NOVEL METHODS OF COAL SEAM GAS CONTENT DETERMINATION FOR ESTIMATION OF GREENHOUSE GAS EMISSIONS FROM MINING

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Coal seam naturally contains greenhouse gases, dominantly methane but also carbon dioxide and to a lesser extent higher hydrocarbons. With coal mining most gas volumes trapped in coal seams and strata are liberated which mostly end up in atmosphere. In order to assess fugitive emissions from mining new methods are devised. In situ gas content of coal seams is a primary parameter required in these methods.

Traditionally the purpose of gas content determination in coal mines has been the safe operation of mining and workers. Over the years various methods of measurement have been developed for ungrounded mining. However, these methods are not always adequate for requirement of emissions assessment for greenhouse gas inventory and new definition of gas content and more accurate measurement methods are required. The liability of the coal producer or coal user or both in relation to the emitted and remaining gas in coal can be a major factor for the way gas content is defined and measured.

In order to accommodate the future emission trade scheme (ETS), one of the first steps is to debate the definition of gas content and developing more adequate methods of measurement.

In this paper the authors looks at possible definitions of gas content in relation to the purpose of its use and suggests novel methods of its determination.

Keywords: Coal seam gas, gas content, greenhouse gas, fugitive emissions, methane, carbon dioxide

INTRODUCTION

Coal seams are high capacity gas reservoirs and to some degree, most coals contain some gas. The mine gas consists generally of methane (CH₄) and carbon dioxide (CO₂) which are partly or totally released during mining.

Mining leads to large disturbance of coal seam reservoir as the fracturing develops both in coal and rocks. Gas escapes to the atmosphere via fractures and exposed coal surfaces. In 2009 the annual greenhouse gas (GhG) emissions from anthropogenic sources in Australia were about 539 Mt CO₂-e. About 40 Mt CO₂-e of these were fugitive emissions. The coal mining is the main source and represents more than 70% of the total fugitive emissions. The emissions are mostly due to release of the
trapped coal seam gas which is liberated during and after the completion of mining.

The intensity of emissions depends on flow properties of strata and diffusivity and matrix permeability of coal. The method of mining affects the extent and density of induced fractures. Permeability could increase by several orders of magnitude. Moreover, fracturing of strata causes the discharge of water from mining area leading to further increase of permeability and acceleration of gas desorption from coal.

Though the rate and intensity of gas release from mining at a given time is primarily a function of temporal gas content and flow properties of coal and strata, the total volume of gas liberated over the life of mine is a function of the virgin, pre-mining magnitude of gas content of coal seams and gas trapping strata. Novel methods are currently being developed to estimate GhG emissions from coal mining. For the case of open cut mining, where the emission is diffuse, direct measurement is difficult and in many cases virtually impossible. In a novel method, developed by author for Australian mines (Saghafi, 2010), the emissions estimate is based on a number of parameters related to the lithology of the strata and coal seam properties. Among these parameters the in situ gas content of coal is of primary importance. Accurate measurement of gas content is therefore primary for reducing the uncertainty of estimation.

The appropriate definition and corresponding measurement method of gas content can influence, sometime largely, the magnitude and accuracy of emissions estimation. While measurement of low gas content may not be of any importance to safety issues in underground mining it is quite important for accurate estimation of GhG emissions from both open cut and underground mines.

In the next sections after discussing various modes of gas storage in coal various definitions of gas content are provided; this is followed by description of the standard method of the gas content determination and proposed method for low gas content testing. Error associated with the new method will be discussed.

MECHANISMS OF GAS STORAGE IN COAL AND GAS CONTENT

Coal is a porous rock where gas can be stored in the large space available on the pores’ internal surface. Gas is stored both in free and adsorbed phases. The adsorbed phase is held on the pore surfaces and constitutes the greatest portion of the stored gas for shallow to medium depths (<600 m). At higher depths due to increase in the density of gas larger volumes of free gas can be stored in pore volumes.

The main and largest part of the pore surface area is located in the micro pore system (size <2 nm) where the pores are only a few times larger than the coal seam gases molecular sizes. The adsorbed phase storage in the micro pore system follows a pore filling mechanism and therefore reaches its maximum value (adsorption capacity) when the pore system is fully filled. The stored gas is then retained due to a combination of adsorption and capillary forces.
Definition of gas content

Gas content can be generically defined as the volume of gas contained in unit mass of coal. In Australia the standard conditions are a temperature of 20°C and an absolute pressure of 101.325 kPa (Standards Australia, 1999). Based on the physics of gas storage in coal, total gas contained in coal is the sum of free gas content and adsorbed gas content. However, the traditional method of measurement does not allow the determination of the free gas component of gas in coal. Using the direct method, the volume of gas which is measured consists only of adsorbed gas. This gas in turn can be divided into the ‘desorbable’ and ‘residual’ components of gas content. Either one or both components could be required depending on the purpose of the emissions studies.

