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COAL MINE GOAF GAS PREDICTOR (CMGGP)

Les Lunarzewski¹

ABSTRACT: Research has consolidated on the knowledge of gas emission characteristics of coal mine goaf in Australia into a form which enables emission predictions to be made using limited input data. The fundamental principles are encapsulated within the coal mine goaf gas predictor (CMGGP) professional engineering software. This easy to use tool is designed to predict the decline of methane emissions and calculate gas reservoir capacity of underground coal mine goaf. The method for estimating abandoned coal mine and goaf area methane potential is applicable to both dry and flooded mines and also takes into account coal mine methane utilisation options. The software will run on a PC with windows XP or vista operating system and can be used by individual specialists, coal mines and/or other institutions involved in coal mine closure, coal mine methane utilisation and greenhouse gas emissions reduction.

INTRODUCTION

When an underground coal mine ceases coal production methane gas continues to flow into the underground workings through the process of desorption from residual coal within strata disturbed by mining activity. For gassy mines this desorption process will continue for many years after closure and can resume when flooded mine workings are dewatered. The coal mine operator is therefore faced with potential long-term liabilities including explosion risks on the surface and possible dangers to the public as well as continuing greenhouse gas emissions. After stopping the ventilation system, pumping mine water and sealing mine outlets to the atmosphere (shafts, inclines, service boreholes etc.) gas release from goaf areas will continue until underground workings and macro-fractures are flooded.

Responsible operators are now looking at ways to exploit methane from closed/sealed underground coal mines where practical to reduce environmental emissions, minimise public liability, to take advantage of an energy resource that would otherwise be wasted, provide some continuing local employment and to gain added value from the mine before total abandonment.

A practical and scientifically-based prediction tool for assessing the methane production potential of underground coal mines goaf areas ranging in size from a single panel to whole-of-mine is presented.

BACKGROUND

In New South Wales and Queensland there are more than 50 underground gassy coal mines, which have ceased coal mining operations since after 1954 (Lunagas, 2004). Whereas various methods for predicting gas emissions in working mines are available and in regular use, no complete methodology has been established for predicting the decay of emissions once coal production ceases and the coal mine is no longer operating. However, extensive studies on gas emission from sealed goaves and abandoned coal mines have been undertaken by Lunagas Pty Limited using data predominantly from N.S.W & Q.L.D underground coal mines complemented by additional data from UK, Poland, Czech Republic, USA and Japan (Lunagas 2005). Thus, a method for forecasting long-term gas emission decay was developed for use by specialist industry practitioners in which predicted and measured data showed good correspondence.

The future development of coal mine methane utilisation from coal mines goaf in Australia will depend on the availability of suitable sites and their proximity to a customer. Viability will also depend on the ability to predict both the quantity and decline rate of coal mine methane from those mines, to meet customer requirements whilst at the same time generating a profit for the operator. The national and local energy market for gas and electricity use is continually changing and schemes must be flexible to accommodate these changes while maintaining commercial viability and customer satisfaction.

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It is therefore in the interests of coal mine operators to monitor and gather gas emission data from goaf areas to accurately quantify current emissions and to predict future emission for exploitation potential assessment.

**COAL MINE GOAF CLASSIFICATION**

All input data were gathered from five underground gassy coal mines (and their sealed longwalls and districts) located in New South Wales (4) and Queensland (1) and have been classified for coal mines goaf categories-stages related to the mining, hydro-geological and ownership conditions.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Mine entries &amp; surface boreholes</th>
<th>Ventilation</th>
<th>Coal production</th>
<th>Water pumping</th>
<th>Responsibility</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temporary closed</td>
<td>Opened, not permanently or partially sealed</td>
<td>Operating on reduced capacity</td>
<td>Ceased Possible future production</td>
<td>Optional</td>
<td>Mine operator (maintenance)</td>
<td>Not a factor</td>
</tr>
<tr>
<td>Closed</td>
<td>Partially or fully sealed</td>
<td>Terminated</td>
<td>Ceased No future production</td>
<td>Terminated Goaves gradually flooding</td>
<td>Mine operator</td>
<td></td>
</tr>
<tr>
<td>Decommissioned</td>
<td>Permanently sealed</td>
<td></td>
<td></td>
<td>Terminated Goaves gradually flooding</td>
<td>Transferred from mine operator to the relevant Government Authority</td>
<td>1-20 years Once transfer occurs</td>
</tr>
<tr>
<td>Abandoned</td>
<td>Sealed longwall or district</td>
<td></td>
<td></td>
<td>Optional Mine operator</td>
<td>Not a factor</td>
<td></td>
</tr>
</tbody>
</table>

Note: For the purposes of this work, goaf is defined as the part or total mine from which the coal has been partially or wholly removed and is no longer ventilated to allow access.

