Application of Gas Content Test Data to the Evaluation of Gas Emission and Hazards During Longwall Development and Extraction

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Abstract

This paper compares aspects of fast and slow desorption methods and attempts to provide guidelines for their application and associated sampling strategies.

The importance of determining Total Desorbable Gas Content (Q1+Q2+Q3) as opposed to Desorbable Gas Content (Q1+Q2) is highlighted. The former involves partial destruction of bore core, but provides considerably more accurate data. It is also more amenable for use in gas reservoir simulation modelling.

Fast desorption techniques are shown to have considerable advantages over slow desorption techniques. These are, greater accuracy in gas composition assessment, the potential to rationalise sampling, fast turnaround involving fewer resources, finalisation of geological logs and early application of the data. Q3 can still be differentiated. A more sensitive indicator of gas desorption rate is incorporated in GeoGAS's fast desorption method (GeoGAS Desorption Rate Index).

Gas reservoir size determination is facilitated by a sampling strategy where relationships between gas content and gas composition with depth and mineral matter are defined. This enables indirect assignment of gas content to those gas bearing strata not directly tested. The importance of testing/assigning gas contents to inferior coaly horizons is indicated.

Gas content test results are basic input into any mining application. An overview of its application to modelling gas emission is given. Statistical analysis of the data enables modelling inputs and outputs to be expressed as means and probability distributions.

Introduction

Gas content testing has become a routine part of most surface borehole exploration programs for underground coal mining. The gas content test data are basic input into costed approaches to gas, ventilation and spontaneous combustion control.

With the development over the past three years of fast desorption methods of gas content testing, the exploration geologist is confronted with additional choice of method and sampling strategy.

This paper compares aspects of fast and slow desorption methods and attempts to provide guidelines for their application and associated sampling strategies.

The most important of determinant of methodology is how the data will be used. Application to longwall development and extraction is broadly covered.

Gas Content Testing

Terminology

The following terminology is used in this paper. It should generally be accepted across the industry.

Total Desorbable Gas Content (TDGC) - the sum of Lost Gas (Q1), Desorbed Gas (Q2) and Residual Gas (Q3)

Lost Gas (Q1) - Gas lost from the sample between coring and sealing in a gas canister.

Desorbed Gas - The gas desorbed (per unit mass) from an uncrushed coal sample in the time between lost gas testing and crushing of the coal. The term is applied to fast desorption testing and is not the same as Q2.

Q2 - The gas desorbed (per unit mass) from an uncrushed coal sample held within a seam gas atmosphere, to the point in time where the partial pressure of the gases in the gas bomb is in equilibrium with the remaining gas in the core. The ambient pressure is approximately 1 atmosphere.

GeoGAS's fast desorption method determines Q2 by difference by subtracting the separately determined Q3 value from the initial desorbed gas, plus the gas on crushing.

Q2 = ("desorbed gas" + "gas on crushing") - Q3

Gas on Crushing - that gas released during crushing of the coal sample, at ambient pressure. Applies to fast desorption testing. The definition is not the same as Q3.

Residual Gas (Q3) - The volume of gas per unit mass desorbed at atmospheric pressure from the crushed coal sample after it has been allowed to desorb to its equilibrium gas content level in a seam gas atmosphere.

Desorbable Gas Content - the sum of Q1 and Q2.

GeoGAS DRI - A measure of the rate of gas desorption during crushing of the coal sample, corrected to the TDGC of the sample. (The gas volume generated after 30 seconds of crushing a 200 g sample corrected from the "Gas on Crushing" value to the TDGC value).

While AS 3980-1991 specifies reporting results to STP (0°C, 101.3 kPa), it is common practice in the industry to report results to 20°C and 101.3 kPa.

A Comparison of Fast and Slow Desorption Methods

Australian standard AS 3980-1991, *Guide to the determination of the desorbable gas content of coal seams* was developed to address the need to adopt a more uniform approach to gas content testing. Since then (1991), a number of limitations and deficiencies have been identified, to the point where a new standard, incorporating fast desorption techniques, is currently being developed.

Traditionally, gas content testing has been undertaken by the slow desorption method (USBM), with testing being mainly confined to Desorbable Gas Content Q1+Q2 determinations. With the emergence of the fast desorption methods and associated review of these and slow desorption methods (as in Working Group MN/1/5/3 - Standards Australia), limitations of these methods have been more clearly recognised.

The comments and comparisons that follow refer only to GeoGAS's method of fast desorption testing and experiences in its application. For a more complete view, the interested reader should contact other organisations who have developed fast desorption methods (ACIRL, BHP, CSIRO, KCC, Lunagas).

