Resources Safety & Health Queensland

Example of active longwall gas and spontaneous combustion management strategies

Gassy and known sponcom prone longwall operations require a greater understanding of the ventilation engineering controls, goaf gas behaviour, post gas drainage control strategies for TG gas management, and well-balanced gas and sponcom management strategies of highly gassy and steep temperature gradient seams. The term ‘sponcom’ is used below to discuss the various stages of coal oxidation to the development of fully uncontrollable combustion when large quantities of coal left in the goaf due to geo-technical safety considerations. Similarly, ‘air wash zone’ a term commonly used is typically referred to as the concentration of relative oxygen in the goaf atmosphere aiding the left-over coal oxidation, and typically referred to oxygen concentration values of 5% to 21%. Fresh air is the concentration that is representative of longwall fresh air intake. It is to be noted that oxygen at high concentrations can be present even in situations where there is no or sluggish airflow movement in the goaf. The contradictory nature of the GM seam sponcom led fire and gassy mine requiring maximised goaf drainage capacity systems and the need to reduce oxygen ingress into the MG and TG active goaf requires careful operational strategies. In this context, it is important to note that use of ventilation driven dilution controls for longwall tailgate gas management that are practiced elsewhere in Australia or the world, are not necessarily appropriate for gassy, steep geo-thermal gradient and known sponcom prone GM seam mines. Following paragraphs provide the spectrum of science based practical engineering controls and monitoring systems developed and improved over the last two decades in underground longwall operations for gas and sponcom management. Additional details are described elsewhere (Belle and Balusu, 2023).

The evolution of major coal oxidation and resulting sponcom incidents are sudden and may result in catastrophic negative safety outcome or in the withdrawal of persons and closure of longwall panels/mines. Historically, gassy longwall workings in Australian Goonyella Middle (GM) seam (late-1990’s to mid-2010’s), have experienced increasing trend in CO levels [sponcom indicator gases] associated with coal oxidation and major safety incidents due to oxygen ingress on the maingate side. Management of the Australian active longwall goaf gas drainage system designs are based on the work of the CSIRO in collaboration with coal industry through ACARP and individual mines. The CSIRO studies in gassy and hot coal mines had carried out numerical and field investigations on goaf gas flow mechanisms and proactive inertisation strategies for preventative spontaneous combustion and gas management. This critical foundational knowledge work contributed to the original goaf gas drainage and sponcom management strategies in Australian longwall mines and potentially extended to rest of the world. Considering the risks associated with sponcom, GM seam operations were the first operations in Australia to introduce proactive N2 injection along the inbye maingate (MG) in late-2000’s, to manage sponcom fire and explosion risks in an active goaf.

Over two decades ago, active goaf gas drainage flow rates were moderate (2,000 l/s to 3,000 l/s) and the oxygen ingress on tailgate (TG) side was not a major concern. With increasing goaf gas drainages rates up to 6,000 l/s 10,000 l/s and manual or automatic mode operation of goaf wells to the extremes to address higher goaf gas emissions, TG oxygen ingress deeper in the goaf has become a major issue in recent years, necessitating the introduction of both TG and MG inertisation strategies now to address this emerging coal oxidation issue. Introduction of MG proactive inertisation strategy had reduced the number of high CO or intensive oxidation incidents over two decades. The following paragraphs provide practical safety benefits of longwall inertisation supported by the original CSIRO computational fluid dynamics (CFD) modelling studies in collaboration with the industry.

Goaf Gas Management

Traditionally, highly gassy mines are to be managed through extensive pre-drainage techniques long before the actual longwall mining to take place. During the active longwall mining, goaf drainage systems are used as the primary control for gas management with adequate drainage capacity for maximized drainage along with ventilation as the secondary control for gas management as a dilution control. Longwall gas emissions have increased significantly in recent years in some of the Australian longwall mines due to increased seam gas reservoir size with multiple upper and lower seams, higher production rates and increase in mining depths. There have been mines that had previously deployed 3 gateroad systems in their longwall panels for continued access to diesel vehicles during maintenance periods. With the greater understanding with extensive and flexible goaf drainage systems, Australian coal mines use 2 gateroad ventilation system for longwall panel development and extraction. Extensive scientific and field work has been carried out to develop optimum gas and spontaneous combustion control strategies for 2 gateroad longwall panels.

