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TOWARD THE DEVELOPMENT OF AN IMPROVED METHODOLOGY FOR ESTIMATING FUGITIVE SEAM GAS EMISSIONS FROM OPEN CUT MINING

by

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DRAFT

SUMMARY

At open cut coal mines fugitive emissions result from seam gas which is emitted once overburden, coal seams and surrounding strata are broken. As part of a scoping study carried out for the Australian Coal Association, Williams et al. (1998) estimated that fugitive emissions accounted for ~50% of the total GHGE from open cut coal mining in Australia. However, as pointed out by Williams et al., the uncertainty associated with the estimate of fugitive emissions was large.

Based on limited measurements in Australia (Saghafi & Williams, 1992; Williams et al., 1993) two specific emission factors by for use by coal mines in the Hunter Valley and Bowen Basin coalfields were developed. For the Bowen Basin the specific emission factor was 1.2 m^3/t (m^3 of methane per tonne of coal production), whereas for the Hunter Valley the specific emission factor was 3.2 m^3/t. This approach is part way between a Tier 1 and Tier 2 methodology. (Note that the Intergovernmental Panel for Climate Change, IPCC, suggested a tiered approach to estimating emissions from sources difficult to quantify. There are three levels known as Tier 1, Tier 2 and Tier 3 where increasing tier requires increasing accuracy of measurement).

The current project goal was to develop a more accurate method for estimating fugitive emissions closer to a Tier 3 or mine-based approach such that an individual mine could estimate its own emissions based on data related to coal gas properties and mining method. In the proposal for this work it was intended that the method would be based on:

- gas content of the mined coal
- gas content of uneconomic seams and neighbouring strata sent to spoil piles and
- coal production and mining method used.

In the course of project C9063 work was carried out at seven open-cut mines in the Hunter Valley and three in the Bowen Basin where measurements of surface emission and gas content of coal were made. Numerous direct measurements of emissions from uncovered coal seams as well as gas released in coal blast holes and exploration surface holes were made. Fresh coal samples from blasted coal seams were also collected and measured for their gas content and composition. Some samples were allowed to release their gas over periods up to 2 months to investigate the kinetics of gas release.

Measurements of the gas contents in the pit for coal collected from blasted seams in the Hunter Valley mines showed seam gas content of ~0.1 m^3/t to more than 1.6 m^3/t. Seam gas compositions for these samples varied from almost pure CO_2 to 30% CO_2, with the remaining gas being CH_4. For some coal samples the rates of gas desorption were also measured over a period of a few weeks. For one coal with lump size of 100 mm 50% of the gas was still present after a time period of 6 weeks and 10% still present after ~4.5 months. This suggests that there may be significant amounts of seam gas in the coal leaving the mine. Further work is required to determine the full significance of this observation.

For the Bowen Basin results, measurements of the gas contents of coal seams in pit for the three mines studied varied from almost un-measurable quantities to 1.5 m^3/t at Moura opencut. The higher gas contents corresponded to the seams with higher methane composition. At Moura the seam gas was ~95% methane while at Goonyella and Burton the seam gas was almost entirely CO_2.

During the course of sample collection and measurement of gas content it was clear that sampling methodology and knowledge of the length of time since the coal seams were uncovered would have significant impacts on the results. Extended time periods from coal being uncovered, to being mined, allow seam gas to desorb. This is an important consideration in considering the rate of release of seam gas from the uncovered yet un-blasted coal seam.

Measurements of the surface emissions from Hunter Valley and Bowen Basin mines showed a wide range of emission rates. For example at Goonyella the emission rates varied from 0.02 to 0.45 $mgs^{-1}m^{-2}$ (CO_2 equivalents) over essentially similar surfaces.

The surface emissions data generally showed wide variability in the emission rate. This is because the surface emission rates depend on

1. The initial gas content of the coal
2. The elapsed time from when the overburden and coal was disturbed and the measurements made
3. The permeability of the layer over which the measurements were made which is in turn influenced by the mining method and blasting of the coal and overburden

Also the emissions can be expected to decrease with time as the gas desorbs from the target coal seam. Consequently it is not possible, at present, to generalise the above results in a manner so as to arrive at emission factors for the mines studied.

During the final phase of the project, effort concentrated on studying a purposely-drilled surface borehole at the Cheshunt site at the Hunter Valley Operation. Gas content of in-situ virgin coal seams up to a depth of 100 m was measured. The gas contents varied from ~0.4 to 3.7 m^3/t. As expected, the smaller gas contents corresponded to the shallower seams. The seam gas composition also varied from almost pure CO_2 near the surface up to almost 90% CH_4 for the deepest seam at 95 m below the surface.

The results from the Cheshunt borehole demonstrated the significance of water in the boreholes and the necessity to dewater these holes in order to measure gas emission rates. The borehole emissions approximate the emissions likely from a highwall on mine closure. This suggests a method whereby post mining emissions (after mine closure) can be estimated. Further work is required for this methodology to be developed to a stage where it can be used routinely to estimate the fugitive emissions after mine closure.

The fresh borecore samples also provided the opportunity to investigate the kinetics of gas release from fresh coal. For example a sample of the Vaux seam was allowed to desorb for a period over ~2 months. From the desorption history it was concluded that it would take 15 months in order for the coal to release 90% of its gas.

Based on the results of the current study it is clear that sampling coal from open cut operations on an opportunistic basis as attempted during this project is insufficient to allow the appropriate data to be obtained for a Tier 3 methodology to be determined. Instead an approach similar to that pursued at the Cheshunt borehole is required so that detailed gas content data can be obtained from a dedicated borehole. These data could then be used, along with data from an extension of the exploration drilling program to include a limited number of gas content measurements, in order to develop a Tier 3 methodology. In addition further work on the emission rates from boreholes could see this approach developed into a method for estimating emissions from final highwalls after mining has ceased.

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TABLE OF CONTENT

DRAFT

1 INTRODUCTION AND BACKGROUND

As part of a scoping study carried out for the Australian Coal Association, Williams et al. (1998) presented an inventory for greenhouse gas emissions (GHGE) in the mining of coal in Australia. Their data are shown in Table 1.1.

Table 1.1 - Greenhouse gas emissions from black coal mining in Australia for the year 1995/96 (from Williams et al., 1998).

Source	GHGE (CO_2e kt) Open cut	GHGE (CO_2e kt) Underground
Energy Consumption	4700 (10%)	1290 (10%)
Fugitive Emissions	6700 (factor of 2)	12600 (25%)
Waste Coal Oxidation	1870 (large)	Low ?
Land Use	0 (±300kt)	0 (±10kt)
Embodied Energy	70 (30%)	40 (30%)
Total	*13,340*	*13,930*

The data in Table 1.1 are expressed as kilotonnes of CO_2 equivalents where methane has been weighted by a factor of 21 to allow for its enhanced contribution to global warming compared with CO_2.

Table 1.1 shows that both open cut mining and underground mining contributed approximately the same amount of greenhouse gas equivalents in total for the year 1995/96. For the year shown in Table 1.1, underground mining produced 60Mt of run of mine (rom) coal while in the same period open cut mining produced 155Mt of rom coal. Thus the greenhouse gas intensity of underground mining when expressed in terms of rom coal is significantly greater for underground coal production than for open cut coal production. The reason for this is clear from Table 1.1 which shows the large contribution to the total GHGE for underground mining from the emissions from coal seams.

The data in Table 1.1, while representing the best estimates possible at the time of writing contained significant uncertainty in some of the estimates. This is shown by the numbers in brackets. While some of the sources were known to within good or tolerable uncertainty the estimates for fugitive emissions from open cut coal mines were known only to within a factor of 2 while the uncertainty in the estimate for waste coal oxidation could not be quantified because of an almost complete lack of data on emissions from this source.

For open cut mining, fugitive emissions account for ~50% of the total GHGE with energy consumption and waste coal oxidation contributing the remainder. At open cut coal mines fugitive emissions result from seam gas which is emitted once overburden and coal seams are broken. However, as is also clear from the data in Table 1.1 the uncertainty associated with the estimate of fugitive emissions was large. This document reports progress on research conducted through ACARP project C9063 which aims to reduce the uncertainty associated with the estimates of fugitive emissions from open cut coal mines.

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1.1 Previous Measurements of Fugitive GHGE from Open Cut Coal Mines in Australia and Overseas

At present there are very few data relating to fugitive emissions from open-cut mines worldwide. In a recent US study (Kirchgessner *et al.*, 2000), methane emissions from six surface mines were measured using a long-path FTIR technique. The estimates reported by this group for these mines (normalised to coal production) were 0.03 to 0.15 m^3/t (coal production).

The first attempt to measure emissions from open cut mining in Australia was undertaken in early 1990s by CSIRO as part of a project to estimate emissions of methane from both underground and open cut mining (Saghafi & Williams, 1992; Williams et al., 1993). That study included gas content measurements from fresh coal samples taken from pits in ten Queensland and seven Hunter Valley open-cut mines. Methane emissions were estimated by using a plume tracking technique developed originally for air pollution studies.

These estimates were made by making crosswind traverses through the plume in a specially instrumented vehicle to establish the methane concentration profile across the plume. By assuming a plume shape and using the measured gas concentration data and wind speed and direction, methane emission rates were calculated.

Figure 1.1 shows an example of traverses around two open-cut mines in the Bowen Basin. It can be seen that the maximum methane concentration in the plume was only 0.2 ppm above the background atmospheric methane concentration which illustrates one of the difficulties associated with this type of measurement.

In Tables 1.2 and 1.3, the results of measurements of methane emissions from Hunter Valley and Bowen Basin mines are presented. Normalising these emission values against total coal production tonnages for the corresponding mines gives specific emission values. For the Bowen Basin the specific emission was 1.2 m^3/t (coal production), whereas for the Hunter Valley the specific emission was 3.2 m^3/t. (Note that the Hunter Valley emission factor does not include emissions from the Lemington open-cut as it was not clear how much methane was emitted from the Lemington abandoned underground mine).

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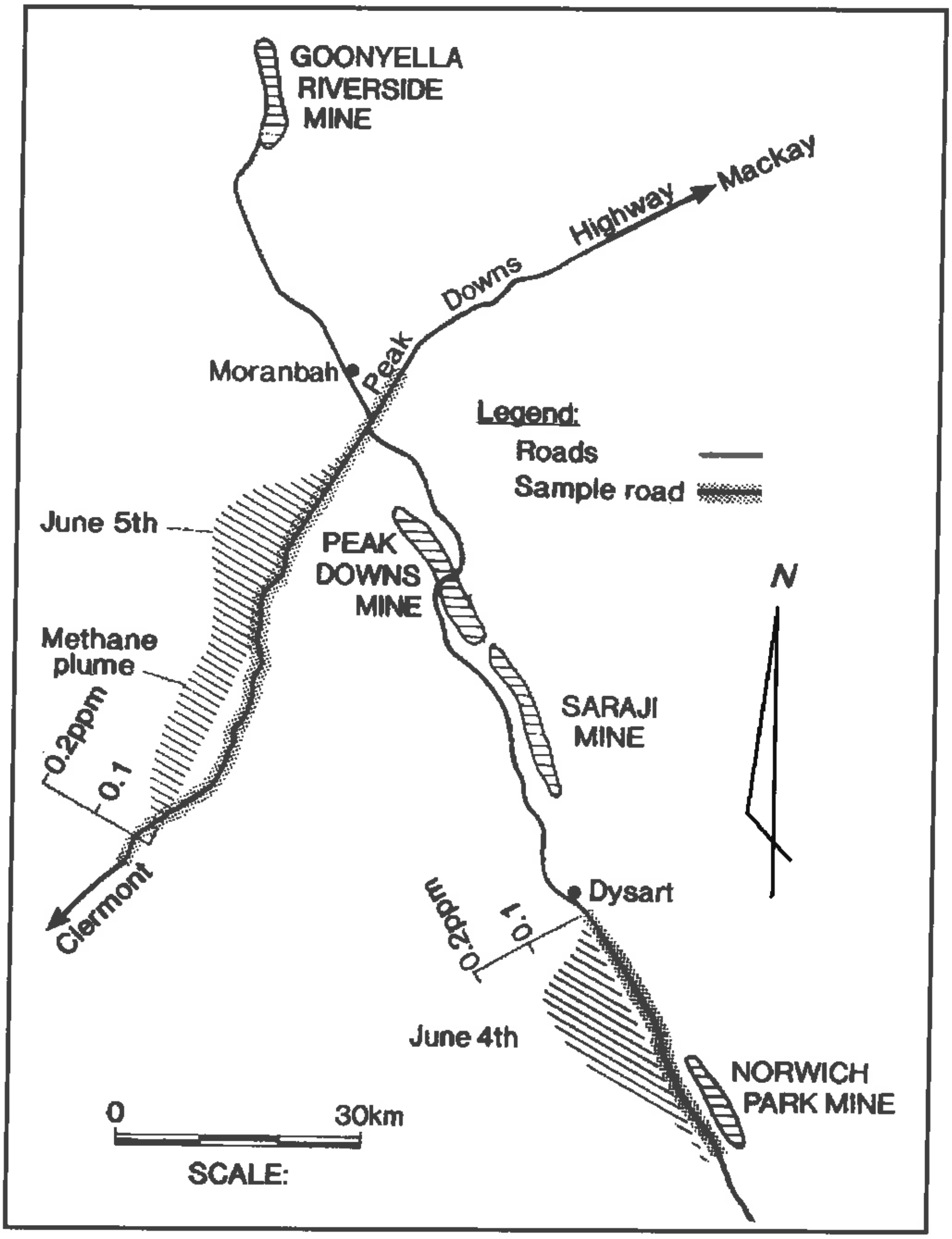

Figure 1.1 - Measurement of methane emissions from Bowen Basin mines using air pollution techniques (Williams et al., 1993).

Table 1.2 – Measured methane emissions from Hunter Valley open-cut mines, using air pollution techniques (Williams et al., 1993).