Fresh core drill samples are generally collected for gas content testing. When the drill rig hits the coal seam coal starts releasing its gas rapidly and almost all free gas is gone before coal reaches the ground surface. At the surface (atmospheric pressure), the adsorbed gas would be released slowly. Desorption processes could continue for days or weeks until there would be no measurable volume of gas. The release of gas is due to forces of gas pressure and gas concentration gradients. In Figure 1 the processes of gas desorption from coal is depicted. Total amount of gas naturally desorbed from coal is called ‘desorbable’ gas content ($Q_d$) while the remaining gas in coal is called residual gas content ($Q_r$). The sum of desorbable and residual gas content constitutes the total gas content ($Q_t$).

$$Q_t = Q_d + Q_r$$

![Figure 1 Desorbable ($Q_d$) and residual ($Q_r$) gas contents](image)

Note that this gas volume is only the adsorbed gas which is released slowly and naturally. The current ‘direct method’ of gas content measurement does not allow the determination of the free gas. Besides the generic definition above the definition of gas content can be a
function of its use as well and other definition for gas content may be required to address the need of various users. For example, from the viewpoint of gas reserves of in coal (i.e. in CBM industry), gas content may include free gas volumes. This definition can also be extended to GhG emissions inventory where it is required to have an estimation of free gas in coal as well.

**MEASUREMENT OF GAS CONTENT OF COAL**

Gas content of coal is determined by direct measurement of the volume of gas desorbed from coal. In Australia two methods are routinely used, namely the ‘slow desorption’ and ‘fast desorption’ methods (Williams et al., 1992; Saghafi et al, 1998). Variants of both methods have been also used in various forms in other coal mining countries. In France a variant of the fast desorption was being used since the early 1960s (Bertard et al, 1970).

In USA various variants of the slow desorption method have been used (Kissell et al, 1973; Diamond and Levine, 1981; Diamond et Schatzel, 1998). The Australian slow desorption method was a development of the USBM method after some enhancement (Australian Standard, 1991). The fast desorption method otherwise known as quick crash method was developed in early 1990s (Williams et al., 1992; Saghafi et al, 1998) and is currently the method of choice for assessment of gas emissions and outburst risk in underground coal mines (Australian Standard, 1999).

Though both methods consist of similar steps to determine the gas content coal, the length of the procedure is significantly longer in the slow desorption method. In the fast desorption method coal is crushed after a short period of natural desorption so that all its gas is forced to release rapidly (minutes up to an hour). An advantage of fast desorption method besides its rapidity is reduction in the risk of dissolution of CO$_2$ in measuring water for mixed gas conditions (when both CH$_4$ and CO$_2$ are present in seam gas).

The slow desorption method and fast desorption methods are both based on measurement or estimation of the volume of gas desorbed from coal in several stages. Both methods start with estimation of ‘lost’ gas during drilling and retrieval of coal sample to the surface. In the slow desorption method desorbs its gas ‘naturally’ until no further desorption is detected. In fast desorption method, however, after a short time allowed for gas to be released naturally during coal transport to the laboratory and in the lab, coal is crushed. Note that in the slow desorption method, the crushing stage may be also included to determine the ‘residual’ gas content of coal ($Q_r$).

The three components of gas contents from three stages of gas content testing in fast desorption method are commonly represented by $Q_1$, $Q_2$ and $Q_3$ parameters. The ‘measured gas content’, $Q_m$, is the sum of the 3 components (Australian Standard, 1999).

The $Q_1$ or the lost gas stage is identical for the two methods. The $Q_2$, gas desorbed during transport and in the lab is also called desorbed gas in the slow desorption method is the main component of the gas content in this method. In this method this stage is allowed to continue until no further measurable gas desorption is observed. In the fast desorption method the $Q_2$ step is generally short as coal is crushed any time after reaching lab depending on the availability of a measuring system and proper conditions. The last
component of gas content is $Q_3$, which is the gas desorbed from crushed coal in fast desorption method is also usually the largest volume of desorbed gas in this method. For the slow desorption method this stage is often of no importance as residual gas is expected to be small.

As discussed the measurement of the volume of gas released (in all three stages) is done using a measuring cylinder. The released gas is admitted into a water filled inverted cylinder. The displacement of water provides the measure of the volume. This system has worked well over the years and is used routinely in Australia.

There are, however, some problems with this way of measuring the volume of gas including gas partial pressure effect and dissolution of gas in water. These have been addressed over the years and improvements have been suggested and applied (Saghafi et al, 1998).