The fast and slow desorption methods primarily differ in a number of ways, among the most important being destruction of the bore core during the test, the time taken to achieve a result and the accuracy of the result (Table 1).

Table 1 Comparison of Slow and Fast Desorption

	Slow Desorption Q1+Q2	**Slow Desorption with Q3**	**GeoGAS Fast Desorption Q1+Q2+Q3**	**Fast Desorption with Q3**
Core left intact	Yes	No (2 x 200 g crushed)	No (2 x 200 g crushed)	No (additional 2 x 200 g crushed)
Result Timing	30 days +	30 Days +	< 1 day	30 days +
Accuracy re Gas Quantity	Rough	Potentially good when added to Q1+Q2	Good (+/- 0.5 m3/t to 95% confidence)	Good
Accuracy re Gas Composition	Rough unless pure CH4	Rough unless pure CH4	Good. Defines CO2 and N2	Good defines CO2 and N2
Accuracy Desorption Rate	Rough	N/A	Good (GeoGAS DR Index)	N/A
Resources	Requires lots of gas bombs/space.	Requires lots of gas bombs/space.	Minimum with quick reuse of equipment.	Uses glass jars, but as many as with slow method.
Adjust sampling strategy "on the fly"	Not possible	Not possible	Yes	Yes
Effect of slow leak in system	High	High	Slight	Slight
No. tests required to define reservoir	Maximum	Maximum	Minimum	Minimum

The main advantage for the slow desorption method (Q1+Q2 only) is that it can be used if the core is required intact for other analyses (eg washability testing), and there are no alternative sampling schemes. In the authors view, there is an unacceptable penalty on result accuracy.

Stopping the test on Q1+Q2 without proceeding to Q3 can result in underestimation of the gas content from between 1 to 4 m3/t. *The Q3 component is important in mining and gas extraction.*

The problem with measuring Q1+Q2 only, is that the test result is very much influenced by the equipment used, in particular, the void space in the gas bombs. Gas will stop desorbing in the canister when the partial pressure of the gas surrounding the core is in equilibrium with the sorbed gas concentration remaining in the core. Finishing a test on “Q2” alone, normally gives high scatter, potentially misleading results because of this effect. The time of terminating the test can also be some what arbitrary.

In fast desorption testing, Q1+Q2+Q3 is determined in the one operation. It is useful to know the Q3 value, so with GeoGAS’s fast desorption method, a small scale “slow desorption” test has been added, to directly determine it. A sub sample (approx 600 g) is taken for Q3 during the fast desorption test, and sealed it in a small “bomb” (glass jar). It is left on line for a sufficiently long period to stop desorbing its gas. The “bomb” is packed full of coal, so that by the end of the test, the equilibrium end point for the desorption is one where the gas surrounding the coal pieces is near pure seam gas (unless the gas content is very low). This material is then crushed, the gas evolved being calculated as Q3.

Gas composition is more accurately determined with the fast desorption method. Gas samples from exploration cores are routinely analysed for CO2, CH4, N2 and O2. Slow desorption techniques do not adequately address CO2 (which is readily lost even in acid brine baths) and are ambiguous regarding the question of N2 being a real component of the seam gas. With the fast desorption method, there is little time available for solution of CO2 in water, or for O2 to react with the core to produce excess N2.

Fast desorption testing allows quick turnaround (result in as little as 2 hours after the sample reaches the laboratory). This means that equipment needs are minimised. Fast turnaround of results frees core up for other tests, finalisation of geological logs and application of the data. Importantly, gas content data can be evaluated as the drilling program progresses, so that decisions regarding sampling can be made in response to the evolving picture.

Gas content is a static measure. In as far as gas desorption rate is affected by gas content, it implies a rate of gas desorption. But other factors significantly affect the rate of gas desorption, these being gas composition, inherent structural characteristics of the coal, and moisture.

The rate of gas desorption is important to quantify. The following techniques are available:

- The initial rate of gas desorption as part of the Q1 determination. This is common to fast and slow desorption testing.

- The rate of gas desorption (desorption history curve) as part of the slow desorption test.

- The rate of gas desorption during coal crushing, as part of the fast desorption test.

Of the three options, the author has found the rate of gas desorption during coal crushing (GeoGAS DRI) to be highly sensitive, enabling differentiation of the effects on desorption rate from gas content, gas composition and inherent structural characteristics of the coal. From a database of over 3000 DRI determinations, characterisation of the desorption rate of a particular coal is readily made, along with associated gas responses during mining, especially in relation to outburst phenomena.

