

Development of new equipment for rapid determination of coal gas content

by

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ABSTRACT

In underground coal mines where high levels of seam gas may present a safety hazard, planning of new developments needs to be based on a prior estimation of gassiness of the area to be mined. Measurements of seam gas content have become a routine activity in Australian underground coal mines. Another area where the knowledge of gas content is important is gas utilisation. In Australia, capture of methane from some deep coal measures is currently being considered and initial exploration drilling has been undertaken.

The method currently used by the Australian coal industry is a modification of the US Bureau of Mines method which consists of measuring the volume of gas desorbed from cored or lump samples of coal sealed in a container. The main problem with this method is the length of time required to accomplish the test. For fast desorption rate an average of one month is needed to reach the flat part of the desorption curve. For slow desorption rates, the desorption period can be as long as 4 months. The other drawbacks of this method are identified further down in this paper. The time required for completion of a test can be a significant problem particularly in coal seams with outburst history, where the assessment of gas content needs to be done in the space of days to maintain a high rate of coal production.

This paper presents a brief description of equipment design for the rapid measurement of gas content in coal samples and compares some results of gas content tests obtained with this method and those obtained in the traditional way.

Three different sets of equipment have been constructed which can measure gas content by pulverising coal samples. This allows the acceleration of the gas desorption rate. Coal samples of 30-50 g or 200-300g or 1000 to

1200 g can be loaded and tested using the three gas content test apparatus. The results of tests are known in less than 2-3 hours. Core samples from in-seam drilling were collected and tested using the USBM and the CSIRO (rapid desorption) methods. With correction for the residual gas content, the two methods gave similar results.

Effect of coal sample size also was studied. The medium and small crushers were used to determine the gas content of samples of the weight 15 to 30 g and 200 to 300g respectively. For the range of studied gas contents, no difference in the results of the two sizes were observed.

INTRODUCTION

Importance of determination of gas content

In a gas control and/or prediction project, the first most important parameter to measure is the gas content of the mined seam and, if feasible, the gas contents of the adjacent coal seams. This is particularly important for those mines that experience gas outbursting or high gas emission rates during mining. For such mines, based on past experience, a gas content threshold is generally set. This gas content identifies the zones of 'hazardous mining'. Wherever this limit is exceeded some kind of preventive measure is undertaken to alleviate the area. The outburst-prone mines may have different threshold contents than the mines with high gas emission. In the outburst situation, gas content, gas pressure gradient and rate of desorption are all very important. However for high gas emission rates, gas content is of paramount importance. Other factors, related to the coal structure, also influence gas release. For example variation in the permeability of coalbed may create a zone of high pressure gradient which when combined with

mechanical properties of coal, may give rise to an outburst when the coal face is close to this zone. Outbursts occur most frequently in those mines with mixed gas and a higher percent of carbon dioxide. This is to be expected as, for the same pressure, coal adsorbs a larger volume of carbon dioxide than methane. Methane explosions can occur when the mine atmosphere has a concentration of 5 to 15% of methane and such a concentration is generally produced in mines with high methane contents in the coal seams. However, there are cases of explosions in mines with very low gas content. In France a methane explosion occurred in a mine with only 0.5 m³/t total gas content (Jeger, 1992). The gas content test therefore, should not only be reserved for gassy areas and it is a good practice to routinely determine gas content during face advance.

Apart from safety concerns in underground coal mines, a new area of gas utilisation requires extensive measurement of in-situ gas content. An accurate and rapid method of gas content test can be used to guide the drilling program and produce a less expensive and more accurate estimation of the gas reserve.

Definition of gas content

Values of the gas content of coal samples appear frequently in technical reports and meetings. However it seems that a universal definition is not yet accepted or understood. Recently, the Australian Standards Association has published a 'Guide to the determination of desorbable gas content of coal seams-Direct method' (1991). In that report, the gas content of a coal sample is presented as -a) lost gas, which is the gas lost during drilling or prior to any measurement, -b) measurable gas, or the gas evolved at atmospheric pressure from the non-pulverised sample, and -c) residual gas, which is released if the sample is crushed at atmospheric pressure. The symbols Q₁, Q₂ and Q₃ respectively are used to identify these three components of the gas content. The 'desorbable gas content' is defined as the sum of Q₁ and Q₂, while the 'total desorbable gas content' is given as Q₁, Q₂ and Q₃. This approach can be compared with those carried out by the USBM and in Europe. In the USBM method there is no Q₃ determination with

