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## **Direct Measurement of Gas Content Without Coring**

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### **Abstract**

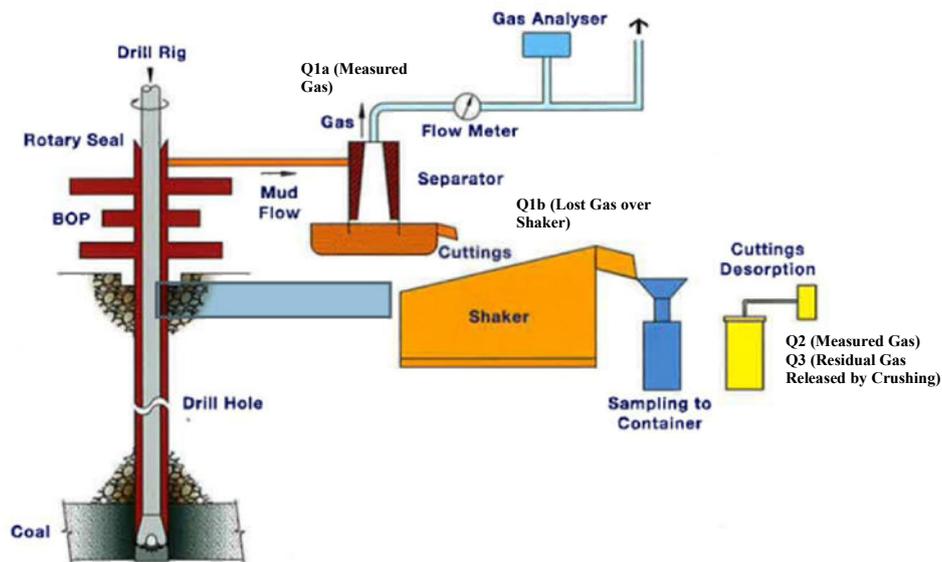
This new process enables the quantitative determination of the gas content of coals and other strata, such as shales or conventional reservoir rocks during overbalanced open hole drilling. This paper presents the results of a field trial through coal seams in Central Queensland where the system was tested and showed favourably comparable results to those obtained from gas content measurement by conventional core desorption in coals.

The system involves drilling in overbalanced mode through so that no reservoir fluids enter the well bore. Under these conditions the only material produced is that cut from the hole. This comprises cuttings and may also include gas and liquids contained therein. This material rises up the annulus and is diverted by a rotary seal to a cyclonic separator. This separates the free gas while the mud and cuttings overflow from the base of the separator and over a shale shaker. The free gas volume is measured directly while the cuttings are separated from the mud on the shaker and are sampled into canisters so as to permit measurement of any gas that may desorb from them freely or further after crushing.

The system thus enables the capture and measurement of all gas contained in the drilled strata with the exception of that desorbed during the brief period that the cuttings are on the shaker. This lost gas is small and may be readily estimated. The system is direct and simple and has the potential to replace core sampling and other more indirect and complex geophysical techniques to measure the gas contained in strata.

## Description of the Process

The process of Gas Content Without Coring (GCWC) is shown schematically in Figure 1.



**Figure 1: Gas Content Without Coring Process Diagram**

In this process de-aired drilling mud is pumped through to the drill string and drill bit and out into the hole annulus for the purpose of clearing the bit face, cooling and carrying the cuttings to surface. Because the system operates in overbalanced mode no fluids enter the well bore. The material rising in the annulus therefore comprises solely of mud and cuttings from the borehole space along with any fluids released from the cuttings. Gas in the cuttings is either directly released from pore space or desorbed as the well bore pressure drops with transport upwards.

At surface a rotary seal leads to the cuttings being diverted into a cyclonic separator which has a base overflow to hold the fluid level reasonably constant. Gas released from the mud and cuttings passes through positive displacement flow meters and past gas composition sensors. Thus the free gas may be directly measured at the well head. The cuttings may still contain further gas which will continue to desorb. This volume of this gas is also measured.

Mud carrying cuttings flows over the shaker and the cuttings are then sampled in canisters for further desorption. Finally the cuttings from the canisters can be ground to speed the desorption process and obtain all the released gas. Thus all the gas contained in the drilled strata is measured with the small exception of the period while cuttings are on the shaker. This gas loss can however be estimated from the desorption characteristics of the cuttings in the canisters.