Mine*	Coal Production	CH_4 emission during mining	Mine specific emission
	Mt/y	Mm^3/y	(m^3/t)
Bayswater	1.0	15	15.0
Drayton	4.1	24	5.8
Hunter Valley	6.2	10	1.6
Mount Thorley	5.2	2	0.4
Ravensworth	4.5	10	2.2
Warkworth	4.0	18	4.5
Total, for measured mines	25	179	

*Measurement of emissions from Lemington was not included in the study of Williams et al. (1993) as the contribution from the abandoned Lemington underground could not be distinguished from the measured emissions

Table 1.3 – Measured methane emissions from Bowen Basin open-cut mines, using air pollution techniques (Williams et al., 1993).

Mine	Coal Production	CH_4 emission during mining	Mine specific emission
	Mt/y	Mm^3/y	(m^3/t)
Goonyella	12.5	1.5	0.1
Peak Downs	9.5	3	0.3
Saraji	7.0	3	0.4
Norwich Park	4.9	3	0.6
Blackwater	5.5	3	0.5
Curragh	6.0	25	4.1
Gregory	4.2	19	4.5
Blair Atholl	8.5	1.5	0.2
Callide	3.9	6	1.5
Meandu	5.4	12	2.2
Total, average from all measured mines	67.4	77	1.1

Although the air pollution measurement techniques referred to above and used in the earlier work offer a viable method for measuring emission fluxes, the techniques are subject to a number of practical problems which limit their applicability to developing an inventory for individual mines. Some of these limitations are listed below;

i. Measurements can only be made during suitable wind conditions.

ii. Methane concentrations in the plume are likely to be only slightly above ambient levels making measurements prone to relatively high errors.

iii. Ground based plume tracking requires suitable access to the plume.

iv. When mines are closely spaced, separating plumes from individual mines becomes difficult.

1.2 Current Method of Estimation

Guided by earlier work on emissions from opencut coalmines, including the Australian data, the Intergovernmental Panel on Climate Change (IPCC) provided guidelines for estimating fugitive emissions from open-cut mines by defining an emission factor (EF) as the total volume of GHG emitted per tonne of coal mined. A country or coal basin emission factor can be defined depending on the data available on the emissions.

Depending on the precision of the estimate required, the IPCC has suggested a tiered system of emission factors:

Tier 1 – This is a generic emission factor, which may be used in the absence of any data for the coal Basin. A generic EF has been specified in the range 0.3 to 2 m^3/t with little guidance provided on how to choose within the range.

Tier 2 – This is a coal basin or coalfield EF derived from available data on in-situ gas contents and emission rates for the coalfield. In Australia specific emission factors have been defined for the Bowen Basin and Hunter Valley coalfields, and these form the basis for the fugitive emissions greenhouse gas inventory from open cut coal mining. The USA also base their greenhouse gas inventory on a Tier 2 approach using basin-wide EFs. The gas content data of the mined seams in the USA are reported to be in the range 0.08 to 1.3 m^3/t (USEPA, 1993).

Tier 3 – This is the most specific and accurate methodology and is based on a mine by mine approach. It requires detailed data from each mine.

Increasing tier requires increasing accuracy of measurement but at present, only Tier 1 or perhaps Tier 2 emission estimates can be achieved. Hence, to develop a more reliable inventory of fugitive emissions it will be necessary to develop better methods of directly measuring emissions from mines.

The IPCC has reviewed the guidelines for preparing national greenhouse gas inventories via a series of international workshops. One of the driving forces for the review comes from the observation that if global emissions of greenhouse gases are to be reduced by 10 percent, then in order to assess the effectiveness of mitigation strategies, the emissions inventory needs to be known with an accuracy of better than 10 percent.

The workshop dealing with fugitive emissions from coal mining – "Good Practice in Inventory Preparation for Energy, Transportation and Fugitive Emissions" – was held in Prague in April 1999. The report from this workshop recommends that for coal, a

DRAFT

full Tier 3 approach should be used wherever possible, because of the inherent variability in the amount of gas contained in coal. A Tier 3 approach is a mine by mine assessment, which as noted above is quite feasible for underground mines, as the flow of methane can be measured in the ventilation return and in any drainage systems. For open-cut mines, this approach is not applicable and an alternative approach has to be developed.

1.3 Sources of Fugitive GHGE from Open Cut Coal Mines

There are two potential sources of fugitive greenhouse gas emissions from open cut coal mining. These are

- The GHG trapped within the strata excavated during the mining process
- The GHG emitted by the strata not excavated but disturbed and exposed by the mining process.

For emissions covered by the first point above, the total GHG available to be emitted is just the total gas content of the material excavated. For the emissions covered by the second dot point above, the situation is less clear as the GHGE depend on gas content and composition as well as the details of the disturbance of the pit floor and highwall and the rate of leakage of the gases.

It is instructive to consider these issues by reference to the schematic diagram in Figure 1.2 below.

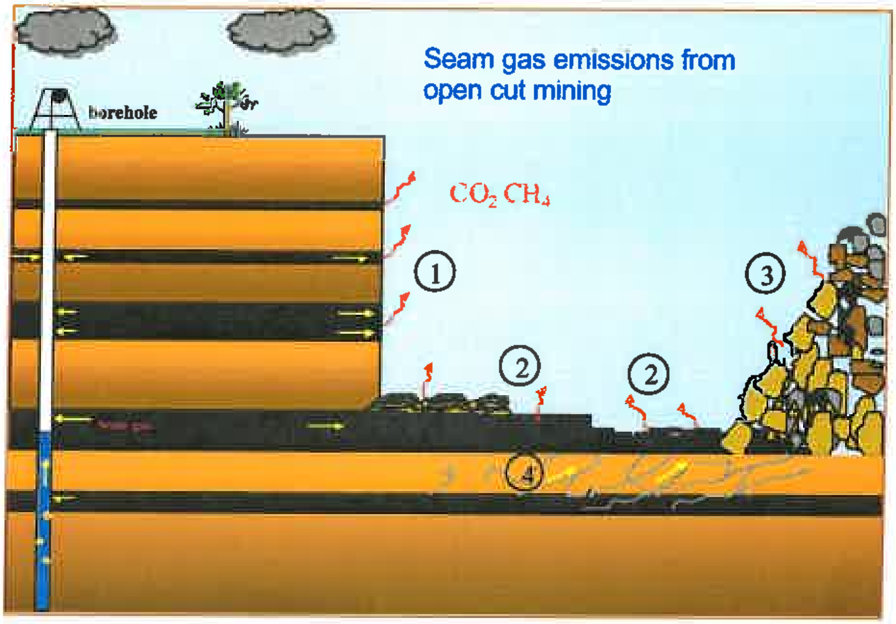

Figure 1.2 – Schematic of the sources of fugitive emissions from open cut coal mine.

Figure 1.2 shows that gas in coal and associated strata may be released during the different stages in mining. Overburden, inter-burden and uneconomic coal is normally dumped in the spoil piles. The GHG contained by these horizons will be released from the broken material. While the total GHG emitted will simply be the sum of the GHG in the strata broken and dumped, and removed as ROM coal, the *rate* at which GHG is emitted will depend on each phase and stage of the mining process. For instance there will be enhanced *emission rates* as

a) The overburden is broken and removed

b) The uneconomic coal seams and overburden are dumped to spoil

c) The ROM coal is exposed and fractured to enable removal

d) The ROM coal is crushed and sized to form the product coal

In addition, emissions will also result from GHG, which seep out of the floor of the pit and through the highwall. These are difficult to quantify. For instance the magnitude of the pit floor emissions will depend on

- The seam gas content of the unmined strata beneath the pit floor
- The proximity of these seams to the pit floor
- The presence of water
- The extent of disturbance of the strata and the effect this has on the permeability, which is important in determining the rate of emission

The magnitude of emissions from the highwall will similarly depend on

- The GHG content of the unmined strata remaining in the highwall
- The presence of water
- The extent of disturbance of the strata near the highwall and the impact this has on the permeability

The magnitude of the pit floor and highwall emissions and their contribution to the total GHGE for an open cut coal mine have not been assessed, to date. It should also be noted that such emissions would continue *after mining operations have ceased.* There are few data on these 'post-mining' emissions and their significance is yet to be determined. In addition, direct measurement of emissions from these two sources is extremely difficult due to technical and safety reasons.

In addition to the above, some GHG will remain in the product coal after it has left the coalmine. There are few data on the magnitude of this residual gas for open cut operations.

1.4 ACARP Project C9063 and Further Development of a More Accurate Method of Emission Estimate

The current ACARP C9063 project goal was to develop a more accurate method of gas emission estimates close to the Tier 3 or mine-based approach such that an individual mine could estimate its own emissions based on a number of data related to coal gas properties and mining method. In the proposal for this work it was intended that the method would be based on the following mine data:

- gas content of the mined coal
- gas content of uneconomic seams and neighbouring strata sent to spoil piles and
- coal production and mining method used.

In the course of project C9063, work was carried out at 10 opencut mines in the Hunter Valley and Queensland where measurements of surface emission and gas content of coal were made. Numerous direct measurements of emissions from uncovered coal seams as well as gas released in coal blast holes and exploration surface holes were made. Fresh coal samples from blasted coal seams were also collected and measured for their gas content and composition. Some samples were allowed to release their gas over a period of a few weeks to investigate the kinetics of gas release.

The focus of Project C9063 since June 2001 until June 2002, which marked the final phase of the project, concentrated on studying a purposely-drilled surface borehole at the Cheshunt site within the Hunter Valley Operation. The borehole was drilled as part of an exploration drilling program conducted by Coal & Allied for their future open cut mining.

This report details the development of techniques for the measurement of various gas emission parameters and describes data obtained for the Bowen Basin and Hunter Valley mines.

DRAFT

2. MEASUREMENT METHODS

In order to provide data on the potential sources of emission outlined in Section 1.3, appropriate experimental methods had to be applied and in some cases developed. This chapter outlines the methods used during the project.

2.1 Gas Content of Coal

During this project, gas content measurements were made on many coal samples collected from pits in numerous mines in both the Hunter Valley in NSW and the Bowen Basin in Queensland. Borecore samples were also taken during the drilling of the borehole at the Cheshunt site in the Hunter Valley (Borehole AQ52). Measurements were made in accordance with the methods specified in Australian Standard AS 3980-1999. These methods are described briefly below.

The gas content of coal is the most important parameter needed for the evaluation of the potential greenhouse gas emissions. It is defined as the volume of gas which is stored in the undisturbed in situ coal. The volume of gas that can be measured under given conditions is termed the measured gas content, Q_m, (Standards Australia, 1999). If the atmosphere surrounding the coal consists of desorbed gas at 1 atmosphere partial pressure, then the volume of gas which can be desorbed is called desorbable gas content Q_d. This is less than the total gas content of coal Q_t. Q_m is usually larger than Q_d but less than Q_t. Q_m will approach Q_t if the partial pressure of gas in the measuring vessel approaches zero.

The measured gas content Q_m comprises the sum of three components:

$$Q_m = Q_1 + Q_2 + Q_3 \qquad (2.1)$$

where Q_1 is the volume of gas lost during drilling, Q_2 is the volume of gas desorbed during the period between measuring Q_1 and crushing the sample and Q_3 is volume of gas released after crushing. The relationship between these terms at constant temperature is illustrated by Figure 2.1.

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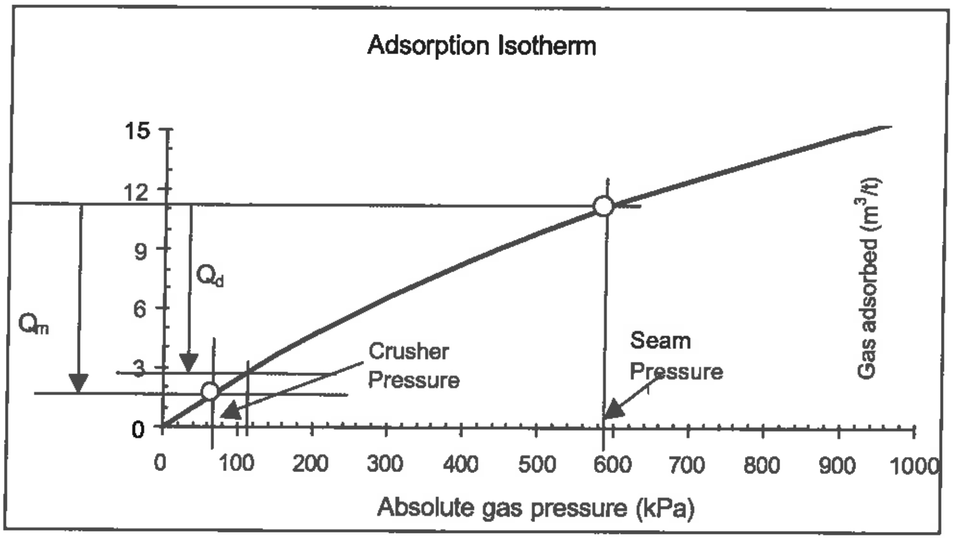

Figure 2.1 - Gas adsorption isotherm showing measured and desorbable gas contents (Qm and Qd).

In order to measure the gas content of coal, fresh coal samples were collected from in-pit or from exploration boreholes. These samples were immediately sealed in gas-tight canisters to prevent any significant loss of desorbed gas. The coal canisters were made of stainless steel and were thoroughly leak tested before they were deployed. The largest canisters used were 1m long and 65mm in diameter and could hold up to 3.0 kg of coal.

2.1.1 Measurement of the Various Components of the Gas Content

The Q_1 component of the total gas content, i.e. the gas lost during drilling, consists of the total gas released from coal between the time that the coal seam in the hole is penetrated by the drill rig and the time that the core is sealed in the gas-tight canister. Q_1 is estimated in the field by measuring the rates of gas desorption from the retrieved core over a period of time of 20 to 30 minutes. This time is similar to the time that it takes to drill the individual cores and bring them to the surface. The value of Q_1 is estimated by assuming a desorption rate equation and then extrapolating the gas desorbed back to zero time. Note that Q_1 is only of relevance for fresh bore core samples where gas content and initial rate of desorption are high. For samples collected from in-pit, the rate of gas desorption and the time of collection being small, only Q_2 and Q_3 were determined.