the methane desorption into the collection cylinder occurring with a methane partial pressure of one atmosphere (Kissell et al, 1973). In the French coal research centre (CERCHAR) method, adopted by the Coal Directorate of the Commission of the European Communities (Handbook for the Coalmining Industry, 1980), the 'desorbable gas content' of coal is defined as the quantity of gas given off when the coal passes from equilibrium with gas at seam pressure to equilibrium with gas at atmospheric pressure in normal conditions. The terms Q₁, Q₂, and Q₃ are defined as follows (Bertard et al., 1970), Q₁ is the gas which is released (lost) between the moment of coal extraction and when the sample is sealed in a canister for transport. Q₂ is the gas released into the canister during transport from underground to the surface and then to the laboratory. In the laboratory the sample is put in a container, flushed with gas and crushed at atmospheric pressure. The released gas is designated as Q₃. The desorbable gas content is defined as the sum of Q₁, Q₂ and Q₃.

The situation becomes more complicated when the coal sample contains mixed gas. The USBM method makes no distinction, whereas the CERCHAR method does, by defining the total gas as the quantity of gas released if coal is crushed under a gas relative pressure of nil. The reason is that for a mixed gas the definition of gas content becomes less accurate and the value measured may correspond to any partial pressure. The partial pressure for each component is less than one atmosphere during the whole test and the partial pressure for each gas changes during the test depending on initial composition in the sample and kinetics of desorption for each gas. The gas content test with the traditional method for mixed gas therefore carry the inaccuracy of a pressure definition as the gas composition changes during desorption.

But for this paper we adopt the Australian Standards definition and use the term 'total desorbable gas content' as the sum of Q₁, Q₂, and Q₃ released at atmospheric pressure and without distinction between methane and mixed gas.

Traditional method of gas content test (Modified USBM method)

The in-situ methane content of coal seams is traditionally measured by taking a section of a core, typically 5-10 kg in weight, placing it in a container and monitoring the release of methane by collecting the gas in a bell-jar. The rate of desorption is such that it can take several weeks to obtain an accurate determination. Clearly, a more rapid procedure would have benefits in speeding up decisions with regard to mine development.

METHODOLOGY

Rapid desorption method

The 'rapid desorption method' is based on the fact that the rate of release of gas from coal is determined by diffusion of gas within the coal particle and is therefore dependent on the particle size. If a diffusion coefficient of 10^{-10} cm²/s is assumed for the gas, then the theoretical solution of the diffusion equation for a spherical sample (Gunther, 1965) suggests that if the diameter of coal grains is reduced to 1 micron, then only 2 seconds is needed for release of 90% of gas contained in the sample. However if the grain size were 1 cm then 15 years would be needed to release the same amount of gas (network of fractures within the coal sample keep the desorption time to much less than 15 years).

Three sets of equipment were constructed, each operating on the same principle, namely crushing the coal sample with a steel ball by shaking it, vertically, inside a stainless steel vessel. The difference between the three sets was size of the sample container and hence the weight of the coal sample used for the methane determination. The sample sizes were 30 g, 300 g and 1.25 kg and brief description of these containers follows:

30 g container

The smallest container consisted of a 138mm x 30mm O.D. with 3mm wall stainless steel tube, closed at one end and threaded on the outside at the other end to take a screw-on cap. The gas-tight seal between the tube and the cap consisted of a Teflon washer. The gas outlet consisted of a small hole in the cap leading to a 3 mm O.D. stainless steel tube

closed by an on/off valve (Whitey) mounted about 15 mm above the cap.

300 g container

This consisted of a 300 mm x 75 mm OD x 3 mm wall s/s tube, closed at one end and internally threaded at the other to accept a screw-in cap. The final 6 mm of the tube was recessed to form a sealing surface for an o-ring mounted on a corresponding shoulder on the cap; this constituted the gas-right seal. The useful internal length of the tube was 150 mm when the cap was fitted. The gas outlet was via a 3 mm flexible hose closed by a Whitey valve.

1.25 kg container

This was identical to the 300 g container, except the length was increased to 530 mm with a useful internal length of 500 mm.

