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# Discussion on determination of gas content of coal and uncertainties of measurement



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#### ABSTRACT

Gas content of coal is mostly determined using a direct method, particularly in coal mining where mine safety is of paramount importance. Direct method consists of measuring directly the volume of gas desorbed from coal in several steps, from solid then crushed coal. In mixed gas conditions the composition of the desorbed gas is also measured to account for contribution of various coal seam gas in the mix. The determination of gas content using the direct method is associated with errors of measurement of volume of gas but also the errors associated with measurement of composition of the desorbed gas. These errors lead to uncertainties in reporting the gas content and composition of in-situ seam gas. This paper discusses the current direct method practised in Australia and potential errors and uncertainty associated with this method. Generic methods of estimate of uncertainties are also developed and are to be included in reporting gas content testing is also presented. The new method would allow the determination of volume of almost all gas in coal and therefore the value of total gas content. This method is being considered to be integrated into a new standard for gas content testing.

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#### 1. Introduction

Gas content can be generically defined as the volume of gas contained in unit mass of coal. Gas content of coal is required for a number of purposes: to assess the gassiness of coal for safe mining in outburst and high gas emission conditions, to estimate gas reserves for coal seam gas (CSG) production projects but also, and most recently for assessment of greenhouse gas emissions from coal and CSG production.

Gas in coal occurs in adsorbed and free phases, but also some gas is dissolved in formation water that fills pores and fracture in coal. The adsorbed gas, which constitutes most of gas in coal is trapped in coal in the form of a liquid-like film over the internal meso- and micro-pores surfaces of coal. The free phase fills the void volume of the pores. Gas in coal is kept in place by combination of forces emanating from adsorption and capillary processes. The free and adsorbed phases in coal pore system are in equilibrium. Gas is desorbed from coal if the pressure of free gas in pores is reduced to below the equilibrium pressure. At equilibrium the

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mass of adsorbed gas and pressure of free gas can only take on specific values. The thermodynamic equilibrium is expressed mathematically through relationships between the amount of adsorbed gas phase and the pressure of the free gas phase adjacent to the adsorbed layer. These relationships are either derived from an equilibrium kinetic approach to gas adsorption, assuming a monolayer formation mechanism or are derived from a potential theory, assuming a pore filling mechanism [1,2].

Various methods have been developed to estimate gas content of in-situ coal. For example the value of gas content may be derived, indirectly, from adsorption gas isotherm of coal and hydrostatic pressure at coal depth, or from empirical relationship between gas content and some coal properties. However, the most trusted and reliable values are obtained by direct measurement of gas in coal, particularly for coal mining where safety is the paramount issue. When it is directly measured it corresponds mainly to the volume of adsorbed gas as the free gas is all released during drilling and retrieval of sample to the surface. As the total volume of pores in coal is relatively small the contribution of free gas to the total gas in coal is also small. However, it increases with depth and may be considered for operation at high depths (>1000 m).

The direct method of gas content testing was initially developed in European coal producing countries with variants of the methods

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applied by their coal operators [3]. Basically the direct method has two main variants: slow desorption and fast desorption method. The slow desorption method is more often used by gas producing companies. In this method, gas is allowed to desorb 'slowly' from solid coal and the accumulated volume of the desorbed gas with time is recorded. The curve of gas desorption with time can be used to deduce some rough estimation of desorption and diffusion properties of coal. In particular, a parameter of desorption called 'characteristic desorption time', otherwise known as  $\tau$  parameter, is calculated from the slow desorption curve. This parameter is used, particularly in older gas flow simulators. For example SIMED, developed by UNSW and CSIRO, and used in Australia for the design of gas drainage system in gassy mines uses this parameter [4]. In these simulators the transport and release of gas from coal matrix to the fractures and fissures (cleats) is assumed to follow a pseudo steady state diffusion-like flow. In such regimes one assumes that there is a steady flow of gas from coal matrix into the fractures, with the source of gas being concentrated in the centre of matrix (solid). The amount of gas which flows out of the solid is proportional to the gas concentration difference between the centre of the solid and its boundary with a fracture (cleat). At each time step the remaining gas content of coal matrix is calculated by subtracting the mass of gas discharged from the matrix. By developing the mathematical expressions for such flow regime it leads to the following transport (mass conservation) equation:

