TOMLINSON BOILER, INERT GAS GENERATOR FIELD TRIALS

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SUMMARY

Cook Resource Mining Ltd., has recently completed the first stage of an ACARP Funded Project at Cook and Laleham No 1 Mines, Blackwater.
During this phase of the project we successfully eliminated a potential explosion hazard at Cook Colliery by pumping a carbon dioxide enriched inert gas into a sealed area of the mine which contained voids of about 700,000 cubic metres.
The Inert Gas Generator was moved to Laleham No 1 Mine at South Blackwater and we commenced the inertisation of the 2 South District which contained voids of about 70,000 cubic metres. After an initial encouraging start, on Thursday 5 June 1997, the Inert Gas Generator experienced a mechanical failure and the trial was abandoned after about 8 hours pumping.
Although this final phase of the trials failed to achieve the Project Objectives, it was decided that the prudent approach was to recommence the inertisation process on Wednesday 11 June 1997 and thereby, eliminate any potential hazard and the possible need to withdraw persons from the mine.
The inertisation of the 2 South District was completed some 23 hours later.
There is no doubt that this entire Project has broken new ground and the overall results were very encouraging. We are confident that Low Flow Inertisation has enormous potential for the elimination of potential explosion hazards and business interruption in some sealed areas which contain flammable gas.

INTRODUCTION

Cook Resource Mining Ltd., and the Project Team has recently completed the first stage of an ACARP funded Project, No C6002.

Sealing, Monitoring and Low Flow Inertisation of a Goaf

The project consisted of three (3) principal phases:

1. Sampling, Monitoring and Interpretation of Mine Atmospheres
2. Sealing of a Panel
3. Low Flow Inertisation using a Tomlinson Inert Gas Generator.

PROJECT AIM AND OBJECTIVES

The Aims and Objectives of this Project are:

- To develop, test and refine a Safety Management Plan for the sealing of a panel
- To identify gas monitoring protocols which will ensure the safety of persons engaged in the sealing process.
- To clearly understand the natural, physical changes which occur in a goaf, before, during and after sealing.
- To demonstrate that low flow inertisation, provided by a Tomlinson Inert Gas Generator, of a sealed area will:
  - Prevent the atmosphere behind the seals from entering the explosive range
  - Be achieved without interruption to the normal production cycle
  - Be cost effective
- To develop a computer model which will enable future predictions for the inertisation of mine areas using either, external inert gas generation, natural processes or a combination of both.

WORK PROGRAM

Defining the Problem

Our initial task was to clearly define the problem to be solved.
This phase of the project consisted of extensive research and a detailed review of mine emergencies in Queensland over the last 25 years, which revealed that there have been:

38 Spontaneous Combustion Events
41 Lives Lost
3 Explosions
4 Mines Lost, and
Many other lives put at risk.

In most, if not all of these events, the first indication was the presence of smell, smoke haze or smoke in an airway.
There is amply evidence to suggest that we have failed to detect the early warning stages of accelerated oxidation. We can and regularly do detect the things that we can see, touch or smell, however, history would strongly suggest that this is too late.
We believe that for a heating to have developed to this stage, undetected, then:

Sampling has failed
Monitoring has failed; and/or
Interpretation of the results has failed.

We therefore set out to ascertain, what if anything we have been doing wrong, and more appropriately:
What attention to detail is necessary for us to confidently identify:

1. The normal state
2. The subtle changes that occur in a goaf before sealing
3. The changes that occur in a goaf after sealing and during the Low Flow Inertisation process

Site Selection

Two areas were needed for the purpose of this research.
Area 1 was provided by CRM Ltd Cook Colliery and this was the 9 West Waste Workings, an extensive area of roadways, pillars, partially extracted pillars and three (3) old sealed panels.
This area contained voids of about 700,000 cubic metres.
Area 2 was provided by South Blackwater Coal Ltd., and this was the 300 Panel and the 2 South District of their Laleham No 1 Mine.
The 2 South District contained a large number of old sealed areas, a pillar extraction goaf edge and the remainder of the main headings.
We estimated that this area contained voids of about 70,000 cubic metres.

