



UNIVERSITY
OF WOLLONGONG
AUSTRALIA

University of Wollongong
Research Online

Coal Operators' Conference

Faculty of Engineering and Information Sciences

2002

Outburst Research

M. Wold
CSIRO Petroleum

Publication Details

This conference paper was originally published as Wold, M, Outburst Research, in Aziz, N (ed), Coal 2002: Coal Operators' Conference, University of Wollongong & the Australasian Institute of Mining and Metallurgy, 2002, 63-69.

Research Online is the open access institutional repository for the University of Wollongong. For further information contact the UOW Library:
research-pubs@uow.edu.au

OUTBURST RESEARCH

Mike Wold¹

INTRODUCTION

The two books published by Dr. Ripu Lama (1995) and Dr. Lama and Dr. Jakob Bodziony (1996) are outstanding collections of literature, observations and original work in the field of gas outburst research and management. They provide a very solid base for further effort and developments; but they also serve to indicate that the problem is one of extreme complexity for which no 'silver bullet' solution is likely to be found. Since 1996, research has continued in several locations in Australia and overseas, generally stimulated by outburst events, or the perceived risk of occurrence in new areas or as mines go deeper.

This short presentation includes a bibliography of various publications in the recent outburst research literature (Appendix 1). These publications indicate that some good progress has recently been made both in Australia and elsewhere in developing a better understanding of outburst mechanisms, and in the author's own experience, in developing quantitative models of those mechanisms. It is hoped that the bibliography provides a reasonably up-to-date introduction for the enquiring reader. It does not cover gas drainage, alleviation and outburst management. More comprehensive information can be found in the reference lists of the catalogued papers, for example in the ACARP report by Wold and Choi (1999) which contains a detailed assessment of research on modelling of outburst mechanisms.

The main body of this presentation comprises an overview of a research project that CSIRO Petroleum has recently commenced with support by ACARP. The project represents an attempt to provide a practical advance for the assessment of safe mining criteria for outburst prone conditions.

VARIABILITY OF COAL SEAM PARAMETERS FOR IMPROVED RISK ASSESSMENT FOR GAS OUTBURST IN COAL MINES

This project is directed to the ACARP Underground Health and Safety Program objective, *Strengthen gas control systems – outburst*.

The aim of the research is to:

- Improve the basis for gas outburst risk assessment.
- Provide a rational basis for extension of criteria for safe mining under gas outburst conditions, beyond the current criteria of gas content and gas composition.

This will be done by:

- Development of a statistical model of spatial variability of permeability and coal strength using new methods developed by CSIRO for the petroleum industry.
- Application of the new CSIRO outburst model to assessment of outburst conditions using the above parameters, and their variability distributions and correlations.

The major benefit of success in this work will be an improved ability to understand mechanisms, conduct risk analyses, and specify outburst threshold values (THV's) that:

- build incrementally on the experience and safety record achieved over a number of years of mining in the Southern coalfields,
- are specifically designed for the particular conditions that prevail at the target coalfield or mine,
- assist in the provision of safe working conditions at increasing depth in the Bowen Basin,
- allow optimum mining development and production speeds,

¹ CSIRO Petroleum

- provides a more quantitative basis for outburst management decision in the face of the new regulatory and legal framework governing safety and accidents.

The work will also demonstrate methods that will provide a blueprint for ongoing collection of data for outburst risk management.

In addition to the paramount issue of worker safety, and liabilities and costs of accidents, there is potential for substantial economic gains through defining optimised safe operating conditions.

The project will tackle the problem by collection and measurement of coal strength and permeability data, development of quantitative statistical models that account for their variability, application of the new CSIRO outburst model to determine sensitivity to these variables, and development of a quantitative risk analysis approach which considers these sensitivity measures.

DEFINITION OF THE PROBLEM

Mining of gassy coal seams such as the Bulli seam in the Southern Coalfield is subject to the hazard of gas outburst, and safe mining is governed by statutory criteria of gas content and gas composition. Application of these criteria has been successful in greatly reducing the incidence of outburst hazard in the Bulli seam, but it is not known whether the criteria might be overly restrictive when applied to some mining conditions, particularly when CO₂ is present.

Furthermore, in other areas such as the Hunter Coalfield and in the Bowen Basin, mines are now operating at increasing depth, with increasing gas contents, and in some cases with high CO₂ composition. The determination of safe working criteria for these mines is becoming a critical issue.

It is important to recognise that improvements in risk assessment must be done incrementally, based on the solid position established by the current methods. This is particularly so under the new regulatory and legal framework governing safety and accidents. Nevertheless, the development of new quantitative approaches to risk assessment appears to be the most promising way forward.

