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LESSONS FROM THE OPERATIONAL USE OF THE GAG JET ENGINE AT MINE SITES

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ABSTRACT: Rio Tinto Coal Australia (RTCA), Queensland Mines Rescue Service (QMRS) and Simtars conducted a partial inertisation of an underground coal mine using the GAG-3A engine in February 2014. This was an ACARP funded project No C23006. This project monitored the environmental conditions and the flow of inert GAG gases into and around the mine. Observations were made by a variety of remote sensing technologies and by direct measurements as well as observations made by mines rescue personnel in the inertised area. This paper documents methodology, observations and the outcomes including a review of previous inertisations. This project proved that the GAG is a reliable and effective inertisation system. It demonstrated the critical requirement for effective sealing of GAG docking points. It is not envisaged that the GAG could be deployed where there is an expectation that mine personnel could be in the vicinity as temperatures of 90°C were measured. Mine infrastructure and strata in zones close to the GAG docking station were detrimentally affected by prolonged exposure to the high humidity and temperature.

INTRODUCTION

Rio Tinto Coal Australia (RTCA) Kestrel North Mine is located 50 km NE of Emerald in Queensland. The mine was accessed by two cross measure drifts, one for the conveyor and one for men and materials. Rope haulage was installed in both drift for man transport and materials transport. Several shafts were sunk as part of the mine development.

Kestrel North Mine was in the process of being closed due to exhaustion of the economical coal reserves and was been made available for the trial. It was initially planned that a week would be dedicated to trialling and monitoring inertisation with the mine being re-ventilated and additional instrumentation moved/installed as required. Operational issues with the water table required a revised scope where inertisation would be monitored on two separate days. This was ACARP funded Project C23006 (Watkinson *et al.,* 2014).

GORNICZY AGREGAT GASNICZY (GAG) SYSTEM

The GAG jet engine system itself is a custom designed zero-thrust jet engine with after-burner; coupled with an extension duct where water is injected into the hot exhaust gases. The system is mounted on a trailer to enable rapid deployment and operation by Queensland Mines Rescue Service QMRS (See Figure 1).

Figure 1: Section of the GAG system showing water injection mechanism

This combination of cooled, jet engine exhaust and water vapour is then introduced into the mine to establish an inert atmosphere.

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The GAG consumes 1800 litres of A1 jet fuel/hr and can produce around 25m3/s of jet exhaust product and water vapour. The untreated exhaust gases are very hot as they exit the engine afterburner so they are then cooled by the injection of water at a rate of 600L/minute. The resultant temperature of the inertisation gases is close to 90°C. Further cooling of the gases occurs as they pass into the mine which results in water condensing out of the vapour phase. This water vapour loss results in a net volume flow rate of inert gas of around 7m3/s.

The composition of the GAG exhaust gases range between these values in normal operation:

- O_2 0.5-5%;
- CO_2 10-16%;
- N_2 & water vapour 79.5-84.5%.
- H_2 20-200 ppm
- CO up to 300 ppm).

KESTREL INERTISATION

All elements of the intended inertisation process were risk assessed and detailed procedures put in place to cover the operation. The "target" of the inertisation was the 311LW block. The planned inertisation circuit was the 1km length of the cross measure conveyor drift to 3CT; the belt road 2km towards LW311; then back around the return to the up-cast shaft, as indicated in Figure 2. The entire route was approximately 5.4km in length the approximate volume to be inertised was around 81,000m3. RTCA teams prepared stoppings and sealed access doors as necessary ahead of the exercise in order to minimise leakage.

On Day 1 a ventilation rate of10 m3/s was established in the GAG circuit with around 30 m3/s being delivered into the vehicle roadways. This enabled QMRS personnel to be underground and enter the GAG circuit under Compressed Air Breathing Apparatus (CABA) at predetermined Look Points (LP). On Day 2 there was no mine ventilation thus no underground observers were in place.