Crushing procedure

The 30 g and 300 g containers were mounted on top of reciprocating pistons. Specially designed holders were bolted to the tops of the pistons to firmly retain the containers. For the smaller one, a cylinder/piston assembly from a small air compressor was used, whilst, for the larger one, a water-cooled car engine block was used. The strokes were 60 mm and 80 mm respectively, and both were driven by electric motors generally at a frequency of a few Hz. The largest container was mounted on a framework which, in turn, was mounted via linear bearings on two slides. The assembly was connected in the usual way to an electric motor to provide reciprocating motion with a frequency of about 5 Hz, the stroke being 200 mm.

The crushing, which was effected by steel balls, was carried out continuously for the smallest container but was interrupted at intervals throughout the crushing cycle for the other two. The purpose of this was to avoid carry over of fine coal dust with the evolved seam gas. Hence, whilst the crushing mills were in action, the on/off valves were closed. Seam gas was only allowed to escape into the gas measuring system after the dust had been allowed to settle in the container for about a minute or so. For the 300 g and 1.25 kg size equipment, sintered metal filters were stalled because of the greater quantities of coal and gas evolution. These were mounted on the

screw-in end caps. The filters nominally removed dust greater than 7.5 μm in diameter and could be cleaned by back-flushing with compressed nitrogen. The intermittent nature of the crushing prevents these filters from clogging.

Gas measurement

The containers were connected via flexible tubing and on/off valves to inverted measuring cylinders filled with acidulated water. During the interruptions in the crushing cycle, the valves were gradually opened to allow seam gas to escape and bubble into the cylinders. Provision was made for taking a sample of the seam gas for analysis by gas chromatography.

Empirically, it was found that the diameter of the steel balls for effective crushing was 18 mm and 25 mm for the 30 g and 300 g containers respectively. For the largest container, 2 x 25 mm balls were used.

The time required to crush the coal samples, such that there was no further gas emission, was 20 - 30 min for the 30 g container and 1 - 2 h for the others. The time varied with coals from different seams. After these times it was found that 70% of the coal sample had been pulverised to less than 90 μm .

RESULTS AND DISCUSSION

Comparison of results from rapid desorption with traditional methods

Comparison has been made of the gas contents measured with the above equipment and those using the traditional desorption equipment (USBM method). In-seam drillings in four different sites were undertaken and cores were taken deep into the seam. Seam gas in all sites consisted of mixed gas. At each drilling site, two canisters were filled with 2 parts of the same borecore. One of the canisters was used for the traditional test with the gas desorbed volume being continuously monitored. The results of these tests are listed in Table 1. The second canister was used to evaluate the new method of gas content testing. Initially this canister was connected to an inverted cylinder and evolved gas was measured by water displacement. After a few days canister was opened, a sub-sample was taken for crushing and the

canister resealed again and connected to the inverted cylinder. The sub-sample was then crushed and gas volume measured. In Fig. 1, the procedure is shown for one of the samples. At point A, the gas evolved from the sample sealed in a desorption canister was $Q_2 = 2.86 \text{ m}^3/\text{t}$, a sub-sample was taken and crushed while the rest of the sample was allowed to remain in the desorption canister. The gas evolved during crushing was $Q_3 = 2.38 \text{ m}^3/\text{t}$, therefore the total desorbable gas content for sample 4 is equal to $Q_2 + Q_3 = 5.24 \text{ m}^3/\text{t}$. We expect therefore to reach this value if we let the sample in the canister desorb for a sufficient length of time. In Fig 1. it can be seen that the line $C = 5.24 \text{ m}^3/\text{t}$ can be considered as the asymptote of the desorption curve.

In Table 1, the results of four tests on bore-cores are shown. The volume of gas desorbed before the first crushing is identified by Q_2 , the gas volume evolved during crushing is Q_3 . $Q_2 + Q_3$ is therefore 'total desorbable gas content'. The same procedure was repeated on the same sample after a few days: another sub-sample was taken from the canister and was crushed. Q_2 in Table 1 is the volume of gas desorbed from start of desorption (after drilling) until the start of this new crushing. The gas desorbed during crushing is named Q_3 . $Q_2 + Q_3$ is another measurement of the 'total desorbable gas content'. To verify the method is accurate one should compare $Q_2 + Q_3$'s with $Q_2 + Q_3$'s. These are presented in Table 1.