Sampling and Monitoring Program

A controlled sampling and monitoring program was commenced and a comprehensive database built up for both areas.
The areas were subjected to detailed inspection and examination which revealed numerous instances of:

- Micro-ventilation circuits
- Stratification or layering of gases
- Abnormal fluctuations in the temperature and humidity of the airflows
- The ability to change the Make of carbon monoxide in the 9 West Waste Workings at will.

A simple Excel spreadsheet was developed which contained:

- The data base
- The calculations necessary to provide the wide range of information deemed necessary for accurate interpretation of the sample results
- An inertisation model
- A graphical interface which assists the interpretation of the results.

For each sample analysed, a total of 21 graphs are produced which provide vital information for the interpretation process.
It should be recognised that this system does not calculate explosibility limits, Coward or Ellicott Diagrams or Tricketts Ratio. This system is designed and used solely to identify the subtle changes that occur in the mine atmosphere with a view to the early recognition of any increased activity.
We believe that we have identified and refined effective Sampling, Monitoring and Interpretation Protocols which provide the tools necessary to confidently determine what is normal and the nature and extent of any activity in the mine atmosphere ventilating a goaf or waste area and this alone, is of major benefit to the underground coal mining industry.

Sealing of a Panel

The new Standards for Ventilation Control Devices and in particular the section dealing with Goaf or Final Seals raises a number of challenges which must be addressed with the most important of these being:

1. Despite what manufacturers say and promote in their sales pitch, the actual volume of material used and the time taken to erect the seals is much greater than previously thought.
2. The construction of a seal, once commenced, must be completed without a cold or dry join and this for one of the seals at Laleham, consumed about 28 hours continuous work.
3. Mines must have the resources, labour, compressed air, pumps etc., to build at least two (2) seals at once, otherwise, we cannot maintain a ventilation circuit through the sealed area.

For the inertisation process to work effectively we need to develop a seal design which can be erected rapidly, but still be capable of permitting adequate ventilation to circulate in the goaf, prior to final sealing and the introduction of the inert gas.
Failing this we could consider the erection of Brattice, Fleity or Tecrete stoppings for the inertisation phase and build permanent final seals outbye when the atmosphere is inert.

Low Flow Inertisation

Preliminary results of the Low Flow Inertisation Trials conducted at Cook and Laleham Mines are very encouraging and we are confident that Tomlinson Inert Gas Generator, has enormous potential for the elimination of potential explosion hazards in sealed areas which contain flammable gas.
Unfortunately the Tomlinson Inert Gas Generator experienced a number of mechanical and electrical problems which resulted in the loss of effective pumping time at both sites.
It should be recognised that none of the problems were serious and most would have resulted in only minor delays had spare parts and a technician been available on site.
We need to appreciate that most, if not all of the delays were avoidable and the actual time taken to complete this phase of the Project, is not a true

indication of the efficiency of the Inert Gas Generator or of Tomlinson Boilers.
Given that we experienced delays totaling about 55 hours at Cook Colliery, the inertisation process performed very well and we successfully reduced the oxygen content in the sealed area to below 12 percent in 181 hours of actual pumping time.
This was below the predicted time of 192 hours and the unit consumed about 7600 litres of diesel fuel less than expected.
There is no doubt that had the unit continued to operate uninterrupted or with only minor delays, the overall efficiency would have been much greater than anticipated.
At Laleham Colliery we commenced the inertisation process at about 11:30 am on Thursday 5 June and within three hours a sharp downward trend was noted in the oxygen content. Unfortunately the unit suffered a serious overheating problem at about 8:00 pm and the trial was abandoned at about 9:00 am the following day.
Following discussions with Laleham Management and Tomlinson Boilers we decided to complete the inertisation of the 2 south District and thereby eliminate the likelihood of any potential danger or possible interruption to production.
Inertisation of the 2 South District recommended at 11:00 am Wednesday 11 June and was effectively completed at 10:00 am on Thursday 12 June 1997.
The total time taken to reduce the oxygen content to below 12 percent was about 31 hours, a little over the time predicted.