Sampling and Testing Strategy

A generic aim for most gas testing programs is to define the stratigraphic and lateral distribution of gas content and gas composition. The extent of sampling required is ideally determined by statistical assessment of the data, with sufficient sampling being undertaken when the mean and probability distribution of the sample results are unaffected by further sampling (to say within 2%).

In an assessment of the effect of gas on mining, all gassy material (any carbonaceous material) will need to be assigned values of gas content and composition, mostly indirectly. It is not practical to test every piece of coal or carbonaceous material. The key is to define relationships between gas content and other parameters that will enable indirect assignment of gas content to those lithologies not tested. The main relationships are gas content and depth, gas content and mineral matter and gas composition and depth.

The lateral changes in these parameters need to be defined and controls also identified (eg. faulting can influence the distribution of carbon dioxide).

The extent to which these relationships are defined determines the amount of sampling required.

Regardless of how good or bad the relationship ends up being, for any particular value assigned to a gas bearing rock, a probability distribution should be associated with that value. GeoGAS modelling of gas emission uses a statistically modelling package called @RISK, where uncertain inputs are defined in terms of probability distributions. The model presents outputs as means and probability distributions, and a sensitivity ranking of the contribution of each input to the output distribution.

The point is more about knowing how the spread of gas content data affect the final calculation (ie input into a mine feasibility or pre feasibility study), and how important gas is to the particular circumstance. If gas content value uncertainty is shown to be a major contributor to assessment uncertainty, then the next stage of drilling can be more focused to overcome these deficiencies.

With slow desorption tests, assumptions need to be made about the gas content variability, and a rigid sampling program put in place. By the time the results are available, it would generally be too late to make adjustments in the sampling strategy - at least in the current drilling phase.

Fast desorption testing opens the opportunity for rationalisation of the sampling program during the current drilling campaign. For example, boreholes for gas content testing could be drilled on a wide spacing (say 4 km) and depth/gas content gradients from each borehole compared. The results would influence the extent of fill in drilling for gas content testing.

A more common approach is to limit the extent of sampling according to the budgetary constraints. With fast desorption testing and the “on the fly” sampling strategy, the opportunity is created to define the gas content and composition distribution with the least number of samples.

Note that Q1+Q2 only slow desorption testing, is inappropriate due to result scatter and error. The author believes that compromising gas content testing by undertaking Q1+Q2 only testing because of the need to keep the core intact, is not an acceptable outcome.

All other forms of testing to define Q1+Q2+Q3 result in partial core destruction. Options to get around this limitation are:

- Test the non economic coal horizons for gas content and composition and leave the economic horizons for quality testing. This option only applies if there are sufficient minor coal seams in the sequence.

- Dedicate bore holes to gas content testing, or wedge off to obtain a coal quality core.

The latter option is clearly preferred. While wedging off is more costly, in the end the better data should represent more value for money. If sample rationalisation strategies can be made to work, then the overall cost to define the gas content and composition distribution should be reasonable.

Definition of the Gas Reservoir Size

For longwall mining, quantification of gas sources in the region 200 m above the working seam to 60 m below the working seam is required. Any carbonaceous material can generate gas, so gas contents need to be assigned to all the potentially gas bearing materials present.

In using gas content data for gas reservoir definition, the effect of mineral matter must be taken into account. Gas content test results are normally expressed in units of m3/t (m3 of gas per tonne of substance). If the material is always pure coal, the gas content results can be used directly - but this almost never occurs.

With variable amounts of mineral matter, expressing the results in m3/t becomes meaningless (m3 of gas per tonne of what). It is important that each gas content determination have an associated density measurement. This facilitates conversion of the gas content data from m3/t to m3/m3 (m3 of gas / m3 of material). In this form it is useable.

> eg a shaly coal unit has a gas content of 5.0 m3/t and a relative density of 1.6 g/cc. The gas content in m3/m3 is 5 x 1.6 = 8.0 m3/m3.

Most of the time, good quality coal is targeted for testing. This is fine, provided inferior coals make up only a small proportion of the total sequence. Where inferior coals are significant (eg Wongawilli seam) it is important to test a range of lithologies (carbonaceous shale, coaly shale, shaly coal, coal) and define a gas content/mineral matter relationship.