Q_2 is the volume of gas desorbed from the sample during the time that it was sealed in the canister, which was usually the time taken to transport the sample to the laboratory for crushing. Typically, this may be one or two days.

Q_3 is the volume of gas released during and after the crushing of coal in a purposely-made crusher. Gas is released at a much faster rate when the coal is crushed to a fine particle size so gas content results can be obtained much more rapidly compared to the slow desorb method where the sample is not crushed. Because of the effect of grain size on the rate of desorption, AS 3980-1999 specifies that the sample be crushed to a particle size of < 200 µm. At the CSIRO seam gas laboratory the measurement of Q_3 may take up to 2 hours depending on the hardness of the coal and the rate of gas desorption.

Q_2 and Q_3 determinations were generally performed at the CSIRO seam gas laboratory located at North Ryde. However, for more remote sites where transporting samples back to the laboratory posed logistical problems (eg the Bowen Basin mines) it was decided to have comprehensive testing facilities close at hand. Consequently, the CSIRO 4WD field vehicle was fitted out as a mobile seam gas testing laboratory to perform all required gas content and gas composition measurements (Figure 2.2).

Figure 2.2 - Interior view of CSIRO mobile gas testing laboratory showing the fast desorption crusher.

2.2 Surface Emissions

Measurements of the emissions from exposed coal and interburden were made using the chamber technique developed for ACARP projects C8059 and C9062 (Carras et al., 2000; Carras et al., 2002). Briefly, this technique involved placing a purpose-built chamber on the ground surface and measuring the concentration of CO_2 and CH_4 inside the chamber with continuous gas analysers located in an appropriately instrumented 4WD vehicle.

The chamber was placed over an area of exposed coal or other surface and a steady stream of ambient air was drawn through the chamber at a known rate with a fan attached to one end of the chamber. The purpose of the air flow was to dilute the gas inside to the chamber so that the concentrations of CO_2 and CH_4 were maintained within the dynamic ranges of the gas analysers. Typically, the air flow was between about 500 to 1000 $Lmin^{-1}$.

Sample air was withdrawn from the chamber through a 6 mm diameter nylon tube by a small diaphragm pump at about 5 L min^{-1} and passed into a polyethylene manifold located inside the 4WD vehicle. The sample air was analysed for CH_4 with a Horiba hydrocarbon analyser (using the principle of flame ionisation detection) and CO_2 with a Leybold Binos 100 non-dispersive infrared analyser. If necessary, the sample was further diluted to keep the concentrations within the range of the instruments. A laptop computer interfaced to these instruments continuously logged the data.

Emission fluxes were calculated using the following expression after the concentrations in the chamber had attained steady state:

$$Q = \frac{f_d(C_s - C_b)}{A} \quad (2.2)$$

where Q is the emission flux expressed as volume of gas emitted per unit time and unit area of ground surface, C_s is the steady concentration of the seam gas (CO_2 or CH_4) in the chamber, C_b is the concentration of the seam gas (CO_2 or CH_4) in the dilution air flowing through the chamber, f_d is the dilution air flow rate and A is the area of the chamber.

In cases where the emission rates from the surfaces were small, no dilution of emitted gas was undertaken. The emitted gas was allowed to accumulate in the chamber. However, the sampling pump would dilute, slightly, the concentration of gas in the chamber. If at time t, the concentration of the gas in the chamber is C_t then the rate of emission at time t is,

$$Q = \frac{V_0 \frac{dc}{dt} + f_d(C_t - C_b)}{A} \quad (2.3)$$

where Q is the emission rate, dc/dt the rate of increase in the concentration of gas in the chamber at time t, V_0 the volume of the chamber, and f_d the sampling pump flowrate, C_b is the concentration of gas outside the chamber which is drawn into the chamber while the measuring pump is operating.

The chamber in use during a measurement campaign is shown in Figure 2.3

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Figure 2.3 - Chamber measurements of surface emissions.

2.3 Measurement of Gas Flow and Gas Composition from Surface Borehole

While the two approaches described above have been utilised previously by CSIRO a new method was required in order to measure the gas flow rate and composition from boreholes intersecting coal seams. Although the total flow of gas from the borehole is important, the initial intention was also to attempt to measure flows from individual coal seams. To achieve this, it was necessary to seal off each seam. Two methods were tried to achieve this. They were

- Use of impervious layers
- Use of borehole packers

Nether of these two attempts were successful but they are described, briefly, below for completeness.

a) Use of impervious layers

Initially it was intended to use a system of backfilling the borehole with alternating layers of gravel and impermeable layers of bentonite clay. A gas sample line positioned between each bentonite layer would collect gas from each seam, which would be transported to the surface by the pressure build up in the sealed section. The success of this technique obviously relied on the effectiveness of the bentonite to form a gas-tight layer between gravel layers. However, experiments performed in the North Ryde laboratories suggested that the sealing properties of bentonite were not sufficiently reliable to be used in this application. It is possible that materials with better sealing properties such as Portland cement could be used instead of bentonite, however the use of such materials in boreholes is difficult at best.

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b) Use of borehole packers

Borehole packers are used used in geotechnical applications such as measuring the permeability of rock strata to water and are commercially available. Each borehole packer is about 1.2 m in length and is comprised of a central steel pipe (1" BSP) surrounded by a rubber sleeve which can be inflated via a 6mm nylon tube with compressed air supplied from the surface. A packer is shown in Figure 2.4. Compared with back filling of the hole to seal the coal seams, the packer solution offered several advantages including, relatively easy handling, large quantities of gravel and other material were not required on site and as the packers are temporary, the borehole remains available since it has not been backfilled.

Figure 2.4 - Photograph of one of the packers.

In order to seal a segment of the borehole, the packer was inflated to a given predetermined pressure (~600kPa), the inflated packer seals and separates the two sections of the borehole, below and above the packer location. The gas desorbed into the lower section of the borehole flows to the surface via the central pipe of the packer. A cap was fitted to the top of the central pipe and a 10mm nylon tube connected the packer to gas flow measuring and sampling equipment at the top of the borehole. Gas flows were measured with a calibrated dry gas meter. Gas was collected in sample bags for later analyses by gas chromatography in the laboratory.

Initial trials of the packer system were made at a 4½ year old exploration borehole (Exploration borehole AV50), known to be venting gas, located between the Hunter Valley and Lemington open cut mines some 200m from the Lemington end highwall. The exploration borehole had been drilled in November 1996 to a depth of 96m and intersected three major coal horizons. The first coal bands at this location start at about 40m depth so seam gas released into the borehole would be originating mainly from coal below this level. The first 27m of the borehole is within the weathered zone.

Gas flows measured at the top of the borehole were found to be within the range of about 2 to 4 L/min mainly consisting of methane gas. However, most of the hole was filled with water to at least 40 m below the surface which covered all of the coal seams. Water inhibits desorption of gas from coal and restricts the flow of gas into the borehole.

In order to determine the full extent of desorption and gas flow it was therefore necessary to remove water from the borehole.

An attempt was made to use compressed air to extract the water from the borehole, however, this proved unsuccessful.

A second and successful attempt was to use a submersible pump to remove the water from the hole. A submersible pump capable of operating with at least a 100m head and a small enough diameter to fit down the 96mm diameter borehole was required. An irrigation pump that met the above criteria and which was also within the project budget was chosen. Although the pump fitted inside the hole, its effective diameter of about 80mm meant that there was only a relatively small amount of clearance between it and the wall of the hole. This rendered the pump prone to jam when it was lowered or raised in the hole. This required further engineering of the coupling of the pump to the winch line and electrical cables for the problem to be overcome.

The pump removed water from the hole via a 25mm diameter UPVC pipe. Each 3m length of pipe could be fitted as the pump was lowered into the hole and removed in a similar fashion as it was withdrawn.

The use of the pump and water removal enhanced significantly the flowrate of gas from borehole AV50. The gas flowrate measured at the top of hole was increased by a factor of ~six after the water had been removed to a depth of 65 m below the surface. At that depth approximately 25m of the water column had been removed. At this depth two coal horizons out of three were uncovered. However during this trial it was not possible to remove the whole column of water (the hole was 96m deep) and the last coal horizon could not be evacuated. The pump also jammed in the hole at this depth.

In order to provide appropriate control over the lowering and raising of the pump a hand winch and frame with a 1000 kg capacity winch designed to fit over the top of the borehole was constructed and deployed in the field (Figure 2.5).

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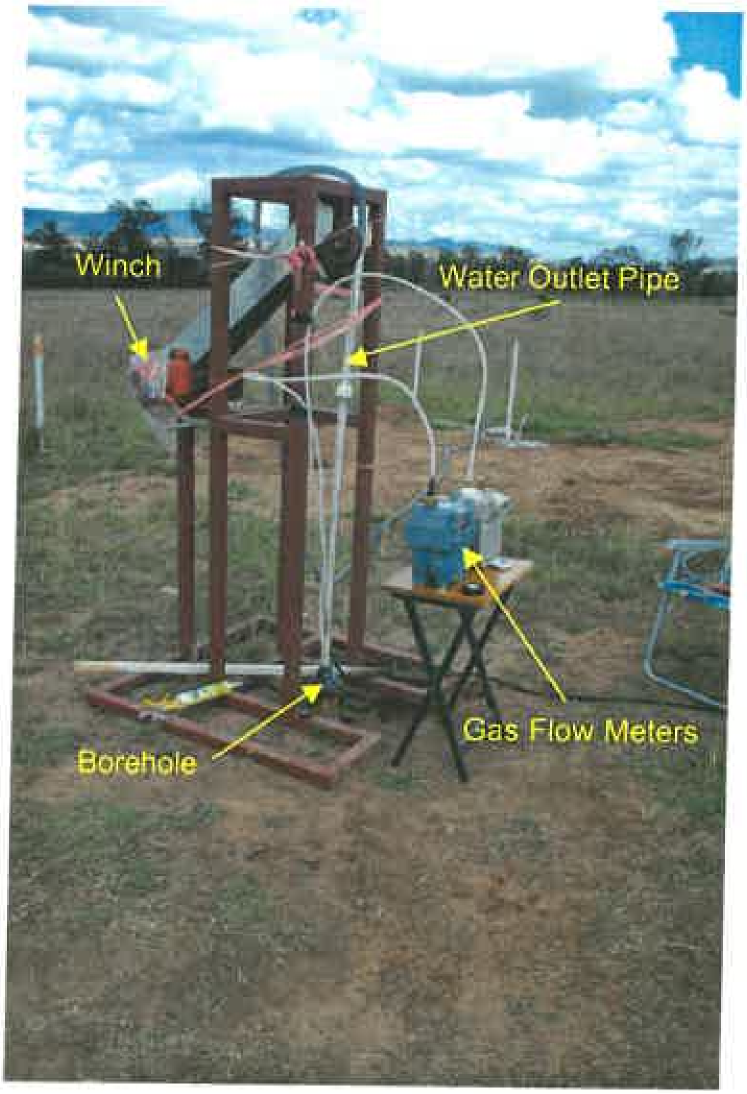

Figure 2.5 - Apparatus used for raising and lowering the pump and packers; the pump outlet pipe and gas flow meters are shown.

Most measurements using this system were undertaken at the Cheshunt purposely drilled borehole (Hole AQ52, drilled in June 2001). However, the rate of ingress of water into this hole was very high and it was not possible to completely dewater the hole. The water level could only be lowered to a depth of about 80m below the surface i.e. the point at which the rate of pumping was equal to the rate of ground water flowing into the hole. Obviously, it was not possible in these circumstances to remove the pump to insert the packers because as soon as the pump was switched off, the hole immediately began to fill with water, hence reducing the gas flow.

Instead of using the packer in this case, the pump was left in position (at a depth of about 80 m) and the top of the hole was sealed with a specially made cap fitted to the borehole casing projecting above the ground. Gas flow meters were connected to the cap to measure total flow (rather than flow from individual seams). This arrangement is also shown in Figure 2.5.

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For this particular hole, the apparatus was left in position and a series of measurements were made over this period where the pump could be run for up to about 10 hours while simultaneously measuring gas flow rates and periodically collecting gas samples for chemical analysis.

Using the equipment in this configuration meant that there was a risk of some of the gas escaping with the water as it was pumped out of the hole and thus was not being measured by the dry gas meters. To check this possibility we collected gas samples from the water at various times during each run. These measurements showed that the amount of gas lost with the water was insignificant and accounted for only about three percent of the total flow.

Removing water from the borehole became the most important issue with measuring gas emission rates from boreholes. The complications of manipulating packers and pumps within the narrow confines of the boreholes rapidly became impractical. Consequently the packer approach was not used further. However for boreholes where dewatering is not a major issue, the packer method will find application.

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3 RESULTS OF BOWEN BASIN MEASUREMENTS

Gas content and surface emission measurements were made at three mines in the Bowen Basin over a two-week period during November 2000. The mines visited were Moura, Goonyella and Burton. A total production of 20 Mt/y was extracted from these mines in 2001 (Table 3.1). The location of the mines is shown in Figure 3.1.

