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Recent Developments in Coal Mine Inertisation in Australia

S Bell\textsuperscript{1}, D Cliff\textsuperscript{1}, P Harrison\textsuperscript{1} and C Hester\textsuperscript{1}

ABSTRACT

During 1997 two different types of coal mine inertisation equipment were trialed in separate underground coal mines in Queensland.

In April 1997 tests of the Polish developed GAG-3A inert gas generator were carried out at the Collinsville No 2 Coal Mine. These demonstrations indicated that the GAG-3A device was applicable in underground coal mines and that with respect to inertisation rate the device outperformed all other currently available techniques. The unit was assembled rapidly and operated safely during surface and underground trials and no mechanical problems were encountered with the device. The GAG-3A is not suitable for every fire scenario particularly if large volumes of fresh air are being drawn into the mine (where multiple units may be required), but with respect to the selection criteria developed by the Moura Implementation Process Task Group 5 criteria, the unit performed up to the specifications required.

In May 1997 tests were carried out at the Cook and Laleham Collieries using a Tomlinson diesel boiler. These demonstrations indicated that a low volume generator, such as the boiler, can proactively inert a large goaf area effectively. At Cook a volume of approximately 700 000 m\textsuperscript{3} was inerted over 10 days and at Laleham an area of approximately 70 000 m\textsuperscript{3} was inerted over 2 days. The boiler is not suitable for emergency use, due to the low flow rate of inert gas generated (approximately 0.5 m\textsuperscript{3}/s). There was no significant seam gas present during either trial.

Both test programs were financially supported by ACARP and the Department of Mines and Energy. BHP, Shell, and MIM also contributed to the GAG-3A project and Cook Resources Mining contributed to the Tomlinson boiler project.

INTRODUCTION

Any coal mine can be beset by problems associated with fires and explosions. Many techniques have been used to control these events with varying degrees of success. Inertisation in various forms has been used for many years and was last used in Queensland to some effect in 1986 when the NSW based Mineshield device vaporised 600 tonnes of liquid nitrogen, which was progressively injected into the post explosion atmospheres of the Moura No 4 coal mine.

Two projects were designed to test devices which either produce large volumes of inert (low O\textsubscript{2} concentration) gas from a commonly available fuel (Avtur) - the GAG - 3A jet engine system or, low volumes of inert gas from a diesel fuel - the Tomlinson boiler. It should be understood that inertisation can be divided into two categories.

Category 1 - Low flow devices, typically 0.5 m\textsuperscript{3}/sec. This equipment includes:

- Pressure Swing Absorption (PSA) - Which uses chromatographic techniques to separate nitrogen and oxygen from normal air.
- Membrane technology - uses molecular diffusion through a membrane to separate nitrogen and oxygen from normal air.
- Distillation - Where air is liquefied and then fractionally distilled to produce oxygen and nitrogen.

\textsuperscript{1} Safety in Mines Testing and Research Station (SIMTARS)
- Tomlinson Boiler - boiler flue gas is produced by burning diesel fuel in a modified hot water boiler. The exhaust gas of the boiler is adjusted through combustion controls, to reduce the oxygen concentration to less than 1 %, with about 15 % carbon dioxide, 5 % water and the residue, nitrogen. A trace of carbon monoxide (< 20 ppm) and unburnt hydrocarbons are also produced.

- Mineshield - Where liquid nitrogen is vaporised and injected into the mine. There are significant problems with respect to the use of liquid nitrogen in Queensland because of the comparatively low production capacity of the current nitrogen generating units and the logistics associated with transportation. This device can generate up to 5 m3/s of inert gas.

- Carbon Dioxide - liquid and solid - similar problems to the Mineshield operation in that the gas has to be produced by vaporisation and then heated to prevent density problems (CO2 density is 1.5 than of air at the same temperature). Dry ice - solid carbon dioxide is particularly stable as it forms an ice skin than prevents volatilisation.

**Category 2 - High flow devices, typically 20 - 30 m3/sec.**

The GAG-3A jet engine system is currently the only operational device on the market, which will produce inert gas at these higher flow rates. Further research on very high flow devices (80 - 100 m3/sec) using a Pratt-Whitney TF30 jet is yet to be carried out and the significant size of this type of device would make its application in coal mines difficult. Fig 1 shows the assembled GAG-3A located in one of the portals of the trial mine and Fig 2 shows a schematic illustrating the main features of the unit. The jet engine burns the fuel consuming the oxygen and producing carbon dioxide and water, similar to the exhaust of the boiler. The jet requires an afterburner to complete the combustion process to the desired low oxygen exhaust concentration and water cooling to reduce the exhaust temperature and remove the thrust developed within the engine.

