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Innovative Tailgate Mobile Goaf Gas Management in Two Gate Road Longwall Panels – Concept to Implementation

B Belle[1,2]

ABSTRACT

In a deep, gassy predrained coalmine, ventilation and goaf drainage systems act as critical controls to manage longwall (LW) panel return gas levels. The goaf capture efficiency of most LW panels ranges from 45 to 85 per cent based on the gas domain at respective workings. Recent operational experiences have indicated that 50 m goaf hole spacing is optimal for management of high production retreat gassy LW panels, where the probability of goaf hole failures are frequent. Due to the horizontal stress direction geotechnical issues, goaf hole failure just behind the LW face is a recurring challenge resulting in significant and immediate increases in LW panel return gas levels. This paper presents a successful implementation of an innovative LW tailgate (TG) road cut through seal goaf fan/venturi system. The system incorporated a 17' (400 mm cased) hole drilled to 320 m deep in a perimeter roadway on a retreating LW TG road drawing the working seam horizon goaf gas behind the perimeter of seals. The surface goaf fan/venturi system was aimed to safely exhaust the LW deep goaf gas and thus withhold the goaf stream spillage to TG drive area and reduce the panel gas load by controlled operation of the system using continuous monitoring of CH_4, CO and O_2 levels. This control philosophy was made operational without impacting the use of the perimeter inbye ventilation shaft used for mine cooling and providing additional ventilation dilution capacity. The instantaneous reduction in TG gas levels of up to 0.3 per cent was observed even when the LW was 300 m away from the c/t seal goaf hole. Success of this concept TG seal goaf gas control system used even when the LW was 1300 m outbye has become an inventory of additional control for future deep and long LW blocks. This paper attempts to share the design process in addressing other risks and desired outcomes in managing the LW gas levels.

INTRODUCTION

[illegible] production gassy longwall (LW) mines, both [illegible] and goaf drainage systems act as two major [illegible] controls to manage LW panel return gas levels. [illegible] gas contents for the mine increases with increasing [illegible]. Furthermore, there is a corresponding [illegible] permeability with depth. Delivering a low [illegible] for development operations requires that [illegible] is conducted well in advance to allow for [illegible] drainage time (up to three years). Typically, *in* [illegible] methane contents of the Australian gassy coal [illegible] from 6–20 m^3/t as the workings get deeper.

[illegible] management in Australia has been a relatively [illegible] practice (less than 30 years in Queensland) [illegible] attempts to isolate and pipe gas from a [illegible] Great Britain that occurred in 1733 as reported [illegible] and Jones (1955). Gas predrainage (ie prior to [illegible] post drainage (ie during mining, such as longwall [illegible]) techniques are utilised to assist in the control [illegible] resulting from continued emission of methane or carbon dioxide gas from the working or adjacent coal seams. Together with adequate mine ventilation, the gas drainage system is recognised as the primary means of controlling the mine gas hazards.

Predrainage system would involve surface to in seam (SIS) and underground in seam (UIS) methods. SIS holes are drilled remotely to the underground operations and predrain gas well in advance of the mining operation. SIS methane drainage holes are generally drilled parallel to longwall gate roadways (flanking holes) to provide 'protection' from gas flowing from adjacent coal blocks to development gate roads. The UIS holes are drilled from an underground development stub. A number of holes are drilled laterally in-seam from a gas drainage stub with holes being connected to a steel pipe in the stub that is connected to the surface gas reticulation system. The advantage of surface-based techniques is that drainage can be carried out independently of the mining operation, but the feasibility of an application depends on the

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depth of drilling, the integrity and permeability of the coal and any limitations imposed by surface topography.

Goaf drainage is typically employed over the retreat longwall behind the working face. It involves intercepting methane released by mining disturbance before it can enter the longwall ventilation circuit keeping the circuit methane levels to acceptable levels. Vertical boreholes are used to drain methane from retreating goaf areas are an effective means to reduce the methane emissions that need to be diluted underground. When the LW retreats past the holes they are connected to the vacuum gas plant that provides suction to the holes to effectively remove high purity gas from the goaf. In a deep gassy predrained coalmine, ventilation and goaf drainage systems act as critical controls to manage longwall panel return gas levels. Goaf gas is typically drained from 250 to 350 mm (10 or 14 inch) vertical holes from surface spaced every 50 m to 100 m located on the tailgate side into strata above the longwall caved area. This strategy typically results in an average 45 per cent to 80 per cent drainage capture efficiency with peaks of about 85 per cent at high gas stream purity (>90 per cent CH_4). Recent operational experiences have indicated that 50 m goaf spacing is optimal for management of high production retreat gassy LW panels, where the probability of goaf hole failures are frequent. Due to the horizontal stress direction geotechnical issues, goaf hole failure just behind the LW face is a recurring challenge resulting in significant and immediate increase in LW panel return gas levels. This paper presents a successful implementation of an innovative LW tailgate road cut through seal goaf fan/venturi system and desired outcome in managing the LW gas levels.

BACKGROUND

Extensive and immediate gas emissions in the retreating longwall goaf require consistent and continued goaf gas drainage for reducing the tailgate (TG) gas levels to below one per cent when TG access is needed. In cases of high gas emission rates, goaf gas drainage from the start-up area is a major challenge due to high permeability of the goaf, which may lead to high ingress of oxygen and dilution of the goaf gas and thereby resulting in low gas concentration through the goaf holes. The development of mobile LW TG cut through goaf seal drainage in an operating gassy and spontaneous combustion (sponcom) prone longwall mine was born out of the challenges faced by the failures of goaf holes that reduced the goaf capture efficiency to below 50 per cent, resulting in elevated TG gas levels. Balusu *et al* (2001, 2002 and 2004) carried numerical and field data investigations on goaf hole gas flow mechanisms and proactive inertisation strategies for prevention of spontaneous combustion in gassy coalmines and investigations resulting in the current goaf gas drainage strategies in Australian underground LW mines (Figure 1).

Typically, for an operating longwall, using longwall specific gas emission (SGE) prediction tools, likely longwall emissions (typically 10–40 m^3/t) from upper coal seam sources are established using multiseam gas content hole. For planned weekly production rates of 120 000 t/wk, the goaf drainage capacity could be in the region of 2000–7000 L/s of methane coming from coal seams that are in the vicinity of up to 200 m above or up to 50 m below the working longwall seam. With the increase in total LW gas emissions due to increase in gas content with depth (Figure 2) and significant increase in weekly retreat rates, the need for innovative and effective gas management is continuing. Current operational experiences clearly suggest that, what has been effective in goaf management system in the past for low gassy regimes is not sufficient for challenging and difficult geological domains of high production longwalls.