This type of analysis is facilitated by “bombing” relatively uniform samples - eg all coaly shale or all carbonaceous shale. Mixtures are sometimes unavoidable, and can be accommodated, but require more extensive laboratory testing involving:

- Defining and weighing each petrographic type.
- Undertaking sub-sampling and crushing of samples of each type.
- Calculating weighted average gas contents and densities for the combined material.

It is also essential to exclude any material that does not contribute gas - eg clay bands.

For situations where only coal has been gas content tested, gas contents can be calculated for associated carbonaceous shaly strata by measuring the density of the carbonaceous shale and calculating the gas content.

> eg A coal sample has a gas content of 5.0 m3/t and a density of 1.35 g/cc. An untested carbonaceous shale unit has a density of 1.9 g/cc. The density for zero gas content is (say) 2.4 m3/t (GeoGAS experience a range from 2.2 to 2.6 g/cc). The gas content of the carbonaceous shale can be calculated as a point on the straight line defined by the coal gas content and density (x1,y1) and the point at zero gas content and 2.4 g/cc density (x2,y2). The calculated carbonaceous shale gas content becomes 2.4 m3/t.

In proceeding to calculate the gas reservoir size, the depth/gas content gradient data and gas content mineral matter data combined with stratigraphic logs enable assignment of gas contents for all potentially gassy material, complete with probability distributions reflecting the level of uncertainty in the data.

eg. Take the following sequence:

Lithology	Directly Measured	Depth base (m)	Thick ness (m)	Q1+Q2 +Q3 (m3/t)	Q1+Q2 +Q3 (m3/m3)	Q1+Q2+Q3 (m3/m2) ie /stratum
Carb. Shale	No	190.0	2.6	N/A	2.4	6.24
Coal	Yes	192.6	0.5	5.0	6.75	3.38
Claystone	No	192.7	0.1	N/A	0	0
Coal	Yes	193.7	1.0	4.7	6.34	6.34
Sandstone	No	205.0	11.3	N/A	N/A	(1)

(1) Defined in m3/m2 units according to porosity and gas pressure

A more detailed account of this approach is contained in Williams and Maddocks (1993).

Application to Mining

The gas desorption rate has direct application in situations where the coal has become detached from the rock mass, as in instantaneous outbursts of coal and gas and in gas emission from coal blocks in the goaf.

The GeoGAS DRI is a particularly important indicator of outburst proneness, enabling quite reasonable assessments to be carried out in the pre mining stage. For low permeability environments (<5 millidarcy), a GeoGAS DRI of >900 is deemed to be outburst prone. The reader is referred to Williams and Weissman (1995) for details on how desorption rate affects outburst proneness.

To assess the rate of gas desorption from goaf coal blocks, GeoGAS has developed a crushing test that measures the rate of gas desorption of coal core under conditions of complete exposure to air, exposure to air and seam gas, saturated moist and dry conditions. These data are then used to model the effect on gas desorption of different block sizes (in collaboration with Dr. A. Saghafi, CSIRO Division of Coal and Energy Technology).

With more emphasis being placed on spontaneous combustion control, the rate of gas desorption is becoming more important in gauging the time taken for a newly sealed off goaf to pass into and out of the explosive range. Too low a gas content could result in goaf gas mixture remaining in the explosive range for an unacceptably long period (pers comm. Andrew Self, Australian Coal Mining Consultants Pty. Ltd.).

Longwall gas emission is a highly complex process. Models that describe the emission process rely heavily on empirical data. GeoGAS uses three approaches:

- **For Greenfield Sites/No Mine Access**. The longwall specific emission is initially calculated. The model is an advance on traditional European methods in that the zone of degassing accounts for the gas desorption pressures, and varying longwall geometries. None-the-less, this static value has then to be related to production by coefficients derived from past longwalls that ideally have similar features to the one being evaluated. The approach and its limitations are described in Williams, Maddocks and Gale (1992).

The accuracy is “rough”. Results are given in terms of probability distributions utilising @RISK modelling.

- **For Mine Access/No Previous Longwalling**. A longwall emission model is essentially custom built, taking into account the various gas sources that individually make up the total gas picture. At this level, more accurate definition is given on gas quantities and concentrations at different positions around the longwall. This includes differentiation of intake gas, gas generated from different sources within the goaf (ribs, coal blocks), gas during cutting of the face.

  The accuracy should be better, but has not been tested as yet (Dartbrook mine). Extensive use is made of probability distributions using @RISK modelling.

- **Previous Longwall Experience**. Provided a high standard of gas emission monitoring has been undertaken, empirical relationships are readily established linking return gas concentration to the main variables of production rate, ventilating air and gas capture described in Williams, Maddocks and Gale, (1992).