![Image](image_url) Fig. 1 - The GAG-3A inert gas generator located at the portal to Collinsville No. 2 Mine
THE GAG-3A INERT GAS TRIALS

The Collinsville project was jointly funded by ACARP, the Queensland Government, BHP, and Shell. MIM made their recently closed Collinsville No 2 mine available for use by the research team. The project was organised to provide four demonstration days for Industry members to witness the use of the GAG-3A device. One day was assigned for the underground demonstration where the jet was located underground and operated to show the inertisation of a panel or small localised area. The other three days were allocated to surface demonstrations where the jet was connected to a portal seal and a large area of the mine. The objective of these latter tests was to rapidly inertise a small coal fire in a steel sled.

Mine layout

The mine was reopened by members of the Queensland Mines Rescue Brigade and was extensively instrumented by SIMTARS to enable real time remote determination of gas concentrations, air velocity, air temperature and relative humidity. Fibre optically linked television cameras were used to provide real time pictures of the movement of inert gas through the mine and also to view the fire sled during the coal burning phase of the tests.

Gas analysis data was provided by SIMTARS Mobile Gas Analysis Facility and the MIM Maihak tube bundle monitoring system. A high speed MTI gas chromatograph was available for more detailed analysis. Data loggers were installed underground to collect information from the sensor arrays and this data was displayed real-time on surface computers.

Figs 3 and 4 show the location of the monitoring systems used during the tests.
Fig 3. -Location of monitoring systems at Collinsville No. 2 Mine - first set of surface trials
Fig 4. - Location of monitoring systems at Collinsville No. 2 Mine - underground trials
Fig 5.- Location of monitoring systems at Collinsville No. 2 Mine - second set of surface trials
The CSIRO mine exploration device, Numbat, was also used during the whole mine inertisation phase and useful corroborative visual data was obtained from this device.

Mine ventilation system

To facilitate the conduct of the demonstration at Collinsville No 2 mine, certain aspects of the mine ventilation system had to be altered for each phase of the trials.

Originally the mine had been ventilated by two axial flow fans located on the eastern and western sides of the main development headings. At closure, the mine was temporarily sealed by constructing Tecrete stoppings in 3 & 5 Headings (see Fig 3), by infilling 4 Heading portal, and Tecreting over the louvres on the two fans. When the mine was re-opened only 5 Heading was fully opened, although an access door was constructed in the stopping in 3 Heading portal and No 3 Fan on the eastern side of the mine was restarted. This provided sufficient ventilation to clear the mine of the predominantly carbon dioxide seam gas and later for the purposes of re-entering and working within the mine.

This however was not a satisfactory arrangement for the inertisation trials with the GAG-3A operating on the surface. For these trials it was intended to locate the GAG-3A in 3 Heading portal and to inert a large part of the mine between 2 and 5 Headings and down to 18 Level. To be able to do this it was necessary to seal 5 Heading at the surface and provide an alternative surface intake if the fan was to be kept running. This was achieved by opening the control louvres on No 1 fan (western side of the mine) without starting the fan. This allowed fresh air into the western returns which travelled to the mine fan across the inertisation zone via the overcasts at 6 & 7 Levels (see Fig 3).

For the first set of surface trials on 7th and 8th April 1997, No 3 Fan was run on its electric drive and measurements were taken underground to ensure the air quantity was sufficient to avoid stalling the fan. Generally the fan flows were about 90 m³/s. A regulator in 3 Heading was used to admit a controlled quantity of fresh air past the GAG-3A as part of these trials.

For the underground demonstrations on 11 April 1997, care had to be taken in establishing a ventilation system that was safe and would prevent the potentially lethal GAG-3A exhaust gases from contaminating outbye occupied areas of the mine. For these trials the GAG-3A was located in 5 Heading, and the exhaust was ducted through a stopping between 14 and 15 Levels (see Fig 4). To provide airflow over the 2000 litre underground fuel pod in 13 Level, the stopping between 5 and 6 Headings was breached and airflow was controlled by a brattice regulator. Airflow over the GAG-3A engine unit was controlled by a sliding door at 14 Level, 5 - 6 Headings. To prevent the possibility of GAG-3A exhaust gas moving above 15 Level, brattice stoppings were constructed in 3 and 4 Headings, and the GAG-3A exhaust directed into the eastern returns by breaching the seal at 16 Level, 5 - 6 Headings. For these trials, No 3 Fan was operating on electrical drive, 5 Heading was fully open and the regulator in 3 Heading was fully open. As a further precaution, sentries provided by Mines Rescue and equipped with gas monitoring equipment and self contained breathing apparatus, maintained a watch on the brattice stoppings in 3 and 4 Headings to ensure no exhaust gas moved up dip against the ventilation. At no stage during the trials was there any indication of this occurring.

