Longwall gas emission modelling: Practical application and research requirements

by

R.J. Williams[1], P.I. Maddocks[1] and W.J. Gale[2]

[1]GeoGas Pty. Ltd., [2]Strata Control Technology Pty. Ltd.

ABSTRACT

A critical aspect of longwall ventilation planning is the assessment of anticipated gas emission and the design of effective gas drainage.

Longwall emission assessments in Australia have largely been based on European empirical models. Many fundamental parameters are different between Australian and European conditions and this results in too high a level of uncertainty in the forecasts.

There are significant inadequacies in the calculation of both specific emission and return gas concentrations. Particular problems relate to the treatment of seam thickness and extraction rate.

A program to improve empirical models is required, that centres upon monitoring gas and rock mechanics parameters and computer modelling of rock failure.

INTRODUCTION

A critical aspect of longwall ventilation planning is the assessment of anticipated gas emission and the design of effective gas drainage. In an operating mine, information is required on:

- Gas concentrations at the tailgate end of the face
- Gas concentrations in the return roadway
- Gas concentrations in the bleeder (where employed)
- The anticipated percentage of gas captured by gas drainage
- Gas composition (CO_2 and CH_4) in the above areas
- The change in gas concentration and composition as the face retreats for the above areas
- How to design gas drainage (if needed) to the greatest effect.

The actual levels of emission are dictated by mining and geological factors. If these are reasonably constant from one longwall to another, it is possible to define gas emission levels with quite good accuracy, provided sufficient detail has been given to gas emission monitoring. This can be accomplished by using an empirical model of the type described by Williams (1991).

In most situations conditions are not uniform between longwalls. Changes often occur in:

- Gas reservoir properties (seam thicknesses, gas contents and compositions, distances from the worked seam, non coal strata gas, permeability, faulting and other geological discontinuities).
- Mining factors (rate of retreat, face width, chain pillar width, interaction with adjacent goaves).

Longwall emission assessments in Australia have largely been based on European empirical models. The aim of this paper is to discuss the suitability of current modelling techniques, highlight their inadequacies and suggest areas of improvement for design of emission control as well as assessment.

EUROPEAN EMPIRICAL MODELS

Calculation of Specific Emission

Probably the worst examples of the over-extended use of empirical models is the application of those based on European conditions to Australia (refer to Boxho *et al.*, 1980, Curl 1978 for descriptions). So many fundamental parameters are different, that if the correct emission is forecast, it would be more due to good fortune than good science.

The large differences in depth of cover (hence stress/permeability), seam thickness, strata type, extraction ratio and extraction rate are sufficient to make any European prediction model invalid. Critical aspects such as the geometry of the relaxation zone and the degree of emission are obviously going to be different in Australia.

A characteristic of Australian coals is the widespread occurrence of mixed CO_2 and CH_4. No account is taken of the differences in the rate of desorption of CO_2 and CH_4 (CO_2 can desorb at up to six times the rate of CH_4). If the worked seam is thick with a high CO_2 gas content, gas made during cutting is going to be considerably higher than if the gas were purely CH_4.

Experience of return gas concentrations at Tahmoor Colliery shows that CO_2 increases more rapidly than CH_4 when cutting begins and declines more rapidly when cutting ceases (Williams, 1991).

Some of the difficulties in the models relate to appropriate choice of relaxation zone geometry, degree of emission and residual gas content. GeoGAS uses Jegers model with the capability of adjusting the shape of the relaxation zone according to judgements made on geological and mining conditions. For example the height of the relaxed zone might be terminated along the base of a thick sandstone stratum or claystone layer that is judged as being a potential barrier to gas migration.

Empirical data from a well documented mining area are used to adjust various parameters (geometry of the relaxed zone, degree of emission, effect of non coal strata etc.) until you obtain the answer you are seeking (so called "tuning the model"). That model can then be applied to other areas in relatively close proximity, where there may be changes in gas content or stratigraphy.

The main problem with this approach is that it is not difficult to vary the input parameters within plausible ranges and still produce the same result by compensating effects.

How do you treat strata gas? In a particular example, sandstone porosities were varied from 0% through to 10%, producing a range of specific emissions from 23 m^3/t to 39 m^3/t.