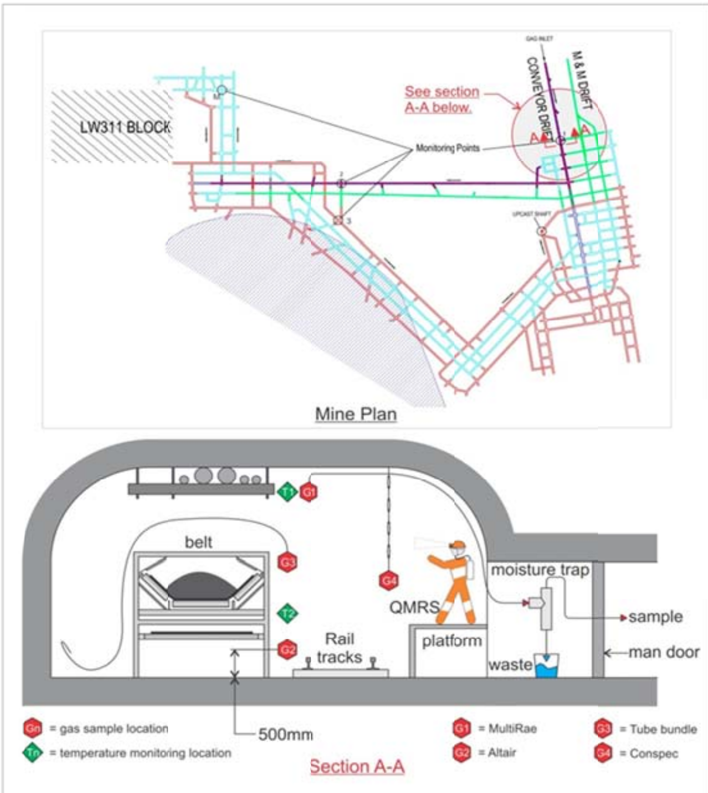

Figure 2: Inertisation Layout, Monitoring Point locations and LP1 test set up

Monitoring

A wide scope of monitoring activities were implemented, in particular as it was possible to have personnel stationed in ventilated areas adjacent to the 3 points in the GAG circuit (look points 1 to 3). During the inertisation these personnel were able to enter the GAG circuit under CABA and following QMRS protocol, to make environmental observations augmented by additional gas and temperature monitoring at other inaccessible positions. The broad scope of the monitoring aims is shown in Figure 3. The scope was achieved by monitoring temperatures, gas levels, relative humidity, air flow, visibility and physical inspections of the mine infrastructure.