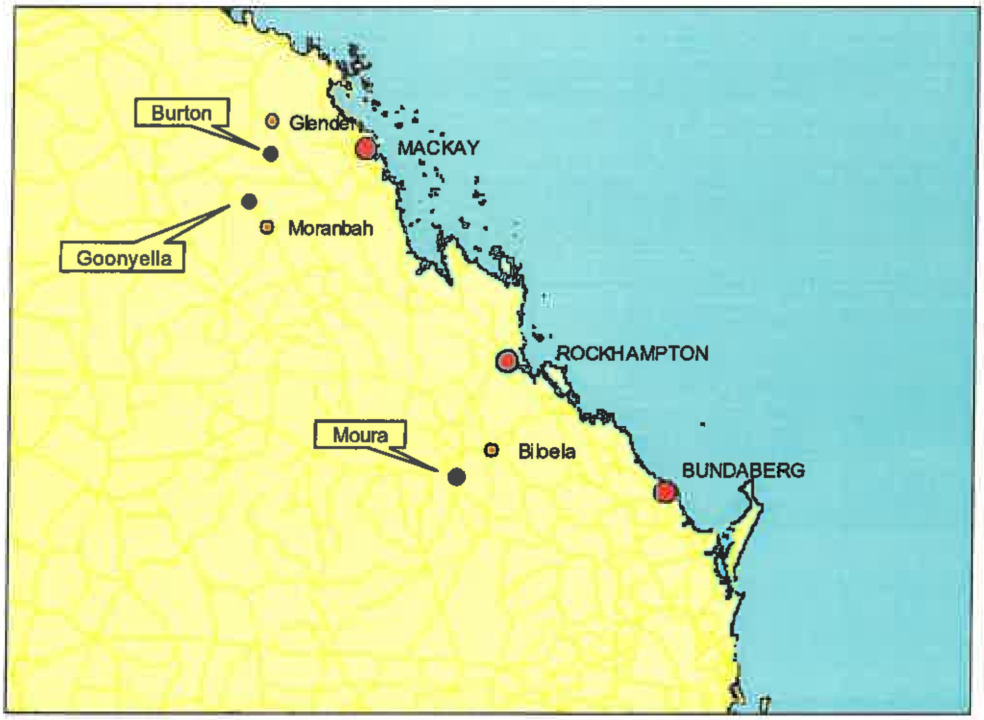

Figure 3.1 - Location of the mines in Queensland for which measurements were made in the current project.

Table 3.1 Bowen Basin mines which were studied in this project.

Open cut	Raw coal production (Mt/y)	Operation Method
Moura	6.0	Dragline, highwall mining
Goonyella	8.0	Dragline, Truck and Shovel, Bucket wheel excavator
Burton	4.0	Truck and Shovel terrace mining
Total	20.0	

3.1 Moura Mine

The Moura mine is located towards the southern end of the Bowen Basin. The mine is operated as a series of pits over a mine site about 28 km in length with the main mining methods being by dragline and highwall extraction systems. Prior to 1994, underground mining was also carried out on the lease.

There are five seams within the mine denoted A, B, C, D and E in sequential order from the top and all generally dip at 6 to 11 degrees. Interburden below the B seam is typically massive channel sandstones with minor siltstone and mudstone units. Above the B seam, the interburden/overburden is thinly bedded siltstone/mudstone with minor sandstone units.

The coal seams exploited by the mine are quite gassy; seam A, for example, has an *in situ* gas content of 9 to 10 m^3/t (J. Hoelle, 2002) having been previously measured in underground mines. This gas is a high quality fuel and the company extracts coal seam gas on a commercial basis for sale into Queensland's gas reticulation network.

3.1.1 Gas Content

Ideally, samples for gas content and composition should be collected from seams immediately after they have been blasted (i.e. within about 30 minutes of the blast), however, due to safety issues and mine production schedules, this was not always possible. At Moura, a number of samples from various sections of seam A in Pit 5A were collected and subjected to gas content determination. The results of measurement of gas contents of these samples are summarised in Table 3.2.

Table 3.2 - Gas contents of samples collected at Moura, Pit 5A, Seam A.

Sample No	Date of Sampling	Gas content (m^3 /t)	Air free gas composition $CH_4/[CO_2+CH_4]$	Time elapsed since seam blasted
PVC8	20-Nov-00	1.06	0.96	3-4 days
SS11	20-Nov-00	0.84	0.95	3-4 days
PVC1	22-Nov-00	0.66	0.95	5-6 days
PVC3	22-Nov-00	0.49	0.97	5-6 days
PVC2	24-Nov-00	0.48	0.94	Less than an hour
PVC7	24-Nov-00	0.48	0.94	Less than an hour

Analysis of the gas desorbed from the coal during crushing (Q_3 measurement) confirmed that the gas consisted mainly of methane (about 95 percent) with the remainder being CO_2.

In the case of the two samples taken shortly after the blast on 24 November, the gas content was only about 0.5 m^3/t. Despite the fact that these samples were sealed in the canisters less than 30 minutes after blasting, the gas contents of these samples were almost half of those collected on 20 November, even though both sets of samples came from seam A in Pit 5. The difference between the measured gas contents is very likely to be a result of different histories of the sampling sites. It is probable that the site sampled on 24 November, with the low gas content, had been uncovered for a longer period of time than the other sites thus providing more opportunity for gas to diffuse out of the coal. Unfortunately, this information was not

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readily available and mine staff suggested that seams may be exposed for periods ranging from a few days to many months before the coal is mined. Other factors that can affect gas contents determined from in-pit samples include the extent of cracking in the seam at the sample site.

In order to estimate the initial gas content of the seam at the time of the blast or at the time of uncovering the coals the residual gas content (Q_3) of the collected coals was measured as a function of time. This was done by taking sub-samples of the collected coals over a period of a few weeks and by measuring the residual gas content in coal by crushing the coal. The initial gas content could then be estimated by fitting a curve to the data and extrapolating it back to zero time.

Figure 3.2 shows the residual gas contents values for 5 of the coal samples shown in Table 3.1

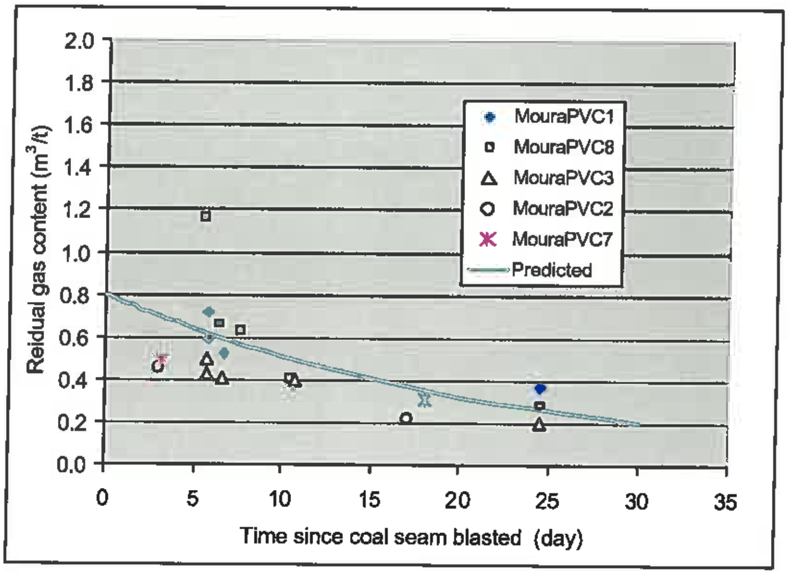

Figure 3.2 - Residual gas content evolution of coal samples collected at Moura Pit 5A, Seam A, November 2000.

In Figure 3.2, the equation that best fits most of the data is:

$$C_r = C_0 e^{-\alpha . t} \qquad (3.1)$$

where C_r is the residual gas content and C_0 and a are experimental coefficients.

The values of the coefficients for the data in Figure 3.2 are:

$C_o = 0.8$ m^3/t, $a = 0.405$ day^{-1}

Thus the average gas content of Seam A at the start of desorption when the coal was uncovered was 0.8 m^3/t.

(Note that the reason for the outlier data point in Figure 3.2 for sample PVC8 at ~5 days is not known at the time of writing).

3.1.2 *Surface Emissions*

A number of surface emission measurements were made on seam A in Pit 5 using the chamber technique described in a previous section. The dynamic and static methods of chamber measurements were used.

Measurements were made on two consecutive days at approximately the same location. The seam had been uncovered 4 days before measurements. The emission measurements on the 2nd day were made while the seam was completely uncovered and blasting boreholes were being drilled at the site. Some measurements of gas flow into these boreholes were also made using chambers placed on the top of the hole.

The summary of the surface emission results of the first day is given in Table 3.3. The second day results are presented in Table 3.4. The measured emission rates show considerable scatter reflecting the inhomogeneity of the surface and the local permeability.

As can be seen from these Tables the seam gas emitted and measured on the first day (21 November 2000) averaged about 2.7 $mgs^{-1}m^{-2}$ CO_2 equivalents compared with 1.9mgs^{-1} m^{-2} CO_2 equivalent for the second day (22 November 2000). The average volume based composition of emitted seam gas was 66% CH_4 (air free composition) for the first day and 73% CH_4 for the second day. While these average emission rates are consistent with the hypothesis that the rate of gas emission from coal would decrease with time, it must also be noted that there is a high degree of scatter in these results, reflecting the inhomogeneous nature of the coal and the sensitivity of gas desorption to the environmental conditions (gas partial pressure and temperature).

Table 3.3 - Coal seam surface emissions measured at Moura 5A Pit, 21-Nov-2000.

Location No	CO_2 Flux (mL/min/m^2)	CH_4 Flux (mL/min/m^2)	CO_2 Equiv. (mg/s/m^2)	Air free* composition CH_4/[CH_4+CO_2]
2	0.0	3.1	0.61	1.00
3	7.3	5.8	1.37	0.44
4	19.2	26.4	5.82	0.58
5	11.0	17.9	3.90	0.62
6	6.6	13.8	2.94	0.68
7	0.0	3.8	0.76	1.00
8	0.0	16.1	3.20	1.00
Average	**6.3**	**12.4**	**2.66**	**0.66**

***The composition ratio is v/v.**

Table 3.4 - Coal seam surface emissions measured at Moura 5A Pit, 22-Nov-2000.

Location No	CO_2 Flux (mL/min/m^2)	CH_4 Flux (mL/min/m^2)	CO_2 Equiv. (mg/s/m^2)	Air free* composition CH_4/[CH_4+CO_2]
10	1.0	4.2	0.87	0.80
11	16.0	17.5	3.95	0.52
11	13.2	28.2	6.01	0.68
12	0.0	3.5	0.69	1.00
12	0.0	7.0	1.39	1.00
13	0.0	2.2	0.44	1.00
14	0.0	5.0	1.00	1.00
15	0.0	6.2	1.23	1.00
16	0.0	6.7	1.34	1.00
Average	**3.4**	**8.9**	**1.88**	**0.73**

Some measurements were also made on blasted coal, however, this proved difficult because the large amount of methane released from the coal resulted in very high ambient methane concentrations (often above 50 ppm) at these locations and hence no "clean" dilution air was available for the measurements. However, it was obvious from the amount of methane measured in ambient air even several hours after the blast that the emissions were very much higher than those measured on undisturbed coal.

3.2 Goonyella Mine

Goonyella Riverside Mine is located at the northern end of the Bowen Basin. There are three principal coal seams in the mine; the Lower Goonyella which is about 5 to 9 m in thickness; the Middle Goonyella which is 6 to 9 m thick and the unmined Upper seam which is 3 to 4 m thick. All seams dip slightly at an angle of about 3 to 6 degrees.

The gas content of the blasted coal from Lower and Middle Goonyella seams measured in the pit were quite low in comparison with those at Moura; less than 0.2 m^3/t for Goonyella Middle seam and less than 0.1 m^3/t for the Goonyella Lower seam with almost 98% of the gas being CO_2. Surface emission measurements were made on the Goonyella Middle and Goonyella Lower seams. On the Middle seam, measurements were made at three areas in Ramp 13 with different exposure histories. These were,

1) The seam had been uncovered for about 1 month with blast holes drilled just prior to the measurements.
2) The seam had been uncovered for less than 1 week but no blast holes had been drilled on this site.
3) The seam had been freshly blasted ~30 minutes prior to the measurements being undertaken.

The results of measurements of surface emissions from Goonyella Middle seam at Ramp 13 are reported in Tables 3.5, 3.6 and 3.7.

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Table 3.5 - Coal seam surface emissions measured at Goonyella Mine, Ramp 13, Middle Seam, seam had been exposed for one month.

Location No	CO_2 Flux (mL/min/m^2)	CH_4 Flux (mL/min/m^2)	CO_2 Equiv. (mg/s/m^2)	Air free* composition CH_4/[CH_4+CO_2]
3	6.2	0.0	0.18	0.00
4	1.8	0.0	0.05	0.00
5	3.4	0.0	0.10	0.00
Average	**5.5**	**0.0**	**0.16**	**0.00**

Table 3.6 - Coal seam surface emissions measured at Goonyella Mine, Ramp 13, Middle Seam, seam had been exposed for one week.

Location No	CO_2 Flux (mL/min/m^2)	CH_4 Flux (mL/min/m^2)	CO_2 Equiv. (mg/s/m^2)	Air free* composition CH_4/[CH_4+CO_2]
7	1.9	0.0	0.06	0.00
8	1.8	0.0	0.05	0.00
9	1.3	0.0	0.04	0.00
10	0.7	0.0	0.02	0.00
Average	**1.4**	**0.0**	**0.04**	**0.00**

Table 3.7 - Surface emissions from blasted coal, Goonyella Mine, Ramp 13, Middle Seam (within 30 min from blasting).

Location No	CO_2 Flux (mL/min/m^2)	CH_4 Flux (mL/min/m^2)	CO_2 Equiv. (mg/s/m^2)	Air free* composition CH_4/[CH_4+CO_2]
5	40.0	0.0	1.18	0.00
6	199.6	0.4	5.95	0.00
7	52.5	0.0	1.55	0.00
8	98.6	0.3	2.97	0.00
Average	**97.7**	**0.2**	**2.91**	**0.00**

As can be seen from Tables 3.5 and 3.6 the rate of GHG emissions for the coal seams that had been exposed but not blasted was generally < 0.2 mg/s/m^2. For coal that had been freshly blasted, however, (Table 3.7) the GHG emission rate was an order of magnitude larger with one value up to ~ 6 mg/s/m^2 CO_2 equivalent. In all cases the emitted gas was composed almost entirely of CO_2.

