



A probabilistic assessment of enhanced coal mine methane drainage (ECMM) as a fugitive emission reduction strategy for open cut coal mines



R. Sander^{*}, L.D. Connell¹

CSIRO Earth Science and Resource Engineering, Private Bag 10, Clayton South, VIC 3169, Australia

ARTICLE INFO

Article history:

Received 13 March 2014

Received in revised form 18 June 2014

Accepted 18 June 2014

Available online 27 June 2014

Keywords:

CMM

ECBM

Coal mine drainage

Enhanced gas recovery

Economics

Monte Carlo simulation

ABSTRACT

Enhanced coal mine methane drainage (ECMM) is a strategy that has been proposed for reducing fugitive emissions during coal mining. This paper presents a methodology for incorporating risk from uncertainty in reservoir properties and economic parameters in a techno-economic assessment of enhanced gas drainage of coal mines. Conventional economic assessments are deterministic and do not provide information on the likelihood of outcomes. Incorporating uncertainty into the analysis means that the probability of specific outcomes can be identified, thus supporting investment decision making. The methodology is demonstrated by means of a representative case study which evaluates the probabilistic economics of enhanced drainage of eastern Australian open cut mines. The approach entails coupling of a reservoir simulator (SIMEDWin) with a techno-economic model. Case specific findings indicate that for coal properties typical of eastern Australian coals the probability of a commercial ECMM project is 33% and the average net present value is A\$0.005/t (US\$0.00425/t applying a long term exchange rate of US\$0.85/A\$), though this result is skewed by the technical difficulties encountered. The study demonstrates that the minimum reservoir property requirements for a successful project are sensitive to the CO₂ penalty. However, the results indicate that even in the absence of a CO₂ penalty ECMM can be an economically viable emission reduction strategy for reservoir permeabilities as low as 0.14 mD or a gas content of more than 3.8 m³/t.

© 2014 Elsevier B.V. All rights reserved.

1. Introduction

For underground mining coal mine methane (CMM) is often drained via boreholes to improve mine safety as this gas constitutes a significant hazard. Additional advantages are a reduction in mine ventilation requirements and potential improvements of mine economics by allowing the mines to produce coal with minimum CH₄ concentration related downtimes (Bibler et al., 1998). Technologies utilising CMM and ventilation air methane (VAM) have been successfully applied on a global basis (Karacan et al., 2011; Somers, 2012). For example, in Australia there are CMM based power generators with capacities ranging from 5 up to 97 MW (GA, 2012a). For open cut mines generally no CMM recovery is performed as the safety hazards of underground mines don't apply. Thus, during mining, the gas becomes fugitive.

The production of CMM using conventional recovery methods is limited by the degree to which the seam pressure can be lowered. Furthermore, drainage can be very slow due to low reservoir permeabilities and increasingly small pressure differentials between the production

borehole and the reservoir. This is particularly true for shallow coal seams such as those typical for open cut mines. As a consequence, even when drainage is practised, there will be residual gas present in the coal that will become fugitive during mining. Enhanced coal mine methane drainage (ECMM) presents an alternative to conventional drainage methods (Brunner and Schwoebel, 2007; Packham et al., 2011, 2012; Sander and Connell, 2012). Puri and Yee were the first to describe an enhanced gas recovery process during which gas is injected to accelerate the release of CH₄ from coal (Puri and Yee, 1990). This process has the potential to provide more comprehensive recovery of the reservoir gases than conventional production methods; Connell et al. demonstrated in laboratory experiments that a displacement efficiency of up to 100% could be achieved when nitrogen (N₂) was injected to displace CH₄ in a coal core (Connell et al., 2011), meaning all CH₄ present in the pores and adsorbed on the coal's surface could be displaced. Others have demonstrated the feasibility of enhanced gas recovery from coal in the field (Mavor et al., 2004; Oudinot et al., 2011; Packham et al., 2012; Reeves and Oudinot, 2004, 2005; van Bergen et al., 2006, 2009; Wong et al., 2006; Yamaguchi et al., 2006). At an Australian coal mine, Packham et al. (2012) showed that the injection of N₂ resulted in accelerated drainage rates which could reduce drainage lead times.

The application of ECMM has potential economic benefits; the CMM recovered during drainage can be utilised for power generation, adding a source of revenue (through gas sales) or cost savings (by reducing

^{*} Corresponding author. Tel.: +61 3 9545 8389.

E-mail addresses: regina.sander@csiro.au (R. Sander), luke.connell@csiro.au (L.D. Connell).

¹ Tel.: +61 3 9545 8352.

external energy requirements). Furthermore, in an environment in which mining related fugitive emissions were to attract penalties, the cost savings as a result of more comprehensive gas recovery and lower residual methane content could be significant. Another advantage is the accelerated gas recovery which can decrease drainage lead times and thus allow for more flexibility in mine development schedules. Even if the business case is negative and there is no safety requirement, there may be other motivations to drain an open cut coal mine prior to mining.