Diamond (1994) had summarised various methane controls for underground coalmines in USA. Amongst the various goaf drainage techniques, the study provided an example of the use of goaf ventilation fans (Figure 3) positioned over the goaf hole in a gassy eastern US coalmine. It documented 13 goaf holes drilled per longwall panel draining between 250 and 300 L/s of methane using goaf ventilation fans. Similar philosophy of employing goaf ventilation fan over the goaf hole was attempted at Dartbrook mine in New South Wales. Because of potential explosion risk, the drained methane gas through degasification systems must not have a methane concentration below 30 per cent, a local lower limit. For example, UK limit is 35 per cent (USA goaf methane cut-off limit of 25 per cent CH_4) at a working mine. If sufficiently high methane concentrations cannot be maintained, the exhaust goaf drainage system should be restricted to maintain a sufficiently high methane concentration or closed off.

The gas management at the operating longwall discussed in this paper involved use of both U-type longwall ventilation and traditional vertical goaf gas extraction management techniques; however, the failure of the goaf holes at the start of the longwall resulted in elevated levels of tailgate (TG) gas levels preventing tailgate access for preventative maintenance purposes. Various strategies were attempted to manage the outbye longwall TG gas levels and TG drive in a crib-less longwall tailgate system with reduced goaf stream and spillage of goaf fringe. Other key features of the operating longwall was that it was the first operating panel that drained the immediate upper P-seam coal with the longest panel to date and the retreating longwall would leave typically ~2 m coal in the goaf. The operating longwall utilises nitrogen inertisation system for managing the spontaneous combustion risks in the goaf (Balusu *et al*, 2002). In addition, the operating longwall utilises the inbye shaft using perimeter roadway for mine cooling purposes to manage the steep temperature gradient.

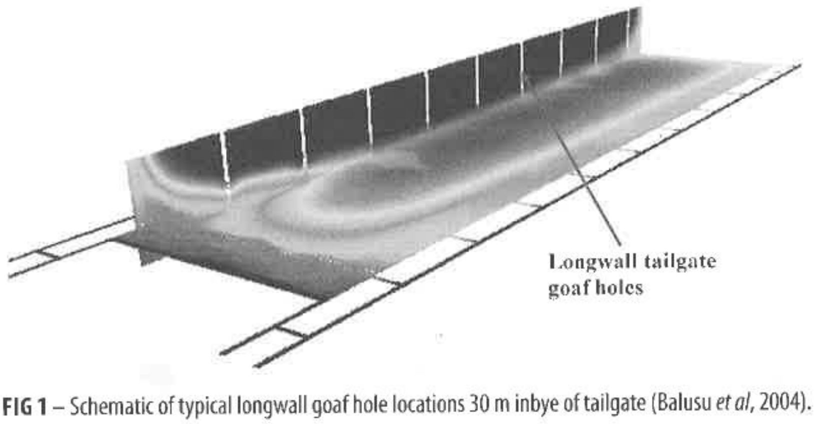


FIG 1 – Schematic of typical longwall goaf hole locations 30 m inbye of tailgate (Balusu *et al*, 2004).

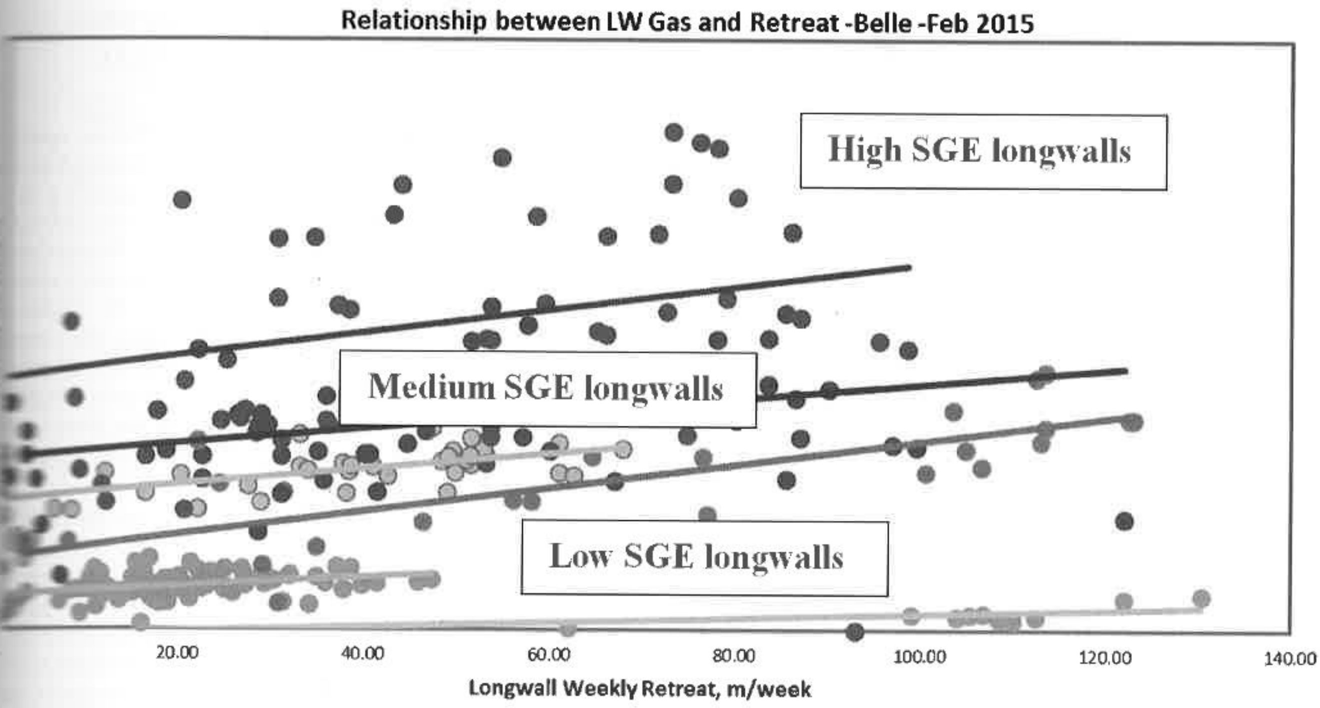
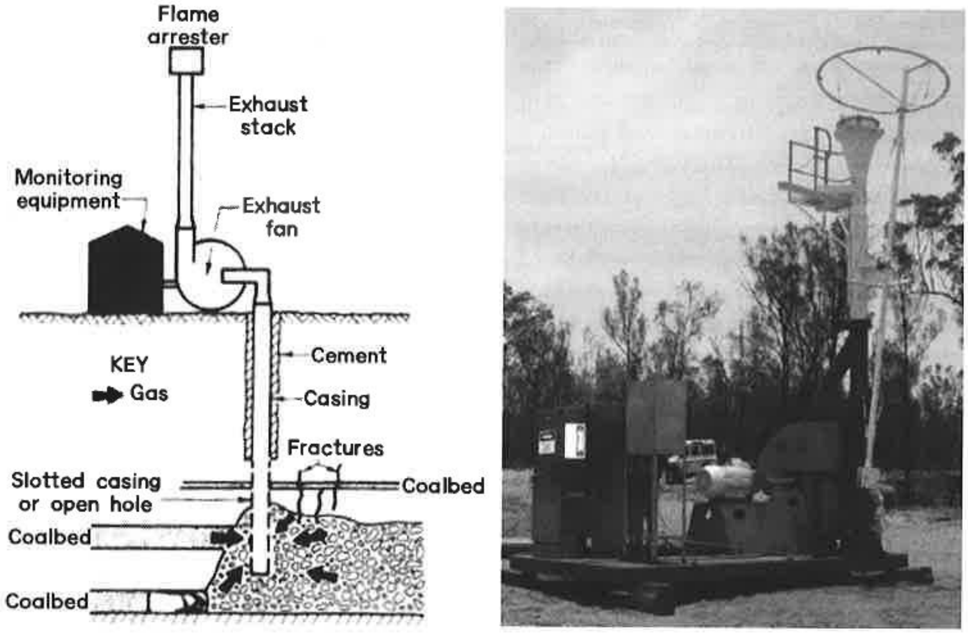