A better measure of the accuracy of the method is to plot $C_2 = Q_2 + Q_3$ against $C_1 = Q_2 + Q_3$, and estimate the distance of the points from line of equal-content, ie the line $C_2 = C_1$. In Fig. 2 the graph of measured contents and the line of equal-content is given. The total deviation from the line of equal gas content is $\text{dev} = [\sum(C_1 - C_2)^2]^{0.5} = 0.79 \text{ m}^3/\text{t}$ for an average deviation of 0.2 m^3/t .

To compare the results obtained from the rapid desorption technique and the results of the traditional methods the gas content result in USBM column in Table 1 were adjusted to represent the 'total desorbable gas content'. Based on some residual gas content tests on similar samples a value of 0.5 m^3/t was considered appropriate for this sample.

In Table 2 the 'total desorbable gas content' for each sample using two methods is given. The gas content for rapid desorption method is the average of C_1 and C_2 as described above.

The average deviation in the results between the two methods was 0.4 m³/t over the four tests (only one of the results from 4 and 5 was used in this analysis). In terms of relative error using each of these methods produces $0.4/6.58 = 6\%$ difference in respect to the other method (the average gas content for the four samples is 6.58 m³/t). In Fig 3, the results of the two methods are compared against the equal-content line.

The average difference of 6 % in results using the two techniques is very small and even if we were using the same technique twice on the same sample we could not expect a variation less than this value. Although the number of test in parallel is small, we think, based on overseas experience and our knowledge of gas desorption from coal samples, that the results of the above tests demonstrate the validity of the rapid desorption method.

Effect of sample size on gas content determination

Construction of three sets of equipment with the capability of crushing coal samples of substantially different sizes allowed the investigation of the effect of the sample size on gas content determination.

Theoretically, for a given coal, one can expect that a change in size would produce some scale effect and gas contents results could vary according to certain rules which may be determined statistically.

If the moisture content of the coal does not vary very much, the reasons for any scale effect can be either, - due to the effect of fissure/cleat network or, - due to the variation of ash content distribution across a segment of coal seam; in our case across the borecore.

The effect of fissures density can be overcome if the size of sample is larger than the average distance between fissures or cleats. For example if the cleat planes naturally divide the coal sample in cubes of $2.5 \times 2.5 \times 2.5 \text{ cm}^3$, then we can expect that for a coal sample of weight higher than 22 g (coal

density is assumed to be 1.4, the effect of size should disappear).

Allowance for variation in the ash content distribution is difficult. In case of in-seam drilling one can expect that along a small length of core (300 mm) its variation should not be substantial. However, for cross-seam drilling the ash content may vary largely across the thickness of coal seam. We suggest that whenever a gas content is determined, an ash content test be also undertaken and the gas content be defined on a free-of-ash basis.

In Table 3, the results of gas contents determined using 30 g and 300 g samples are presented. Fig. 4 compares the two gas contents by visualising the positions of experiment points and the line of equal-content.

CONCLUSIONS

Three sets of equipment were constructed to pulverise different size of coal samples and measure the 'total desorbable gas content'. The results obtained show that the rapid gas desorption method can be used to determine the total desorbable gas content. A maximum of 2-3 hours is needed to determine the gas content compared to few weeks by the traditional method. Contrary to the traditional method, the gas content determined with the rapid desorption method is not dependent upon the size of coal grains. Moreover in the case of a mixed gas, the rapid desorption method is more accurate because the results of the tests are not affected by different rates of desorption of methane and carbon dioxide.

The coal samples of 2 different sizes were tested using the medium and small size crushers. The results of gas content tests show no difference in values obtained for the gas contents in the range of 0.4 to 3 m³/t.

ACKNOWLEDGMENTS

The authors would like to thank Dr R. Williams (GeoGas Ltd), Mr T Sharkey (Metropolitan Colliery) and Mr S Battino (Gas-Trade) for their assistance during testing of the rapid desorption equipment. Our thanks

are extended to Dr R. Lama (Kembla Coal and Coke Pty. Ltd.) for useful discussions.