  Provided there are no significant geological changes (and this frequently occurs), the results can be highly accurate (example for Tahmoor Colliery, Williams, 1991). Again, probability distributions using @RISK modelling are relevant here.

Basic to all these models are detailed assessments of the gas reservoir size along the longwall pillar. Quite marked changes can occur in stratigraphy, gas content and composition, resulting in conditions at the start of a longwall being very different to conditions at the end of the pillar (100% change).

Gas reservoir simulators that model the fundamental characteristics of gas migration through coal are directly applicable to assessment of rib emission and design of gas drainage. Apart from gas content and composition data, basic model input includes permeability, relative gas/water permeability curves and gas sorption pressures (Meany et al., 1995). Permeability and relative permeability can be derived from surface bore hole well tests, with relative permeability determined from curve matching well test data using a gas reservoir simulator (eg SIMED II) or laboratory testing (Meany and Paterson, 1996).

Water has an enormous effect on the rate of gas flow from a reservoir. The relative permeability curves enable modelling of this effect. None-the-less, for a greenfield site, a high level of uncertainty remains. Measurements from within operating coal mines frequently show a high variability in gas flow and residual gas contents, reflecting changes in permeability and relative permeability (apart from more direct causes such as partially collapsed boreholes).

For gas drainage and ventilation design an approach used by GeoGAS involves:

- Drilling wide (say 100 m) spaced test in-seam boreholes, and taking a profile of cores for gas content determination along their length. The rib should be old enough that the gas content profile reflects the state of rib degassing. The tests can be carried out in orthogonal boreholes to measure the effect of directional permeability due to cleating or stress effects.

- The gas flow history from the test bore holes is measured.

- The history of rib emission is defined (ideally measured prior to the test borehole drilling).

- Model the measured gas content profile using curve matching in SIMED II.

- Validate the model by using it to define the gas flow rates from the borehole and the rib emission rates. If differences occur between the measured and simulated results, changes to the permeability and relative permeability flows are required until all three independent sets of data can be modelled.

Having developed the model, runs can then be made assessing the effect of different hole spacings and drainage times on the remaining gas content.

For an operating mine requiring gas drainage, it is potentially an ongoing effort to balance bore hole spacings with the drainage time allowed by the mine plan, in an environment where the gas content and composition is changing laterally. Most mines are not set up to account for these changes and drill on a set spacing regardless of the drainage time available or changes in gas content.

Primarily used as a planning aid for gas drainage, gas extraction plant design and gas utilisation, GeoGAS use another program called GASTOT. It draws on a data base built mainly from SIMED II simulation data, of all the possible combinations of gas content, gas composition and hole spacing applying to the deposit. On entering the mining and drilling schedule on a panel by panel basis, the model is run, involving “drilling” every borehole in what could be the life of the mine and totaling the gas drained. Results are given in terms of gas quantity and quality to the gas extraction plant and remaining gas content in the coal. Areas where the remaining gas content is still too high can be flagged, and the mine plan adjusted accordingly.

Gas content data used in SIMED II models use Total Desorbable Gas Content (Q1+Q2+Q3) recalculated to zero absolute pressure (ie Q1+Q2+Q3+”Q4”) with the aid of gas sorption isotherms, where Q4 is that component of gas content between 1 bar and 0 bar absolute. The importance of determining Total Desorbable Gas Content rather than just Desorbable Gas Content (Q1+Q2) is reinforced in this application.

Conclusions

Assessment of gas reservoir size and distribution is another aspect of resource definition very much in the realm of the exploration or mine geologist to oversee. Geological training provides a sound basis for understanding the controls on the gas distribution and designing sampling and testing strategies to suit the particular situation.

Bore core requirements create pressure on the geologist to cut the gas content testing short, either through shortened desorption or by not proceeding to test for residual gas content (Q3). The author makes the point that Desorbable Gas Content (Q1+Q2) only testing compromises later application of the data. With increasing importance of gas in mining, Q1+Q2 testing should rarely be acceptable. With appropriate sampling strategies, there should be sufficient material for bore core testing and determination of Total Desorbable Gas Content.

Fast desorption methods are clearly preferred. Advantages over slow desorption methods are, greater accuracy in gas composition assessment, the potential to rationalise sampling, fast turnaround involving fewer resources, finalisation of geological logs and early application of the data. Q3 can still be differentiated. A more sensitive indicator of gas desorption rate is incorporated in GeoGAS's fast desorption method (GeoGAS Desorption Rate Index).

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