FIG 2 – Relationship between longwall panel return gas levels and retreat rate for low, medium and high specific gas emission (SGE) longwalls.



– Schematic section view of complete US longwall goaf gas vent hole system (Diamond, 1994) and deep goaf fan system at central colliery (Balusu *et al*, 2004).

…oncept of deep goaf drainage is discussed in detail in … ACARP Project C10017 (Balusu *et al*, 2004). A field … at Central Colliery showed that the number of goaf … could be reduced by using this technique, where the … goaf drainage capacity was less than 2000 L/s. It was … that the operating longwall goaf in the current scenario … probably behave differently to Central goaf, probably … due to different lithology although the methane gas … is significantly higher to that at Central Colliery. The … Colliery goaf drainage system had used the surface … fan over the start-up area goaf holes; however, the … cut-through seal goaf fan concept discussed later on … not attempted before while maintaining longwall inbye … shaft for mine cooling. Theoretically, it was envisioned … this system can guarantee that the only place where … is drawn from the goaf area behind the LW shields.

Previously, in order to manage the significant variations in diurnal barometric pressure in a very high gassy mine, an attempt was made to draw the goaf gas fringe from surface using goaf hole in tailgate roadway (Belle, 2014). The deep goaf drainage strategy assisted in minimising the gas fringe as well as providing additional drainage capacity. During this set-up venturis were used to extract the gas as the goaf fan was not immediately available. The full benefits of this system could not be demonstrated due to the finishing of the gassy longwall panel.

Due to the decision to not have goaf holes as practiced in previous longwall panels and the subsequent failure of drilled goaf holes at the start of the high SGE longwall, and to manage the longwall tailgate gas levels various ventilation and gas management controls were attempted, *viz*:

- increasing the longwall face ventilation airflow by increasing the main fan speed
- use of ventilation curtains and air venturi to dilute and direct goaf gas towards the tailgate return
- high maintenance Sherwood curtain system directing the airflow towards the tailgate drive
- additional goaf holes in the start-up face line area
- regulating conveyor belt dogleg return airflow to increase the longwall face airflow
- attempt of antitropal belt option but discontinued due to increased heat and dust management risks
- goaf hole on main gate side and middle of the longwall block with an attempt to move the goaf fringe away from the tailgate as these goaf holes could be managed from the surface
- considering the significant underground safety risks (sponcom – risks and previous history of failures to maintain the regulator) associated with the main gate back regulator (MGBR) to create a low pressure on the main gate side of the longwall and bleeding the goaf gas back to in bye shaft control was not attempted
- concept of mobile longwall tailgate (TG) cut through goaf seal drainage system operated from surface without impacting longwall inbye intake shaft airflow.

Amongst the various gas management controls available in a longwall face, the proposal of MGBR often comes up. This proposal is based on its effectiveness as a gas management control in a low gassy, non-sponcom mine with limited provision for surface goaf hole drilling. Typically, the use of MGBR to bleed goaf gas from an operating longwall has been attempted previously where the next longwall block is already holed through thus providing additional air to mix with bleed air to manage the gas levels. This has resulted in occasional spikes of two per cent on bleeder and longwall return when the total air flow ranges between 130 m^3/s and 190 m^3/s. In addition, the 'perimeter' roadway for MGBR purposes would have added a between 100 Pa and 1000 Pa increase in pressure to the ventilation system.

Two challenges to increase the airflow across the LW face to manage the gas levels was the operational changes in the tailgate area configuration and the higher level of resistance at the tailgate intersection with estimated LW pressure differentials of up to 400 to 500 Pa. Amongst the various control solutions identified, the option of using the perimeter roadway as a MGBR was dismissed due to:

- the restrictions of the main ventilation system, as it was difficult to achieve a minimum quantity on the LW cutting face of 50 m^3/s compared to the original 70 m^3/s airflow, and bleed sufficient air around the perimeter roadway
- difficulty in balancing the methane levels in the perimeter roadway and longwall return roadways without impacting on the evacuation trigger action response plans (TARPs)
- maintenance of MGBR being a high-risk activity and in the event of roof falls in TG could mean there would be a limited fresh air base
- the configuration of the LW and mine network, the benefits from the change of LW inbye shaft to return shaft would negate the additional dilution capacity of the LW
- the spontaneous combustion risk could be elevated by the regulators adjacent to an active or sealed goaf.