**COAL MINE GOAF GAS RESOURCE MODELLING**

Gas is emitted from the worked seam ahead of mining, from unworked coal seams above and below a longwall as a result of the de-stressing caused by coal extraction and from any natural gas reservoirs disturbed by the mining activity (Lunarzewski 2001 & 2007). Once coal production stops, no further new gas release sources are activated but the existing gas sources continue to emit gas at a decreasing rate.

Gas emission from coal seams in the disturbed zone around a longwall occurs as a result of desorption from the coal matrix and pressure flow through the natural and mining induced fractures. Where there are few coal seams above and below the worked seams, methane emissions at mine closure tend to be very low. However, Australian experience is that an exception might occur where there has been extensive room-and-pillar mining, with no pillar recovery, in moderately permeable coal when residual gas in coal pillars can contribute significant gas flows.

Where de-pillaring is practised the situation is analogous to longwall extraction and gas flows from any adjacent seams will add to the emissions.

For the proposed model a specific input data and information have been selected which include the most typical and achievable mining, gas and geological records.

**COAL MINE GAS DECLINE PHENOMENON**

The “dry mine” case refers to the condition where underground water is being controlled by pumping and gas released to the underground workings is either vented to the atmosphere or recovered for methane utilisation purposes. During coal production activities, gas emissions include both;
‘Production gas’ released from the strata as a consequence of mining activities, and
‘Background gas’ which remains and is released to the goaves during mining activities after stoppage or cessation of coal production

When mining ceases production gas rapidly declines, however, the background gas declines slowly and stabilises after mine is closed and/or sealed.

This occurs in a two phases of the decline process;
1. Rapid short-term decline phase, and
2. Slow long-term decline phase.

Background gas represents the theoretical maximum emissions from mine goaf, however, gradual reduction of desorption from gas sources can be accelerated under suction. The rapid decline of production gas depends largely on the continuity and rate of mining (longwall retreat) over the period of a few weeks prior to cessation of the mine coal production. The final methane make before decay starts is taken (if recorded) as the average of the last month of coal production. For other cases the last five years average tonnage and methane make (relative gas emission) is used.

**Rapid short-term decline phase**

The initial rapid decline and stabilization phases take place during the first three to twelve months after mine finishes coal extraction. During that period of time the coal mine production gas is substantially reduced to the level of 30%-70% of the final gas make as a consequence of terminating strata relaxation process and continuation of strata reconsolidation phenomenon.

**Slow long-term decline phase**

The background gas long term gas decline phase starts from year one after time of longwall/mine closure and will last up to 15 to 20 (30) years decline limit time'

![Figure 6 - Composite methane emission decay from a series of longwalls and the district (coal mine)](image)

**GAS DECLINE CURVES**

Gas decline curves - ‘Drysim’ and ‘Wetsim’ have been generated using multi longwall excel spreadsheet models for selected underground coal mines with long term and full range data and information (Lunagas 2005). Both curves represent coal mine methane quantity and decline rate
applicable to the nominated underground coal mines. A new concept has been developed and demonstrated in this paper for wider application in the general case where individual longwall and/or mine input parameters are not known in detail.

The computer simulation program encapsulating the concept uses basic key-data and information available for the mine. This engineering software integrates the exponential function and a proprietary curves fitting routine to derive the exponential decay constants for various mines category.

‘Drysim’ decline curves

Mathematical formulae for the decline curves of each phase have been developed (Lunagas 2005) using long term empirical results from the selected longwalls and underground coal mines as a relationship between quantities of gas $Y = \text{litres CH}_4$ per second and time $X = \text{months}$. The formula includes two variable coefficients ‘$a$’ - methane emission intensity and in situ gas sources productivity and ‘$b$’ - the decline rate with time i.e. speed of decay.

$$F(x) = ae^{-bx}$$

Where:
- $x$ - time (months)
- $a$ - quantity constant
- $b$ - decline constant

‘Wetsim’ decline curves

Two different methods can be used for predicting coal mine gas emission decline rates in a flooding coal mines goaf:

1. Simulation,
2. Flooding time constrained empirical decline curve.

The Wetsim simulation method involves progressively reducing the decaying goaf emission sources contributing to a part or whole of a mine’s gas emission to mirror the isolating effect of rising water (Figure 2).

Data from all extraction panels in a closed mine are required for this method; but such information is not typically available in coal mines so was deemed not to be an appropriate method for use in the software model, however, if available could be calculated manually (Lunarzewski, Creedy, 2006).

The constrained empirical decline curve

The constrained decline curve methods make use of the characteristic exponential equation representing the slow long-term decline phase established for dry mine. Total coal mine gas resource is obtained by simulation using stratigraphy and in situ gas content. The basic expressions representing the background gas emission decline curve and the gas reservoir area graph shape which are respectively:

$$\begin{align*}
F(x) &= ae^{-bx} \\
F(x) &= ae^{-(a/GR)x}
\end{align*}$$

This neat, simple concept illustrated in Figure 3 yields first order estimates when limited data are available.