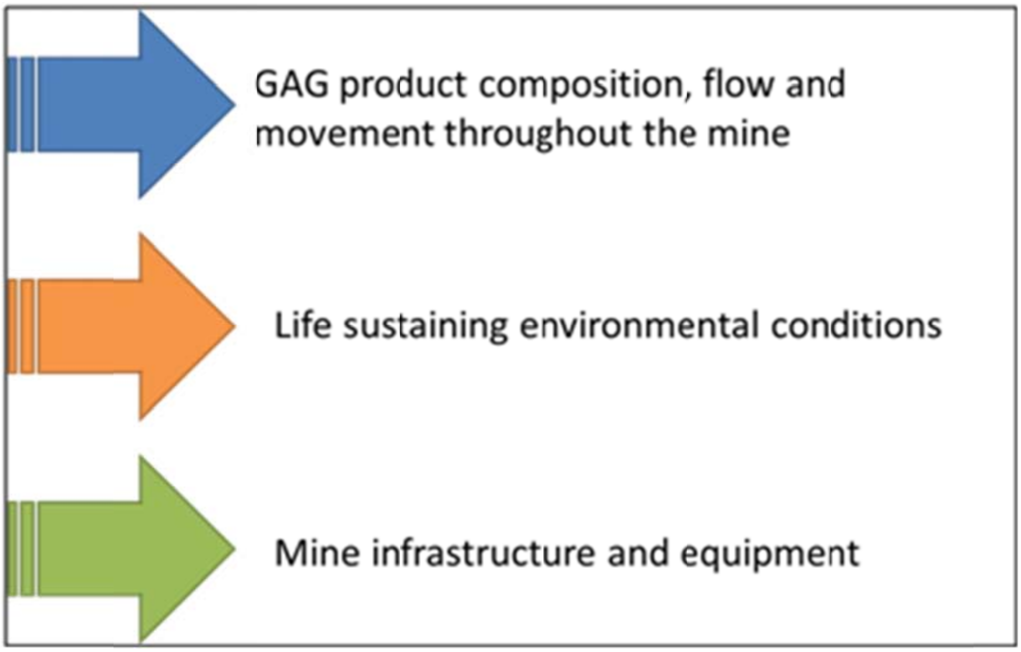

Figure 3: Scope of the monitoring during the inertisation at Kestrel North

Gas monitoring

Gas monitoring was conducted using a variety of techniques, which included the mine's tube bundle and real time systems. Additional sampling was set up at each LP. Queensland Mines rescue used XAM7000 hand held gas detectors to monitor gas concentrations during their inspections of the zone being inertised.

Temperature

Temperature in the drift was monitored continuously over a range of 0-400m, in 1m intervals. This was achieved by the use of a SensorNet Distributed Temperature Sensor (DTS) system. The DTS is a laser and fibre optic based device that can measure temperature at 1m intervals over distances of 10 km. Thermocouples were used at each LP at the roof and floor level. The primary concern was to ensure the safety of the QMRS personnel and that they did not enter the conveyor drift if the atmosphere presented them with unmanageable risks. Monitoring was established to give the underground crew live gas and temperature readings from inside the inertisation circuit.

Monitoring at LP1 consisted of:

- Two thermocouple positions.
- MultiRAE gas analyser sampling through water traps.
- Tube bundle point (in the drift).
- Conspec real time oxygen and carbon dioxide sensors (in the drift).
- Altair gas detector measuring in situ, (50cm off the ground under the conveyor).

Additional observations carried out by QMRS personnel at all 3 LPs included:

- Visibility.
- Relative humidity.
- Gas concentrations.
- Taking bag samples for subsequent gas chromatograph analysis.

Note: At LP1 the Real Time (RT) system provided data on carbon monoxide and oxygen for just 2 hours.

Day 1 Inertisation

Temperature distribution in the drift is shown in Figure 4.

