the explosion of methane gas. The existing spontaneous combustion detection techniques have largely helped the mining industry in the early detection of spontaneous combustion in longwall panels, however, there are several instances when these techniques have failed. This paper discusses the current status of spontaneous combustion detection systems used in various mines around the world on the early detection of spontaneous combustion in longwall panels.

Keywords: Spontaneous Combustion · Longwall · Coal Mine

1 Introduction

The consequences of methane explosions at underground longwall panels are severe (Li et al. 2020). Several explosions in underground longwall panels are caused by undetected spontaneous combustion events that occur at the longwall goaf area. These explosions have resulted in many fatalities in Australia and other regions of the world (Zhang et al. 2020; Qin et al. 2009). Spontaneous Combustion events have resulted in the suspension or closure of many coal mine operations which resulted in huge financial losses to the operators and affected the employment of many coal mine workers (Surendran 2022b).

A likely Spontaneous Combustion event caused a methane explosion at Grosvenor Coal Mine in Central Queensland, Australia in May 2020 (Martin & Clough 2021). Five coal mine workers were severely burned in this incident. A self-heating event of coal triggered a Spontaneous Combustion event causing a major mine fire which resulted in the suspension of operations and sealing of North Goonyella Mine at Moranbah, Central Queensland in September 2018 (NSW Resources Regulator 2021).

In January 2011, a methane explosion event occurred at Blake field South Mine, Mount Thorley, New South Wales. At the time of the incident, forty-seven coal mine workers were underground. The investigation into this event could not establish if spontaneous combustion caused this occurrence. However, the investigation report pointed towards the limitations of the existing spontaneous combustion detection systems at the mine (NSW Resources Regulator 2011). According to a study on fatalities in Australia in mining activities, conducted by the Mineral Council of Australia for ten years from

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2003, seven per cent of the total deaths were either due to a fire in a mine or an explosion (Stutsel 2014). Though existing methods for the detection of self-heating of coal have helped the industry in preventing many possible unwanted events largely, there are occurrences where the mines failed to detect the spontaneous combustion of coal in longwall panels which resulted in subsequent explosions (Martin & Clough 2021).

2 Literature Review

The section gives a comprehensive review of the current status of the detection of self-heating of coal in underground mines where the longwall mining method is used. The section identifies the research/knowledge gap in this area.

2.1 Gas Monitoring and Analysis in Detecting Spontaneous Combustion

Gas monitoring systems provide vital information on mines' atmosphere based on constituents of various elements observed from the gas samples collected. There are many gas ratios used by the industry that can predict the existence of spontaneous combustion at Longwall Panels (Guo et al. 2019). Spontaneous combustion detection methods used during a coal mine in Shanxi Province of the People's Republic of China (PRC) were studied by (Cheng et al. 2021).

In this research, the researchers collected, analysed and interpreted gas monitoring information from the mine using a quantitative methodology. The detection of Spontaneous Combustion from analyses of gas data caused a stoppage of mining activities at the mine to take preventive actions to control an escalating situation.

The variations in the coal mines mine's atmospheric temperatures were studied by Ozdeniz et al. (2014) to understand their relation to self-heating events at an underground longwall mine in Ermenek, Turkey (Ozdeniz et al. 2014). The observations of the temperature difference between the intake and return airways of the mine and the analysis of gas monitoring data from the longwall return were used in a simulation model to establish the existence of spontaneous combustion in the mine. The analysis and simulation results established the significance of gas monitoring and gas ratios.

The research by Cheng et al. (2021) and Ozdeniz et al. (2014) identifies the importance of gas monitoring in the detection of self-heating of coal. The study by Cheng et al. also points towards the limitations of the existing gas monitoring systems in the early detection of spontaneous combustion as the longwall panel referenced in the study created an elevated risk to the coal mine workers' health and safety. The panel subsequently needed to be sealed. However, neither of the studies identified the exact location of spontaneous combustion in the longwall panel. Self-heating of coal in longwall goaf starts in a small, localised area. Due to the dynamic nature of the LW goaf atmosphere and large quantities of ventilation airflow through the LW Panels, the intermittent gas flows from these locations in goaf areas goes unnoticed in gas monitoring. The findings by Cheng et al. (2021) and Ozdeniz et al. (2014) demonstrate the limitations of gas monitoring as an independent technique in the detection of spontaneous combustion.

2.2 Significance of Ethylene in Spontaneous Combustion Detection

As heating in coal progresses above 100 °C, ethylene gas is generated. The ethylene gas in the mine environment is a strong indication that the self-heating activity has progressed to an advanced state. Research by Xie et al. (2011) led to the development of an ethylene-enriching system that enables the early detection of advanced coal heating in a longwall goaf environment. Their study made use of numerical information from gas analyses of samples taken from longwall panels at the PRC coal mines of Beizao and Jinyuan. The physical adsorption and desorption characteristics of ethylene were used in the study to detect coal heating. A study was conducted to understand the reignition risks of underground coal fires after extinguishing (Ma et al. 2022). The study identified that ethylene even at low concentrations could be used as a credible indicator.