As part of the process it is important to ensure that no air is pumped down the drill string as this will mask the measurement of gas released from the cut volume of the hole. This is achieved by de-airing the drilling mud before it is pumped down the hole and by ensuring that air does not enter the drill string during drill pipe changes.

The de-airing of the mud is necessary if the mud is sufficiently viscous that it does not readily release bubbles introduced into it while passing through the shaker. It is advantageous to use such muds for drilling purposes and for the gas content measuring process as viscous mud slows the sinking of cuttings and rising of bubbles within the hole. The de-airing is achieved by pumping it through a cyclonic separator used specifically for this purpose. Once de-aired the mud is delivered to the mud pump and pumped through an anti-dribble valve into the drill string and then through a pressure relief valve and out of the bit and into the borehole.

The purpose of these two valves is to prevent air entering the drill string. The pressure relief valve at the base of the drill string maintains the liquid column in the string during pipe changes. The anti-dribble valve prevents mud from dribbling out of the swivel and being replaced by air.

The procedure when a pipe is added is to break the connection at the swivel and add a drill pipe. The drill pipe is then filled with mud, the swivel made up and drilling continues. The exact mode for doing this will depend on the drill rig and whether it is a top head or Kelly Drive Unit.

Cuttings samples are collected in a canister from each formation drilled after they have passed over the shaker. The canister is then placed in a water bath held at formation temperature and is permitted to desorb gas. The volume of gas produced is either manually or automatically measured.

The samples can be taken on a regular basis, when the gas meter indicates gas make, or when carbonaceous cuttings are visible on the shaker. Gas measurements and cuttings samples are related to the depth at which they have been generated. This is achieved principally by maintaining a drill pipe count and recording the drill head position and the mud pump rate.

The position of drill bit is always known by using a manual rod count and an automatic head position sensor and all this is continuously recorded by the GCWC software. The mud pump rate is also continuously recorded and as the drill bit size is known, the mud velocity can be calculated. By combining the drill head position with the mud velocity, a basic estimate of the origin depth of the chips and gas bubbles reaching the surface can be calculated.

This basic depth estimate is adjusted by taking into account the tendency of bubbles to rise relative to the mud and the tendency of chips to sink relative to the mud. As more information, such as the geophysical log, becomes available, the cuttings and gas origin depth estimates are refined and recalculated. There is a practical limit to the precision of these estimates due to spreading of cuttings and gas bubbles as they rise, but the precision and accuracy obtained in the prototype was adequate to identify the origin coal seam of cuttings and gas. The spreading of cuttings and bubbles can be reduced by periodically flushing the hole clean from bottom up without drilling. Sometimes an air slug deliberately introduced into the drill pipe can act as a good marker within the fluid coming from the hole.

### **Safety Considerations**

The GCWC rotary seal would normally be placed on the top of the BOP stack with an outlet to the separator. Any sudden changes to fluid volume produced from the hole will cause the liquid level within the separator to surge. This is detected by a pressure switch and causes the actuation of the BOP and a valve which diverts the flow to the choke outlet 20 metres away from the rig.

### **Terminology**

The following gas quantities are referred to:

*Q1a* – The gas volume measured from the separator as the hole is drilled, divided by the mass of formation drilled.

*Q1b* – The estimated lost gas volume over the shaker during the transit time expressed per mass of formation drilled.

*Q2* – The cumulative gas released by the cuttings sample over an extended period. This is divided by the mass in the sample to derive gas content per tonne value.

*Q3* – The residual gas recovered from crushing subsamples of the material in a chip sample. This is divided by the mass in the subsample to derive gas content per tonne value.

*Qm* – Measured gas is the sum of the *Q1a*, *Q1b*, *Q2* and the *Q3* results. Results are expressed in terms of cubic metres per tonne for each sample.

The terminology here approximately resembles that used in AS3980 used for the description of gas content measurements in coals.

In all cases the volumes are corrected to standard conditions and the gas contents may be converted between mass and volume by geophysical logs. In practice it is easier to work initially in terms of volume of hole for *Q1a*, and *Q1b* and to use mass for the samples desorbing *Q2* and being crushed to yield *Q3*. Drilled volume calculations may be subsequently refined by the use of a calliper log.