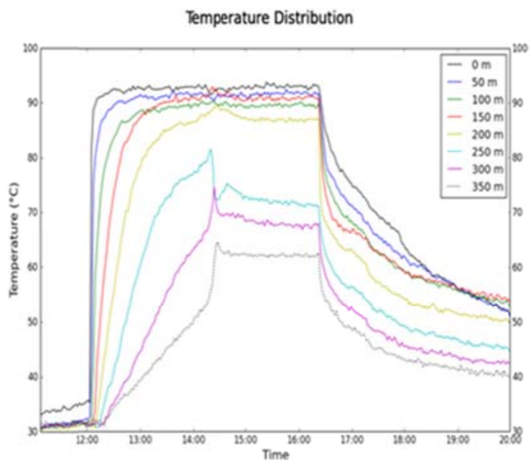

Figure 4: Temperature distributions in the conveyor drift

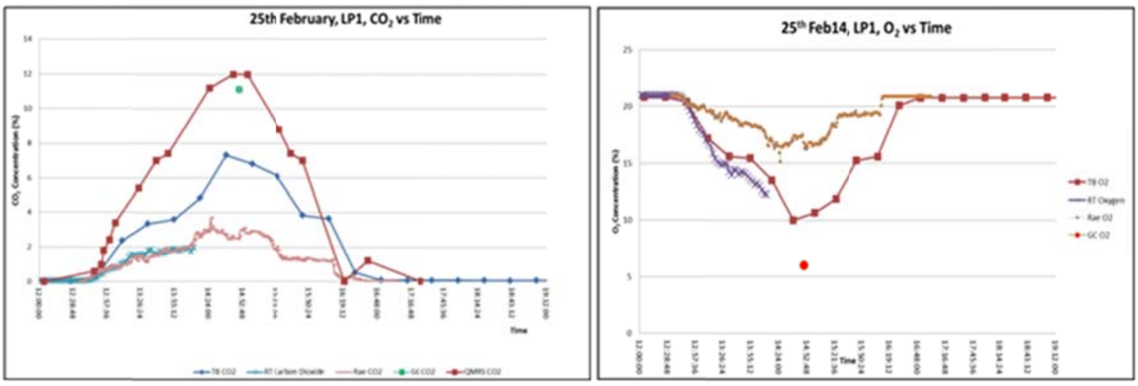

Figure 5: CO2 and O2 measurements at LP1 on Day 1

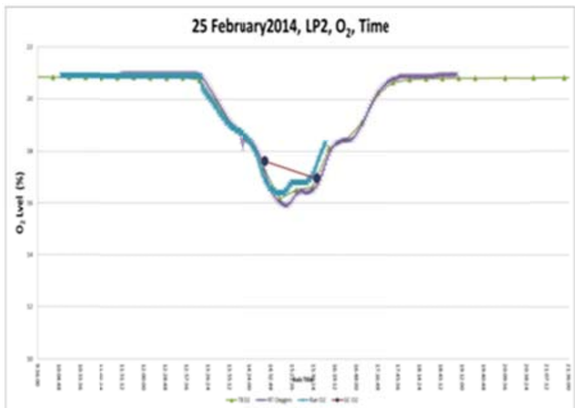

Figure 6: Oxygen level results at LP2

LP3 gas monitoring results

Very little GAG product made it to LP3.

The maximum (minimum for O_2) gas levels measured at LP3 were:

- CO 13.4 ppm
- CO2 0.73%
- O2 dropped by 1% from the baseline levels

Day 1 - concluding observations

- The leakage around the conveyor drift door was substantial and adversely impacted the process of inertising the mine. In preparation for the second inertisation event, RTCA staff provided additional sealing around and behind the conveyor door
- The inertisation run on day 1 was curtailed due to the break in the compressed air line, which rendered any further attempt at inertisation futile.
- Comparative gas measurements at LP1 showed a wide variation between instruments. See figure 5
  - This could be due to layering of the GAG product as it emerged from the conveyor drift at pit bottom
  - Further investigation into layering is necessary
- The CO levels at LP1 were much higher than measured by gas monitoring at the GAG. An additional tube bundle line was installed in the conveyor drift; close to the GAG inlet position to verify readings.
- The real time monitoring system at LP1 failed after 2 hr. See figure 5
- Despite the leakage at the surface, the zone around LP1 (1km from the portal) had an inert atmosphere (less than 10% oxygen) after 2 hr and 45 min. At LP2 the oxygen level fell to 16% see Figure 6
- Visibility remained good 1 km from the GAG inlet.
- Temperatures close to the GAG reached 93°C, but remained at ambient in the mine.
- After the conveyor drift had cooled the surface roller door was opened and inspection showed deterioration of exposed rock/coal areas and buckling of the steel rail track in places.

Day 2 - concluding observations

- There was no mine ventilation on day 2, but natural ventilation paths allowed the inertisation to take place and the GAG gases were delivered much more effectively than on day 1 due to the improvements of the conveyor drift portal door seal.
- Leakage through an open door at 3CT reduced the impact of inbye inertisation however; the process was unaffected up to LP1 as seen from the progress of temperature gradients in the drift and with GAG product migration.
- Maximum temperatures in the conveyor drift reached the same levels as on day 1, i.e. close to 90°C as shown in Figure 7.
- A low oxygen atmosphere (less than 5%) was achieved after 2 hrs and 19 min (Figure 8).

The main visual observations in the conveyor drift were that the rail tracks had buckled and split in places due to the 90°C heat and the lack of rail expansion joints (Figure 9). Surface areas of the drift had deteriorated following exposure to the GAG product. Shotcrete areas had fared better, but exposed rock and coal were spalling and in places had fallen away.