DEVELOPMENT OF MOBILE LONGWALL TAILGATE CUT THROUGH GOAF SEAL DRAINAGE SYSTEM

In the midst of goaf failures, with respect to the operating longwall goaf drainage, a lot of different control ideas were attempted (as discussed in previous paragraphs) in an operating longwall with methane capture from 1500 L/s to 3000 L/s without benefiting the TG drive or LW panel return gas levels. What was needed was the efficient and continued capture of goaf gas from just behind the LW shields and working goaf horizon. In order to minimise the longwall panel TG return gas levels to below 0.8 per cent to provide ready access and an attempt to hold back the goaf fringe from spilling onto the TG drive, it necessitated the development of an innovative solution of a mobile longwall tailgate cut through goaf seal drainage system.

The concept of mobile longwall tailgate cut through goaf seal would involve additional extraction of the goaf gas from the working seam horizon to reduce the ventilation gas load by creating an alternative low pressure point in the goaf. For example, a longwall air flow of 65 m^3/s that produced spikes of up to 2.2 per cent (spikes) would result in a longwall panel gas load of 1500 L/s of methane. To reduce the gas at panel return to 0.8 per cent (ie 500 L/s CH_4 in the ventilation system) would require an additional gas sink of 1000 L/s over and above the existing goaf drainage capacity.

To provide this additional capacity, the system incorporated a 17' (400 mm cased) hole drilled to 320 m deep in a perimeter roadway on a retreating longwall TG road drawing the working seam horizon goaf gas behind the perimeter of seals (Figure 4). The extraction of goaf gas was achieved by a goaf fan/venturi capacity of 2000 L/s at 15 kPa operating from the surface. This surface goaf fan/venturi system aimed to safely exhaust the longwall deep goaf gas and thus withhold the goaf stream from spilling into TG drive area and reduce the panel gas load by the controlled operation of the system using continuous monitoring of CH_4, CO and O_2 levels.

The position of the cased hole was outside the seal in more stable ground. This avoided contamination of particles and water that otherwise would have the potential for blockage of the flame arrester and pipes placed through the seal. This technique works without impacting back the inbye intake shaft (50 m^3/s) used for summer cooling, and without impacting longwall return airflow for tailgate panel return dilution (10 m^3/s at two per cent CH_4 ~200 L/s). Figure 5 shows the concept plan of underground pipes of the TG cut-through seal, which causes CH_4 to migrate away from TG.

Mobile tailgate C/T seal goaf fan/venturi system (Figure 6) would involve, *viz*:

- TG C/T split hole diameter – 400 mm with casing at a location on the retreating TG roadway decided using appropriate risk assessment
- goaf fan (1300 mm H40A-SWSI high pressure, backward inclined plate blade) – 2 m^3/s (methane) at 14 kPa (variable speed)
- auxiliaries including:
  - variable speed drive motor
  - flame traps
  - pipes
  - monitoring
  - water trap
  - detonation arrestor
- real-time goaf fan monitoring system to measure:
  - CH_4 (per cent)

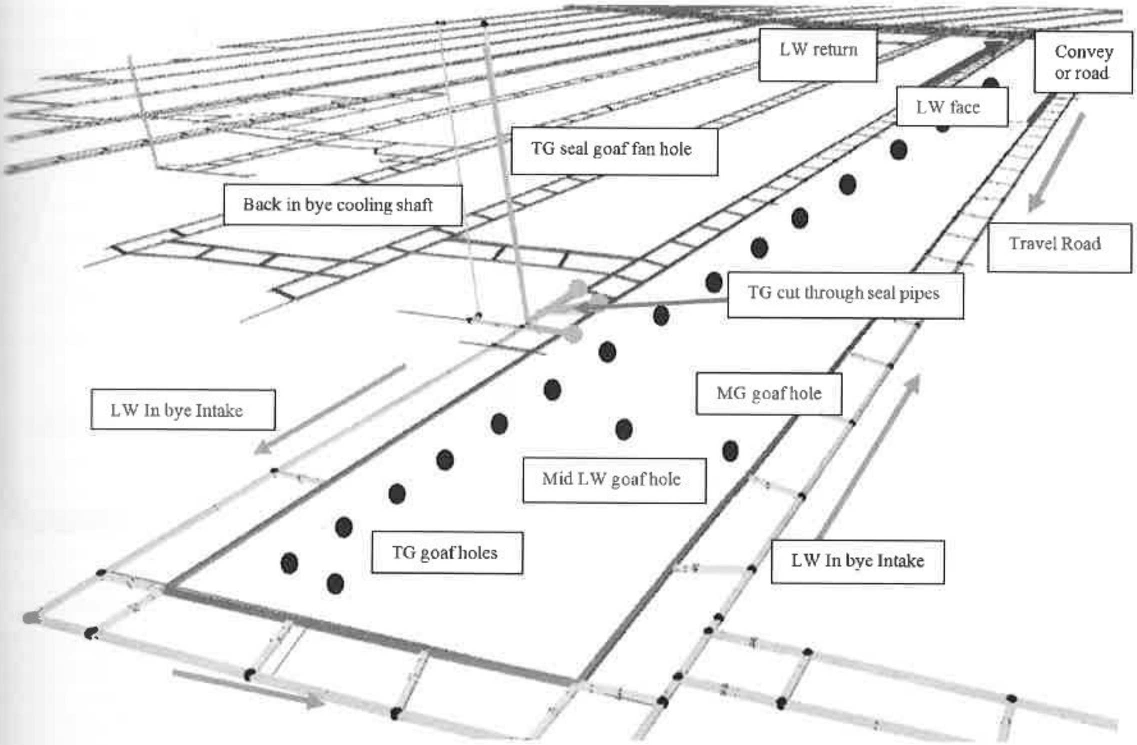


FIG 4 – Schematic view of mobile longwall tailgate cut through seal goaf drainage system.