STATE OF THE ART

Efforts to understand and manage the outburst problem have been hindered by the complexity of the physical mechanisms involved, the difficulty in determining the various contributing factors and how they interact, and the need to continuously measure and monitor underground conditions as mining progresses. Nevertheless, in the last decade outburst risk has been brought under control in Australia by the introduction of in-seam gas drainage ahead of mine development and production. Under strict government regulation, drainage to meet safe gas content THV's, is carried out in all mines assessed as at risk. This concept is based on the work of Lama particularly with respect to the outburst problems at West Cliff Colliery (Lama, 1995). The regulations also mandate the use of outburst management plans, prepared and implemented at each mine. These are based on the recognition that sound management has a major and essential role to play, in conjunction with technical and operational procedures (McKensy, 1995).

In the management of outburst risk, the two prime issues are safety and productivity. Worker safety is an essential requirement with which there is no compromise. This underpins the setting of THV levels, and provides a fixed reference for discussion of mine productivity issues. Application of the THV criteria has been successful in virtually eliminating outbursts. However, the criteria are limited to the factors of gas content and gas composition, whether CH₄ or CO₂, with modified mining methods required in the close presence of major coal structures.

It is widely recognised that other physical factors have the potential to modify the risk, but a much-improved understanding of how these factors interact and contribute to the evolution of outburst conditions is required before they could be taken into account. The THV criteria were developed based on West Cliff mine experience with the Bulli Seam, and are applied to other mines such as Appin, operating under similar conditions (Lama, 1996). Technical arguments may be put to modify the criteria on the basis of comparative conditions, but the high safety level must be maintained.

If it is considered that a gassy mine might operate safely with increased THV's, there is the potential for increased development rate and reduced gas drainage costs. In marginal economic operating conditions, this could impact on

total mine viability. In undertaking a risk analysis for this purpose, both operational and geomechanical-reservoir factors must be considered, with weighting factors being assigned to a number of variables in a decision tree process. Methods that improve the quantitative basis for weighting factors, and broaden the range of variables that can be quantified, may therefore contribute to maintenance of safety standards while increasing productivity and viability.

CSIRO OUTBURST MODEL

A new model that can quantitatively simulate the evolution of outburst initiation has been developed by CSIRO, supported by ACARP (Wold and Choi, 1999; Choi and Wold, 2001a,b).

The initiation of outburst depends on the complex interaction of some important processes and factors. These control the evolution of a range of reservoir, geomechanics and fluid-dynamics field variables. The main processes and factors may be broadly categorised under the headings of

- gas desorption and two-phase fluid flow,
- effective stress and poroelastic effects,
- mechanical strength and geological structure,
- time-rates of mining and drainage,
- energy in free gas,
- coal fragmentation and fluid-particle interaction.

The current model development was undertaken to produce an improved understanding of outburst mechanisms, and to quantitatively model the influence on risk of outburst of a range of geomechanical, reservoir and operational factors. The method adopted was to couple a geomechanical model and a CBM reservoir model.

Model development and applications have been matched where possible to insitu data, observations and operations, taking into account broad natural variability. The main model variables are as follows:

- opening geometry and mining advance rate,
- vertical stress based on depth; horizontal stresses based on field measurement and depth,
- intrinsic permeability and permeability anisotropy based on field measurement,
- desorption isotherms from laboratory measurement; initial reservoir pressure based on depth, or reduced to various pressures to represent drainage or under-saturated conditions,
- sorption times based on production well history matching,
- CH₄/CO₂ composition in the range 0-100%; and coal strengths from laboratory measurements.

RESERVOIR HETEROGENEITY AND GEOSTATISTICAL MODELS

Permeability and strength values in coal can vary strongly over short distances, undergoing step changes often associated with presence of features such as bright and dull bands, cleat and fractures at various length scales, and mineralisation in the fractures. This heterogeneity poses problems in trying to estimate the permeability and strength properties that take effect at various length scales. The question of how to upscale measurements made on core to represent the behaviour of the coal face with dimensions of metres involves the application of statistical methods which account for the abrupt changes in properties, and their distribution in space. This has obvious importance when trying to understand mechanisms of outburst failure and the risk of its occurrence, particularly when considering one set of seam conditions compared with those at another site. Experience with the CSIRO outburst model has shown that permeability and strength are major determinants in outburst mechanisms. Therefore, in seeking to incorporate consideration of permeability and strength in assessing outburst risk, this project aims to quantify the variability at a scale suitable for the outburst model to handle, typically at a scale of 1-2m.

