ARTICLE IN PRESS

International Journal of Mining Science and Technology xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

International Journal of Mining Science and Technology

journal homepage: www.elsevier.com/locate/ijmst

Spatial context in the calculation of gas emissions for underground coal mines

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ARTICLE INFO

Article history:
Received 15 January 2017
Received in revised form 5 March 2017
Accepted 12 April 2017
Available online xxxx

Keywords:
Gas emission prediction
Spatial analysis
Underground coal mining
Risk management
Greenhouse gas
Climate

ABSTRACT

The prediction of gas emissions arising from underground coal mining has been the subject of extensive research for several decades, however calculation techniques remain empirically based and are hence limited to the origin of calculation in both application and resolution. Quantification and management of risk associated with sudden gas release during mining (outbursts) and accumulation of noxious or combustible gases within the mining environment is reliant on such predictions, and unexplained variation correctly requires conservative management practices in response to risk. Over 2500 gas core samples from two southern Sydney basin mines producing metallurgical coal from the Bulli seam have been analysed in various geospatial context including relationships to hydrological features and geological structures. The results suggest variability and limitations associated with the present traditional approaches to gas emission prediction and design of gas management practices may be addressed using predictions derived from improved spatial datasets, and analysis techniques incorporating fundamental physical and energy related principles.

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1. Introduction

Underground mining methods account for approximately 20% of total black coal and a proportionally higher amount of metallurgical coal production in Australia [1]. In NSW, hard metallurgical coal is exclusively mined from the Illawarra coal measures in the southern region of the Sydney Basin. Co-located with these coal reserves are significant quantities of methane (CH_4) and carbon dioxide (CO_2) gas [2].

Fugitive emissions of gas from mining via ventilation air not only contribute towards greenhouse gas (GHG) inventory, but in the case of methane, also represent a lost opportunity for energy recovery. Gas reserves are not limited to economically recoverable coal seams, but also include coal measures and other porous stratigraphy both above and below the working seam [3].

Emission predictions are essential for the quantification and management of risk associated with sudden gas release during mining (outbursts), and accumulation of noxious or combustible gases within the mining environment. Unexplained variation in gas character rightly requires conservative mining practices to manage such risks [4].

In many cases, risks are identified later in the mining cycle where remedial action is typically more expensive and is more likely to incur production delay or loss.

Over 2500 gas core samples from three southern Sydney Basin mines producing from the Bulli seam have been analysed in various geospatial context including relationships to hydrological features and geological structures.

Improved spatial datasets, particularly those containing a vertical dimension and derivatives thereof, may be applied to prediction and management of gas emission using fundamental principles. The application of the physical and spatial techniques described enhance the potential future use of high volume and high resolution real time measurement data for proactive management of gas emission risk much earlier in both the gas and mining life cycle.

The improved resolution and definition in the prediction of site specific transient gas emission character, in terms of source location, quantity, composition, flow path and timing is acknowledged by several authors as critical for maintaining current production rates in higher gas content environments [3,5,6].

Gas emissions will increase well beyond the practical management capacity of ventilation and current pre and post drainage systems at several Australian underground coal mines [4]. Hence the traditional approach of increasing ventilation quantity is unlikely

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http://dx.doi.org/10.1016/j.ijmst.2017.07.007
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Please cite this article in press as: Booth P et al. Spatial context in the calculation of gas emissions for underground coal mines. Int J Min Sci Technol (2017), http://dx.doi.org/10.1016/j.ijmst.2017.07.007

to be sustainable due to practical constraints such as roadway area and maximum air velocity therein.

Only a step change improvement in gas drainage, capture and utilisation practices will allow coal to remain a sustainable source of energy in a low emission world [3]. The identification and use of gas management controls which are fundamentally based and incorporate improved spatial and time resolution will not only make mining safer, delivery of this outcome will reduce interruptions for reasons of safety management and lift both coal and overall energy productivity.

2. Historical gas emission prediction

The prediction of methane emissions arising from underground coal mining has been the subject of extensive research for several decades and techniques range from simple geometric models to modern finite element models [7–12]. Despite improvement in computation processing power and speed over this time period, calculation techniques remain empirically based and are hence limited to the origin of information in both application and resolution.

Gas emissions due to mining extraction are transient and a complex function of the *in-situ* resource character, the space where *in-situ* character and gas equilibrium is affected by extraction, the degree to which character and equilibrium is affected, and the system response [9].