Although 3 gateroad system provides more ventilation capacity during gateroad development and assists in providing more ventilation dilution capacity in tailgate during longwall extraction, its effect on goaf gas distribution and explosive fringe gas profiles in the longwall goaf areas was historically unknown. There is a continued perception that as the 3 gateroad system provides more ventilation capacity for gas dilution in the longwall tailgate return, it would also reduce the explosive fringe gas distribution profile near the tailgate area in the longwall goaf to manage the explosion risk. The results of the CFD modelling simulations indicated that there is a significant increase in the spread of explosive fringe (or close to explosive range) zone in the goaf under 3 gateroad conditions. Based on the results of these investigations, appropriate strategies have been developed for gas control and minimization of the spread of explosive fringe gas distribution in the longwall goaf under field conditions.

One of the major difficulties in the ventilation and gas flow dynamics is our inability to visualize the complex likely gas concentration profiles in the active goaf with time and non-constant retreating longwall. The advances in the CFD numerical calculations have enabled the industry by providing an understanding of gas management or the extent of 'air wash zone' that is often used colloquially during risk assessment or emergency situations. The CSIRO studies (Balusu et al., 2001) provided a visual scenario of potential oxygen distribution in an active LW goaf and goaf well nearer to the LW face (Figure 1). The field studies have noted that (Balusu et al, 2006; Balusu et al., 2011) the oxygen concentration was above 19% for up to 100 m behind the longwall face and reduced to 6% at 250 m behind the face in the absence of any inertisation control and poor MG brattice control practices.

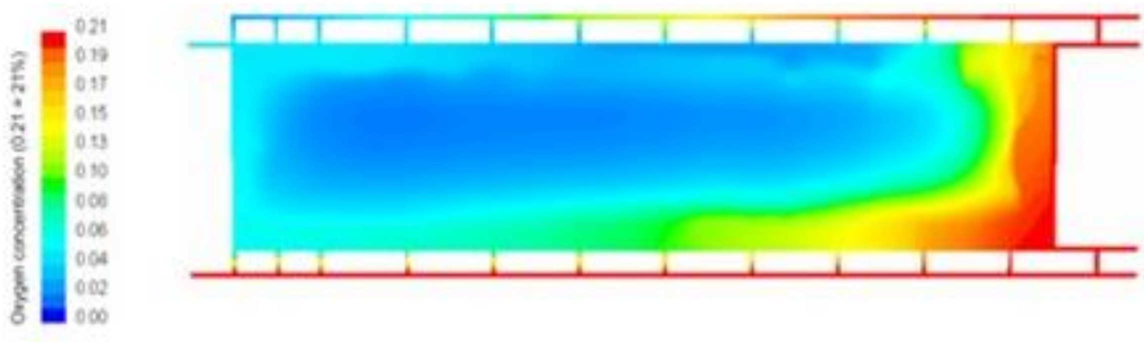

Figure 1: Oxygen gas distributions patterns in longwall goafs under low goaf gas emissions conditions

Maximised Goaf Drainage Strategies - Lessons Learned

A number of factors including goaf gas emission flow rates and composition, panel ventilation, coal seam gradients, overlying and underlying coal seams, face retreat rates, caving characteristics, and goaf gas flow patterns need to be considered during development of goaf gas drainage operations. The recent practices of draining gas from 2 to 4 goaf holes only near the face and operating at its peak capacity (l/s) would not solve the tailgate gas problems, but exasperate the oxygen ingress into the deeper portion of tailgate area of an active LW goaf. Based on the results of various CSIRO studies and investigations supported by the industry over the last two decades, the following guidelines are recommended for optimum maximized goaf gas drainage strategies at highly gassy mines:

- Surface goaf holes for gas drainage provide the highest capacity and lowest cost option for goaf gas drainage under most circumstances.
- Goaf holes should be drilled on return side of the goaf, preferably at 20 to 70 m from gateroad depending on the longwall caving conditions.
- Goaf holes are to be drilled 80 m to 100 m away from faults/dyke areas.
- Uniform and continuous operation of goaf holes (sudden peaks and lows in goaf drainage flow rate increases the coal oxidation resulting in spontaneous combustion risk).
- Goaf gas drainage hole diameter should be in the range of 250 to 400 mm for optimum flow rates and the goaf holes may be drilled at 50 to 300 m spacing depending on the goaf gas emissions and other conditions.
- The total capacity of the goaf gas drainage plants should be around 2 to 3 times the expected goaf gas emissions to cater for deep goaf holes gas drainage, shifting of goaf plants or goaf hole connection changes and reduced plant efficiencies due to high pressure losses. Provision of a high-capacity and flexible gas drainage system allows optimisation of goaf gas drainage strategies, flexibility, improves the overall efficiency and provides better gas control on the face.
- The goaf gas drainage system should include a combination of goaf holes near the face and deep goaf holes in the panel in order to improve the overall gas drainage efficiency and to reduce the effects of barometric pressure changes on tailgate gas levels.