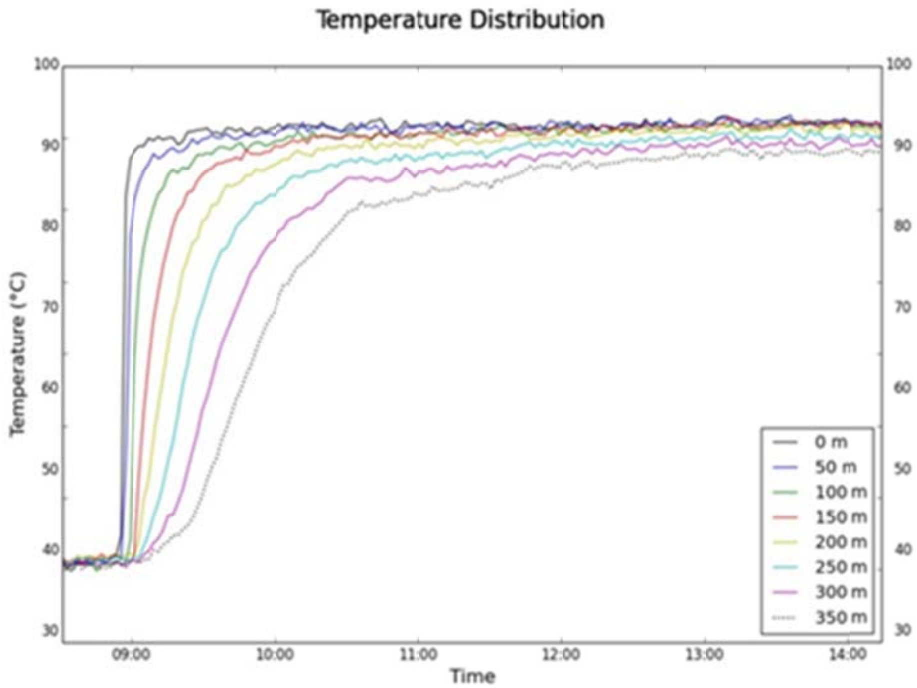

Figure 7: Temperature distributions in the conveyor drift during Day 2

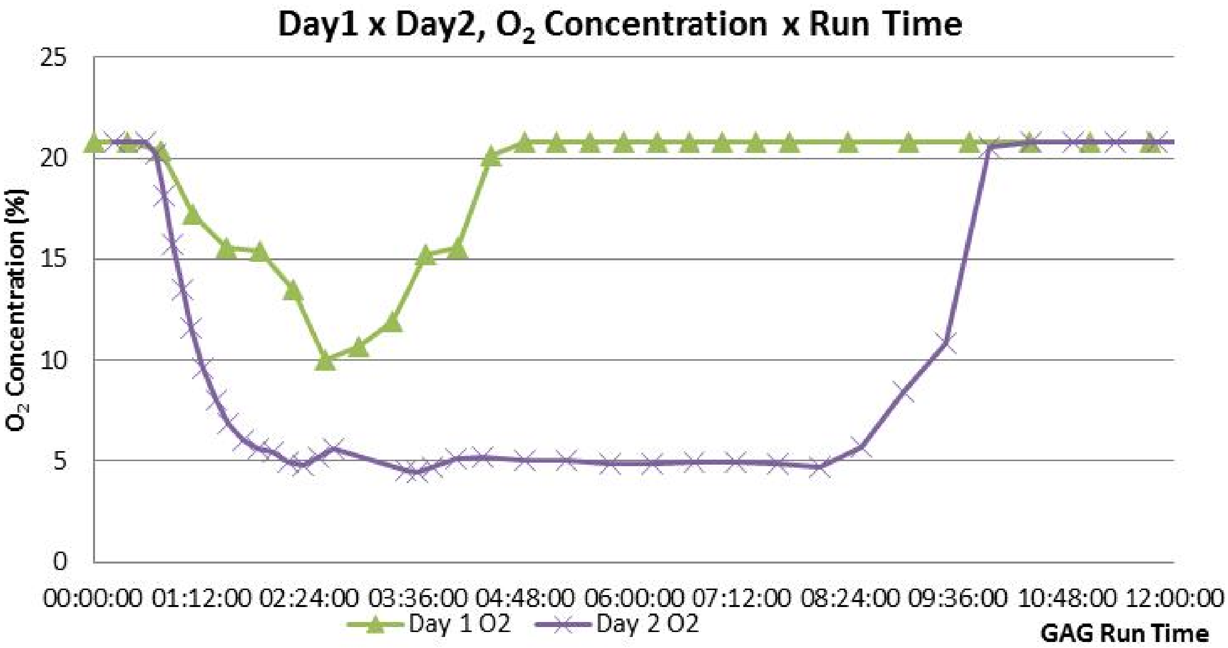

Figure 8: Oxygen percentages at LP 1, Day 1 & Day 2

Figure 9: Damage to dolly-car rail & spalling in the conveyor drift

OTHER INERTISATIONS

Kestrel North Mine – August 2013

In August 2013 the RTCA decided to seal and inertise an area of the mine in bye of 12CT in the 300 series longwalls to protect the 311LW block to enable coal production to continue for as long as possible. (Kachel, J, 2013). The area to be sealed would contain a void of over 200,000 m3. All adjacent goafs were inert.

In preparation for the inertisation, substantial preparatory works were carried out to direct the GAG product to the 313 area and to allow continued coal production elsewhere in the mine, without putting personnel at risk of exposure to potential high temperatures or GAG gases. The progress of the GAG gases was monitored using the tube bundle system.

Observations

- Introduction of GAG gases down a shaft worked well.
- Real time sensors are needed during a GAG operation as the tube bundle delay times were in excess of 60 minutes. So the tube bundle system couldn't be used to control the process.
- The inertisation route split into 3 roadways and may have resulted in excess dilution rather than a displacement of the fresh air out of the area to be sealed.
- Gas samples from the GAG jet system, tube bundle, gas chromatograph and real time were similar.
- GAG output temperatures were higher than anticipated.
- The target of <5% O2 in the sealed area wasn't achieved. (13% was achieved)
- Some equipment in the mine was damaged from high temperatures. This included pogo sticks, guide cones on the escape routes and the real time telemetry equipment.
- Some rib spall occurred
- Stone dust was washed away
- After shut down, underground crews couldn't access the zone for over 5 hours

Collinsville, 1997

Surface and underground trials of the GAG-3A jet inertisation device were held at the Collinsville No 2 underground coal mine from 7th April to 18th April 1997. (Bell, *et al.*, 1997)