PERFORMANCE STANDARDS

The performance standards developed for this project are based on those activities and processes which must be satisfied if we are to achieve the Project Objectives.
Performance Standards were selected over the more commonly used Pass Vs Fail Criteria, due to the fact that the latter normally ranks the outcome of a particular activity as acceptable or unacceptable, against a known or established standard.

Therefore, an activity which has just achieved the desired or specified standard is deemed to be just as acceptable as one which has achieved the specified standard with ease.
For this project, we were of the opinion that established or specified standards were non existent or at best, inadequate and it was therefore necessary to establish Performance Standards that met our needs.

PERFORMANCE CRITERIA

The overall performance of all phases of the Project was determined by a comprehensive assessment conducted on each of the nominated tasks or activities which must be satisfied if we were to achieve the Project Aims and Objectives. The most important of these were:

Validation of Safety Management Plans
a) Sampling, Monitoring and Interpretation of Mine Atmospheres
b) Sealing and Low Flow Inertisation of a Panel

Validation of Goaf Atmosphere Changes
a) Identification of the natural and physical changes which occur in a goaf before, during and after sealing.
b) Identification of the induced changes in the goaf atmosphere which may be directly attributed to the low flow inertisation process.

As a minimum requirement the nature and characteristics of the goaf atmosphere must be identified with regard to:
Temperature
Humidity
Air Movement
Layering
Gases Present
Effect of Barometric Changes

Validation of the Low Flow Inertisation Process
a) Quality of Inert Gas
b) Consistency of the Inert Gas Produced
c) Discharge Rate of the Inert Gas Produced
d) Ascertain Cost per Cubic Metre of Inert Gas Produced
e) Ascertain the direct operating cost per day
f) Ascertain overall efficiency of the process

The baseline parameter for this efficiency determination was as per the Inertisation Model developed by the author, which predicted that the goaf atmosphere would contain less than 12% Oxygen in:
Cook 9 West Waste Workings
192 hours
Laleham 2 South District
27 hours

PROJECT OUTCOMES

Safety Management Plans
Two Safety Management Plans were developed for the Project:
1. Sampling, Monitoring and Interpretation of Mine Atmospheres
2. Sealing and Low Flow Inertisation of a Panel

These Plans were developed in accordance with the Approved Standard for Safety Management Plans and they provide an excellent reference manual for the management of the potential hazards associated with these activities.

Sealed Area Atmosphere

Prior to sealing we had identified the nature and characteristics of the atmosphere in the Waste Workings and we were satisfied that:

a) There was no evidence of accelerated oxidation of coal
b) The air temperature inbye of 7 c/t C Heading was 27°C Wet 29°C Dry and inbye of 21 c/t C Heading 28°C Wet and 29°C Dry bulb.
c) Thirteen sample points had been established throughout the Waste Workings.
d) The Make of seam gas was sufficient to cause the Waste Workings to self inert in about 22 days.
e) The Make of methane gas was sufficient to cause the atmosphere in the Waste Workings to enter the explosive range within 16 days.

The sealing of the District at Cook Colliery was achieved by closing the doors in the seals P2 Intake and P5 Return Airways and then balance the mine ventilation pressure acting on all these seals.

Balancing the ventilation pressure required some effort and regular adjustment of regulators located outbye, however, this was achieved with the aid of suitable low pressure ventilation gauges fitted to all seals.

Prior to commencing the inertisation process the aim was to achieve zero pressure on the ventilation gauges on the intake and return side seals when the barometer is at the mid point of the diurnal variation.

To identify the changes in the sealed area, we used the services of the Queensland Mines Rescue Service and a total of ten (10) Teams and 55 Team Members, plus support personnel, to explore the area at Cook Colliery.