Surface emissions were also measured on the other seam mined at Goonyella namely the Lower Goonyella seam, Ramp 10, At this location the coal had been exposed several months previously, but drilling for blasting was in progress during the measurement period.

The results of these measurements are shown in Table 3.8.

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Table 3.8 - Coal seam surface emissions measured at Goonyella, Lower Seam, Ramp 10, seam uncovered several months earlier, blast hole drilling in progress at the time of measurement.

Location No	CO_2 Flux (mL/min/m^2)	CH_4 Flux (mL/min/m^2)	CO_2 Equiv. (mg/s/m^2)	Air free* composition $CH_4/[CH_4+CO_2]$
4	3.6	0.0	0.11	0.00
5	4.7	0.0	0.14	0.00
Average	**4.1**	**0.0**	**0.12**	**0.00**

Emissions from the Lower seam were similar to the values from the unblasted Goonyella Middle seam (0.1 mg/s/m^2). The composition of the emitted gas was also almost entirely CO_2 consistent with the results of the measurement of gas content and composition of coal samples collected from this seam.

3.3 Burton Mine

The Burton mine is located about 150 km west of MacKay and commenced operation in late 1996.

In contrast to the other mines examined in this project, Burton mines a single coal seam about 10 m thick which dips steeply at an angle of 20 to 22 degrees. The coal seam is extracted along strike from south to north taking a single strip then backfilling the void created as the pit moves north. At the time these measurements were made the pit was 110m deep at the highwall.

The coal seam is relatively gassy with bubbling in water next to the highwall usually observed from the exposed coal seam after mining. This gas is predominantly CO_2 and exploration boreholes have yielded gas contents of 12 m^3/t at a depth of 300 m and 2 m^3/t at 100 to 150 m. Our measurement of gas content of coal samples collected from the pit showed gas content of less than 0.15 m^3/t with 97% CO_2 as the seam gas.

Like the other Bowen Basin mines, surface gas emissions were also made in the pit at Burton. Measurements were made on,

- Unblasted overburden,
- Coal which had been exposed the previous day, and
- Blasted overburden.

The results of these measurements are shown in Table 3.9, 3.10 and 3.11.
The overburden measurements were made near a single borehole that had been freshly drilled through the overburden to the top of the coal about 15 m below.

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Table 3.9 - Surface emissions from unblasted overburden at Burton (30-Nov-2000).

Location No	CO_2 Flux (mL/min/m^2)	CH_4 Flux (mL/min/m^2)	CO_2 Equiv. (mg/s/m^2)	Air free* composition CH_4/[CH_4+CO_2]
4	4.2	0.1	0.14	0.02
5	2.7	0.0	0.08	0.00
6	0.6	0.2	0.05	0.20
Average	**2.5**	**0.1**	**0.09**	**0.07**

The data in Table 3.9 show that the GHG emission rates from the uncovered yet unblasted overburden were relatively small.

Table 3.11 - Surface emissions from blasted overburden, blasted a day before measurement, Burton (1-Dec-2000).

Location No	CO_2 Flux (mL/min/m^2)	CH_4 Flux (mL/min/m^2)	CO_2 Equiv. (mg/s/m^2)	Air free* composition CH_4/[CH_4+CO_2]
2	11.1	Not measured		
3	2.3			
4	6.8			
Average	**6.8**			

The blasted overburden measured a day after blasting showed, on average, an increase in the emission rate of CO_2. Unfortunately CH_4 concentration could not be measured at this location as the ambient methane concentration was large and masked the measurement results.

Table 3.10 - Surface emissions from coal seam, uncovered a day before measurement, Burton (30-Nov-2000).

Location No	CO_2 Flux (mL/min/m^2)	CH_4 Flux (mL/min/m^2)	CO_2 Equiv. (mg/s/m^2)	Air free* composition CH_4/[CH_4+CO_2]
1	10.9	0.6	0.43	0.05
2	12.5	0.3	0.43	0.03
3	7.4	0.3	0.27	0.04
4	11.8	0.5	0.44	0.04
5	15.3	0.7	0.58	0.04
Average	**11.6**	**0.5**	**0.43**	**0.04**

On the unblasted coal surface still higher emissions were recorded (up to about 0.6 $mgs^{-1}m^{-2}$ CO_2 equivalent).

3.4 Summary and Conclusion for the Bowen Basin Results

Measurement of the gas content of coal samples collected in pit from Moura, Goonyella and Burton opencut mines showed large differences between the gas content and gas composition of coals from these mines. At Moura the seam gas was more than 95% methane with gas content of the coals varying between 0.5 to 1.0 m^3/t. At Goonyella and Burton however seam gas was almost entirely CO_2 (90%). Gas contents were small and in the range ~ 0.1 to 0.2 m^3/t.

The elapsed time between collection and measurement of the coal samples can have a significant impact on the results. For instance back extrapolation of the results of gas content measurements of coals which were collected in Pit 5A at Moura and were exposed for different lengths of the time since the uncovering of the coal seam, showed that the Moura coal could have had an initial gas content of up to ~1 m^3/t. These results show the importance of knowing the length of time since the coal seams were uncovered. Extended time periods between coal being uncovered and mined, may lead to an underestimation of the gas content of the coal.

Measurements of the surface emissions from Moura, Goonyella and the Burton mines showed a wide range of emission rates. At Moura the emission varied by more than a factor of ten from ~0.4 to ~6 $mg/s/m^2$ CO_2 equivalent. The emitted gas was almost 100% CH_4, however, in a limited number of places CO_2 constituted 30 to 60% of the gas emitted.

At Goonyella the emission rates varied from ~0.02 to 0.2 $mgs^{-1}m^{-2}$ CO_2 equivalent for the uncovered coal seam surface and from ~1.2 to 6 $mgs^{-1}m^{-2}$ CO_2 equivalent for the blasted coal seam. The gas emitted was almost 100% CO_2.

At the Burton mine the emissions from the uncovered seam ranged from ~0.3 to 0.6 $mgs^{-1}m^{-2}$ CO_2 equivalent, while for the unblasted overburden the emission rates varied from ~0.1 to 0.15 $mgs^{-1}m^{-2}$ CO_2 equivalent. The gas emitted at these locations was almost entirely CO_2.

The surface emissions data show the wide variability in the emission rate. This is because the emission rates depend on

1. The initial gas content of the coal
2. The elapsed time from when the overburden and coal was disturbed and the measurements made
3. The permeability of the layer over which the measurements were made which is in turn influenced by the mining method and blasting of the coal and overburden

Also the emissions can be expected to decrease with time as the gas desorbs from the target coal seam. Consequently it is not possible, at present, to generalise the above results in a manner so as to arrive at emission factors for the mines studied.

4 RESULTS OF HUNTER VALLEY MEASUREMENTS

Gas content and surface emissions were measured at seven opencut coal mines in the Hunter Valley coalfield (Figure 4.1). Total raw coal production from these mine was about 40 Mt in 2000 (Table 4.1, based on data from 2001 NSW Coal Industry Profile).

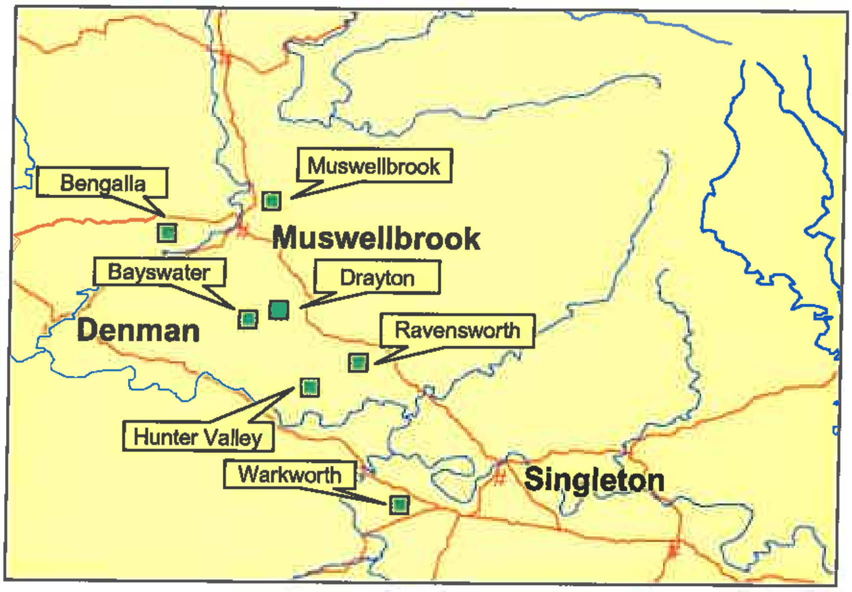

Figure 4.1 - Location of Hunter Valley mines at which gas content and/or surface measurements were made.

Table 4.1 Hunter Valley mines which were studied in this project.

Open cut	Raw coal production (Mt/y)	Operation Method
Bengalla	4.04	Dragline, Truck and Shovel
Bayswater	4.90	Truck and Shovel, Excavator and Front & End Loader
Drayton	4.91	Dragline, Excavator and Truck
Hunter Valley No1	7.76	Truck and Shovel
Muswellbrook	1.28	Truck and Shovel
Ravensworth* East	2.25	Truck and Shovel
Ravensworth* (East & Narama)	6.04	Dragline
Warkworth	8.85	Dragline, Truck and Shovel
Total	40.03	

* Both Ravensworth mines are treated as a single mine in this study

Gas content of coals collected from pits in all the seven mines were measured. In three of these mines surface emissions measurements were also undertaken. Gas content measurements were made on samples from freshly blasted or ripped coal samples.

Surface emission measurements were performed in three of the above mines, namely,

- Hunter Valley No1,
- Ravensworth, and
- Warkworth

Emissions from uncovered coal seams, blasted coal and from the seam floor were measured for these mines.

4.1 Measurement of Gas Content

Measurements were undertaken during two intensive field campaigns in 2000 and 2001. Coal samples were collected by CSIRO or mine staff, sealed in gas tight canisters and dispatched to the CSIRO laboratory for gas content and gas composition determination. The results of the gas content measurements are summarised in Tables 4.2 and Table 4.3.

As can be seen from Table 4.2, the data from 2000 concentrated on the Hunter Valley No 1 operation. This mine was actively committed to the project and was the site of development of the borehole gas flow measurement technique, described in Chapter 2. In 2001, however, in order to broaden the data set, purposely made gas tight canisters were sent to 6 other mines with the request that appropriate mine personnel collect samples of freshly blasted coal as it became available. This approach was quite successful and allowed the collection of gas content data for a wide range of seams from the Hunter Valley. The gas content measurements for the year 2001 and shown in Table 4.3 are from these samples.

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Table 4.2 - Gas contents of mined coal seams in open cut mines of Hunter Valley coalfield (August and September 2000).

Mine	Coal seam	In pit gas content (m^3/t)	Air free composition $CH_4/[CH_4+CO_2]$
Ravensworth	Bayswater	0.07	0.26
Ravensworth	Bayswater	0.11	0.30
Ravensworth	Bayswater	0.08	0.27
Ravensworth	Bayswater	0.09	0.29
Ravensworth	Bayswater	0.08	0.27
Warkworth	Woodlands Hill (Seam 23)	0.68	0.70
Warkworth	Woodlands Hill (Seam 23)	0.77	0.70
Warkworth	Woodlands Hill (Seam 23)	0.63	0.68
Hunter Valley 1	Mt Arthur	0.15	0.10
Hunter Valley 1	Mt Arthur	0.15	0.10
Hunter Valley 1	Mt Arthur	0.13	0.10
Hunter Valley 1	Mt Arthur	0.09	0.11
Hunter Valley 1	Mt Arthur	0.09	0.11
Hunter Valley 1	Lower Vaux seam	1.36	0.24
Hunter Valley 1	Lower Vaux seam	1.28	0.24
Hunter Valley 1	Lower&middle Vaux	1.46	0.20
Hunter Valley 1	Vaux	1.06	0.31
Hunter Valley 1	Vaux	1.06	0.32
Hunter Valley 1	Vaux	1.12	0.32
Hunter Valley 1	Vaux	1.28	0.37
Hunter Valley 1	Lower middle Vaux	1.63	0.23
Hunter Valley 1	Lower middle Vaux	1.05	0.24
Hunter Valley 1	Lower middle Vaux	1.61	0.27

Table 4.3 – Gas contents of mined coal seams in open cut mines for the Hunter Valley coalfield (May and August 2001).

Mine	Coal seam	Gas content (m^3/t)	Air free composition $CH_4/[CH_4+CO_2]$
Bengalla	Bayswater (BY1 seam)	0.10	0.04
Muswellbrook	Lewis seam	0.16	0.05
Muswellbrook	Lewis seam	0.13	0.05
Bayswater	Woodlands Hill (#3 seam)	0.22	0.02
Bayswater	Woodlands Hill (#3 seam)	0.23	0.02
Drayton	Balmoral coal (Ply B3)	0.18	0.07
Drayton	Balmoral coal (Ply B3)	0.17	0.07
Warkworth	Bowfield (Seam 19, West pit)	0.13	0.02
Warkworth	Bowfield (Seam 19, West pit)	0.13	0.02
Ravensworth South/Narama Mine	Bayswater (9 South)	0.10	0.08
Ravensworth South/Narama Mine	Bayswater (9 South)	0.11	0.07
Narama Mine	Bayswater (9 North)	0.11	0.08
Narama Mine	Bayswater (9 North)	0.10	0.08
Hunter Valley No 1	Vaux	1.14	0.37
Hunter Valley No 1	Vaux	1.08	0.40

Tables 4.2 and 4.3 show that the gas contents of mined coal seams varied considerably, from about 0.1 m^3/t to ~ 1.6 m^3/t. Composition of the seam gas also varied significantly from almost entirely CO_2 to 70% CH_4 (30% CO_2).

The largest gas contents measured were at the Hunter Valley No 1 mine. They also contained the largest amounts of methane compared to most other mines where the gas was predominantly CO_2.