**Reporting error of gas content testing**

Note that in each step of measurement of gas content there would be some level of error. ‘Measured’ gas content inherits all these errors. The total error of gas content ($\varepsilon_m$) could be calculated as follow,

$$\varepsilon_m = \varepsilon_1 \frac{Q_1}{Q_m} + \varepsilon_2 \frac{Q_2}{Q_m} + \varepsilon_3 \frac{Q_3}{Q_m}$$

(2)

where $\varepsilon_1$, $\varepsilon_2$ and $\varepsilon_3$ are the errors produced in measuring $Q_1$, $Q_2$ and $Q_3$ components. As an example in one case we had,

$Q_1 = 0.5 \text{ m}^3/\text{t}$, $\varepsilon_1 = 20\%$

$Q_2 = 3.0 \text{ m}^3/\text{t}$, $\varepsilon_2 = 15\%$

$Q_3 = 2.5 \text{ m}^3/\text{t}$, $\varepsilon_3 = 5\%$

The measured gas content is then presented as $Q_m = 6.0 \pm 0.67 \text{ m}^3/\text{t}$.

**GAS CONTENT MEASUREMENT FOR GREENHOUSE GAS ESTIMATION**

Fugitive gas emissions from coal mining are considered to be an important source of total anthropogenic emissions. Gassy mines are generally underground mines and estimation of emissions is straightforward as the total gas released is either captured through drainage pipeworks or through ventilation shafts. These quantities can be accurately measured and hence there are no major issues with quantification of such emissions.

However, emissions from surface mining are subject to significant uncertainties due to diffuse character of emissions. One parameter influencing largely the emissions is the gas content of in-situ coal. However, the gas content of coals from a surface mine coal can be very low. Note that this is also true for ‘non gassy’ underground coal mines. In these cases the conventional method of measurement of volume by using water displacement may be quite impossible and prone to large relative errors.
To illustrate the limit of measurability using the standard method it should be noted that the smallest volume that can be confidently measured by using the water displacement in a 250 cm$^3$ measuring cylinder, is about 5 cm$^3$. Therefore for a sample of 100 g size the method can measure low gas content of about 0.1 m$^3$/t if some appropriate level of confidence is to be respected. The accuracy and limit of detectability of measuring gas content could have important impact on coal mining economics as the carbon credit/tax is based on amount of emissions from mine and given the large volume of production even small change in gas content can affect the economy of mining.

**Measurement of low gas content**

For very low gas content coals ($Q_m<0.1$ m$^3$/t) the water displacement method of measuring the volume is not adequate. For this case there would be no measureable $Q_1$ and often no measurable $Q_2$.

For measurement of gas content of these coals (‘non-gassy coals’), the author suggests that the best practice would be to seal the fresh sample in a gas tight canister in the field, and then dispatch it to the lab for crushing. Ideally coal could be sealed in a canister which can be directly mounted on the crusher so that there would be no need to open the coal canister before crushing. The total desorbed gas can then be indirectly evaluated using a method based on measurement of gas composition rather than measuring gas volume.

One method to measure the volume of desorbed gas and determine the gas content is to keep the crushed coal in the crusher container for sometime after the completion of crushing and measure gas composition in the crusher canister after a period of time (a few hours).
composition values. This method was used by the author at CSIRO in the course of a number of national mining projects on determination of gas content of coal. The method was applied after the completion of the three stages of gas content testing ($Q_1$, $Q_2$ and $Q_3$). This new component of gas content was called $Q_3'$ ($Q_3$ prime). In Figure 2, relative quantity of $Q_3'$ component of gas content for a coal is given.

For routine measurement of low gas content of coal, a similar approach is suggested. The set up is conceptually illustrated in Figure 3. The crushing canister is initially flushed with helium (He) and then coal is placed in the crusher and crushed. After the completion of the crushing and allowing time for temperature equilibrium, the canister is opened to a closed circuit with an in-line pump. A gas sample is collected from the system after a sufficient period of time and gas composition is measured using gas chromatography. Knowing the volume of the total void space in the system the gas content is determined.

CONCLUSIONS

Coal mining is the main source of fugitive greenhouse gas emissions in Australia. It presents more than 70% of the total fugitive emissions. The emissions are mostly due to release of the trapped coal seam gas and strata liberated during mining and after the completion of mining.
As the inventory of emissions is becoming part of the economics new methods are being developed to estimate GhG emissions. In the new methods the in-situ gas content of coal is a primary parameter for evaluation of emissions. However for low gas content conditions the methodologies in use are not accurate and in some cases can not detect the gas. Because of the large volume of coal produced in mining any small error of gas content measurement is magnified and reflected in the emission inventory.

A novel method of measurement for low gas content coals is suggested based on measurement of gas composition. The method should largely increase the limit of detectability and accuracy of gas content measurement. The analysis of the method indicates that theoretically gas content of two orders of magnitude smaller can be measured by using the new method instead of current methods.

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REFERENCES