Where the gas is overwhelmingly held in carbonaceous matter it is convenient to work in terms of gas volume content per unit mass of carbonaceous material.

## Analysis

The analysis primarily consists of five stages.

1. Knowing where the gas bubbles and cuttings that reach the well head collar come from. This is a calculation based on the:

- Bit position
- Mud flow rate
- Hole size

With corrections for bubble floatation and cuttings sinking rates if these are significant.

2. The calculation of the gas produced per unit volume of hole. This is the gas produced per unit length divided by hole volume created. The hole diameter may be corrected by a subsequent caliper log and the figure converted to gas volume per unit mass via the density log. This then delivers the measurement Q1a.

3. The calculation of the desorbed gas from cuttings is arrived at by measuring the total cumulative desorption from the canister and then opening the canister and separating mud from solids using a centrifuge and weighing the mud and solids. The solids may then have their density measured further by pycnometer. The fluids in the sample are driven off by heating. Thus a volume of gas per mass of solids is calculated. This is Q2.

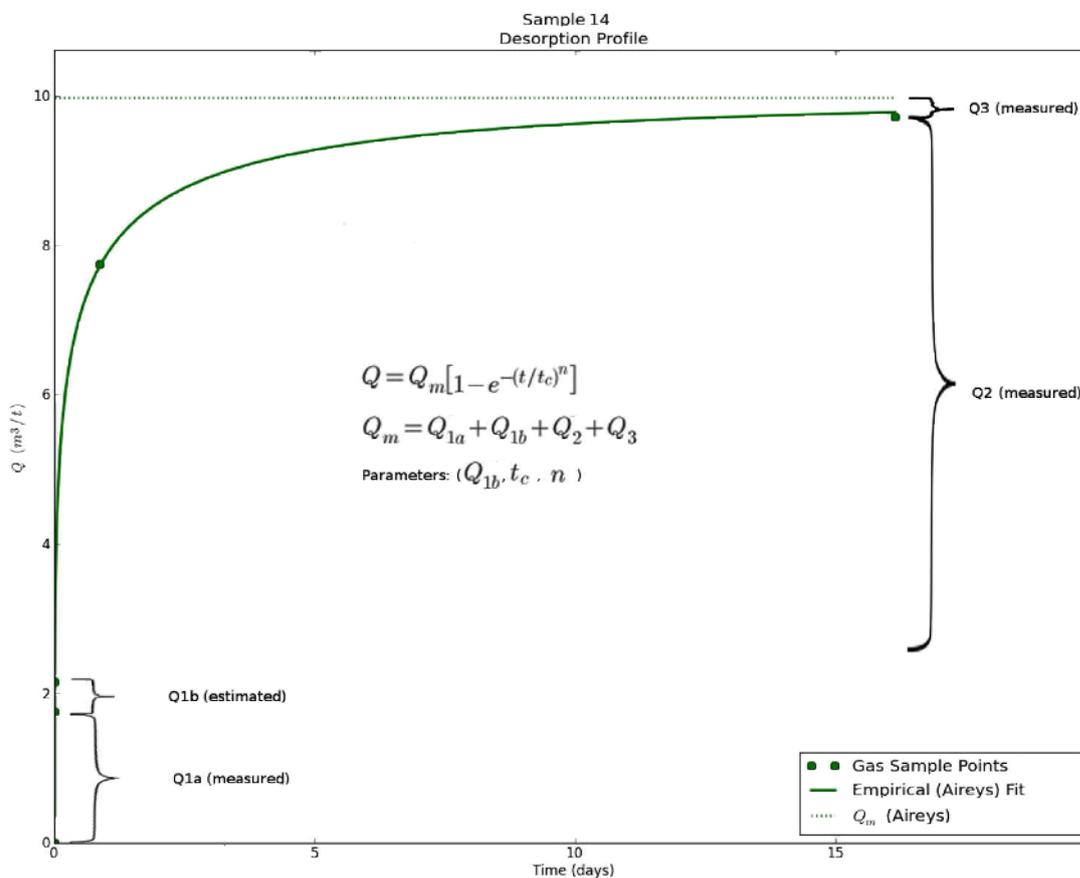


Figure 2: Total gas release in stages with time.