Geostatistics offers a collection of deterministic and statistical tools aimed at understanding and modelling spatial variability. Generating stochastic realisations of reservoir and geomechanics properties with a suitable level of spatial correlation in the values of permeability and strength is one of the more difficult challenges in petroleum statistical modelling. CSIRO Petroleum has had success in quantifying permeability variability using both

standard geostatistical models and by developing non-conventional models which better account for high levels of heterogeneity, in particular using Levy Fractal models (Liu, *et al.* 1996).

The field measurement components of this project are designed to provide data that can be analysed using geostatistical tools that appropriately model the spatial variability. If valid models can be built, comparative studies between different mine conditions may provide better risk assessment for safe mining conditions.

FIELD AND LABORATORY MEASUREMENTS

Permeability of coal can be measured in-situ using well testing methods familiar to the petroleum industry, and in laboratory on core samples, but examples from the coal mining industry are fairly sparse. CSIRO has had more than decade of experience in the development and application of field and laboratory methods for measuring permeability, strength and stress in coal and porous sedimentary rocks. A recent example is provided by Wold and Jeffrey (1999). This study included a well interference test from which permeability anisotropy was quantified. However, strength and permeability in particular may have high spatial variability, and no evidence has been found in the literature of attempts to quantify this variability for coal seams.

In this project, the majority of the laboratory tests will be done in house by CSIRO using standard techniques and equipment. Of particular interest will be the application of the rock strength device to measure strength parameters. This a portable device that could be readily deployed at a mine site to provide rapid turnaround of results from core with no special preparation required. This aspect may be of particular importance in practice, for ongoing outburst risk management by mine operators at a future time. The field well tests will be done in collaboration with a consultant. The reservoir model SIMED will be used in interpretation of results from the well tests, which are of novel configuration.

RISK ANALYSIS

Broadly speaking, the goal of risk analysis is to help the decision-maker choose a course of action, given better understanding of the outcomes that could occur. Risk analysis provides some qualitative and/or quantitative methods for assessing the impacts of risk on decision situations, and there are many different approaches that might be taken. Conceptually, sensitivities determined from the outburst model results could contribute to the assessment of probability of initiation of outburst event as a function of the permeability and strength variables. However, the scope of these considerations will be limited to comparative and incremental risk from the base position of the existing THV's that result from a decade of experience in outburst management and control.

CSIRO Petroleum has formed a specialist risk analysis group that has commenced working across a range of industry problems.

SAFETY IMPLICATIONS

The ACARP Program recognises the need to strengthen gas control methods with respect to gas outburst, within the underground health and safety program. The core issue of this project is healthy and safe working conditions in gassy coal seams. It is implicit that the proposed methods developed will incorporate safety standards to at least the same level as currently exist. It seeks to promote increased certainty in setting safety levels for mining under increasingly gassy conditions, in newer areas.

BENEFITS TO COAL PRODUCERS AND DELIVERABLES

The major benefit of success in this work will be an improved ability to understand mechanisms, conduct risk analyses, and specify outburst THV's that:

- build incrementally on the experience and safety record achieved over a number of years of mining in the Southern coalfields,
- are specifically designed for the particular conditions that prevail at the target coalfield or mine,
- assist in the provision of safe working conditions at increasing depth in the Bowen Basin,

- allow optimum mining development and production speeds,
- provide a more quantitative basis for outburst management decision in the face of the new regulatory and legal framework governing safety and accidents.

The work will also demonstrate methods for the measurement and analysis of permeability and strength, which will provide a blueprint for ongoing collection of data for outburst risk management.

Estimating the value of benefits to be gained depends on the scenario chosen, and those with knowledge and experience of the issue could readily do this. However, a simple example is indicative. If at a mine, development rates are slowed by gas drainage to meet excessively stringent THV requirements, such that overall longwall production is impeded by a total of five days in a year; then an estimated 50,000 tonnes of production would be lost at a net value of greater than \$1,000,000. Conversely, a fatality caused by outburst where too lenient THV requirements applied is completely unacceptable.

DELIVERABLES

The project will produce a number of strategic deliverables and a number of technical deliverables.

Strategic deliverables:

- Rational basis for extension of existing criteria for safe mining under gas outburst conditions to include other key variables.
- Improved basis for outburst risk assessment using quantitative measures.

Technical deliverables:

- Method demonstrated on site for measuring permeability at a length scale appropriate to the outburst problem.
- Demonstration of portable test equipment for rapid and inexpensive measurement of coal strength.
- Improved quantitative understanding of spatial variability of permeability and strength.
- Improved quantitative understanding of the sensitivity of outburst mechanisms to variations in coal permeability and strength.
- Improved approach to quantitative risk assessment.