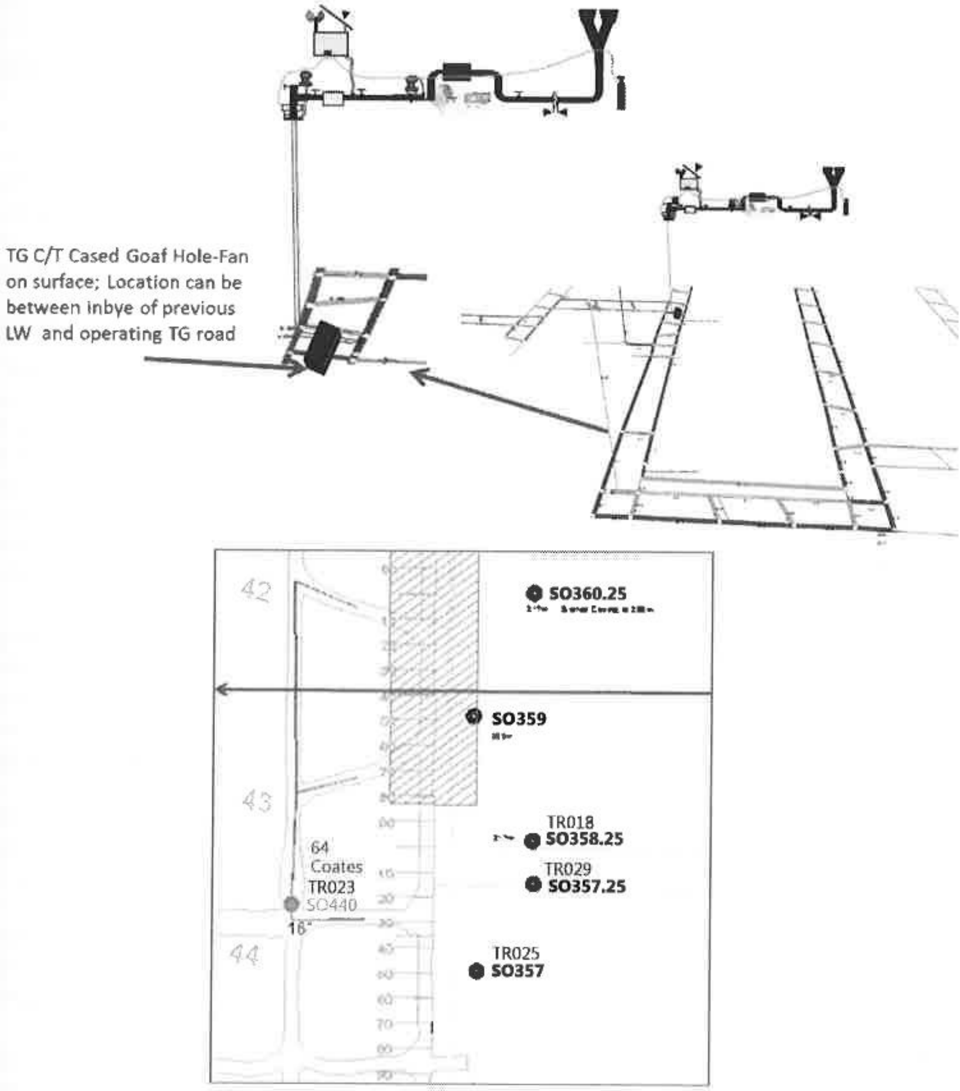


FIG 5 – Schematic view of mobile longwall tailgate cut through seal goaf drainage system.

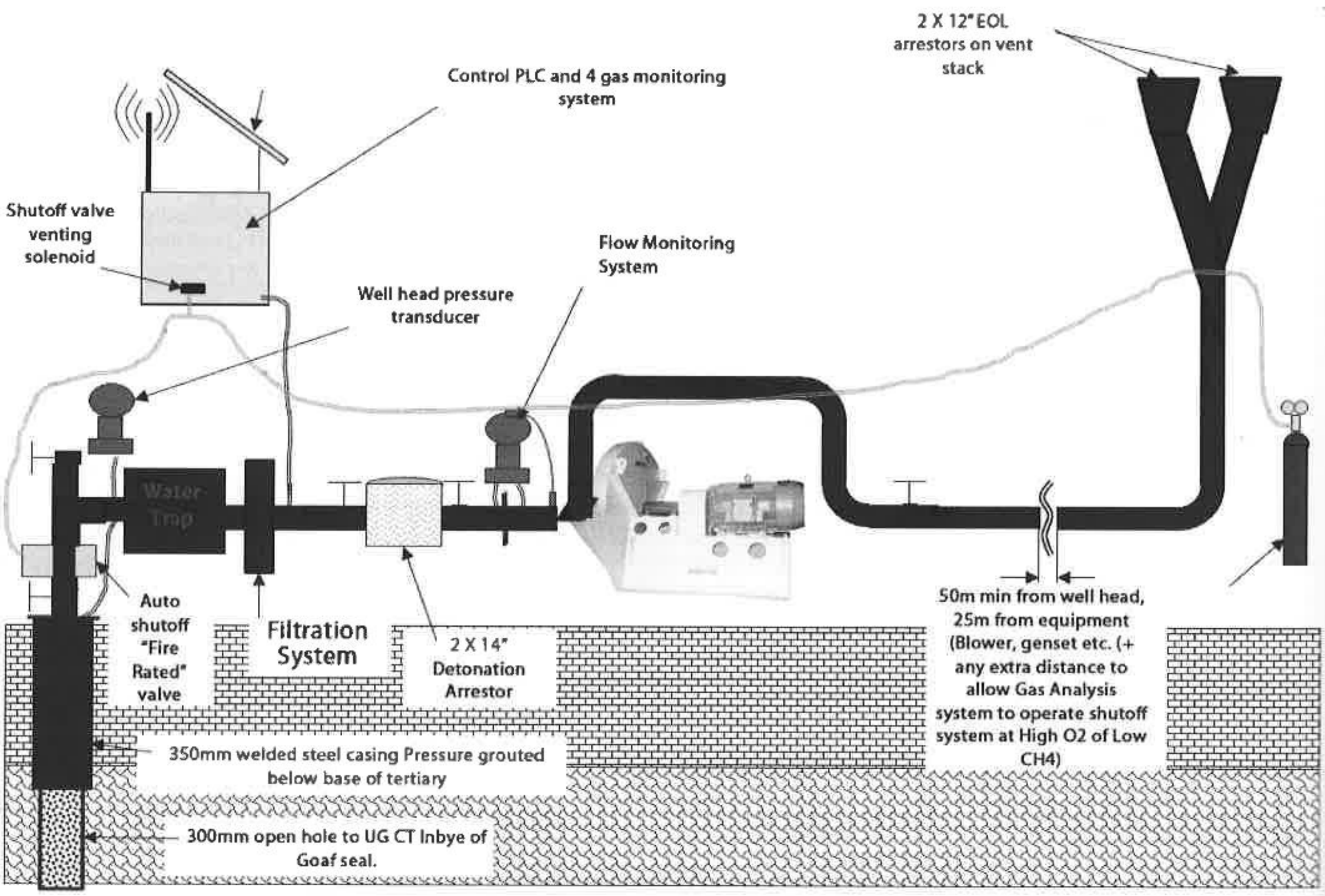


FIG 6 – Mobile tailgate c/t seal goaf fan specifications.

- O_2 (per cent)
- CO_2 (per cent)
- CO (per cent)
- flow (L/s)
- temperature
- static pressure.