4. As part of stage 3 the cumulative gas volume release should be measured with time. This provides a basis for backwards extrapolation of desorption in time so that the lost gas over the shaker may be determined. The most straightforward basis for extrapolation is to use Airey's empirical equation (1) derived for gas release from broken coals.

$$\frac{Q}{Q_m} = 1 - e^{-(t/t_c)^n} \quad (1)$$

Where  $Q$  is the cumulative gas volume released at time  $t$

$Q_m$  is the total gas volume contained

$t$  is time

$t_c$  is the characteristic time for the sample

$n$  is a shape factor

The solution of the constants in equation (1) may be achieved using a Newton-Raphson procedure over a least squares solution provided at least three timed points exist on the gas release curve for stage 3 (Figure 2). Once the constants have been calculated then the lost gas may be calculated for the period of transit from the separator across the shaker until the sample is sealed in the desorption canister.

A more sophisticated analysis may be used which will yield lost gas and a diffusion coefficient of the material. It is outlined in the Appendix. The greater precision of this is not however justified for the calculation of the lost gas alone as it is a very small fraction of the total gas contained in the sample.

The lost gas  $Q_{1b}$  is the gas volume divided by the sample mass measured in stage 3.

5. The residual gas is determined by taking a sub sample of the solids from the centrifuge in stage 3. This is weighed and then placed in a sealed ring mill and crushed. The gas volume released is measured and the sample is then heated to obtain a dry mass. The gas release volume divided by the dry sample mass is  $Q_3$ .

Further heating may be used to determine the volatile matter (as in coals) and if heating continues with air to reduce the sample to ash so that the carbonaceous matter may be determined. These processes are conducted in accordance with AS1038. Doing this enables the gas released to be related to the carbonaceous matter in the sample.

The total gas content is then arrived at by addition as in equation (2).

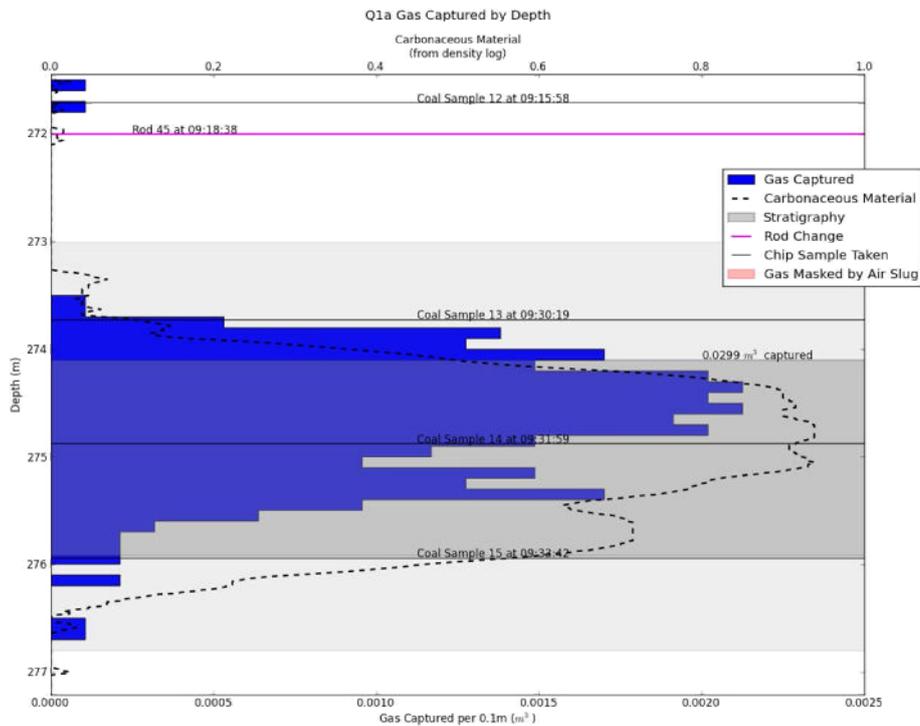
$$Q_m = Q_{1a} + Q_{1b} + Q_2 + Q_3 \quad (2)$$

### Field Testing Example

The system was used in two 99 mm diameter boreholes drilled through the coal seams of the German Creek formation at Grasree mine in Central Queensland. A core hole was drilled nearby and the gas content of the seams was measured using very sophisticated core desorption procedures. These were significantly in advance of those described in AS3980 as they involved desorption at seam temperature using automated gas flow monitoring and took into account the desorption characteristic of the coal rising in the core barrel and on surface prior to it being placed in a canister for desorption. The work also involved wetting the non carbonaceous core to see if there was any sign of gas release. This was found to not be the case.