Exploration of the sealed area was carried out on the following days:

23rd May 97	2 Teams
26th May 97	2 Teams
27th May 97	2 Teams
28th May 97	2 Teams
29th May 97	2 Teams

The information provided by the Rescue Teams may be summarised as follows:

a) The temperature in the Waste Workings at Cook during the inertisation process was found to be in three (3) broad zones.

		Wet °C	Dry °C
Zone 1	Outbye of 7 c/t	24	26
Zone 2	9 c/t to 15 c/t	25	27
Zone 3	20 c/t to 25 c/t	27	29

These observations strongly suggest that there was little change to the temperature or humidity inbye and close to the inertisation borehole, despite the fact that the temperatures of the inert gas was about 50 °C at the top of the borehole.

The temperature in the outbye zone was up to 3 °C lower, than that recorded prior to sealing and the introduction of inert gas.

b) The atmosphere in the sealed area was very still, with good visibility and comfortable working conditions.
c) There was no evidence of layering or stratification of gases found in any of the roadways travelled. This was confirmed by spot tests and bag samples taken from the floor, roof and mid seam heights in a number of roadways.
d) The Make of methane was much lower than expected.

The inertisation process produced a positive pressure in the Waste Workings at Cook of about 300 pa and about 650 pa, at the seals for the 3 South District at Laleham.

It was noted that this pressure increase was maintained regardless of diurnal variations in the mines barometer of up 900 pa and it would appear that provided the ventilation pressure across the seals has been balanced effectively, then the barometric pressure has little, if any effect.

The overpressure induced by the Tomlinson Inert Gas Generator is very small, being equivalent to 0.044 and 0.096 psi respectively, or 1.22 and 2.66 inches of Water Gauge.

To put this into perspective, this force would be similar to that acting on a man door in a stopping located between intake and return airways, at the inbye end of a reasonably sized mine.

We have no evidence to support a hypostasis that this overpressure suppressed the release or desorption of seam gas and in particular, methane, into the workings, but it is an interesting thought and worthy of due consideration and research by the scientific community.

Low Flow Inertisation

The Tomlinson Inert Gas Generator burns diesel fuel very efficiently, to produce a flue gas which is very low in oxygen and when adjusted correctly, very low in carbon monoxide.

The flue gas is cooled from an initial temperature of about 1200 °C via a heat exchanger and air blower to a temperature of about 20 °C above ambient. This gas is then compressed in a water ring compressor to about 100 Kpa prior to discharge into the mine, via a 150 mm hose and borehole.

Capacities of Tomlinson Inert Gas Generator

		Specification	Actual
Inert Gas Capacity	M^3/hr	1800	1600
Delivery Pressure	Kpa	100	100
Gas composition	O_2%	2.0	2.4
	CO_2%	13.4	13.8
	N_2%	84.0	83.6
	CO ppm	>2	15 ppm
Fuel Diesel			
Fuel Consumption	ltrs/hr	200	176
Cooling Water Consumption	ltrs/hr	2000	2400

It should be noted that during the initial commissioning of the Inert Gas Generator, higher concentrations of Carbon Monoxide were produced due to an incorrect burner setting, however for the Laleham Trial, the unit consistently produced an inert gas which contained between 3 and 5 ppm Carbon Monoxide and an Oxygen concentration of about 1.5 percent.

We are satisfied that the Tomlinson Inert Gas Generator, once commissioned, produced a consistent product at a consistent rate and pressure.

The overall efficiency of the inertisation phase of the project is difficult to judge in that:

a) The Inert Gas Generator was new and commissioned on site and during the Inertisation Trials.
b) Due to prior commitments, Tomlinson Boilers were unable to provide a qualified technician on site for the entire period of the trials.
c) This meant that minor delays developed into major delays, waiting on parts and labour.

A total of 55 hours was lost due to these delays at Cook Colliery and this is equivalent to 23 percent of the total time spent on site.

The Waste Workings were deemed effectively inert by the Mine Manager after 181 hours of effective pumping time and there is little doubt that the trial would have been completed much sooner than the predicted 192 hours had we not experienced the lengthy delays, during the commissioning period.