For the operating longwall, the proposed system (seal goaf fan) should have a capability of up to 2000 L/s of methane at STP out of 400 mm cased hole and 300 mm surface infrastructure, this would equate to 3 m^3/s of gas at 67 per cent methane. Even at 40 per cent CH_4, the system would be able to remove ~1000 L/s of gas. Any gas that is not removed by the system is added to U/G LW panel return (ie 750 L/s × 24 hours × 60 days) results in 3.9 million cubic metres of additional methane that would be diluted by the ventilation system of 75 m^3/s of air at one per cent methane.

The overall practical benefits of the TG c/t seal goaf drainage system are summarised as follows:

- continued use of inbye cooling shaft to manage the thermal stress with working place of up to 40°C and ambient wet-bulb temperature of 25°C in summer months
- continued goaf drainage in the event of surface goaf drainage hole failures under difficult geological conditions.
- creation of low pressure points away from the longwall tailgate, thus withholding the goaf gas volume away from the longwall tailgate area
- improving the 'window' period for quicker tailgate access during the maintenance period
- planned to be a mobile system, the reduction in infrastructure over that of a typical pipeline system
- can be implemented in future longwalls
- can be set up quickly/ready to operate system
- simple, reliable and relatively low maintenance system
- energy and cost-efficient compared to a venturi and a goaf plant system (if surface pipe line losses included).

IMPLEMENTATION RISK ASSESSMENT

Prior to the implementation of the concept of TG cut through seal goaf drainage system for identifying any shortcomings, a detailed risk assessment (RA) as required by the Queensland Coal Mining Safety and Health Regulation (CMSHR, Queensland Government, 2001) was carried out. The purpose of this risk assessment was to identify hazards, analyse and assess the risks that are specific to the establishment and operation of a goaf gas borehole in the longwall tailgate. In line with the CMSHR 2001, a risk assessment was carried out to:

- document the process used to identify foreseen hazards and analyse the risk associated with the hazards
- comply with the mine Safety and Health Management System's risk management requirements and the requirements of the Coal Mining Safety and Health Legislation
- develop a prescribed way that will achieve an acceptable level of risk when conducting the designated task.

This risk assessment was formulated using Queensland Recognised Standard 02 – Control of risk management practices (Department of Natural Resources and Mines, 2009) and form part of the mine Safety and Health Management system. Key elements of the RA (including hazards and control measures) are as follows:

- ensuring the purity of goaf gas extracted is of safe level by means of continued monitoring and adhering to gas management TARPs

... adequate safety measures for spontaneous ... means of continued monitoring and ... sponcom TARPs

... pillar

... LW TG corner

... spontaneous combustion

... mixture in pipe range

... to consolidate ribs to minimise leakage

... monitor in bye goaf

... into balance chamber of seals

... sampling point on manifold at bottom of ...

... AND DISCUSSIONS

... operation of the TG c/t seal goaf fan system ... chainage) in the first week of the operation ... in bye (3513 m chainage) of the goaf fan ... the criteria used to evaluate the early success ... difference caused by turning off the TG c/t seal ... that the system was removing ~200 L/s ... per cent purity) resulting in 0.3 per cent ... general purity, ie reconciled value of ... per cent ~210 L/s of CH_4. From the operational ... noted that for two gate roads and for safe ... reduction in gas levels assist. It was also ... the TG c/t goaf system as switched off, the ... from 33 per cent to 48 per cent without ... production for the period.

... that turning off the TG c/t goaf seal system ... resulted in tailgate gas levels rising from ... per cent when the LW face (3306 m chainage) ... from the control system. In simple terms, ... gas results showed that induced negative ... the goaf fan/venture system was assisting ... the goaf gas fringe from the TG drive and ... the panel return ventilation stream and thus ... gas levels in the tailgate. A finer quantitative ... extremely difficult to perform considering ... nature of various mining and natural factors (controllable and uncontrollable) involved therein. What was obvious was that the concept was working for the gassy longwall; ie taking away the goaf stream behind the LW shield-goaf horizon.

One of the learnings from the first few days of this new goaf control system operation was the slow decrease in gas flow from the venturi system. Upon investigations on the temperature fluctuations of the gas flow, it was speculated that there had been water building up at the bottom of the vertical pipe. With high-operating air-gas (lower density mixture) velocities in the vertical goaf drainage pipe, one would not expect 'dancing effect of droplets' as sometimes seen in exhaust ventilation shafts. After emptying the water out of the bottom of the gas riser, flow from the venturi returned with a flow of 500 L/s and the practice of routinely draining the water was continued. The system was operated for nearly three months, when the longwall (2294 m chainage) was draining methane with 70 per cent purity and 880 L/s flow, when the longwall face was beyond 1300 m from the TG c/t goaf fan system. Figure 9 indicates the superior performance of the TG c/t goaf fan system performance against other surface goaf holes in managing the TG drive fringe, as well as managing the total goaf gas effectively.

While the new goaf seal drainage system was operational, the oxygen and CO levels were monitored with a tube bundle monitoring system. At that stage, the analyses of the main gate tube data noted that the continued operation may be contributing to the oxygen ingress through the main gate in bye seals, but the data analyses proved to be inconclusive (Figure 10). While it was difficult to adjudge whether the continued use of the venturi or the poor seal quality was the driver for elevated levels of oxygen at main gate seals, the operation of the T/G goaf fan system was discontinued; however, the oxygen levels were continuously monitored to understand the source of oxygen ingress over the longwall panel. It is noted that the phenomena of oxygen ingress and the resulting elevated CO levels due to low-level oxidation would be similar to the traditional goaf hole operations.