### Gas Released (Q1a) by Depth and Time Plots

While drilling the strata, gas is released from the seams and is clearly measured during the drilling process logged by gas meters.



**Figure 3: Gas by Depth Plot for the Aquila Seam**

Figure 3 shows the case of the Aquila seam. Here gas released per metre of drilling (in blue) and the fraction of carbonaceous material in the strata (dotted black line) while the overall location of the coal as defined by a density of less than 1700 kg/m<sup>3</sup> taken from the density log is shown in grey.

Figure 4 shows similar plots for the entire German Creek formation. It may be noted that negligible gas was released for the Tieri seam group. This is because it is heat affected by a sill and very little gas remains. No gas is released from the strata between the coal seams. Both these observations are consistent with the results from the adjacent core hole.

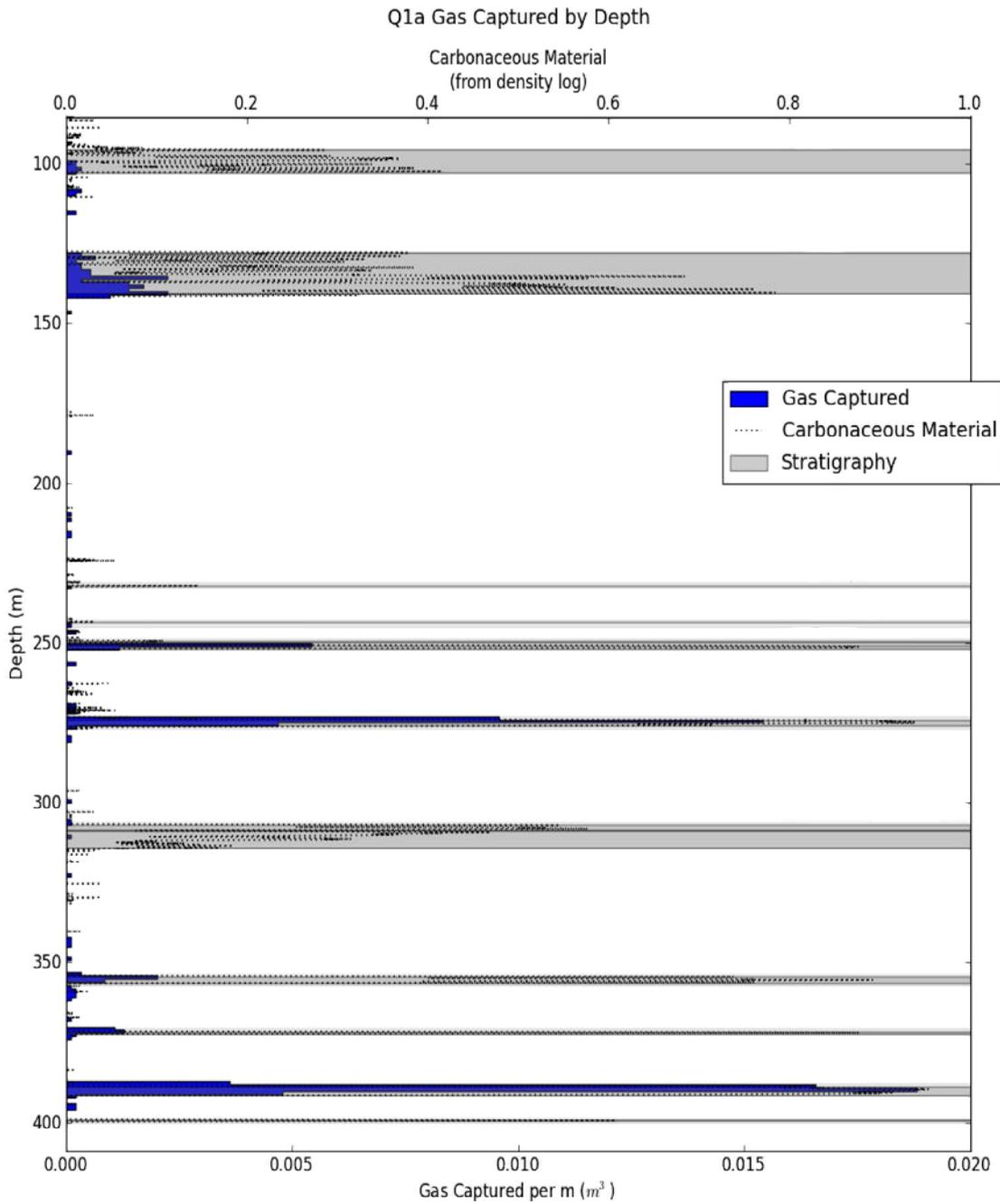


Figure 4: Gas by Depth Plot for German Creek Formation

The plot in Figure 5 shows gas release with respect to time as well as the Mud Pump Rate and change in compositions when gas is released from the seam struck while drilling.

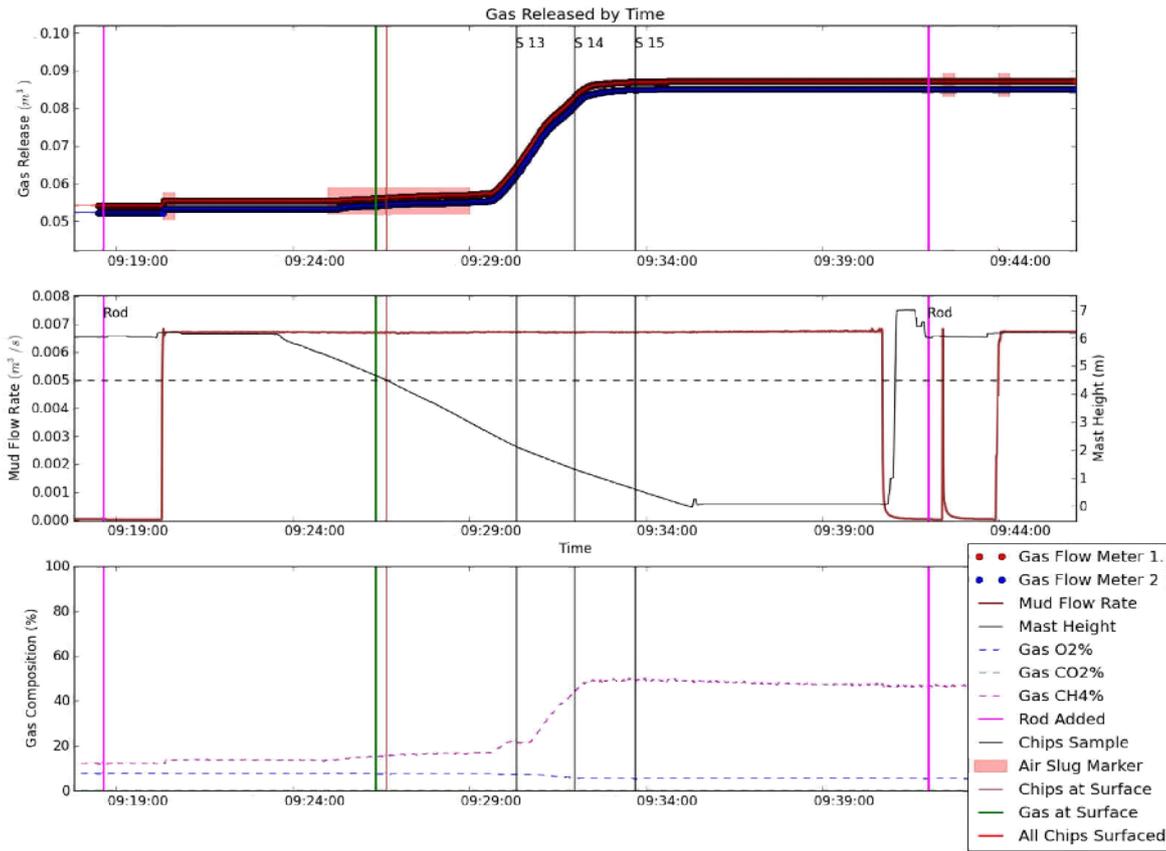


Figure 5: Gas by Time Plot showing gas release by time and change in gas compositions