During the project a variety of sample canisters were used. These included the stainless steel canisters used for storing core samples, however, these were relatively small and could not accommodate the larger lumps of material commonly found in the freshly broken coal. In order to accommodate the larger pieces of coal several containers were made from steel drums but it was found that these containers were difficult to seal and were prone to leak. Instead, a set of canisters were constructed from PVC pipe. These canisters, with an internal diameter of about 100 mm and length of about 1 m, could hold up to about 5 kg of lump coal without gas leaks.

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One of the large canisters contained 11.6 kg of lump size coal (100 mm top size) and desorption of gas in this canister was monitored over a 6 week period to study the kinetics of desorption. The results of these measurements are presented in Figure 4.2.

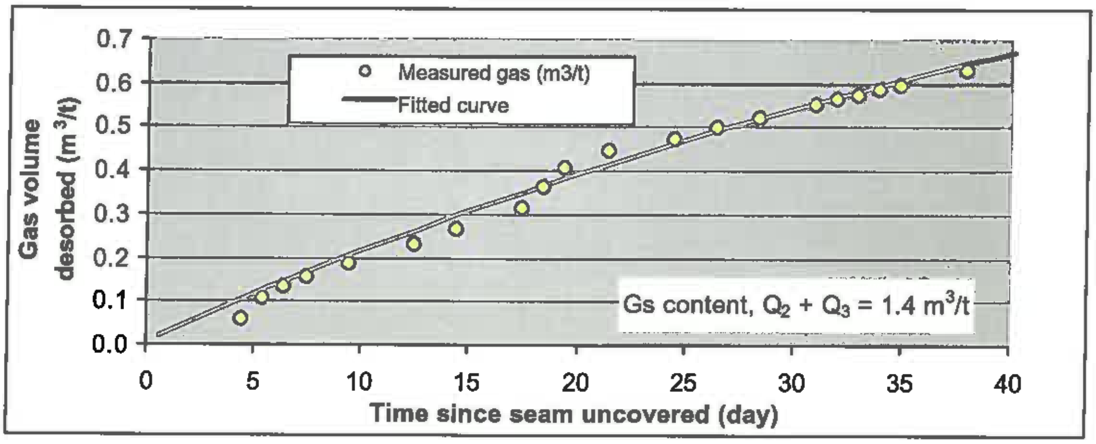

Figure 4.2 - Gas desorption evolution for a large coal sample (11.6 kg) collected in pit from the Vaux Seam in Hunter Valley No 1 Mine.

The coal in Figure 4.2 was obtained 12 hours after the Vaux seam had been uncovered at that location. At the end of 6 weeks the gas evolved from the sample was ~0.7 m^3/t. This gave the Q_2 component in the sequence of gas content determination. A sub-sample was then crushed to release all its gas with ~0.7 m^3/t being released at this stage. This represented the Q_3 component. The total desorbed gas from this sample was therefore 1.4 m^3/t.

The evolution of gas volume desorbed from coal during this 6 weeks of slow desorption (Q_2 component) shown in Figure 4.2 was used to construct a mathematical expression of the emission from the Vaux coal.

On the assumption of an exponential form for the desorption and diffusion of gas through coal then the volume of gas desorbed from unit mass of coal since its exposure would follow the following expression:

$$C = C_0(1-e^{-\alpha t}) \qquad (4.1)$$

where C_0 is the initial gas content and t is time since coal has been exposed. a is an experimental coefficient related to the effective transport of gas in coal. For the Vaux coal presented in Figure 4.2, the measured values of C_0 and a were: C_0 = 1.4 m^3/t, a = 0.016 day^{-1}

The above values suggest that 50% of the seam gas would have desorbed after a period of 43 days and 90% after 144 days. These results apply to coal lumps with a top size of 100 mm and suggest that considerable quantities of seam gas may still be present in the coal for considerable periods after mining.

4.2 Measurement of Surface Gas Emission from Uncovered and Blasted Coal Seams

Direct surface emission measurements were undertaken at three mines of the Hunter coalfield, namely Warkworth, Hunter Valley No 1 and Ravensworth.

The chamber techniques, both static and dynamic, were used and emissions from uncovered and blasted coal seams were undertaken. Also surface emissions from the floor of the seam were measured at one of the mines.

4.2.1 Warkworth Mine

Two sets of surface emission measurements were made at two sites in this mine. The first site was the South Pit – North End Wall, where the Piercefield seam was being mined (Seam 9/10). This was an area where a dragline had been extracting coal and placing it in a large pile during the previous night shift. Table 4.4 gives the results of measurements.

Table 4.4 - Emission measurement at South Pit, Piercefield seam, Warkworth opencut, 8 August 200.

Location No	Type of emissions	CO_2 Flux (mL/min/m^2)	CH_4 Flux (mL/min/m^2)	CO_2 equival. (mg/s/m^2)	Air free composition CH_4/[CH_4+CO_2]
9	**Uncovered seam***	10.9	3.3	1.09	0.23
10	**Seam floor ****	4.7	1.5	0.49	0.24
11	**Blasted coal seam*****	126.5	40.4	13.04	0.24

* Seam surface had been exposed ~12 hours prior to the measurement
** Chamber was placed on floor of the seam underlying rock where the blasted coal had been removed
*** Chamber placed on piled coal, which had been piled on site ~12 hours before measurement

The second set of measurements were undertaken at the West Pit where the Arrowfield seam was being mined (Seam 22L). Table 4.5 gives the results of measurement.

Table 4.5 - Emission measurement at West Pit, Arrowfield seam, Warkworth opencut, 8 August 200.

Location No	Type of emissions	CO_2 Flux (mL/min/m^2)	CH_4 Flux (mL/min/m^2)	CO_2 equival. (mg/s/m^2)	Air free composition CH_4/[CH_4+CO_2]
12	**Uncovered seam**, freshly uncovered	2.5	1.2	0.36	0.33
13	**Uncovered seam**, freshly uncovered	1.1	1.1	0.29	0.51

4.2.2 Hunter Valley No. 1 Mine

At the Hunter Valley No 1 mine dynamic chamber measurement of emissions were made on 7 and 8 of August 2000. At that time the Mt Arthur seam was being mined and surface emissions were measured from the uncovered Mt Arthur seam. Measurements were made from the floor of the seam (where the seam had been removed) and from the blasted coal.

Floor seam emission measurements were made at a site where the coal seam had been removed ~12 hours prior to measurement. The results of the emission measurements are presented in Table 4.6 and 4.7.

Table 4.6 - Emission measurement at Hunter Valley No 1 open cut, Mt Arthur seam, 7 August 2000.

Location No	Type of emissions	CO_2 Flux ($mL/min/m^2$)	CH_4 Flux ($mL/min/m^2$)	CO_2 equival. ($mg/s/m^2$)	Air free composition $CH_4/[CH_4+CO_2]$
1	**Blasted coal seam,** freshly blasted coal	19.6	1.0	0.81	0.05
2	**Uncovered seam,** seam had been uncovered 2 days prior to the measurement	0.9	0.0	0.03	0.01
3	**Uncovered seam,** seam had been uncovered 2 days prior to the measurement	0.9	0.0	0.03	0.03
4	**Uncovered seam** surface emission next to a hole drilled for blasting	4.3	0.0	0.13	0.00

Table 4.7 - Emission measurement at Hunter Valley No 1 open cut, Mt Arthur seam, 8 August 2000.

Location No	Type of emissions	CO_2 Flux ($mL/min/m^2$)	CH_4 Flux ($mL/min/m^2$)	CO_2 equivalent ($mg/s/m^2$)	Air free composition $CH_4/[CH_4+CO_2]$
5	**Blasted coal seam,** ~18 hours after blasting	8.4	0.0	0.26	0.00
6	**Blasted coal seam,** ~18 hours after blasting	2.5	0.0	0.08	0.02
7	**Seam floor,** the blasted Mt Arthur coal had been removed overnight	2.4	0.1	0.08	0.02
8	**Seam floor,** the blasted Mt Arthur coal had been removed overnight	6.9	0.1	0.22	0.01

4.2.3 *Ravensworth Opencut Mine*

At 7 South Pit at the Ravensworth mine, surface emissions were measured from the Bayswater seam. Measurements were carried out on the morning of 14 September 2000 with the seam being uncovered only a few hours before the measurement. The seam was 8 m thick at the location of measurement and was covered by 45m of overburden. The results of the surface emission measurements are presented in Table 4.8.

Table 4.8 - Emission measurement at Ravensworth open cut, Bayswater seam, 7 South Pit, 14 September 2000.

Location No	Type of emissions*	CO_2 Flux (mL/min/m^2)	CH_4 Flux (mL/min/m^2)	CO_2 equival. (mg/s/m^2)	Air free composition $CH_4/[CH_4+CO_2]$
1	Uncovered coal seam**	28.4	0.2	0.91	0.01
2	Uncovered coal seam**	31.1	0.3	0.99	0.01
3	Uncovered coal seam**	33.5	0.1	1.04	0.00
4	Ripped coal***	70.4	0.3	2.18	0.00
5	Ripped coal***	415.9	2.0	12.96	0.00
6	Ripped coal***	177.2	1.0	5.57	0.01
7	Uncovered coal seam**	31.2	0.2	0.98	0.01

* Measurement was undertaken using the static chamber technique
** Coal seam had been exposed 2-3 hours earlier
*** Coal seam was ripped with dozer, measurement being made immediately after

The results in Table 4.8 show that gas emitted from the Bayswater seam is almost pure CO_2. As expected, emissions from the ripped seam are larger compared to the emissions from the uncovered but undisturbed seam, by a factor of ~2 to 14.

Results at locations 1,2,3 and 7 in Table 4.8 show similar values for the emission rates from the fresh (2-3 hours old) uncovered Bayswater seam. At locations 4, 5 and 6 where the coal seam was ripped by a dozer, emissions varied from 2 to 13 mg/s/m2 CO_2 equivalent. This variability reflects the channelling of emitted gas through the interstices of the coal broken by the dozer. The above results highlight one of the difficulties in applying the chamber method to broken surfaces where significant variability is expected due to the large variation in permeability for broken material.

4.3 Summary and Conclusion for the Hunter Valley

Measurements of the gas contents of coal were obtained for seven mines in the Hunter Valley. The gas contents varied from ~0.07 to 1.6 m^3/t. The gas composition ranged from almost pure CO_2 up to 70% CH_4. The largest gas contents were measured at the Hunter Valley No 1 mine for the Vaux seam. The larger gas contents also had higher CH_4 composition. Measurements of the rate of gas desorption for one coal with top size 100mm showed that 50% of the seam gas was still present after a time period of 41 days with 10% still present after 144 days. This suggests that there may be significant concentrations of seam gas in the coal leaving the mine. Further work is required to determine the full significance of this observation.

Surface emissions were measured in three mines, namely, Warkworth, Hunter Valley No. 1 and Ravensworth.

Surface measurements at Warkworth were undertaken for the coal seams Piercefield and Arrowfield. For the Piercefield seam emissions from the seam floor was ~0.5 mg/s/m^2, from uncovered seam ~ 1.1 mg/s/m^2 and from the blasted coal, ~13 mg/s/m^2 CO_2 equivalent. For the Arrowfield emissions from the uncovered seam was measured to be ~0.30 to 0.35 mg/s/m^2 CO_2 equivalent.

Surface measurements at Hunter Valley No1 were undertaken from the Mt Arthur seam. Emission rates from the seam floor were ~0.1 to 0.2 mg/s/m^2 CO_2 equivalent. The uncovered seam showed smaller emission rates of ~ 0.1 mg/s/m^2 CO_2 equivalent and the blasted coal emission rates were ~0.1 to ~0.8 mg/s/m^2 CO_2 equivalent.

Surface measurements at Ravensworth were undertaken over the Bayswater seam. The emission rate from the freshly uncovered seam was ~ 1.0 mg/s/m^2 CO_2 equivalent and from the ripped coal surface was ~2 to 13 mg/s/m^2 CO_2 equivalent.

As for the Queensland mines the surface emissions data showed wide variability for the reasons stated in Section 3.4. Consequently it is not possible, at present, to generalise the above results in a manner so as to arrive at emission factors for the Hunter Valley mines studied.

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5. GAS BOREHOLE MEASUREMENTS AT THE CHESHUNT SITE AT THE HUNTER VALLEY OPERATION

The Hunter Valley No 1 open cut is located 16 km west of Singleton in the Hunter Valley. It is a Truck and Shovel operation and produces some 6.3 Mt of raw coal per year. There are seven seams all of which are mined. These are;

- Woodlands Hill
- Arrowfield
- Bowfield
- Warkworth
- Mt Arthur
- Piercefield, and
- Vaux.

At Hunter Valley Operations, two boreholes were measured. The first set of measurements was undertaken in Borehole AV50/59.4 as described previously in Section 2.3. A second set of measurements was carried out on a borehole purposely-drilled for this project. This new borehole, AQ52, was drilled a few hundred metres away from the old borehole in the middle of an undisturbed paddock surrounded by the current and future mining operations. The borehole will be allowed to stand in place for some five years before being mined through.

5.1 Exploration Borehole AV50/59.4

A number of measurements were carried out at this exploration borehole during May and June 2000.

5.1.1 Results of Gas Flowrate and Composition Measurements

In the first measurement period (2/05/00), the CSIRO single and double packer system was used to seal different sections of the borehole and measure flowrate of gas from below the packer level as described previously in section 2.5.

As the hole initially was filled with ground water to a depth of 40 m, the measurement stopped at this depth. Table 5.1 presents the results of the measurement of gas flowrate and the air free composition of the gas.

Table 5.1 - Gas flow rate and composition, Borehole AV50
Borehole filled with water to the depth of 40 m.

Packer Depth (m)	Flow rate (L/min)	Air free composition $CH_4/[CO_2+CH_4)$
20	3.5	0.69
30	3.4	0.69
40	3.7	0.70

In a second set of the measurements undertaken on 25th of May 2000, gas flowrate and composition were measured again using the packer system. Initially, the measurement was undertaken without pumping the water out of the hole. The packer was inserted to 30 m below the surface so that gas released into the hole from below this depth was measured. The gas flow rate from this level (Table 5.2) was consistent with the previous data from this hole (Table 5.1).