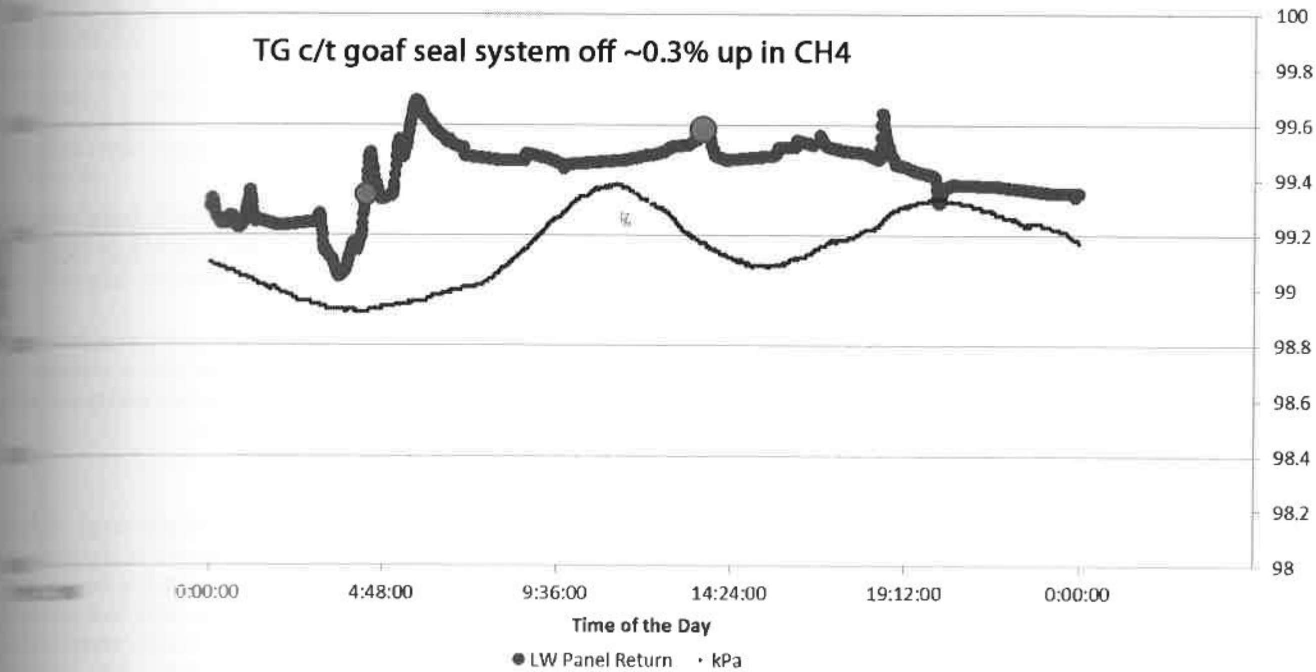


FIG 7 – Effect of tailgate (TG) c/t goaf seal drainage system (longwall face is 70 m away) longwall return gas levels.

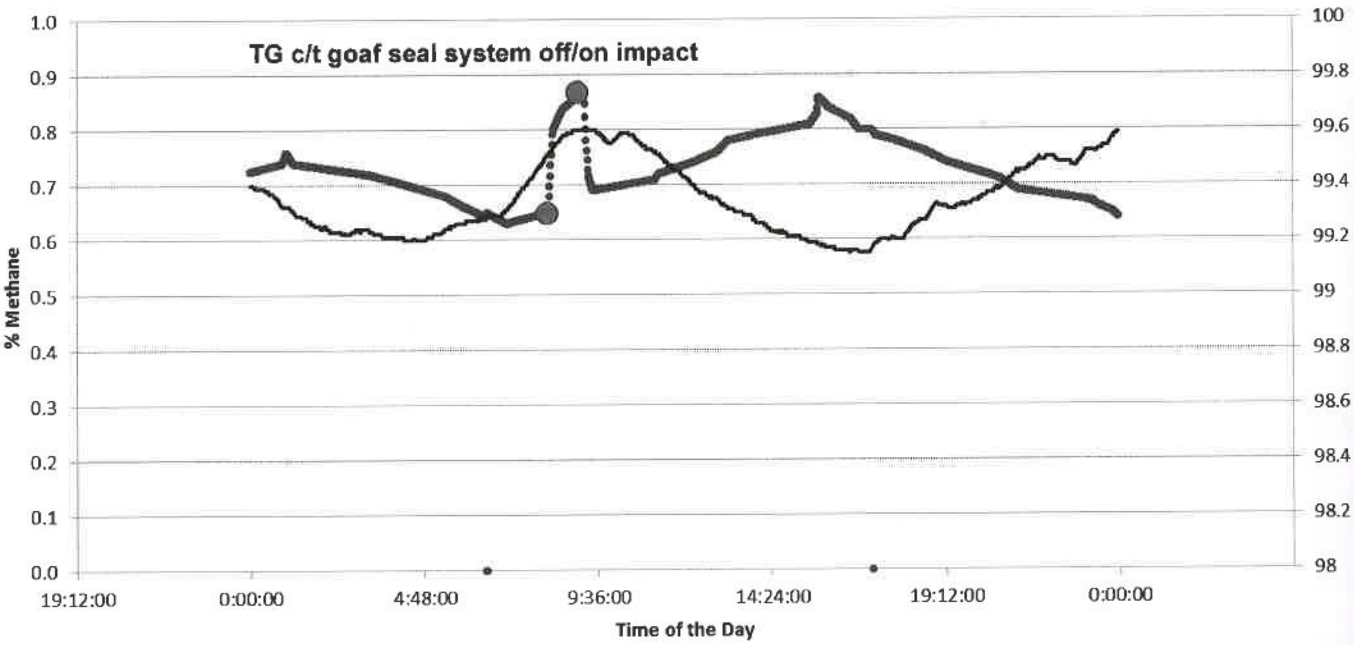


FIG 8 – Effect of tailgate (TG) c/t goaf seal drainage system (longwall face is 300 m away) on panel return gas levels.