For the second set of surface trials conducted between 14 and 18 April 1997, the same basic configuration was used as in the first set of surface trials (see Fig 5). However, to reduce undesirable leakage of fresh air into the inertisation zone, it was decided to run No 3 Fan on its diesel emergency drive and to short-circuit the fan at the surface by opening the airlock doors. The regulator in 3 Heading was also sealed up with boarding and cement to reduce leakage. The combined effect of these measures was to reduce the airflow underground to about 30 m³/s and to greatly reduce the potential for leakage into the inertisation zone.

As part of these trials a controlled underground coal fire in a steel fire sled was established. The inertisation trials would involve attempting to extinguish this contained coal fire. The location of the fire was in 5 Heading between 14 and 15 Levels, the same as the GAG-3A location for the underground trials (see Fig 5). The Tecrete stoppings built around the GAG-3A site at 5 Heading, 14-15 Level, and at 14 Level, 4 - 5 Heading, were both demolished so that the inert gasses were directed over the fire site. The brattice stoppings in 3 and 4 Headings, 14 - 15 Level were left in place, and the breached stoppings at 13 Level and 16 Level were closed off.
Fig 6 (a - b) The spread of inert gas fan on
For the surface trial of 15 April 1997, it was decided to attempt to run the GAG-3A with the fan switched off. The ventilation configuration was otherwise identical to the other surface trials of that week.

After each of the surface trials, the inertisation zone was cleared by opening the 5 Heading stopping, the access door and regulator in 3 Heading, and closing the louvres on No 1 Fan. This caused the maximum volume of fresh air to enter the mine and effectively cleared the inertisation zone in time for the next trial. The mine was extensively monitored, using the original fixed Maihak system and SIMTARS Mobile Minewatch gas analysis laboratory, to ensure that all areas of the mine were safe for personnel entry. No personnel were allowed underground after a trial until the area was comprehensively inspected by a deputy.

### Experimental results

Figs 6a - 6c depict the spread of inert gas with the fan operating through the sections of the mine covered by the demonstration. In a period of 360 minutes the bulk of the area of interest had the oxygen level reduced to below 12%. A similar exercise in 1986 at Moura No 4, in a smaller area, took 600 tonnes of vaporised liquid nitrogen and five days to achieve a comparable result.

Figs 7a - 7b depict a similar though slower outcome with the mine fan off. There were some problems with seal leakage and loss of inert gas at the surface, but the jet was still effective.
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Fig. 7 (a - b) The spread of inert gas fan off
Demonstration outcomes

The selection criteria for the trial developed by the Moura Implementation Process Task Group 5 Committee were met with the exception that output flow rates were slightly below the levels predicted (19 m³/s against an expected 20-25 m³/s). This diminution in flow rates was attributed to higher ambient air and water temperatures than expected from operation in more temperate climates.

The Task Group 5 Criteria for the Demonstration were as follows:

1. Unit can continuously deliver 20 m³/s of oxygen deficient atmosphere.
2. When operating normally the unit is to operate without any evidence of external flame.
3. The unit is to deliver oxygen deficient atmospheres containing less than 5% oxygen.
4. Automatic shutdown of equipment following failure of the water supply system.
5. The unit is to demonstrate the ability to extinguish flames from an underground coal fire within specific operating conditions as determined from the trial.

The unit was assembled rapidly and operated safely during all aspects of the trial and no mechanical problems were encountered.

Over 100 industry stakeholders visited the demonstration and feedback questionnaires were generally positive. The demonstration supported the view that the device was suitable for coal mine use.

No external flame was visible on the device.

The unit produced noise levels in excess of 124 dB(A) (when measured 1 m from the jet) in both surface and underground operations.

Environmental noise levels measured 2.3 km from the GAG-3A were not influenced by the operation of the unit.

The simulated fire in the mine was extinguished by the inert gas from the GAG-3A. This was evidenced by temperature profiles and actual video footage.

The limited gas stratification experiment conducted indicated that the gas produced by the GAG-3A tended to move closer to the roof than the floor.