Table 5.2 - Gas flow rate and composition measurement before and after dewatering the hole to a depth of 65m, Borehole AV50/59.5 (25 May 2000).

Packer Depth (m)	Flowrate (L/min)	Air free composition $CH_4/[CO_2+CH_4)$
30*	4.1*	0.70*
Hole is dewatered		
30	24.6	0.91
40	15.6	0.91
50	7.5	0.90

** Measured before dewatering the borehole*

Following the measurements with water in the hole, the pump was inserted into the borehole to a depth of 65 m and water pumped out to that depth. There was still 30 m of water below this point to the bottom of the hole. The packer was inserted into the borehole and measurements were undertaken with the packer at various depths. The effect of removing a 25 m column of water was significant. Table 5.2 shows the gas flowrate and composition for different sections of the borehole for the packer at different depths. At each depth the gas flow rate corresponds to gas from a section of hole limited by the packer and the top of the water column in the hole (65m).

As can be seen the flowrate of gas at a depth of 30 m jumped from ~4 L/min before water removal to ~25 L/min after the water level dropped to 65 m depth. This section of borehole, between 30 m to 65 m below the surface, includes mainly the Mount Arthur and Piercefield seams but does not include the Vaux seam, which is the gassiest seam in this sequence. Unfortunately the pump could not dewater rapidly enough to allow the Vaux seam emissions to be measured. The data in Table 5.2 show that pumping water out of the hole increased the gas flow six fold and increased the methane component of the seam gas from 70% to 90% of the air free composition.

5.2 New Borehole AQ52

In June 2000, the borehole AQ52 was purposely drilled ahead of mining in a greenfield and will remain for 5 years before being destroyed by the advancing highwall. For future reference the coordinates of this borehole are given in Table5.3.

Table 5.3 – Geographical coordinates of Borehole AQ52.

	(m)
Northing	1400660.262
Easting	300720.373
Ground level relative to sea	80.59

The coal seams intercepted by borehole AQ52 were:

- Warkworth (56.1 to 58.3 m)
- Mt Arthur (59.3 to 65.5 m)
- Piercefield (75 to 79.1 m), and
- Vaux (90.7 to 94.7 m).

The overburden and interburden horizons mainly consist of sandstone bands. Coal seams contained layers of claystone and shalestone.

5.2.1 Measurement of Gas Content of Coal Seams Intercepted by Borehole AQ52

Sixteen borecore samples were collected from this borehole. Each sample weighed ~2 kg so that it could be considered to represent the coal seam at the point of collection. For each of these samples gas content was measured. The details of the coal samples, gas content and composition obtained from the Cheshunt borehole are given in Table 5.4.

As can be seen the in-situ virgin gas content of coals varied from 0.4 m^3/t to 3.7 m^3/t. The lowest gas content corresponded to the shallowest coal seam (Warkworth) at a depth of ~57 m below the surface. The highest gas content was exhibited by the Piercefield and Vaux seams at depths of ~75 to ~95 m.

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Table 5.4 – Gas content and composition of the borecore samples from AQ52 borehole.

Sample No	Coal Seam	Coal core depth from (m)	Coal core depth to (m)	Average depth (m)	Thickness (m)	Gas content m^3/t	Air free $CH_4/[CH_4+CO_2]$
1	**Warkworth F2**	56.80	57.25	57.03	0.45	**0.37**	0.03
4	**Warkworth G2**	57.74	58.32	58.03	0.58	**0.60**	0.08
3	**Mount Arthur A**	59.34	61.59	60.47	2.25	**0.74**	0.16
5	**Mount Arthur A + B2**	61.59	62.78	62.19	1.19	**0.85**	0.21
6	**Mt Arthur C (Top)**	63.29	63.95	63.62	0.66	**1.26**	0.33
8	**Mount Arthur C**	63.95	64.66	64.31	0.71	**1.80**	0.45
9	**Mt Arthur C (Bottom)**	64.66	66.12	65.39	1.46	**1.67**	0.45
10	**Piercefield A2**	75.07	76.07	75.57	1.00	**2.10**	0.54
12	**Piercefield A4 + PFB2**	76.07	77.05	76.56	0.98	**3.67**	0.57
11	**Piercefield B2 + B4**	77.05	77.74	77.40	0.69	**3.31**	0.60
13	**Piercefield C2 + D2**	78.46	79.61	79.04	1.15	**3.45**	0.61
14	**Vaux A2 +A4**	90.73	92.13	91.43	1.40	**3.64**	0.85
17	**Vaux B2**	93.20	93.78	93.49	0.58	**3.40**	0.86
15	**Vaux C2 (upper)**	93.92	94.50	94.21	0.58	**3.52**	0.88
16	**Vaux C2 (Lower)**	94.50	94.92	94.71	0.42	**2.78**	0.88

The data in Table 5.4 show that the gas content of the coals increased initially with depth which but appeared to approach an approximately steady value at a depth of ~76m. On the other hand the methane component of the seam gas increased steadily with depth reaching 88% methane for the deepest Vaux seam at a depth of ~95 m. These trends are illustrated in Figure 5.1 which shows gas content and composition plotted against depth.

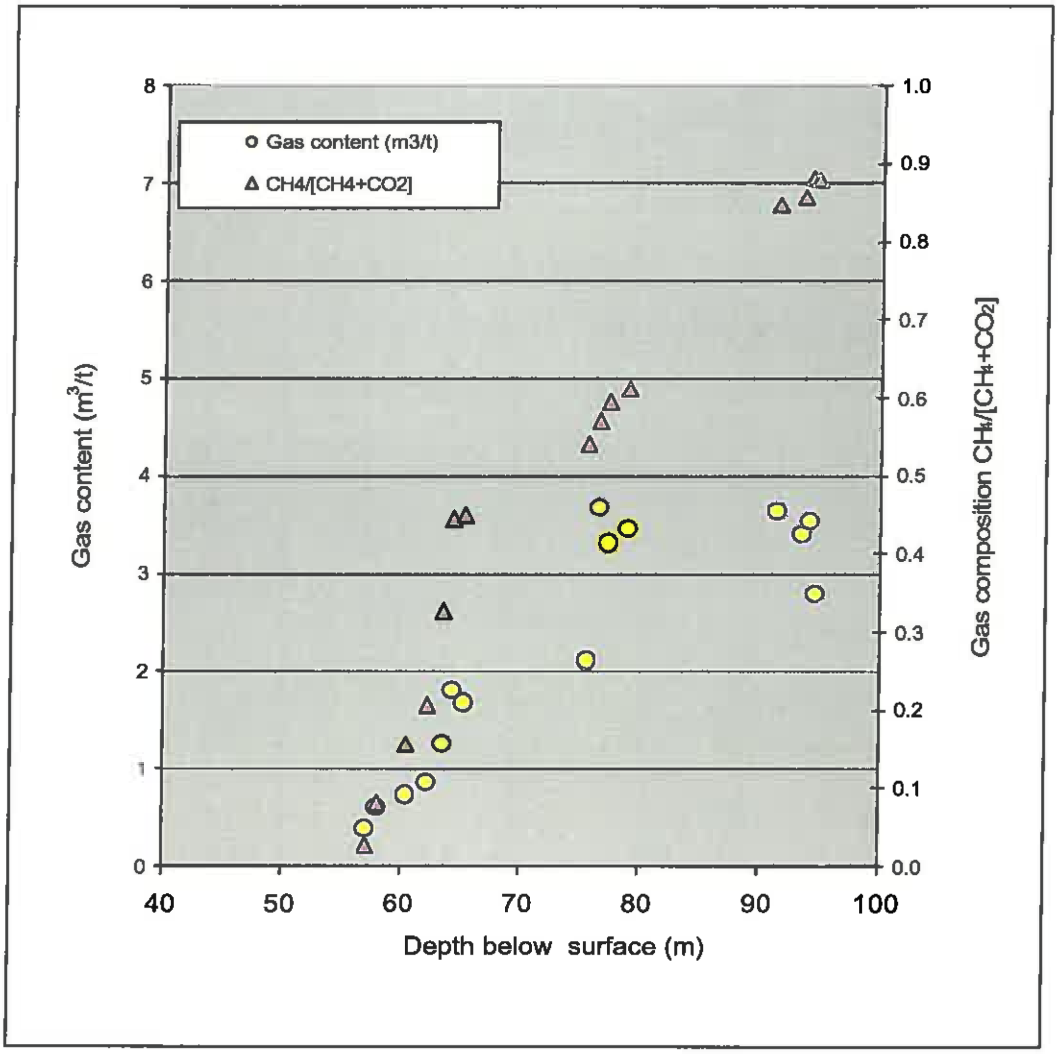

Figure 5.1 – Gas content and composition as a function of depth, coal seams intercepted by AQ52 borehole.

Some of the coal samples were left in stainless steel canisters and allowed to release their gas for many weeks. The desorption curve for a Vaux seam coal (sample 14) is shown in Figure 5.2.

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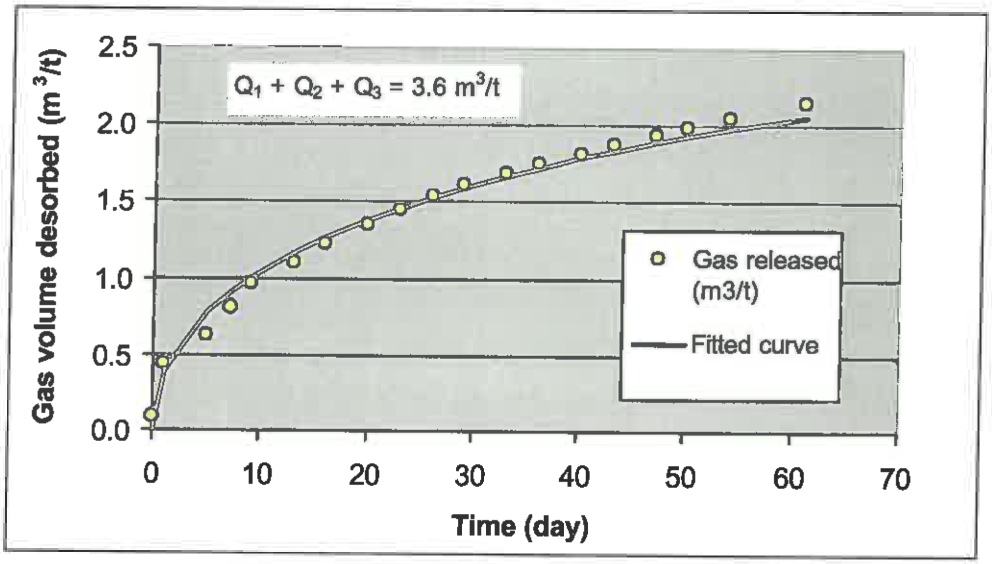

Figure 5.2 – Gas desorption from Vaux seam, borecore sample (Sample 14), lump coal, grain size< 60 mm.

The data in Figure 5.2 correspond to the Q_2 component of the gas content. After 61 days of slow desorption some 2.3 m^3/t of gas had been released by the coal (Q_1+Q_2). (Note Q_1 was measured to be 0.18 m^3/t). The coal was then crushed to release all of its remaining gas. The gas released at this stage was found to be 1.3 m^3/t. Therefore the measured gas content of the coal was 3.6 m^3/t.

The line of best fit to the data in Figure 5.2 has the form

$$C = C_0(1 - e^{-\alpha\sqrt{t}}) \tag{5.1}$$

where C is the gas volume per unit mass of coal released from the time that coal was removed from the borehole. From the data in Figure 5.2, C_0 = 3.6 m^3/t and a = 0.108 $day^{-0.5}$

Equation (5.1) suggests that it takes 41 days for the coal to release 50% of its gas in the early stages of desorption.

Note that the form of equation 5.1 is different to that of equation 4.1, fitted to the data in Figure 4.2. In the latter equation the exponential depended on t^1 rather than $t^{0.5}$ as is the case for equation 5.1. These two different dependencies reflect different gas loss regimes. While the coal sample for equation 4.2 was also from the Vaux seam the sample was collected after overburden had been removed and gas had desorbed from the sample prior to it being uncovered. Note also that the form of equation 5.1 is commonly used to describe desorption of gas from fresh borecore samples.

5.2.2 *Measurement of Gas Flow Rates of Coal Seams Intercepted by Borehole AQ52*

Figure 5.3 shows the flowrate data measured from the Cheshunt borehole on 31 January and 10 April 2002 plotted against time. Also shown are the gas composition data measured on 10 April.

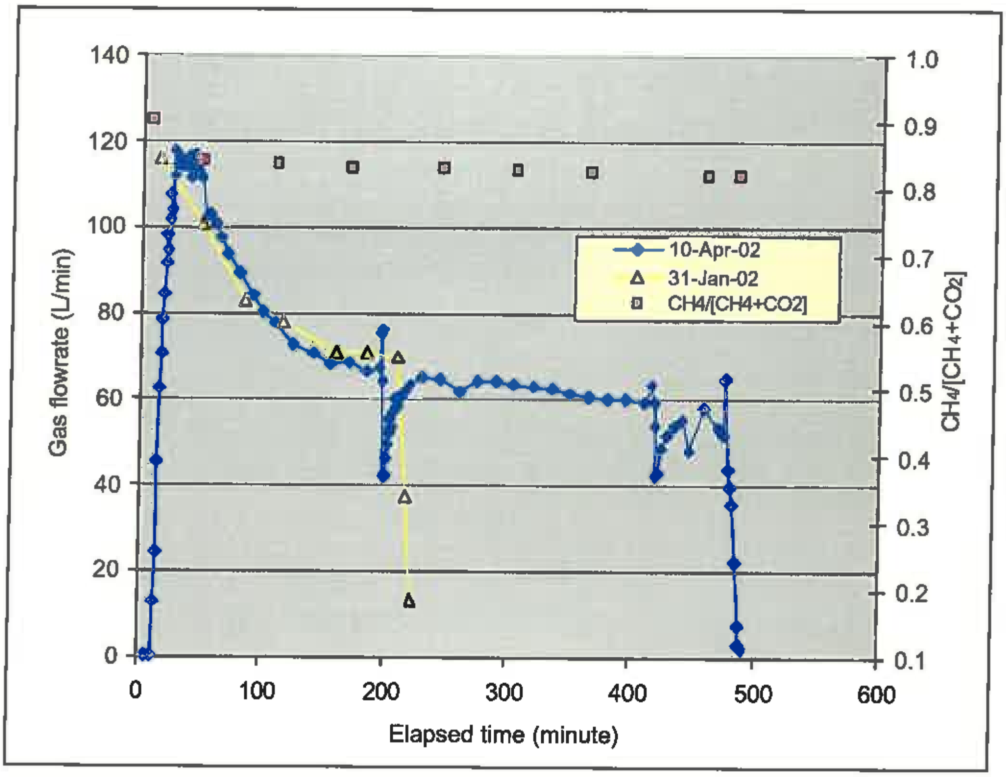

Figure 5.3 - Evolution of gas flowrate and composition from AQ52 borehole.