Seam thickness is only treated in the European models in the effect it has on face retreat rate (calculation of "relative thickness"). In the same scenario that looked at sandstone porosity changes, changes in seam thickness were tested. These gave specific emissions ranging from 15 m^3/t for a 4 m thick seam to 53 m^3/t for a 1 m thick seam. In other words, a thick worked seam produces a low specific emission compared to a thin seam. This is reasonable when you consider that for the same production rate a thin seam will result in a faster rate of disturbance to the surrounding strata - and this is what the models are intended to show.

But what about the effect of seam thickness on the geometry of the relaxed zone and the degree of emission?

These models take no account of this effect. In Australia, 4+ m mining sections will be more common in the future, particularly in the Bowen Basin.

When mining occurs, all the cracks do not instantly propagate. When a seam is relaxed, all the gas available does not instantly flow. The adsorbed gas begins desorbing. Thus there is a delay between mining and the reaching of peak gas emission, the magnitude of which depends upon (among other things) the proximity of the major gas sources to the working seam. Mining a thicker seam or slowing the rate of face retreat will have an effect on this delay by giving the fractures more time to propagate and gas to desorb. Thus more of the gas that would have been emitted deeper into the goaf is released in the face area.

Here we reach a level of detail beyond the scope of the European models. These models provide an overall estimate of gas make. Equally important is knowledge on where the gas will be concentrated. This will depend upon emission delay criteria, ventilation schemes (particularly pressure drops) and even gas composition (Williams ,1991).

Calculation of Gas Concentrations

Nearly all emphasis is placed upon calculating the specific emission, with little coverage on the next step of using specific emission to calculate gas concentrations in return roadways. Given a correct specific emission value (from back analysis) the method described in

Boxho *et al.*, (1980) tends to over estimate the effect of increasing levels of production.

It essentially assumes that gas emission will increase in direct proportion to the production rate. While it makes sense that the faster you retreat, the greater the gas emission will be, in reality it is not such a simple relationship.

GeoGAS has found good correlation of calculated against actual return emission using these formulae:

$$GMCO2 = ACO2 \times t_w^{-BCO2} \quad \ldots\ldots\ldots (1)$$

$$GMCH4 = ACH4 \times t_w^{-BCH4} \quad \ldots\ldots\ldots (2)$$

where:

GMCO2 is the CO_2 gas make

GMCH4 is the CH_4 gas make

t_w is the weekly coal production in tonnes.

ACO2, BCO2, ACH4 and BCH4 are coefficients that reflect the dependency of gas emission on production rate. They are related by this relation:

$$BCO2 = -0.08294 \times \ln ACO2 + 0.112526 \quad (3)$$

(same for CH_4)

BCO2 has been found to range between -0.5 and -1. A value of -1 indicates no dependency on production rate.

Average weekly return gas emissions are then calculated using the expressions:

$$RaCO2 = 100x(1-CCO2)xGMCO2\ xT_d/(86400 \times Q_a) \quad \ldots\ldots\ldots (4)$$

$$RaCH4 = 100x(1-CCH4)xGMCH4\ xT_d/(86400x\ Q_a) \quad \ldots\ldots\ldots (5)$$

where:

RaCO2 is the weekly average return CO_2 percentage,

RaCH4 is the weekly average return CH_4 percentage,

CCO2 is the percentage capture of CO_2,

CCH4 is the percentage capture of CH_4,

T_d is the average daily coal production in tonnes,

Q_a is the return air quantity in m^3/s.

An irregularity coefficient is then applied (around 1.5 for both CO_2 and CH_4) to give peak daily emissions.

The European methods use essentially equations (4) and (5), but substitute their calculated specific emission for the values GMCO2 and GMCH4.

A reason why gas emission is not proving to be directly related to production rate is that for fast face retreats, recompression of the relaxed strata under the rear abutment inhibits further gas emission release.

With this mechanism, thick seams need to be given a higher weighting than thin seams, where the time for emission between initial relaxation and recompaction is greater.

Where to now?

We need both improved empirical models, and models that are less reliant on empirical input.

SUGGESTED DIRECTIONS

Ideally, a model is required that is based on physical principles of rock and fluid mechanics - together with the ability to measure sufficient of these basic parameters.

The industry is a long way from having such a model. The work involved would be an enormous task given the complexity of the processes involved. Modelling of rock stresses and deformations behind the face is a big enough task in itself, but application to gas emission calls for one large additional step - adding fluid flow modelling covering the plethora of stress, permeability, fluid and rock property conditions.