TABLE 1
Cook Inertisation Trials
Sample Results

	POINT 5			POINT 10		
DATE	O_2	CO_2	CH_4	O_2	CO_2	CH_4
21-5-97	18.84	.43	.44	20.20	.16	.23
22-5-97	17.86	1.04	.45	19.76	.21	.30
23-5-97	16.30	1.73	.44	19.20	.29	.35
25-5-97	14.74	2.53	.46	18.30	.30	.40
26-5-97	13.46	3.48	.46	17.28	.83	.50
26-5-97	11.36	4.55	.42	16.50	1.50	.50
27-5-97	12.14	4.30	.55	16.30	.70	.60
28-5-97	12.28	4.26	.59	14.70	3.00	.60
29-5-97	12.38	3.76	.66	14.20	3.00	.80
30-5-97	11.76	3.92	.69	13.83	2.54	.72
31-5-97	10.96	4.32	.72	12.70	3.03	.77
03-6-97	10.24	4.81	.74			
05-6-97	9.88	4.33	.85	10.9	3.14	1.43

	POINT 8			POINT 10		
DATE	O_2	CO_2	CH_4	O_2	CO_2	CH_4
05-6-97	20.93	.05	.0005	20.82	.13	.02
07-6-97	17.92	1.35	.05	18.71	1.15	.08
10-6-97	16.57	1.50	.01	16.91	.88	.41
11-6-97	16.24	1.55	.13	17.10	1.36	.15
11-6-97	15.84	1.89	.12	17.18	1.47	.11
11-6-97	15.43	2.13	.12	16.67	1.85	.09
12-6-97	10.38	6.11	.07	14.05	3.62	.07
12-6-97	10.14	6.12	.06	13.75	3.80	.07

Cost Effectiveness

Final cost for the Inertisation Trials have not been computed at this stage however there is no doubt that both trials were conducted without the need to withdraw persons from the mine or to interrupt production in any way.

CONCLUSIONS

The observations made by ourselves and the Rescue Teams during their exploration of the sealed area have raised a number of issues which at this stage, remain unanswered.

The most important of these are:

- The Make of methane into the sealed area was far less than expected at both Cook and Laleham. At Laleham Colliery the sample point adjacent to the goaf edge contained 0.4% Methane at the start of the Trial on Wednesday 11, however this was reduced to 0.07% Methane by the end of the Trial.
- There was no layering or stratification of gases found by the Rescue Teams or in the bag samples taken by them for analysis.
- The wet and dry bulb temperature in the zone outbye of 15 c/t was about 3 degrees cooler than it was when the area was ventilated normally.
- The Tomlinson Inert Gas Generator produced a positive pressure in the sealed area of over 300 pa at Cook and 650 pa at Laleham No. 1.
- Segregation of atmospheres with low levels of oxygen can be achieved with simple, single line, brattice sheets. An oxygen level of 8% was found on one side of the stopping with 18% oxygen on the outbye side of a brattice stopping.

QUESTIONS

- Does the increased pressure prevent or slow down the desorption of seam gases?
- Has the seam gases been displaced or forced into sealed areas or voids in the coal?
- Has the increased pressure resulted in some form of endothermic reaction which has resulted in lower temperatures?
- The downward trend in the oxygen content at sample points away from the inertisation bore hole continued even when the pumping was

interrupted for up to twenty (20) hours. During these periods the pressure in the sealed area dropped. Did this drop in pressure release some of the inert gas from the coal, old sealed areas or voids?

The above points suggest that the scope of Low Flow Inertisation may be much wider than previously thought possible and that there may be many benefits that are yet to be identified.

There is no doubt that there are many challenges to be identified and solved before we can establish with a high degree of confidence that Low Flow Inertisation can effectively eliminate a wide range of potential hazards in a cost effective manner.

At this stage we are not in a position to draw any final conclusions, however, the indications are that the entire operation was a success and that this provides the platform for ongoing research and similar trials at mines with a higher flammable gas content.