**Basic Calculations Aquila Seam Case**

**Q1a**

Seam Thickness = 1.82 metres  
 Gas Captured during drilling = 29.868 litres  
 Gas Captured adjusted to standard temperature and pressure (STP) = 28.427 litres  
 Drilled Volume Material = 0.014 m<sup>3</sup>  
 Drilled Material Weight = 20.516 kg  
 Carbonaceous Material Weight = 16.212 kg

Q1a = 1.753 m<sup>3</sup>/t ..... 1

**Q2 and Q3**

The samples were put into a water bath which is brought up to seam temperature for further Q2 desorption. On completion of Q2 desorption, the gas bag volumes are measured, the samples dried by centrifuge and then weighed, and then Q3, moisture content and ash content samples taken.

An extensive collection of volumes and weights are recorded throughout the process, in order to measure the dead volume in the container, the actual weight of the chips, and their relative density.

Subsamples were taken and crushed to find Q3 gas release measured according to AS 3980. Moisture and ash composition subsamples are tested according to AS 1038.3

As the collected samples can have a lot of rock mixed in with the carbonaceous material, estimating the ash content based on relative density can be unreliable. Ash content is therefore measured by cooking the sample in an oven, as specified in standard AS1038.3. Moisture content is similarly measured, as we are interested in the carbonaceous weight. There is no need to dry the sample first, as it is not necessary to differentiate between surface moisture and bound moisture. The Dry Ash Free Weight (DAF wt) is taken to be:

$$\text{DAF wt} = [\text{Sample Weight}] \times (1 - [\text{Ash Content}] - [\text{Moisture Content}]) \quad (3)$$

*Sample Calculations shown for Q2 for the Seam from Sample 14 taken during the drilling*

Weight of the sample = 1.148 kg  
 Ash Content = 60.3%  
 Moisture Content = 5.6%  
 Dry Ash Free (daf) Weight = 0.391 kg  
 Q2 Sample Bag 1 Volume STP = 2.151 litres  
 Q2 Sample Bag 2 Volume STP = 0.761 litres  
 Q2 Vol. STP = 2.151 + 0.761 = 2.911 litres  
 Q2 Gas Content = 2.911/0.391 = 7.437 m<sup>3</sup>/t.....2

*Sample Calculations shown for Q3*

Weight of the sample taken = 0.150 kg  
 Ash Content = 60.3%  
 Moisture Content = 5.6%  
 Dry Ash Free (daf) Weight = 0.051 kg  
 Q3 Vol. STP = 0.0197 litres  
 Q3 Gas Content = 0.384 m<sup>3</sup>/t.....3

### **Q1b**

The vast majority of gas is collected as Q1a, Q2 and Q3; however there is still some lost gas Q1b, to be determined. This has been achieved by fitting the measured points to the equation (1) by Airey (1968).

Although this is purely an empirical equation, it allows a quick and effective determination of Q1b. Because Q1b is in the order of only 5% of the total gas content, even a poor fit has only a minor effect on the total gas content estimate. In future operations, a more rapid sampling and frequent monitoring technique will reduce the magnitude of Q1b so as to provide greater accuracy.

Estimated Q1b = 0.402 m<sup>3</sup>/t.....4

Hence

Q<sub>m</sub> = Total Gas Content

$$Q_m = Q_{1a} + Q_{1b} + Q_2 + Q_3$$

$$Q_m = 1.753 + 0.402 + 7.437 + 0.384 = 9.977 \text{ m}^3/\text{t}.....5$$

Multiple samples were taken to get the average gas content of the seam.