The trial demonstrated that the GAG-3A device has applications in underground coal mines and that it outperformed all other available technologies with respect to volume of inert gas produced.

It is clear that the GAG-3A produces lower oxygen levels over a wider range of excess air conditions and therefore has a much wider range of applicability than other available technology.

Conclusion

The GAG-3A jet inertisation device demonstrated its capability with respect to the inertion of relatively large underground volumes in a short time span. No other available inertisation technology has flow rates comparable to the GAG-3A unit. The unit operated without problems and the underground demonstration particularly showed the non-intimidatory nature of the device.

The GAG-3A does not have universal applicability and high fresh air fan intakes would tend to swamp the inert gas output of the jet. However innovative ventilation solutions are needed to get around this problem because in the final analysis the GAG-3A (or multiples thereof) is simply a tool to produce large volumes of inert gas. This generator must be utilised by
competent ventilation engineers to maximise the benefit from the device. Furthermore this device has been used successfully for decades in coal mines in Eastern Europe where the use of the jet has been professionally supported by ventilation engineers working in mines with complicated ventilation layouts.

THE TOMLINSON BOILER TRIALS

Introduction

Cook Colliery in association with Mr John Brady of Statutory Management Services successfully tendered to ACARP to carry out an inertisation trial at Cook Colliery using the low flow inertisation generated by a Tomlinson diesel fuel boiler. The experimental phase of the project was completed on 1 June 1997.

SIMTARS was contracted to carry out part of the gas monitoring to augment the tube bundle system already installed at the Colliery.

Methodology for analysis and testing

Background:

Full details of the project are contained within the formal ACARP final report (Brady, 1997). The aim of the project was to inject the inert exhaust gas from the boiler down a borehole and displace the air within a large open goaf area rendering the goaf area inert. The progress of the inertion was carefully monitored both through fixed gas monitoring, and by inspections, by rescue teams in breathing apparatus, to investigate the effectiveness of the inertisation and identify any layering or stratification of the gases and unusual air flow patterns.

Briefly an area of Cook Colliery consisting of sections: 9 West, 10 West, 7 South, 12 South, 6 South, and 5 North, was inerted using the exhaust gas from the Tomlinson boiler (see Fig 9). Exhaust gas (typical analyses as in table 1) was pumped via compressor through a borehole at the intersection of 9 west and 5 north into this area. From the supplied mine plans the volume of goaf to be inerted was estimated to be approximately 417 300 m$^3$ - i.e. the volume of the roadways and other voids within the goaf. The volume of the goaf was also estimated from the tonnage of coal extracted which gave a higher estimate of 670 000 m$^3$. Fig 8 shows the boiler in operation.

![Fig. 8 - The Tomlinson boiler installation at Cook Colliery](image-url)
The inert gas was supplied at a rate of approximately 0.5 m$^3$/s at 1 atmosphere pressure and less than 40 °C. The exhaust temperature was controlled to be less than 20 ° above ambient.

Table 1 - Typical exhaust concentrations

<table>
<thead>
<tr>
<th>Component</th>
<th>Exhaust Concentration</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen</td>
<td>&lt; 2 %</td>
<td>values as low as 0.1 % were achieved but at this level CO was in excess of 1000 ppm</td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td>&lt; 20 ppm</td>
<td>Start up and very low O$_2$ emissions (&lt; 1.0%) caused significantly higher levels of CO to be generated</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>13.5 %</td>
<td></td>
</tr>
<tr>
<td>Nitrogen</td>
<td>balance (&gt; 84 %)</td>
<td>traces of unburnt hydrocarbon fuel were present as well as ppm levels of NO$_x$ and SO$_x$.</td>
</tr>
</tbody>
</table>

Sample collection

The principal method for collection of samples was through a series of tubes run underground to specific locations, although additional samples were collected from gas bags filled underground by rescue teams during monitoring of the.
inertisation process. In addition check samples were taken on a regular basis from the Cook Colliery tube bundle system for correlation.

A total of eight locations were established underground.

Sample analysis

Two methods of analysis were employed. The eight tubes were plumbed directly into a manifold and then to a bank of analysers, infrared for CO, CO₂ and CH₄, paramagnetic for O₂. In addition bags were filled and could be analysed on the MTI portable gas chromatograph (GC). It was able to analyse for O₂, CO₂, N₂, CH₄, H₂ and higher hydrocarbons but not for CO. Samples collected from the Cook Colliery tube bundle were analysed this way. Cook analysed the bags on their CAMGAS GC system also as an additional comparison. Results were logged in a record book and into the SPLUS for Windows computer analysis and interpretation program.