$$l\frac{dc}{dt} = -\frac{D_e}{l}(c - c_f) \tag{1}$$

where *l* is the distance that a gas molecule must travel within the coal matrix to reach a fracture; and  $D_e$  an equivalent diffusion coefficient; and *c* and *c*<sub>f</sub> the gas concentrations (gas content) at the centre of matrix and at its boundary with a fracture (cleat). The integration of Eq. (1) over a time period *t* yields the cumulated amount of gas, desorbed from coal over that period of time:

$$q(t) = q_0 \left(1 - e^{-\frac{t}{\tau}}\right) \tag{2}$$

In Eq. (2) q(t) is the amount of gas desorbed over time period t;  $q_0$  the amount of gas initially trapped in coal; and  $\tau = l^2/D_e$  the characteristic or desorption time. As can be deduced from Eq. (2), time  $\tau$  corresponds to the time required for coal to release 63.3% of its initial gas  $(t = \tau)$ . In practice, the variants of this equation are used to explain gas desorption from cored coal for gas content testing, from which characteristic desorption time is estimated. For example a modified version of Eq. (2), used by the author for some coals and their gas desorption data, is as follows:

$$q(t) = q_0 \left( 1 - e^{-\sqrt{\frac{t}{\tau}}} \right) \tag{3}$$

More sophisticated gas simulators, which use transient gas flow regimes, may use diffusivity properties (gas diffusion coefficient), rather than  $\tau$  as part of their inputs. The diffusivity of gas in solid coal can be directly measured by flowing gas through solid coal samples under nil pressure gradient [5].

While the time allowed for slow gas desorption is generally days or weeks, so that the incremental desorbed volume is so small that cannot be accurately measured, some variants of this method, mainly used in Europe, allow much shorter time for slow desorption [6–10]. Once slow desorption is interrupted, coal is removed from the desorption canister and is placed in a gas tight crusher, then pulverised (generally to less than  $200 \,\mu\text{m}$ ) to desorb its gas rapidly. The volume of desorbed gas from pulverised coal is then measured. These methods with shorter slow desorption period can be classified as hybrids of slow and fast desorption method. Variants of this method have been used as early as 1960s in Europe. In fast desorption method the slow desorption is quite short

and is mainly to allow the necessary transport of coal sample from field to laboratory for gas content testing, and some hours while in the laboratory.

Although a multitude of methods are used in coal producing countries today, at present there are only limited number of agreed standards across the world for the determination of gas content of coal. In Australia, since the early 1990s work has been conducted to produce standard 'guides' for the determination of gas content. The most recent document, which was developed under the auspice of the Australian Standards is AS 3980-1999 [11], which is an update and improvement of a previous document AS 3980-1991 [12]. More recently the US ASTM also published a document, D7569-10 on the determination of gas content with references to the Australian AS 3980 document [13]. In the next section we describe the standard method used in Australia and present generic methods of quantifying the uncertainties associated with the use of this method.

#### 2. Gas content definition and determination method

#### 2.1. Definition of gas content

Based on the physics of gas storage in coal, total gas contained in coal is the sum of a free gas and an adsorbed gas component. The direct method of measurement does not allow the determination of the free gas component as it is released during drilling and prior to sealing coal in desorption canisters. Hence, measured gas content is basically adsorbed gas. If required, free gas can be indirectly estimated from the knowledge of porosity of coal and in-situ gas pressure or hydrostatic pressure assuming that two pressures are equal.

The gas content, particularly when using the slow desorption method consists mainly of what is termed 'desorbable' gas content  $(Q_d)$ . This is generally the bulk of gas initially trapped in coal, which is desorbed in an environment of gas partial pressure equal to atmospheric pressure, such as in a desorption canister, kept at atmospheric pressure. The remaining gas, which is not desorbed at atmospheric pressure, is termed 'residual' gas content  $(Q_r)$ . The sum of desorbable and residual gas contents is called total gas content  $(Q_t)$ . In Fig. 1, the processes of slow desorption of gas from coal and  $Q_d$  and  $Q_r$  components are schematically presented.

In coal mining projects, for emission calculation the desorbable gas has been used as it is assumed that residual gas trapped within coal pores system is not able to leave coal for pressures below atmospheric pressure. However, for estimation of emissions including post mining emissions in longwall goaf, or abandoned mines, where partial gas pressure can go below atmospheric pressure, this component of gas content should be assessed.



**Fig. 1.** Desorbable  $(Q_d)$  and residual  $(Q_r)$  component of gas contents using slow desorption method.

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