In order to simplify the calculation process of most current prediction techniques, key inputs for gas content, material properties and spatial attributes are generally either (1) provided as input variables at low resolution, (2) held constant, or (3) neglected altogether.

Of the many prediction techniques available, the Flügge technique continues to be used for the purpose of total specific gas emission calculation at many Australian mines [13,14]. However, limitations in describing spatial and time based gas emission character with any resolution renders this technique ineffective for design of gas drainage programs. Evidence provided through finite element analysis and micro seismic observations suggest the triangular prism representation is only valid in specific geological conditions and does not cater well for changes in either geology or operational practices [15].

Research by Lama in the 1990s led to the significant reduction of risk associated with gas outburst through the development of composition dependent gas content threshold levels for the Bulli seam [16]. These thresholds or derivations thereof largely remain in place in the Australian coal industry to the present day due to the principles based methodology used. Further research during the latter part of the decade also focussed on developing an understanding of fundamental mechanisms driving gas emission behaviour from coal and surrounding strata [16–18]. The importance of cleat and joint geometry and net effective stress in the control of fluid movement was highlighted.

A detailed description of the process for measurement of gas content and its' contributing components may be found in Australian Standard AS 3980 [19]. Limitations of some of the measurement techniques used, specifically including assumptions of the timing of initial desorption and the lost gas component Q_1, are discussed further by Saghafi [20].

Other factors considered in emission prediction include differential sorption properties of coal under the effect of a shear structure, and gas pressure measurements which change as a result of changes in the permeability of the structure. Significantly, the fracture density and sorption properties may change up to 20 m away from the shear structure, but gas pressure changes can occur up to 100 m away from the structure.

The GeoGAS Longwall "pore pressure" model described by Ashelford took account of many gas reservoir and geological parameters of coal seams and allowed variation of mining operations in arriving at a gas emission value [11]. The model relies upon measured gas reservoir properties for the determination of gas release such as; measured gas content (Q_m), gas desorption rate, gas composition, gas sorption capacity, seam thickness and mineral matter above and below the working section, pore pressure and coal and sandstone porosity. The model parameters and how they are measured are described by Williams et al. [21].

The advantage of this model over prior techniques was its' ability to accurately predict the magnitude of gas emission from the floor seams below the Bulli seam in the southern Sydney Basin. This was due to the significant deformation and order of magnitude changes in horizontal and vertical stress in the floor strata recognised and displayed by finite element software. Whilst the pore pressure model remains the most adaptive and fundamentally based calculation of gas emission for longwall operations, the input assumptions limit the application of this technique to the increasing spatial and time resolution required for design of gas drainage programs.

The availability of increasing computational processing capability has enabled the management of the increased size and complexity of the data available for gas emission analysis in recent years. Studies including those by Karacan used statistical, principle component analysis (PCA) and artificial neural network (ANN) based approaches to predict the ventilation methane emission rates of U.S. longwall mines [10,22,23].

Critically, all techniques which involve the use of large historical data sets for gas emission prediction by analysis using statistical, PCA or ANN approaches rely on a fundamental assumption that input conditions will not materially change. Model outputs are based in fundamental scientific principles however the model design and structure limits the ability for its use in locations where input conditions change rapidly.

Comparison of the output of various prediction models is difficult due to lack of a common gas, material and spatial datum reference and also for the reasons discussed in Jensen et al. [24].

3. Relevant gas fundamentals used

3.1. Gas generation

Coalbed or coal seam gas are general terms used to describe gases contained within coal measures that are generated as part of coalification and other geological and hydrogeological processes [25]. Similar to the creation of coal itself, coal bed gas generation pathways are also dependent on fundamental physical and chemical character and changes in both level and form of energy within the environment. Coal bed methane can be classified as either biogenic or thermogenic in origin [26].

Biogenic methane is generated at low temperature by anaerobic microbes (methanogens) when coal beds are exposed to groundwater recharge after basin deformation. The dominant biological processes involved in the generation of biogenic methane include carbon dioxide reduction and acetate reduction or fermentation which are described in chemical Eqs. (1)–(3). Two significant factors must be carefully considered in the characterisation of the origin of biogenic gas. Firstly, for carbon dioxide reduction to methane, hydrogen must be present. Secondly, in addition to the methane, the two-part acetate fermentation process also produces CO_2 [27].

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O \tag{1}$$

$$CH_3COO^- + H^+ \rightarrow H_4 + CO_2 \tag{2}$$

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