CONCLUSIONS

The work in outburst research of Dr Ripu Lama and others has provided a very sound basis for ongoing developments and applications of research in gas outburst management. Australian and international researchers are continuing to work in the field, and several projects are currently being sponsored by ACARP. Work by CSIRO Petroleum is directed towards improving the technical foundation for gas outburst risk management, based on a program of field measurement, numerical modeling and risk analysis.

REFERENCES

- Choi, S. K. and Wold, M. B. (2001a). Advances in simulation of gas outburst conditions in underground coal mines. In Proceedings 2001 International Coalbed Methane Symposium, University of Alabama, Tuscaloosa, May 2001, p283-294.
- Choi, S. K. and Wold, M. B. (2001b). A mechanistic study of coal and gas outbursts. Proceedings 38th US Rock Mechanics Symposium, Washington DC, July 2001, Vol.1, p343-350.
- Lama, R. D. (1995). Safe gas content threshold value for safety against outbursts in the mining of the Bulli Seam. International Symposium-cum-Workshop on Management and Control of High Gas Emissions and Outbursts in Underground Coal Mines. R. D. Lama (Ed.) Wollongong, March 1995, p 175-189.
- Lama, R. D. (1996) Assessment of threshold values for safety against outbursts of gas and coal in the Bulli /seam at Appin Colliery. Tech Effect, Kembla Coal and Coke Pty Limited. 1996.
- Liu, K., Boulton, P., Painter, S. and Paterson, L. (1996). Outcrop analog for sandy braided stream reservoirs: permeability patterns in the Triassic Hawkesbury Sandstone, Sydney Basin, Australia. AAPG Bulletin, V. 80, No. 12, December 1996, p 1850-1866.

- McKensy, B. (1995). Issues and direction in the management of outburst risk in New South Wales. International Symposium-cum-Workshop on Management and Control of High Gas Emissions and Outbursts in Underground Coal Mines. R. D. Lama (Ed.) Wollongong, March 1995, p 389-396.
- Wold, M. B. and Jeffrey, R. G. (1999) A comparison of coal seam directional permeability as measured in laboratory core tests and in well interference tests. SPE Paper 55598 presented at 1999 SPE Rocky Mountain Regional Meeting, Gillette, Wyoming, May 1999, p185192.
- Wold, M. B. and Choi, S. K. (1999) Outburst mechanisms: coupled fluid flow – geomechanical modelling of mine development. ACARP Project C6024, Final Report. CSIRO Petroleum, Australia. Dec. 1999 94 p.