The gas emission start and end with time and flow rates are well defined in the flooding case. Gas emission will be zero when the mine is finally flooded and the time when this occurs is estimated from the void and water inflow data.

The final ‘Wetsim decline curve’ becomes the combination of the above assumptions and the ‘Drysim decline curve’ mathematical formulae for the nominated conditions i.e. mine category (Lunagas 2005).
The time taken for the workings to flood is calculated using a void volume model and inferred water inflow data. This method is practical, intuitive and seems to yield reasonable estimates and was therefore selected for use in the software model (Lunarzewski and Creedy, 2006).

![Figure 2 - Dry and wet coal mine goaf methane make decay simulation](image1)

![Figure 3 - Wetsim curve concept using zero methane emission](image2)

**EXAMPLES OF CASE STUDIES**

Prediction of coal mine methane emission decline quantity with time is determined by various decline curves which use the empirical coefficients defined for typical underground coal mines and consequently applicable to any coal mine goaf with a similar mining, gassy, geological, and hydrogeological conditions i.e. mine category (Table 2).
Figures 4 and 6 show maps-selected districts of coal mine goaf categories and selected examples of gas emission trend graphs (Figures 5 and 7) for individual longwalls, district and the whole mine.

Figure 4 - Category I - ‘High gassy mine’ U/G workings

Gas emission phases and coal mine categories

Following cessation of mine coal production the coal mine gas emission (production and background gas make) has been classified into three consecutive phases:

1. Production gas rapid decline,
2. Background gas stabilisation period, and
3. Background gas long-term decline.

The decline curve computes the quantity of coal mine gas (methane make) and its decline rate using the specific constants for selected category of the mine.

Coefficients

There are two major constants which classify and characterise the individual coal mine categories: quantity coefficient = ‘a’ and decline rate coefficient = ‘b’
Figure 5 - Category I mine - Longwalls and mine goaves methane emission versus time graph

Figure 6 - Category VI and VII - 'District and longwall goaves' U/G workings

Table 2 - Coefficients for various goaf categories

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
<th>Quantity coefficient</th>
<th>Decline rate coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>High gassy</td>
<td>$a_1$</td>
<td>$b_1$</td>
</tr>
<tr>
<td>II</td>
<td>Low gassy</td>
<td>$a_{II}$</td>
<td>$b_{II}$</td>
</tr>
<tr>
<td>III</td>
<td>Low permeability</td>
<td>$a_{III}$</td>
<td>$b_{III}$</td>
</tr>
<tr>
<td>IV</td>
<td>Temporary closed</td>
<td>$a_{IV}$</td>
<td>$b_{IV}$</td>
</tr>
<tr>
<td>V</td>
<td>Sealed district goaves</td>
<td>$a_V$</td>
<td>$b_V$</td>
</tr>
<tr>
<td>VI</td>
<td>Room &amp; pillar goaf</td>
<td>$a_{VI}$</td>
<td>$b_{VI}$</td>
</tr>
<tr>
<td>VII</td>
<td>Sealed longwall goaf</td>
<td>$a_{VII}$</td>
<td>$b_{VII}$</td>
</tr>
<tr>
<td>VIII</td>
<td>High permeability or shallow mine</td>
<td>$a_{VIII}$</td>
<td>$b_{VIII}$</td>
</tr>
</tbody>
</table>
Figure 7 - Category VI and VII- ‘District 1 & individual longwall goaves’ methane emission versus time graphs

COAL MINE GOAF GAS PREDICTOR SOFTWARE

The Lunagas Pty Limited Coal Mine Goaf Gas Predictor (CMGGP) is simulation software for predicting the decline rate of gas make and calculating the gas reservoir capacity of coal mine goaves (Lunagas, 2009). The software comprises three main sections.

1. The “Coal mine parameters” in which data are entered to facilitate calculation of the decline curves for both dry and wet mines.
2. “Gas reservoir characteristics” which allows entry of stratigraphical data for calculating the available gas reservoir.
3. “Methane decline curves and gas reservoir” charts (decline curves) showing the results of calculations made based on data in the above two sections.

Flowchart

The flowchart (including required input data) shows software application and availability for the nominated coal mine goaves.
Software inputs and outputs

Figure 8 - High gassy mine inputs for decline curves and gas reservoir
REFERENCES


Lunarzewski, L, 2005, Gas emission curves for sealed goaves or abandoned mines, Lunagas Pty Limited, ACARP 2004 project No.C13007 Final Report, June., pp 4-25 and Appendix, pp 2-4