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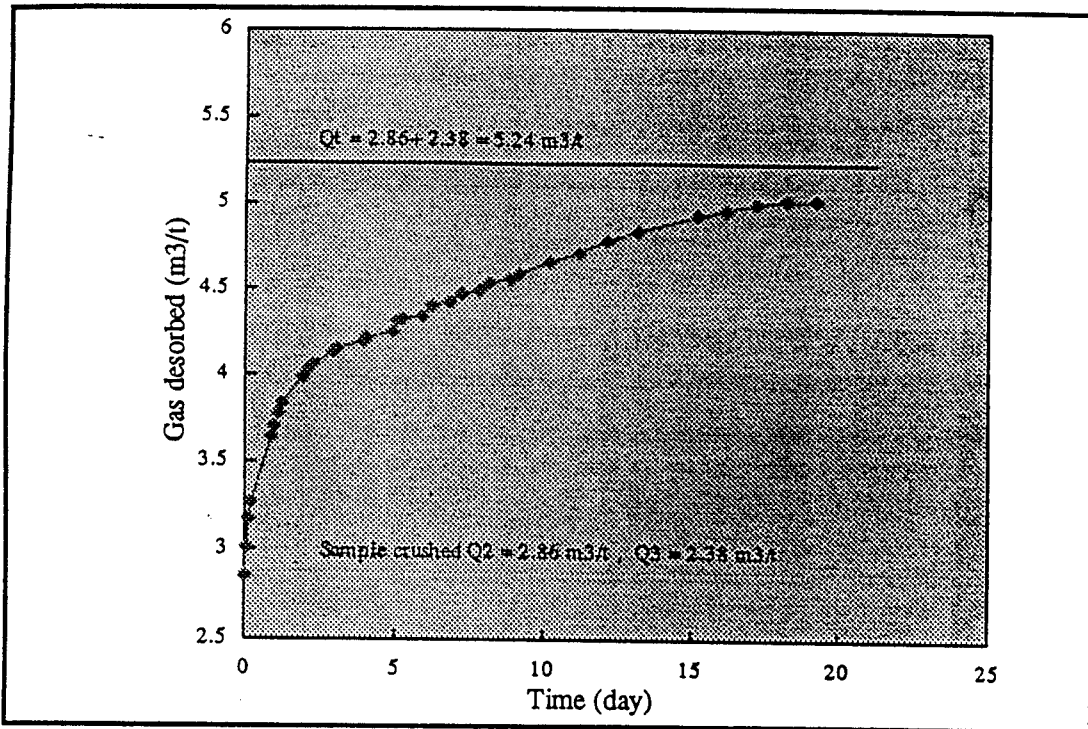


Figure 1. Gas desorption curve for a sample from which a sub-sample had been crushed, Q_3 is the amount of gas released during crushing.