The smaller flowrates at the beginning of the measurement period was prior to dewatering of the borehole. The increasing flow rates up to ~50 minutes elapsed time show the effect of water being removed. After ~1 hour the maximum flow rate is achieved and begins to decline during the period of the measurement. The dip in the gas flowrate (at ~190 minutes for the measurements of 10 April) corresponds to a period when the water pump was switched off in order to refuel the power generator. The corresponding dip at ~210 minutes for the data from 31 January and at 490 minutes for the data from 10 April correspond to termination of the measurements.

Figure 5.3 shows that the gas flowrate during the measurement period for 10 April (~8 hours) decreased from a maximum of 120 L/min to level out to about 60 L/min toward the end of the day. Note that for this hole, the water level was kept at 81 m depth so that the Vaux seam remained under water. If the borehole could be fully dewatered, the Vaux seam would also contribute to the gas flow into the borehole and the hence the flowrate would be larger than its measured values of 60 to 120 L/min.

The data in Figure 5.3 also show that the gas composition measured during the course of the day for 10 April remained essentially constant and was composed mainly of methane.

Table 5.5 shows the maximum gas flowrate and composition measured on each occasion since October 2001. Two gas flowrates are presented. One is for the hole without dewatering, while the other is for the dewatered borehole.

Table 5.5 - Measurement of gas flowrates and composition at Cheshunt AQ52.

Date of measurement	Time elapsed since the hole was drilled (days)	Flowrate before dewatering (L/min)	Flowrate after dewatering (L/min)	Air free composition $CH_4/[CH_4+CO_2]$
21-Oct-01	116	0.6	UD*	0.89
08-Nov-01	134	-	UD*	0.92
22-Nov-01	148	-	UD*	0.85
06-Dec-01	162	1.1	UD*	0.89
20-Dec-01	176	2.4	99.3	0.86
22-Jan-02	209	0.8	123.0	0.86
31-Jan-02	218	0.6	116.0	0.85
13-Mar-02	259	1.1	125.3	0.84
10-Apr-02	287	0.6	117.9	0.84

* A leaking end cap resulted in unreliable data

The gas flowrate before starting the water pump was generally ~ 1 L/min.

The data from Table 5.5 have been plotted in Figure 5.4 to show variation in the maximum flow rate and gas composition as a function of elapsed time after drilling of the borehole.

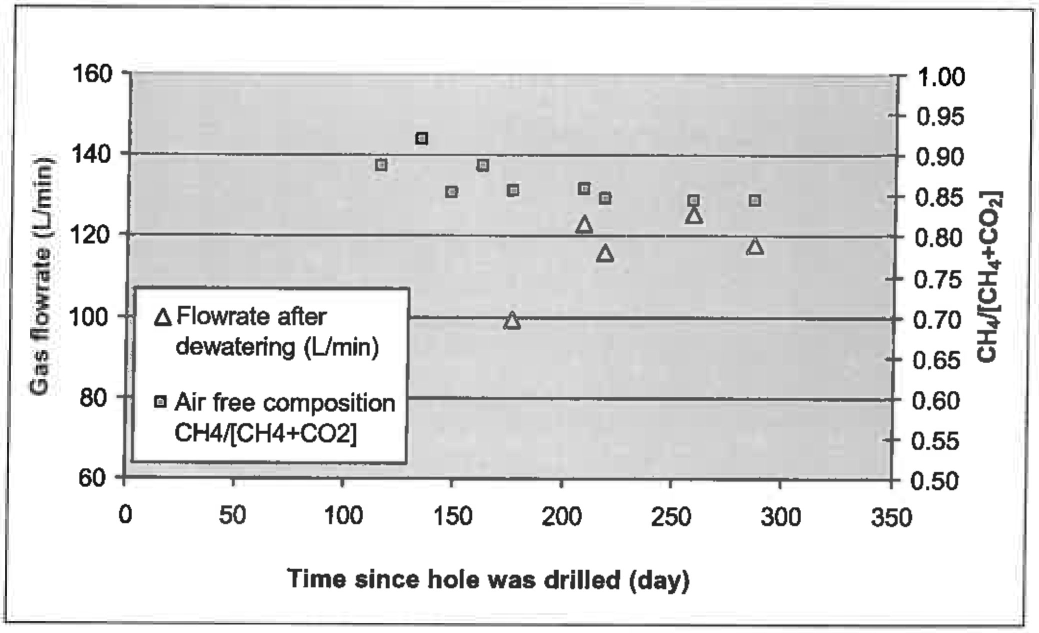

Figure 5.3 - Gas flow rates and composition from Cheshunt hole.

The data in Figure 5.3 show a fairly constant maximum rate of gas emission after ~200 days. This is not surprising as the borehole refills with water in between measurement campaigns and this acts as a seal for gas release. Similarly gas composition stabilised at ~ 85 % methane and 15 % carbon dioxide.

5.3 Summary and Discussion of the Cheshunt Borehole Data

In situ gas content of individual seams was measured from the borecore samples at Cheshunt AQ52 borehole. The maximum measured gas content was ~3.7 m^3/t for the deeper Piercefield and Vaux coal seams with gas composition up to ~90% methane at these deeper depths. This gas would be released during different stage of mining and post mining.

Measurement of the desorption of gas from the coal showed that it can take significant time for gas to be released naturally from these coal. A borecore sample of fresh Vaux coal showed that it took 41 days for the coal to release 50% of its gas. It must be noted that the coal lump size was under 6 cm and for larger size lumps this time would increase significantly.

The results of flowrate measurements from the Cheshunt borehole demonstrate the significance of water in the boreholes and the necessity to dewater these holes in order to measure gas emission rates. The borehole emissions approximate the emissions likely from a standing highwall on mine closure. This suggests a method whereby post-mining emissions (after mine closure) can be estimated. Further work is required for this methodology to be developed to a stage where it can be used routinely to estimate the fugitive emissions after mine closure.

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6 CONCLUSION

In the course of project C9063 work was carried out at seven open-cut mines in the Hunter Valley and three in the Bowen Basin where measurements of surface emission and gas content of coal were made. Numerous direct measurements of emissions from uncovered coal seams as well as gas released in coal blast holes and exploration surface holes were made. Fresh coal samples from blasted coal seams were also collected and measured for their gas content and composition. Some samples were allowed to release their gas over periods up to 2 months to investigate the kinetics of gas release.

Measurements of the gas contents in the pit for coal collected from blasted seams in Hunter Valley mines showed seam gas content of ~0.1 m^3/t to more than 1.6 m^3/t. Seam gas compositions for these samples varied from almost pure CO_2 to 30% CO_2, with the remaining gas being CH_4. For some samples the rates of gas desorption were also measured over a period of a few weeks. For one coal with lump size of 100 mm 50% of the gas was still present after a time period of 6 weeks and 10% still present after ~4.5 months. This suggests that there may be significant amounts of seam gas in the coal leaving the mine. Further work is required to determine the full significance of this observation.

For the Bowen Basin results, measurements of the gas contents of coal seams in pit for the three mines studied varied from almost un-measurable quantities to 1.5 m^3/t at Moura opencut. The higher gas contents corresponded to the seams with higher methane composition. At Moura the seam gas was ~95% methane while at Goonyella and Burton the seam gas was almost entirely CO_2.

During the course of sample collection and measurement of gas content it was clear that sampling methodology and knowledge of the length of time since the coal seams were uncovered would have significant impacts on the results. Extended time periods from coal being uncovered, to being mined, allow seam gas to desorb. This is an important consideration in considering the rate of release of seam gas from the uncovered yet un-blasted coal seam.

Measurements of the surface emissions from Hunter Valley and Bowen Basin mines showed a wide range of emission rates. For example at Goonyella the emission rates varied from 0.02 to 0.45 $mgs^{-1}m^{-2}$ (CO_2 equivalents) over essentially similar surfaces.

The surface emissions data generally showed wide variability in the emission rate. This is because the surface emission rates depend on

1. The initial gas content of the coal
2. The elapsed time from when the overburden and coal was disturbed and the measurements made
3. The permeability of the layer over which the measurements were made which is in turn influenced by the mining method and blasting of the coal and overburden

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Also the emissions can be expected to decrease with time as the gas desorbs from the target coal seam. Consequently it is not possible, at present, to generalise the above results in a manner so as to arrive at emission factors for the mines studied.

During the final phase of the project, effort concentrated on studying a purposely-drilled surface borehole at the Cheshunt site at the Hunter Valley Operation. Gas content of in-situ virgin coal seams up to a depth of 100 m was measured. The gas contents varied from ~0.4 to 3.7 m^3/t. As expected, the smaller gas contents corresponded to the shallower seams. The seam gas composition also varied from almost pure CO_2 near the surface up to almost 90% CH_4 for the deepest seam at 95 m below the surface.

The results from the Cheshunt borehole demonstrated the significance of water in the boreholes and the necessity to dewater these holes in order to measure gas emission rates. The borehole emissions approximate the emissions likely from a standing highwall on mine closure. This suggests a method whereby post mining emissions (after mine closure) can be estimated. Further work is required for this methodology to be developed to a stage where it can be used routinely to estimate the fugitive emissions after mine closure.

The fresh borecore samples also provided the opportunity to investigate the kinetics of gas release from fresh coal. For example a sample of a borecore for the Vaux seam (top size < 6cm) was allowed to desorb for a period over ~2 months. It took ~41 days for the sample to release 50% of its gas.

Based on the results of the current study it is clear that sampling coal from open cut operations on an opportunistic basis as attempted during this project is insufficient to allow the appropriate data to be obtained for a Tier 3 methodology to be determined. Instead an approach similar to that pursued at the Cheshunt borehole is required so that detailed gas content data can be obtained from a dedicated borehole. These data could then be used, along with data from an extension of the exploration drilling program to include a limited number of gas content measurements, in order to develop a Tier 3 methodology. In addition further work on the emission rates from boreholes could see this approach developed into a method for estimating emissions from final highwalls after mining has ceased.

DRAFT

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DRAFT

8 REFERENCES

AS 3980-1999: Guide to the determination of gas content of coal - Direct desorption method.

Australian Coal Year Book (2001) 15th Edition, Australian Mining Series Pty Ltd, Springwood, Qld.

BHP Corporate brochure for Goonyella-Riverside Mine.

Carras J. N., Day, S. J., Saghafi, A. and Williams, D. J. (2000) *Measurement of greenhouse gas emissions from spontaneous combustion in open cut coal mines.* CSIRO Energy Technology Investigation Report CET IR 333R. ACARP Project C8059 Final Report.

Carras J. N., Day, S. J. and Watson, J. (2002) *Airborne infrared thermography as a method for monitoring spontaneous combustion and greenhouse gas emissions.* CSIRO Investigation Report CET IR 511R ACARP Project C9062.

Holle, J. (2002) Moura Mine, Private communications.

Kirchgessner, D. A., Piccot, S. D. and Masemore, S. S. (2000) An improved inventory of methane emissions from coal mining in the Unites States. *J. Air & Waste Manage. Assoc.* 50, 1904 - 1919.

NSW Coal Industry Profile (2002) NSW Department of Mineral Resources, St Leonards.

Piccot S. D., Masemore S., Ringler E. s. and Kirchgessner D. A., (1995) *Developing improved methane emission estimates for coal mining operations.* In Proceedings of the 1995 Symposium on Greenhouse Gas Emissions and Mitigation Research, US Environmental Protection Agency, Air Pollution Prevention and Control Division, NC, USA.

Regan, J. (2002) *Establishing a commercial coal mine methane business at Moura Mine*, The Australian Coal Seam and Mine Methane Conference, Sydney, June 2002.

Saghafi, A. and Williams, D. J. (1992) *Estimation of methane emission from Australian coal mines.* Proceedings of Symposium on Coalbed Methane Research and Development in Australia, Townsville, 19-21 Vol 5, p 7-20.

Saghafi, A., Williams, D., J. and Lama R., D., (1997) *Worldwide methane emissions from underground coal mining.* In the Proceedings of the 6th International Mine Ventilation Congress, Pittsburgh, PA, USA, pp. 441-445.

DRAFT

Williams, D. J., Saghafi, A., Lange, A. L. and Drummond, M. S. (1993) *Methane emissions from open-cut mines and post-mining emissions from underground coal.* Report to the Department of Environment, Sports and Territories, CSIRO Investigation Report CET/IR173.

Williams D J and Saghafi A (1993) *Methane emissions from coal mining - A prospective.* The Coal Journal, number 41, pp37-40.

Williams, D. J., Carras, J. N., Mallett, C., Mark, M., Cooke, D. and Randall, C. (1998) *Scoping study on the management and abatement of greenhouse gas emissions.* Report to the Australian Coal Association, CSIRO Investigation Report CET/IR46.