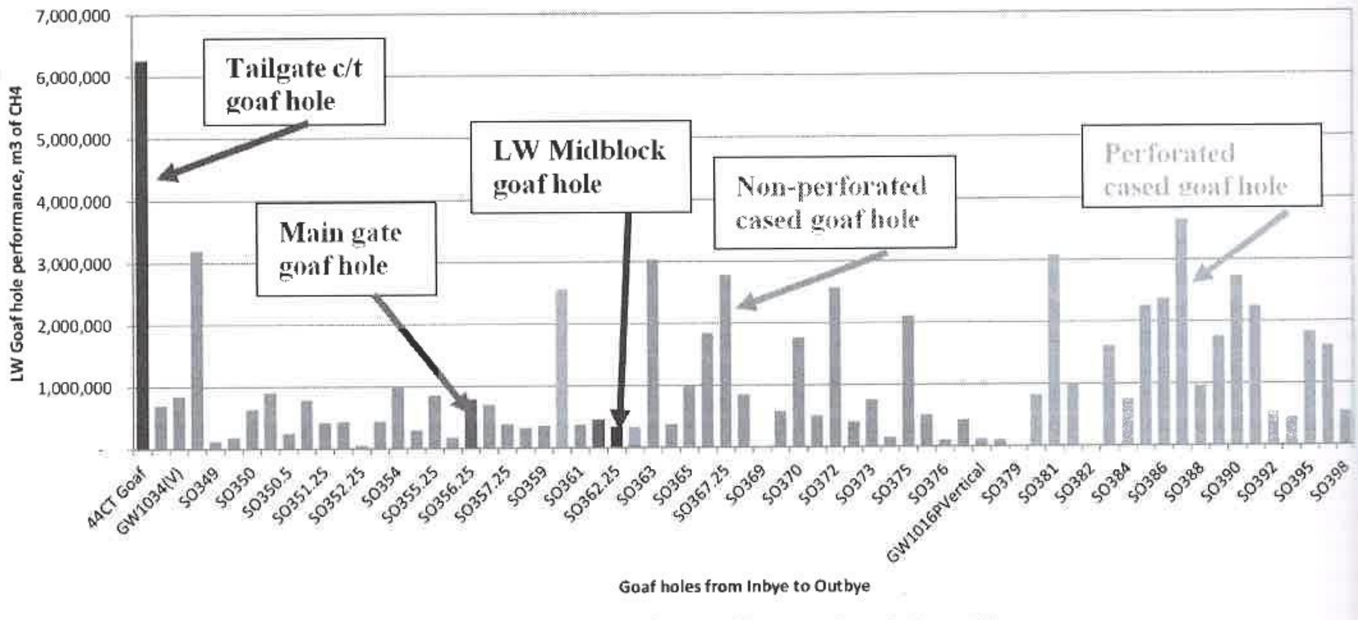


FIG 9 – The performance of tailgate c/t seal goaf fan system along the longwall face.

CONCLUSIONS

The operational experiences of a concept of an innovative tailgate c/t seal mobile goaf gas management system to its implementation process resulted in the following conclusions in managing the gas hazards in high SGE longwalls:

- For the first time the tailgate cut through seal mobile goaf drainage system was attempted at a gassy longwall mine successfully with positive results.
- On an average, the new tailgate c/t goaf seal drained 550 L/s of methane and a maximum of 950 L/s of methane for a period of 138 days in reducing the gas load to the longwall tailgate drive area and the longwall ventilation stream.
- This control philosophy was made operational without impacting the use of perimeter in bye ventilation shaft used for mine cooling and providing additional longwall ventilation dilution capacity. The instantaneous reduction in TG gas levels of up to 0.3 per cent was observed even when the LW was 300 m away from the tailgate c/t seal goaf hole.
- Success of this concept tailgate seal goaf gas control system used, even when the longwall was 1300 m outbye; it has now become an inventory and standard additional control for future deep and long LW blocks.

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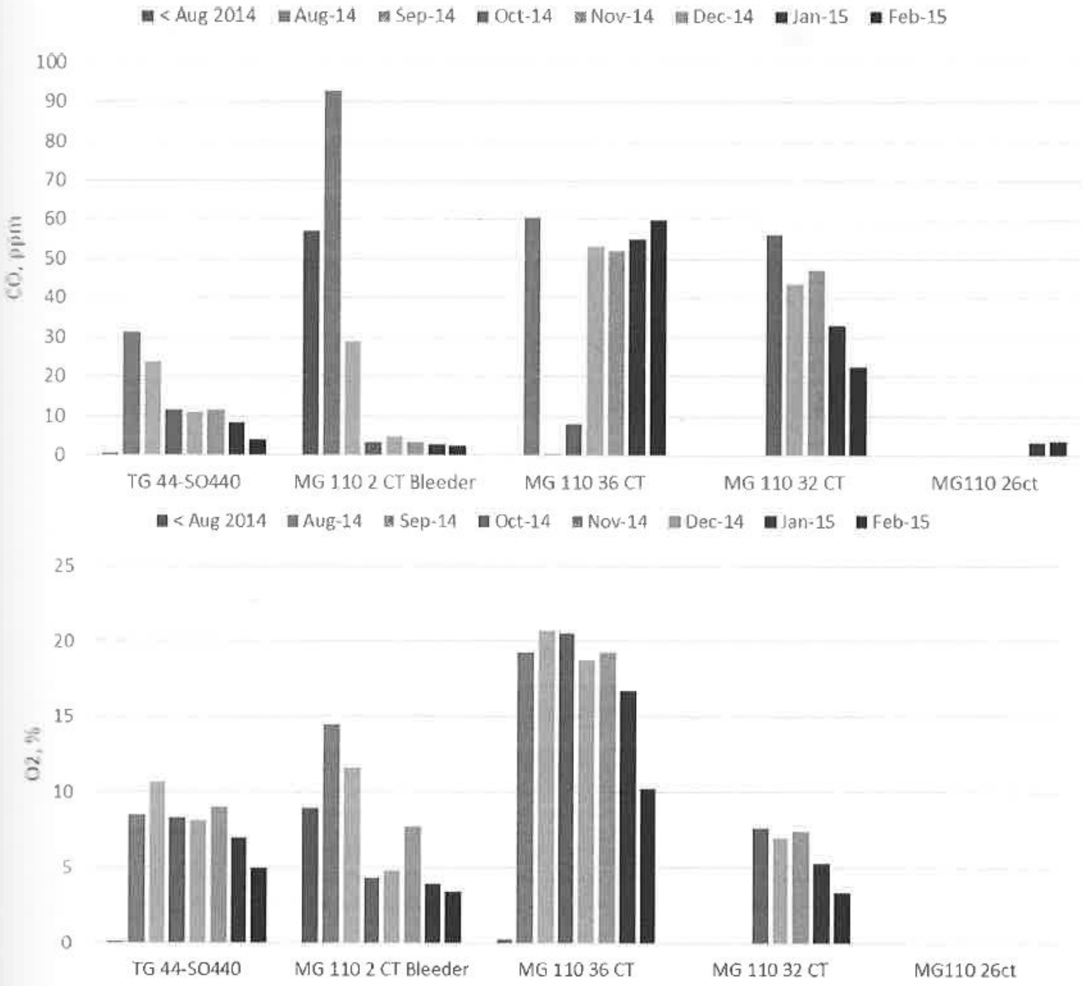

FIG 10 – Impact of tailgate (TG) c/t seal goaf fan system on longwall main gate (A) CO and (B) O_2 levels.

[illegible] its possible field application is appreciated. Lastly, [illegible] is grateful to the Anglo American U/G senior [illegible], D Haage and G Britton, for publication of [illegible] knowledge share and external technical reviewers, [illegible] and R Moreby, for their constructive criticism to [illegible] quality of this submission.

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