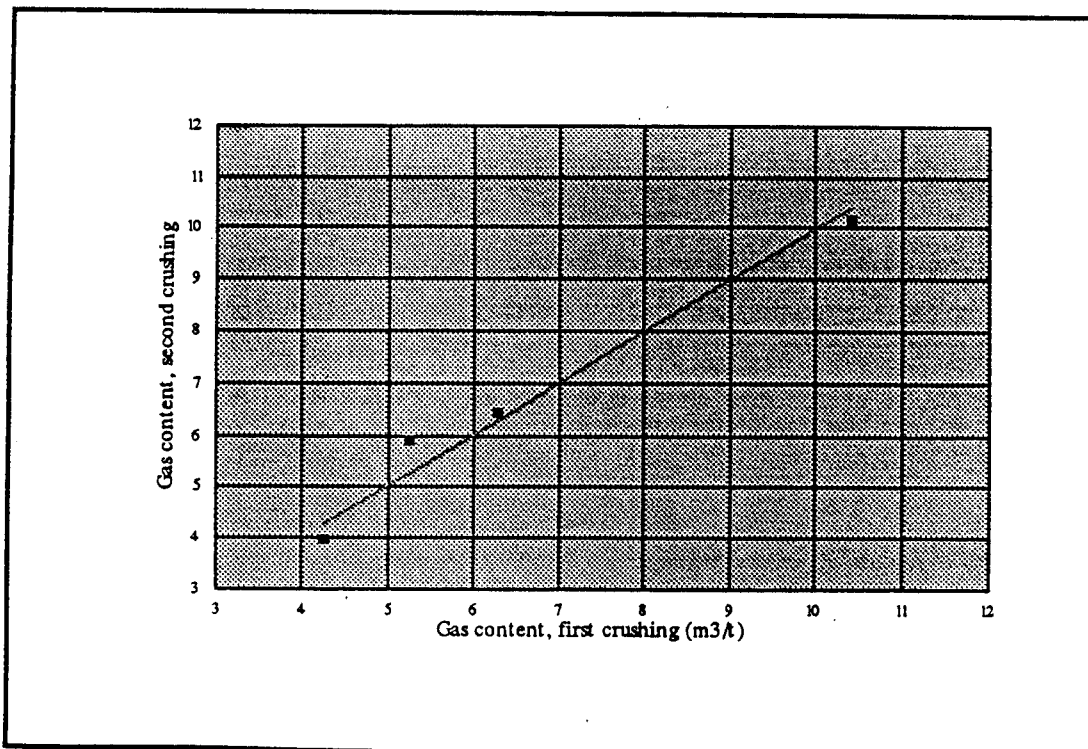


Figure 2. Comparison of gas contents for first and second crushings.

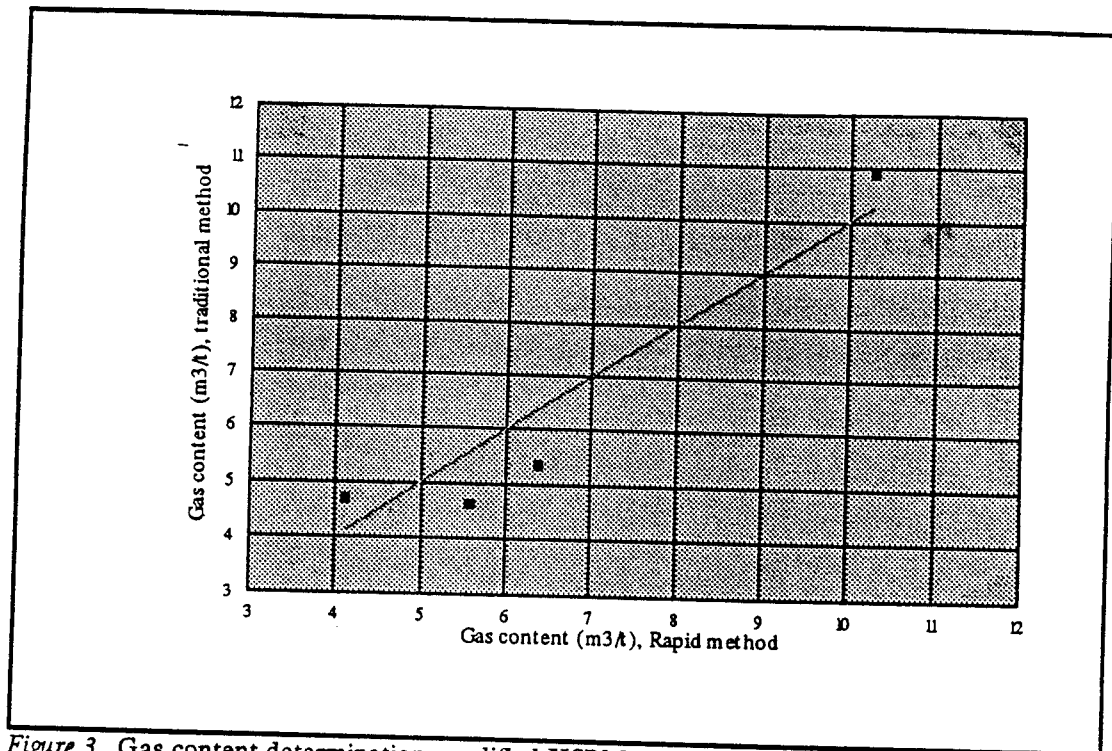


Figure 3. Gas content determination, modified USBM and rapid desorption techniques.