The test criteria for the trial were developed by the Moura Task Group 5 Committee. This committee was tasked with investigation of inertisation and sealing strategies in underground coal mines.

- Output flow rates during the trial were measured at 19 m3/s (against a target of 20-25 m3/s).
- The GAG output was stable around 90°C, oxygen 6-8%, carbon dioxide 8-10%
- Control of ventilation was a major priority
- Limited stratification of the GAG gases showed that it tended to move closer to the roof than the floor.
- Simtars concluded that the GAG-3A system is a good solution to inertise an underground coal mine.
- It is not considered a universal solution

Goede Hoop Colliery South Africa, 2005

A fire was detected on 10 April 2005 in Goede Hoop Colliery in South Africa. The mine is a bord and pillar mine and the fire was detected near a downcast shaft some 12 km from the main intakes of the mine. Underground seals were built to isolate the fire area. An evaluation of inertisation capability was undertaken and the Steamexfire fire unit selected on availability and weight for transport. The unit was run from 21 April 2005 to 6 May 2005. Initial use introduced 14-18% oxygen underground due to the settings on the unit. One working section and associated equipment became trapped in the fire area. The area was not recovered after the inertisation. The inertisation process pressurized the affected area to maximum of 6.5 inches of water gauge (1.6 Kpa). The system ran for a total of 191.5 hours. The estimated volume of the product inserted into the fire affected area was approximately 17.2M m3. This is three times more than the estimated volume to fill the workings of 6M m3. (Romanski M 2005)

Svea Nord Norway, 2005

Little is known of the operation at Save Nord other than what is provided in the 2005 Store Norske Spitsbergen Grubekompani annual report: "On the night of 30th July 2005, a plastic pipe in the C drift of main drift 3 caught fire. The pipe had been welded to its full 1.3 km length only a few hours earlier by a specialist contractor. The mine was quickly evacuated, and in a few hours the fire was ablaze along the entire length of the pipe. After a month of inertisation with the steamexfire unit the mine was recovered in February 2006. Production was resumed on 1st April 2006.