- The strategy of continuous operation of deep goaf holes at moderate capacity should be implemented i.e., intermittent operation of deep goaf holes at high capacity may not improve the overall efficiency and may lead to problems.
- Goaf gas drainage should be carried out from around maximised number of goaf holes with the retreating longwall goaf in the panel (including deep holes), instead of the practice of gas drainage from just few goaf holes closest to the face.
- Application of increased suction pressure to drain more gas from goaf holes closest to the face might result in increased air dilution, without any net increase in gas drainage flow rates.
- The ventilation system in the panel should be designed to minimise oxygen ingress into the goaf, including immediate sealing-off all the cut-throughs behind the face, in order to improve overall gas drainage efficiency.
- Oxygen concentration level in the goaf hole flow should be less than 5% in goaf holes beyond 100 m from the face line to reduce spontaneous combustion risk in the longwall goafs.
- Gas drainage from adjacent old goafs should also be carried out wherever possible, depending on the goaf gas emission flow rates and adjacent seal strengths.

Spontaneous Combustion Management

Major events in Queensland demonstrates the critical importance of proactive sponcom management for underground coal mines extracting/working in known sponcom prone Moranbah region GM seams. Widely referred low sponcom propensity (R70) of coal risk ratings in PHMP documents and frequency of their testing may be misleading the likely initiation or risk frequency estimations. For example, both German Creek and Goonyella Middle Seam R70 levels are similar but the left-over roof coal in GM seam workings increase the oxidation risk with increasing depth due to geo-thermal gradient.

The evolution of major coal oxidation and sponcom incidents are sudden and may result in catastrophic negative safety outcome or result in the withdrawal of persons and closure of panels/mines. In view of the recent incidents in a number of mines working in GM seam (irrespective of the cause of the incidents), elevated oxidation may potentially become an ignition source and inadequate control may result in the undesirable safety outcome.

Based on two decades of close collaboration between the industry, ACARP and CSIRO, resulted in the current sponcom management knowledge. The learning from these studies have resulted in the following proactive preventative sponcom management goaf inertisation strategies. Presence of oxygen in the active goaf is unavoidable when carrying out goaf drainage activities to manage tail gate gas levels of an active longwall. Extensive monitoring activities of goaf dynamics and goaf gas distribution studies have been carried out by the industry for over two decades. Figure 2 shows one such historic work of impact of oxygen profile as a result of proactive N2 injection on both TG and MG areas. The reduced air wash zone is clearly evident in the active goaf thus minimising the conducive environment for any elevated oxidation events (Balusu, 2005). Figure 3 provides the latest CSIRO study using calibrated CFD model of MG and TG inertisation strategy for an operating high gassy longwall mine.

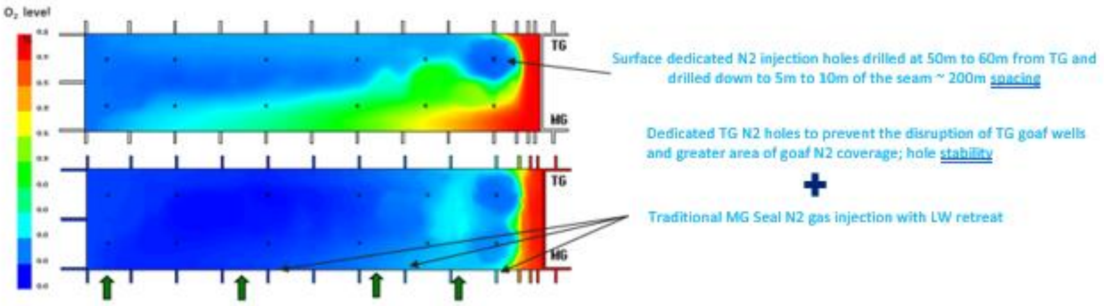

Figure 2: MG and TG inertisation conceptual strategy for gassy longwall mines.