APPENDIX 1

Bibliography of Recent Outburst Research

- Barakat, M.A. and St. George, J.D. (1998). Permeability of coal in relation to gas outburst and drainage. Proc. AusIMM Annual Conf.
- Beamish, B.B. and Crosdale, P.J. (1998). Instantaneous outbursts in underground coal mines: an overview and association with coal type. *Intl. Jnl. of Coal Geology* V.35, pp.27-55..
- Butt, S.D. (1999). Development of an apparatus to study the gas permeability and acoustic emission characteristics of outburst-prone coal. *Intl. Jnl. of Rock Mechanics & Mining Sciences*.
- Cao Yunxing and Liu Ruixin (1997). The deformation metamorphism of tectonic coal and its application in geological mining hazards. *AAPG Bulletin*.
- Cao, Yunxing; He, Dingdong and Glick, D.C. (2001). Coal and gas outbursts in footwalls of reverse faults. *Intl. Jnl. of Coal Geology*, V.48, pp.47-63.
- Choi S. K. and Wold, M. B. (2001). Advances in simulation of gas outburst conditions in underground coal mines. In *Proceedings 2001 International Coal Bed Methane Symposium*, University of Alabama, Tuscaloosa, 14-18 May p283-294.
- Choi S. K. and Wold, M. B. (2001). A mechanistic study of coal and gas outbursts. In *Rock Mechanics in the National Interest*, Elsworth, Tinucci & Heasley (eds.) 2001 Swets & Zeitlinger Lisse, ISBN 90 2651 827 7. p343-350.
- Cyrul, T. (1998). Prognostic model of rock and gas outbursts. *Trans. Inst. of Mining & Metallurgy, Section A: Mining Industry*.
- Eremin, I.V. et al (1997). Petrographic characteristics of coals from outburst-susceptible beds. In: *Khim. Tverd. Topl. V.2*, pp.32-41 (in Russian)
- Flores, R.M. (1998). Coalbed methane: from coal-mine outbursts to a gas resource. *Intl. Jnl. of Coal Geology* V.35, pp.3-26.
- Frid, V. (2001). Calculation of electromagnetic radiation criterion for rockburst hazard forecast in coal mines. *Pure & Applied Geophysics* 158, pp.931-944
- Frid, V. (1997). Rockburst hazard forecast by electromagnetic radiation excited by rock fracture. *Rock Mechanics & Rock Engineering*, V.30/4, pp.229-236
- Frid, V. (2000). Electromagnetic radiation method water-infusion control in rockburst-prone strata. *Jnl. of Applied Geophysics*, V.43, pp.5-13.
- Frid, V. (1997). Electromagnetic radiation method for rock and gas outburst forecast. *Jnl. of Applied Geophysics*, V.38, pp.97-104.
- Gawor, M., Litwiniyszyn, J., Rysz, J. and Smolarski, A.Z. (2000). Rock and gas outbursts. *Archives of Mining Sciences – Archiwum Gornictwa*.
- Gurba, L. W., Gurba, A., Ward, C., Wood, J. Filipowski, and Titheridge, D. (2001) The Impact of coal properties on gas drainage efficiency. In *Geological Hazards*, R. Doyle & J. Moloney (eds.) Newcastle, p215-220.
- Kovalenko, Yu.F. and Karev, V.I. (2001). Dynamics of gas release from a coal seam in driving a working. *Jnl. of Mining Science*, V.37/1, pp.51-57
- Lama, R.D. and Bodziony, J. (1998). Management of outburst in underground coal mines. *Intl. Jnl. of Coal Geology*, V.35, pp.83-115.
- Li, Huoyin (2001). Major and minor structural features of a bedding shear zone along a coal seam and related gas outburst, Pingdingshan coalfield, northern China. *Intl. Jnl. of Coal Geology*, V.47, pp.101-113.
- Li, Huoyin and Ogawa, Y. (2001) Pore structure of sheared coals and related coalbed methane. *Environmental Geology*, V.40, pp.1455-1461
- Lin, B. and Zhou, S. (1996). Studies of gas outburst mechanism and its dangerous prediction in coal tunnels. *Proc. Intl. Sym. Min. Sci. Technol.*, ed. Guo, Y. and Golosinski, T.S., Balkema, Rotterdam. pp.241-244
- Liu Mingiu and He Xuequi (2001). Electromagnetic response of outburst-prone coal. *Intl. Jnl. of Coal Geology* V.45, pp.155-162.
- Noack, K. (1998). Control of gas emissions in underground coal mines. *Intl. Jnl. of Coal Geology*, V.35, pp.57-82.

-
- Stevenson, R. (1999). Thoresby colliery outburst; a lesson learned. Intl. Mining & Minerals.
- Suarez Fernandez, M., Lopez Garcia, H. and Robles Alvarez, A. (1998). Fuzzy system for coal and gas outburst risk assessment. Publication Series – A/Asian Inst. of Mining & Metallurgy.
- Valliappan, S. and Zhang, Wohua. (1999). Role of gas energy during coal outbursts. Intl. Jnl. for Numerical Methods in Engineering, V.44, pp.875-895.
- Valliappan, S. and Zhang, Wohua. (1997). Role of methane gas emission in coal outbursts. Proc. Intl. Symp. Eng. Geol. Environ., V.3, pp.2549-2554.
- van der Gaag, J.M. (1997). Characterization of outburst channel sandstones in the Phalen Colliery, Cape Breton, Nova Scotia.
- Williams, R. J. (1996). Application of gas content test data to the evaluation of gas emission and hazards during longwall development and extraction,. In Geology in Longwall Mining, G. H. McNally & C. R. Ward (eds.) University of New South Wales, P 35-40.
- Williams, R. J. (1997). Definition of outburst threshold limits from core testing. In Safety in Mines: the Role of Geology. R. Doyle, J. Moloney, J. Rogis and M. Sheldon (eds.) Newcastle. p85-90.
- Wold, M. B. and Choi, S. K. (1999). Outburst mechanisms – coupled fluid flow-geomechanical modelling of mine development. ACARP Project C6024 Final Report, CSIRO Petroleum, Australia, 94p.
- Wold, M. B. and Choi, S. K. (2001) Understanding the role of geological structures on outburst risk – a new modelling approach. In Geological Hazards, R. Doyle & J. Moloney (eds.) Newcastle. p205 214
- Xu, L. et al (1997). Study on chemical composition and macromolecular structure of outburst zone coal. In: Chongqing Daxue Xuebao, Ziran Kexueban, V.20, pp.69-73 (in Chinese).