A simulation study was conducted under an experimental setup at Xi'an University of Science and Technology on fire prevention due to spontaneous combustion (Liu and You 2020). The study used the gas data derived from laboratory experiments using coal samples obtained from Bojianghaizi underground coal mine, People's Republic of China (PRC). This study established that index gases such as carbon monoxide and carbon dioxide and gases generated by coal pyrolyses such as ethylene and acetylene could be good indicators of spontaneous combustion. The study by Xie et al. (2011), Ma et al. (2022) and Liu and You (2020) identified the significance of ethylene detection indicating an advanced stage of heating. Since the initial self-heating of coal in the longwall goaf area starts in a very small, localised area as that of a football-size, the gas generated from these areas would be intermittent and would be hard to notice due to the dynamic goaf environment and high ventilation volumes. The experiments conducted by the researchers suggest Ethylene is generated when the heating has reached an advanced stage (Xie et al. 2011) hence ethylene detection does not aid in the early identification of self-heating of coal. While the detection of ethylene indicates advanced heating somewhere in the area the exact location of the heating is still unknown. It will be hard to treat a self-heating event occurring in a large goaf area without knowing the precise location of the heating. These studies point towards limitations of existing techniques and gaps in the research area.

2.3 Gas Monitoring and Computational Fluid Dynamics (CFD) Techniques

Numerical modelling using Computational Fluid Dynamics (CFD) techniques provides vital information on the existence of a self-heating event in a longwall goaf atmosphere (Li et al. 2020). The importance of the collection and interpretation of numerical data from gas monitoring systems to determine mine atmospheric conditions and to identify the presence of indicators of self-heating was studied by Cheng et al. (2021). The goaf environment of an underground longwall panel is dynamic; hence it is paramount to select ideal locations for gas monitoring in the panel considering techno-commercial parameters. This exercise assumes significance as the information flowing out of these locations determines the accuracy of determination of the area of any existing heating in a longwall panel.

To determine the most suitable locations for gas monitoring in a longwall panel, Yuan and Smith (2012) conducted a study using numerical modelling simulation techniques supported by Computational Fluid Dynamics. Carbon Monoxide concentrations at various regulator locations in the bleeder ventilation system of the mine were used in the com putational fluid dynamics model for their research.

The research findings of Yuan and Smith (2012) and Cheng et al. (2021) identify the significance of gas monitoring in the early detection of spontaneous combustion in a longwall panel. The study of Yuan and Smith (2012) signifies the importance of the prudent selection of ideal gas monitoring locations in a longwall panel in spontaneous combustion detection. However, it does not consider the dynamic nature of the goaf atmosphere.

With the retreat of longwall to new locations in the seam the dynamics of the goaf and mine atmosphere change rapidly. With these changes, the ideal locations for gas monitoring also will change. The research of (Yuan and Smith 2012; Cheng et al. 2021) further demonstrates the limitations of the existing techniques in the determination of self-heating events at longwall panels and the research gap in the area.

2.4 Effect of Ventilation Pressure on Spontaneous Combustion

The ingress of air into the goaf areas from the mine ventilation current is a significant factor causing spontaneous combustion. A properly engineered mine ventilation system that reduces the oxygen ingress into goaf areas is important to control Spontaneous Combustion at longwall goaf. A study was performed by Liang et al. (2018) at Bulianta colliery, the Peoples Republic of China using 'Ventsim' Ventilation simulation software to control mine fire in an extraction panel adjacent to a longwall panel. Simulation studies using the 'Ventsim' software aided in determining the pressure differentials that caused air ingress into goaf areas from subsidence-induced cracks from the surface areas of the mine.

Research at the Sitai Coal Mine of PRC used numerical modelling of the goaf gas data to establish a connection through fissures and subsidence cracks to the goaf area adjacent to the Dadougou Coal Mine, located at a distance of 2.5 km (Wang et al. 2019). The researchers also conducted a field study to identify surface locations of subsidence cracks. A tracer gas (SF6) was used in the study to establish the connection between the goaf areas through subsidence cracks. Grouting of the subsidence cracks and pressure balancing techniques were used to mitigate the situation and eliminate oxygen ingress into goaf areas.

Though both researchers identified the significance of Ventilation pressures and the importance of engineered ventilation modelling in controlling spontaneous combustion, these studies do not provide solutions for the early detection of spontaneous combustion.

2.5 Research Gap

The literature review has identified limitations in current techniques in the early detection of spontaneous combustion. The review recognises the importance of gas monitoring and computational fluid dynamic modelling in the early detection of spontaneous combustion at longwall panels. Though the gas monitoring techniques provide vital information on the status of the mine's atmosphere significant information from the gas analysis is lost due to the dynamic nature of the goaf and flow of large quantities of ventilation air current in the longwall panel. The literature also provides the limitations in early detection of self-heating of coal in the longwall goaf area due to a small, localised area of heating and restricted airflows.

Though significant advance in computational fluid dynamic techniques has been made in the prediction of heating in goaf areas through simulation techniques, it is identified that current CFD modelling techniques do not provide continuous monitoring of goaf areas. Due to the dynamic nature of longwall mining, it is vital that CFD Modelling techniques adapt to the changing goaf environmental conditions and provide continuous data for early identification of spontaneous combustion.

3 Concluding Remarks

Research is currently under progress at Central Queensland university to address the gaps identified through this literature review (Harilal Surendran 2022a). The current limitations in the early detection of Spontaneous Combustion at underground longwall panels are studied in this research through a mixed methodology which involves quantitative and qualitative techniques. A comprehensive dynamic model that integrates CFD Modelling techniques and gas monitoring data obtained through numerical modelling is being developed through this research.

The comprehensive dynamic model developed will alert model users to signs of self-heating activity and provide the mine management with ongoing information on vulnerable self-heating locations in a longwall goaf area. The authors believe the successful completion of this research can provide solutions to improve the safety and health of coal mine workers by early detection of spontaneous combustion.

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