Pike River

A bespoke docking device created form an old shipping container and placed into the mine opening. The area around was sealed with shotcrete and PUR. Despite several issues with leakage, the mine was successfully inertised and the fire brought under control. This was a single entry and the fire was approximately 2.4 Km from the portal with the vent at the upcast shaft.

Blair Athol

Underground mine fires in old mine workings at an open cut mine were brought under control by using the GAG to fill the mine with inert gas then keeping it topped up using the Tomlinson Boiler. In preparation the open roadways in the high wall were plugged with inter-burden and clay to create a seal. This was an ongoing issue and over $1 million was spent on diesel for the Tomlinson boiler. The GAG was instrumental in bringing the situation under control by the flooding the fire zones with inert gas.

Loveridge

On the afternoon shift of Friday 13th February 2003 coal cars loaded with garbage gathered from the operating sections and throughout the mine was brought to the slope bottom in order to be sent out of the mine for dumping. One of the cars caught fire. The fire was thought to have been extinguished, using several fire extinguishers. Within a short time the fire had flared up again. The decision was made to pull the cars out of the mine to the surface via the slope track. Whilst undertaking this task several adverse events took place that prevented the cars from being sent out via the slope track. The fire then spread from car to car and subsequently out of control. The mine was sealed and the GAG was selected for the inertisation process. There were issues with the sealing of the belt drift and leakage up to 30% of the GAG product was being lost. The GAG operated for a period of 13 days and a maximum back pressure of around 2.2kPa was measured. An inert atmosphere was established over 14km from the GAG docking station. The fire was extinguished and the mine recovered successfully (Parkin, 2003).

Newland Southern Underground

The Newlands Southern underground mine was inertised using the GAG placed at the fan shaft. Little is known of the outcomes other than there was a failure of the shaft collar some 6 months after the GAG had been used and the failure was attributed to the hot GAG gases.

Southland

The GAG was deployed to the Southland mine fire in 2003. The use was suspended and the full benefit of the GAG was not realised due to the mine not being sealed and the GAG product being diluted. The GAG was run 27 to 29 December 2003. The main fan stopped on 29th December and the mine was sealed and left to naturally inertise up to 27 January 2014 (Haynes PJ, Davis J Southland).

Carborough Downs

There was a spontaneous combustion identified in a longwall goaf an attempt was made to use the GAG for inertisation , however due to the fact the mine was not completely sealed and no direct control over the ventilation circuit little or no GAG product made it to the longwall. The heating was brought under control by nitrogen foam injection

CONCLUSIONS

It has been demonstrated that the GAG is an effective tool for whole-mine inertisation. There are clear outcomes, namely:

- Successful deployment of the GAG depends on the mine being effectively sealed.
- It is likely to take many days for the GAG to inertise a typical longwall mine in Australia.
- Attempting to direct the GAG product to a specific, remote location underground is not practical without pre-existing infrastructure.
- The integrity and position of normal mine ventilation control devices doors/stopping regulators can have a major influence on the spread of the GAG gas through the mine
- GAG temperatures rise to a maximum of 90°C.
- Temperatures would rise quickly to levels that would not permit men to survive if they were close to the GAG docking station.
- Areas of rock or coal in the roof and rib that become exposed to high temperatures and humidity can be expected to experience deterioration.
- In the event of an underground emergency access to the portal will be restricted.
- Strategically located tube bundle sampling locations appear to be the optimum solution for monitoring the spread of the GAG gas underground.
- The GAG gas can contain up to 300 ppm of carbon monoxide and 200 ppm of hydrogen.

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