The Cook Colliery tube bundle system monitored for CO and CH₄ and was reported separately in the ACARP report.

Results And Discussion

Operation of the boiler

Inertion efficiency

The boiler initially suffered a number of breakdowns before settling into reliable production. The estimated total operation time 219.25 hours which generated 394 650 m³ of exhaust gas over an elapsed period of 266.33 hours.

Fig 10 shows the cross site oxygen concentrations versus time. Essentially the oxygen concentration in the goaf when the boiler began operation was 19%. At the conclusion of the trial the oxygen concentrations at the monitoring points varied between 9.7 and 11.5%, averaging about 10.5%.
The graphs of oxygen concentration versus time show that the points closest to the boiler were reduced in oxygen first. This is consistent with the gentle seepage of a cloud of gas low in oxygen mixing with the goaf gas. In addition up until mid morning on 26 May there was a brattice curtain across the top of E and F headings in 5 North and across what would be F heading of 9 West between 21 and 22 cut through to isolate 5 North from the rest of the goaf area. This would have the effect of speeding up the inertisation of this area over the rest of the goaf.

If the goaf gas was displaced by the boiler gas then the expected average oxygen concentration, using the smaller estimated goaf volume, throughout the goaf would be:

\[
O_2 \% = \frac{394650 \times 1.3 + (417300 - 394650) \times 19)}{417300}
\]
where the average oxygen concentration in the exhaust gas was 1.3% and the goaf gas was 19%. This gives an average oxygen concentration of 2.3% or 8.6% using the larger goaf volume. Clearly the goaf gas was not simply displaced by the exhaust gas. The graphs indicate good mixing of the gases. Thus a better model would be calculated using the recursive formula:

\[
O_{2(t)} = -\left\{417300 - O_{2(t-1)} \right\} + 1.3/\Delta t \\
\Delta t \rightarrow 0.5/\Delta t
\]

where \( t \) is the difference between time \( t \) and \( t-1 \). As \( t \) tends to 0 this tends to 8.2% for an inertisation time of 219.25 hours. When the larger goaf volume estimate is used the average oxygen concentration is predicted to be 11.2%. There were various approximations made in setting up the calculation and in the estimations inherent in the calculation including flow rates and temperatures, and the lack of monitoring in some sections of the area to be inerted. Thus the calculation at best indicates that the mechanism of dispersal was consistent with a well mixed gas cloud diffusing/seeping around the area. This seepage must have been assisted by air currents within the goaf region, perhaps set up by the inertion process based on temperature and density differentials.

Crudely speaking this indicates a very high (70 to 100%) inertion efficiency (i.e. change in oxygen predicted with perfect mixing etc to that obtained). This is a very simple calculation and ignores the unknown mixing efficiency occurring in 12 South and 7 South. For the purposes of this calculation natural oxygen loss and seam gas infiltration have been ignored. Calculations by John Brady indicate that they will only perturb the calculations in a very minor way (approximately 10%).

Other effects

Other effects due to the inertisation process were observed by the rescue teams during their visits to the goaf area. These included:

- An absence of layering, despite the gas being 20°C hotter than the goaf gas and more dense than air if at the same temperature. This was probably due to the mode of injection through a narrow vertical borehole which facilitated good mixing with the goaf atmosphere.

- A suppression of the methane seam gas make. This was also evident in the Laleham study - reported separately (Brady, 1997).

The expected methane make is 3900 m³ per day, based on methane content of return air from panels when ventilated (Brady, 1997). Over the period of inertion this would equate to 46,656 m³ of methane being released. Assuming full mixing and similar losses to above this would equate to an end concentration of methane of approximately 5% by volume. In fact the methane level measured was less than 1%, starting at 0.4%. A rise of approximately 10% of that expected. Thus if the projected methane emission rate is accurate inertisation actively suppresses seam gas emissions.

CONCLUSIONS

- Inertion of a large open goaf area using a low flow inertion device as a Tomlinson boiler was successfully achieved.

- The goaf tested had a small seam gas influx which was suppressed by the action of the boiler.

- The inertion gas showed no evidence of layering and mixed well with the goaf gas and distributed well throughout the goaf through diffusion rather than plug flow.
ACKNOWLEDGEMENTS

The contribution to this research by many others is acknowledged especially David Humphreys and John Brady.

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