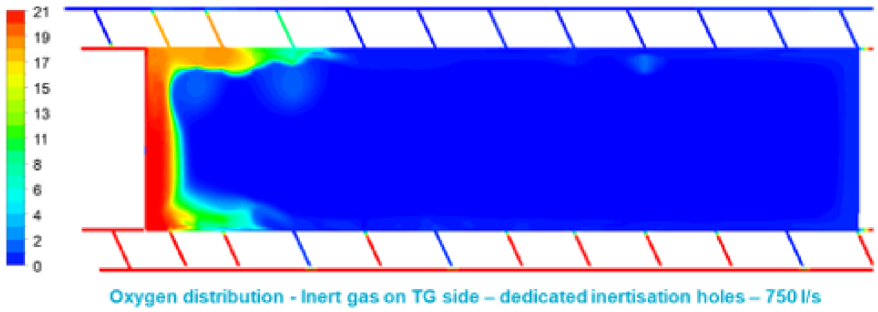

Figure 3: Calibrated MG and TG inertisation strategy for an operating high gassy longwall mine.

Optimum Gas and Spontaneous Combustion Strategies

Conjointly managing the gas and sponcom risk is fundamental to securing a safe underground place of work at GM GM seam longwall operations. With the increasing gassy and known sponcom prone coal seams and a working depth with steep geothermal gradient is contributing towards the step changes in goaf drainage managements for gas and sponcom management in order to be compliant with legislative safe TG gas limits as well as greenhouse gas management with reduced ventilation air methane (VAM) emissions. This strategy reinforces the fundamental importance of the pre-drainage systems with long lead time prior to longwall mining. Furthermore, contrary to the views in relation to elevated coal oxidation and sponcom events related to goaf hole spacing and maximized goaf drainage practices, it is prudent to note that there have been historic cases of sponcom events with 400 m to 200 m goaf hole spacing, and even with no goaf drainage practices.

Following gas and sponcom management strategies aided with both MG and TG inertisation using proactive N2 injection during various phases of longwall production and stoppages provides appropriate guidance:

- In the absence of continuous proactive N2 inertisation, maintaining 5 % to 8 % O2 levels in the active goaf would be very difficult and may exasperate the oxidation in active goaf when the longwall retreat rates slows down or stops for weeks and months.
- Any reduction in goaf drainage to minimise the O2 ingress in deep goaf area of TG region will significantly increase the longwall TG gas levels. This approach would put operations in a dangerous position from gas management perspective.
- It is the operational management of goaf wells (not sudden or automatic operation of the goaf wells to the extreme flow rates, rather stepwise increase) with proactive LW active goaf inertisation for sponcom management will enable the appropriate maximised goaf drainage gas management to manage the longwall return gas levels.

- The introduction of TG inertisation assists in reducing the airwash zone along the TG side of the active goaf.
- Every longwall operations need to continue with the leapfrogging of the well-established MG seal inertisation strategy [including quicker and timely MG seal build, and tight MG brattice control], and dedicated tube bundle monitoring points for goaf gas monitoring.
- As a general long-term strategy, known sponcom prone longwall operations to ensure flexible and contingency inertisation infrastructure is readily available and to remain in a state that it is able to be recommissioned within a single shift at any time during the monitoring period.
- The association of slow retreat due to known or unknown geological structures in the longwall hazard plan and known historic oxidation related incidents, have reinforced the benefits of proactive inertisation system with around 2,200 l/s of inert flow into the active panel [around 1200 l/s on the MG side and 1000 l/s on the TG side using dedicated vertical N2 holes drilled 5 to 10 m from the working seam height].
- Inert gas injection into the active longwall must be through multiple injection points distributed appropriately, depending on the oxygen ingress profiles. One of the inert gas injection points on the MG side should be at around 200 to 300 m behind the longwall face. Inert gas locations on the TG side should be designed based on the goaf gas drainages strategies behind the operating longwall face. Considering the various uncertainties associated with the LW operations in sponcom prone seams, recommendation of inertisation holes at 200 m spacing on TG side is appropriate for long term risk management planning and design purposes. If the evidence suggests otherwise, i.e., constant increased retreat or no stoppages, then TG proactive inertisation may be carried out through inertisation holes at increased spacing (i.e. alternate inertisation holes) in those areas. This would mean that the intermediate dedicated holes and other old/deep inertisation holes can be equally used for oxygen ingress or airwash zone monitoring and sponcom monitoring on the TG side of the goaf as per the oxygen limit recommendations of an active goaf.
- It is to be noted that these gas and sponcom management strategies are not merely based on the LW retreat rate, but also includes the inherent nature of seam propensity for sponcom despite it being equally rated as “low” risk sometimes, geo-thermal gradient, existence of faults and structures, amount of coal left behind, changes to the goaf hole designs, delay in operational related building of MG seals, inadequate MG brattice leakage control for long periods. other engineering related uncertainties associated with the LW equipment, strata control uncertainties associated with moisture/water in TG roadways, and uncertainties associated with cavity control measures.
- Finally, strengthening the proactive inertisation strategy on both MG and TG with flexible inertisation capacity and responding to the up-to-date trigger response values of the oxidation scenario rapidly developing into an advanced stage using appropriate early monitoring strategy is essential in the future proofing of the sponcom risk.