Is the effort worth it? If such a project could be funded, would sufficient use be made of the modelling to justify both its creation and maintenance. From a commercial viewpoint it is unlikely to be worth the effort.

None-the-less, something better than we currently have is certainly needed. There is scope to at least go part way along this path and address the rock mechanics aspects of the model and perhaps some of the gas dynamic aspects.

EMPIRICAL MODELS

Virtually no work has been done in Australia to directly define the height of the relaxation zone, the degree of gas emission and residual gas levels. In particular, gas contents need to be determined for coal seams surrounding the worked seam in previously mined areas.

Extensometry in support of subsidence studies needs to be tied in with gas emission to try and gain a feel for the shape of the relaxed zone and how it propagates with time after mining.

Longwall gas balances using real time monitoring of the type used at Tahmoor Colliery are a fundamental requirement to support the above work.

ROCK MECHANICS MODELLING

Rock mechanics modelling has the potential to give much needed insight into the underlying processes controlling gas emission. Its potential is clearly beyond providing a better estimate of gas emission. It should also be of use in:

- Assessing cyclic emission phenomena such as floor break gas outs which are a major concern in some South Coast mines.
- Assisting gas drainage design by targeting the most prospective (fractured/relaxed) ground.

Computer modelling has been used to obtain generalised distributions of potential zones of strata relaxation and failure in the rock mass (Summers and Jeffery, 1992).

Field monitoring involving measurements of strata movement, fluid flows and zones of fractured rock is then necessary to detail the actual response of the strata to these changed stress conditions.

On the basis of this information, gas emission predictions, gas drainage programs or water flow predictions can be formulated to accommodate the conditions anticipated.

In many mining situations, the ability to detail the strata behaviour and ground relaxation from measurements can be limited. This is particularly so for strata below extraction panels.

In these situations, a means to simulate the behaviour of the ground would be of benefit in calculating gas emissions and optimising drilling by targeting horizons for gas drainage.

To undertake such simulation requires the ability to model the rock failure process with sufficient detail to reflect the actual site response. Computer modelling of rock failure about mine roadways has been successfully undertaken by SCT using a Finite Difference code, FLAC.

This code allows large movements to be accommodated in the computations and provides a realistic simulation of the post failure characteristics of the rock.

The application of this code, and other codes which can simulate the appropriate rock failure relationships, to caving or ground movement about extraction areas is difficult, due to the scale and complexity of the problem. However, initial applications of these methods indicate that the mechanisms of ground failure and movement can be simulated, together with the associated stress redistributions.

Where sufficient detail of the strata distributions exists, it is considered possible to use modelling to better define the potential zones of induced permeability and the dominant rock breakage mechanisms about extraction panels.

While the application of computer modelling to simulate the mechanics of these processes is in its infancy when applied to caving and permeability, it is considered to be an area where significant advances can be made.

CONCLUSIONS

Improved empirical and numerical modelling is required as a basis for a significantly better way of assessing longwall emissions and designing control measures.

This is seen as requiring a base of gas and rock mechanics modelling. In that strata movements dictate gas flows, initial emphasis needs to be on rock mechanics modelling supported by detailed monitoring of gas emissions, residual gas contents after mining and strata deformation.

Although subsequent work could include gas emission simulation tied to the rock mechanics modelling, at this stage, the focus should be on gas emission and rock mechanics monitoring and rock mechanics computer modelling.

The authors are confident that this approach will lead to the significant improvements in assessment and design for the control of gas emission - improvements that are sorely needed.

REFERENCES

Boxho J., Stassen P., Mucke G., Noack K., Jeger C., Lescher L., Browning E.J., Dunmore R. and Morris I.H. 1980 *Firedamp drainage* Verlag Gluckauf GmbH Essen.

Curl S.J. 1978 Methane prediction in coal mines Report number ICTIS/TR04 IEA Coal Research

Summers J.W. and Jeffery R.I. 1992 Numerical prediction of strata deformation associated with longwall mining Trans. of the Inst. of Min. & Metall. Section A, Mining Industry, Vol. 101, A1-74, A63-A74

Williams R.J. 1991 Carbon dioxide and methane emission at Tahmoor Colliery in Gas in Australian coals Ed. Bamberry W.J. and Depers A.M. GSA Symp. Proc. 2