## Comparison of Results

Table 1 shows the results of gas content of the two GCWC holes and the core holes on a dry ash free basis. Some variation is present but this could be expected in this geological environment.

| Seam   |      | Fair Hill | Pleiades | Aquila | Aquila Lower | Tieri  | Corvus | German | German Creek Lower |
|--|------|-----------|----------|--------|--------------|--------|--------|--------|--------------------|
| Depths (m)   | From | 136.38    | 261.75   | 284.29 | 296.81       | 325.71 | 372.75 | 407.37 | 417.50             |
|  | To   | 148.89    | 262.68   | 285.32 | 297.60       | 327.56 | 374.68 | 410.04 | 417.77             |
| Cored Hole Gas Content dry ash free (m <sup>3</sup> /t)  |      | 6.23      | 5.68     | 7.22   | 5.58         | 1.59   | 5.1    | 5.45   | 6.78               |
| GCWC Hole 1 Gas Content dry ash free (m <sup>3</sup> /t) |      |           | 5.5      |        |              |        | 3.71   | 5.73   | 4.98               |
| GCWC Hole 2 Gas Content dry ash free (m <sup>3</sup> /t) |      | 5.82      | 5.87     | 10.49  | 6.87         | 2.23   | 5.08   | 8.21   | 5.73               |

**Table 1: Comparison of Gas Content on a Dry Ash Free Basis of the Cored Hole versus GCWC Holes**

The three holes were roughly in a line and spaced at approximately 400 metres from each other. In this environment some variation in gas content would be expected over this distance.

## Conclusions

This first trial of gas content without coring worked reasonably successfully, particularly on the second hole when some experience had been gained with the system. It is not possible to determine whether GCWC or core desorption system provided the more accurate result.

The system could be implemented with relatively little effort on most drill rigs that are used in petroleum drilling operations. The main components that are additional are the rotary seal and the cyclonic separator between the rotary seal and the shaker. A mud de-airing separator may also be required. The other requirement is to set up a smooth and quick sampling procedure to collect samples off the shaker. These are not particularly difficult changes. It was in fact more difficult to put the trial system on a mineral drilling operation that lacked a mud processing system rather than on a standard drill and mud processing system used for petroleum purposes.

The perceived uses for the system are in determining gas content in open hole exploration drilling or to confirm gas contents in infill drilling.

The main challenge is in determining where the sample came from because of the spread that occurs in the gas and cuttings when they travel up the drill pipe. In the case of the coal sequence being drilled in this operation this was a simple process because all of the gas came from the coals and the coals were readily identifiable by the geophysical log that was subsequently run. In thick reservoir material this identification problem is less of an issue. In the case of some of the narrow seams encountered in this operation we found that the gaseous coals became mixed with rock cuttings and that it was best to work on the basis of gas contents in the carbonaceous material of the samples. Periodic mud sweeps of the hole enabled clearing of the hole of cuttings and gas and permitted measurement to start from a new base.

The system has great promise for use in the coal seam gas industry (CBM), in shale gas and in conventional reservoir rocks provided they do not contain vugs or large fissures. Where gas is stored only in pore space it will provide an instant measurement of gas content of the strata. Where desorption is required it will take a little longer.

The gas content without coring system is subject to patent applications.

## Acknowledgements

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## Appendix – Alternative Process to Analyse Cuttings Desorption and Lost Gas

Where a particle size distribution is conducted on the cuttings the use of a theoretical, spherical diffusion model (Crank, 1975) may be considered for analyses

$$\frac{Q}{Q_m} = 1 - \frac{6}{\pi^2} \sum_{n=1}^{\infty} \frac{1}{n^2} e^{-Dn^2\pi^2 t/a^2} \quad (4)$$

Where  $t$  is time,  $D$  is the coefficient of diffusion and  $a$  is the particle radius.

This is solved for the diffusion coefficient using the summation of desorbed volume for the various cuttings size components to yield a diffusion coefficient.

Using the derived value of  $D$  and the actual particle size distribution of the sample it is possible to solve for the lost gas  $Q/b$  for the time interval from the separator to when desorption is monitored from the canister.

In a case such as that of a sample which may contain a mixture of coal and surrounding strata it is advantageous to separate the coal from the other rock using a sink – float separation and to conduct the particle size analysis on the coal alone. This will ensure a higher accuracy solution as the coal is the prime contributor to the gas and may have a difference characteristic particle size distribution to the rock.