Working Example of Proactive Goaf Monitoring and Inertisation Locations

Active goaf continuous monitoring is paramount to understanding of goaf gas distribution, spontaneous combustion management and the effectiveness of the proactive inertisation. Where an opportunity is possible whereby goaf gas monitoring is possible on both sides of the LW panel, it is recommended to install monitoring points on both sides of the longwall. This would enable, detailed goaf gas distribution on both sides of these initial longwall panel or extended LW panel from the previous panel. It is very rare to have access to such valuable data for multi-hazard Longwall ventilation, gas and spontaneous combustion management to understand the goaf dynamics.

In remaining longwall panels, one can only monitor on the maingate side of the panel due to access issues and potentially consider the manual goaf hole samples. Figure 1 and Figure 2 below provide a general monitoring locations as a guidance. Mining operations may amend the monitoring point locations with qualified reasons in order to obtain sufficient gas composition data for reviewing the spontaneous combustion indicator gas levels from the active goaf, inertisation effectiveness and for developing appropriate control responses.

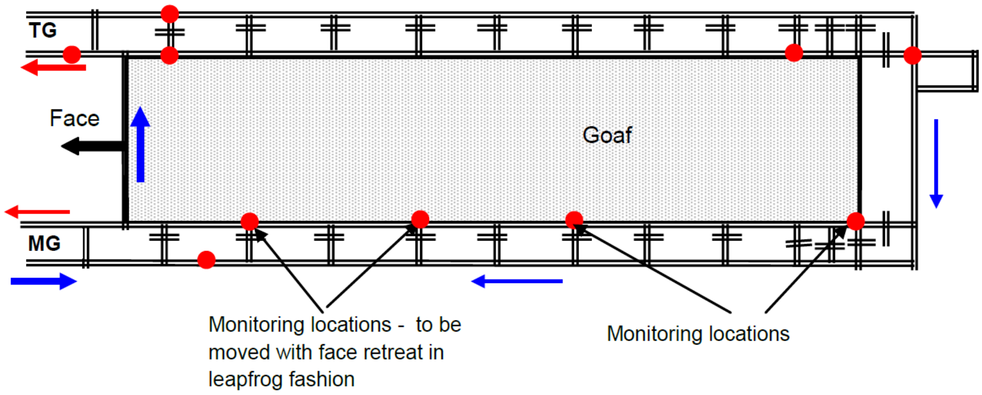

Figure 4: General layout of monitoring locations when TG seals are accessible

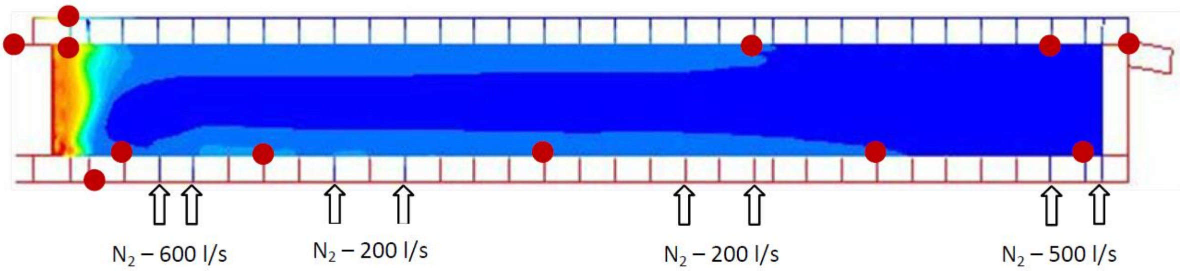

Figure 5: Generalised layout of monitoring and MG inert gas injection locations