Sample	Q_2	Q_3	$Q_2 + Q_3$	Q'_2	Q'_3	$Q'_2 + Q'_3$	USBM method
1	2.16 (3 days)	4.12 76% CH ₄	6.28	4.37 (33 days)	2.08 84% CH ₄	6.45	4.94 (35 days)
2	2.30 (2 days)	1.96	4.26	3.37 (7 days)	0.58	3.95	4.29 (16 days)
3	7.43 (33 days)	2.97 54% CH ₄	10.40	9.18 (3 days)	0.99 80% CH ₄	10.17	10.50 (48 days)
4*	2.86 (1 day)	2.38 51% CH ₄	5.24	5.01 (15 days)	0.91 89% CH ₄	5.91	4.24 (8 days)
5*	2.86 (1 day)	2.38 51% CH ₄	5.24	5.03 (19 days)	0.90 90% CH ₄	5.93	4.24 (8 days)

* Samples 4 and 5 are taken from the same borecore and sealed in two different canisters

Table 1. Results of gas content tests using rapid desorption and traditional methods.

Sample	Rapid	USBM
1	6.37	5.34
2	4.11	4.69
3	10.29	10.90
4,5	5.58	4.64

Table 2. Comparison between 'total desorbable gas content' obtained by rapid desorption and traditional techniques.

15-30 g sample	200-300 g sample	Composition CH ₄ /(CO ₂ +CH ₄)
2.09	2.07	84%
1.99	1.92	
2.98	2.95	54%
0.61	0.62	92%
2.39	2.36	51%
0.92	0.91	89%
0.49	0.51	100%
0.43	0.42	100%

Table 3. Comparison of gas content using small and medium size crushers.

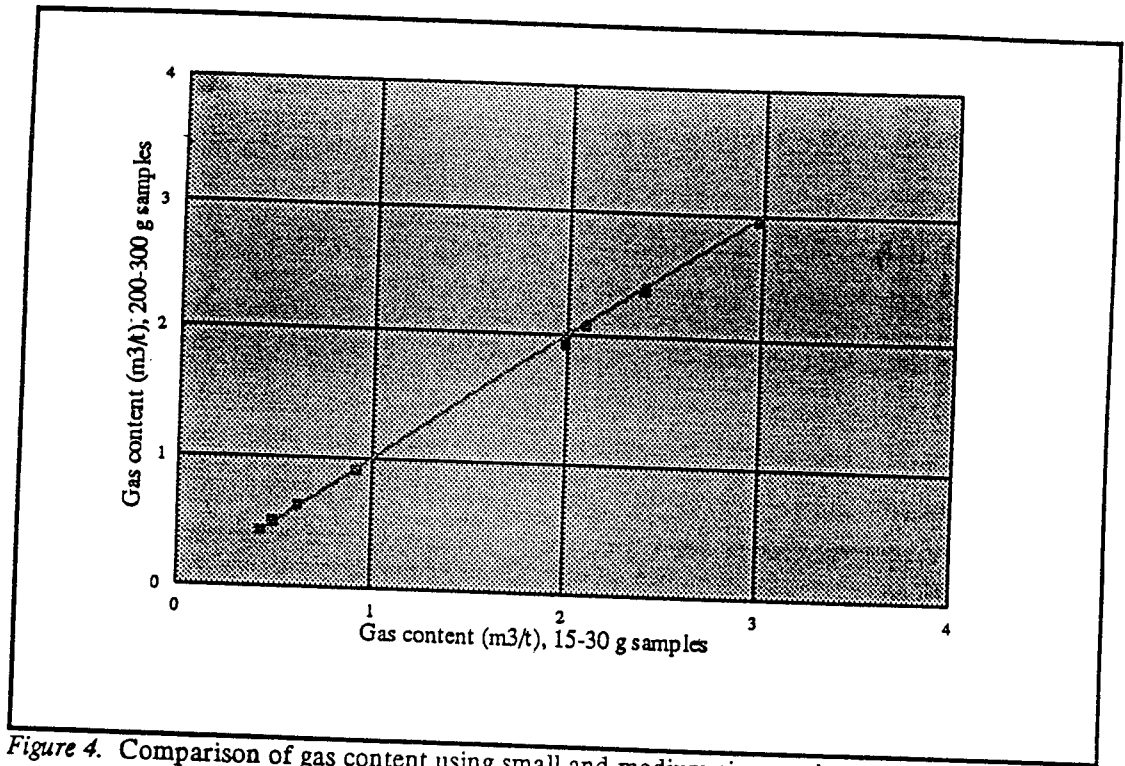


Figure 4. Comparison of gas content using small and medium size crushers.