Injectant gases usually considered for ECMM are N₂ or flue gas — a mixture of N₂ and CO₂. The injection of N₂ works in that it strips CH₄ off the coal by lowering the CH₄ partial pressure in the seam. The total pressure within the reservoir is maintained or increased (Puri and Stein, 1989; Puri and Yee, 1990), depending on the injection rate. Thus, production rates may not reduce as during conventional recovery, but could be higher. As the enhancement caused by N₂ injection is not associated with adsorption, the response in production is immediate. However, because of the low affinity to coal, early N₂ breakthrough is generally observed at the production well (Gunter et al., 1999). The injection of CO₂ into coalbed methane reservoirs is often considered for the enhancement of coalbed methane recovery (ECBM) and as a GHG mitigation strategy. The production enhancement generated by CO₂ requires more time to develop than that achieved with N₂. CO₂ has strong sorption characteristics (CO₂ is adsorbed preferentially over CH₄) that tend to retard the flow of CO₂ through the reservoir (Zhu et al., 2003), so that only after a sufficient volume of CH₄ has been displaced does the gas drive become effective and CH₄ productivity increases (White et al., 2005). For ECMM in underground mines the injection of pure CO₂ is not an option as it could lead to higher gas contents in the seam and thus an increased outburst risk. By taking advantage of the sorption characteristics of CO₂ paired with the fast production response generated by N₂, the injection of flue gases into coal seams is expected to delay injectant breakthrough while increasing production enhancement.

In a previous paper (Sander and Connell, 2012) we presented a methodology for the economic assessment of conventional and enhanced mine drainage as a fugitive emission reduction strategy. The economic feasibility of drainage at open cut mines was evaluated for site specific characteristics and operational practices. The approach treated reservoir properties and economic parameters deterministically. This means the outcome of the analysis was only valid for a certain, specific set of parameters and provided no information regarding the likelihood of outcomes. The focus of this work is to demonstrate a methodology that incorporates uncertainty into the assessment of the viability of ECMM and to provide an indication of its commercial potential. The method described in Sander and Connell (2012) is extended by integrating stochastic treatment of the key uncertain variables into the reservoir simulation and the subsequent economic analysis. This approach enables the assignment of confidence levels to specific outcomes which can aid substantially in investment decision making processes as risk becomes quantifiable.

The methodology is demonstrated by means of a case study in which the probabilistic economics of enhanced drainage of eastern Australian open cut mines is evaluated (using data representative of coals from the Sydney Basin, New South Wales and the Bowen Basin, Queensland). The uncertain project parameters are described by probability distributions which are used for Monte Carlo simulation. Monte Carlo simulation is performed as part of the reservoir simulation study as well as the economic analysis. The properties described by probability distributions are permeability, gas content, isotherm properties, CO₂ penalties, electricity prices, and well costs. The injectant gas used for ECMM is flue gas (90% N₂, 10% CO₂). The economic feasibility is assessed relative to the business-as-usual scenario in which the coal is not drained of gas prior to mining. The dependence of the economics on reservoir permeability, the CO₂ penalty, and drainage lead time is investigated in detail and critical values for the uncertain reservoir properties are established.

The critical value is defined as the minimum value of a property below which enhanced drainage is not economic.

2. Methodology

2.1. Probabilistic analysis (Monte Carlo simulation)

The enhanced drainage process is predicted using the program SIMEDWin (Stevenson, 1997), a dual porosity, multi-component, compositional reservoir simulator. SIMEDWin has a Monte Carlo simulation functionality which allows the association of some reservoir parameters with probability distributions. In the Monte Carlo analysis random samples of the specified reservoir parameters are generated which are used in the reservoir simulator to generate realisations of the enhanced drainage process. In combination with samples from probability distributions assigned to economic parameters, realisations of the net present value (NPV) of ECMM are established.

The sensitivity of the predictions to the reservoir properties is an important aspect of the uncertainty analysis. A study was performed to determine the sensitivity of the predicted gas production rate to various reservoir parameters to identify the key parameters. The results of this sensitivity study are presented in Appendix 1. The reservoir properties investigated in the sensitivity study were initial gas content, permeability, CH₄ Langmuir volume and pressure, N₂ Langmuir volume, volumetric swelling strain, Young's Modulus, and Poisson's ratio. As CO₂ only constitutes 10% of the flue gas, the impact of variations in CO₂ Langmuir properties on gas production rates was not further assessed. Furthermore, the sensitivity to porosity was not considered because the Shi–Durucan model is applied to describe the permeability behaviour in the reservoir during gas recovery and injection. The Shi–Durucan model uses geomechanical properties of the coal, such as Young's Modulus and Poisson's ratio, as well as volumetric sorption strain to predict permeability (Shi and Durucan, 2004). The simulated gas production rates were most sensitive to the following reservoir properties and these were included in the treatment of uncertainty

- gas content
- CH₄ adsorption properties (Langmuir volume and pressure)
- permeability

In their deterministic analysis of ECMM at open cut mines, Sander and Connell (2012) found that the economic feasibility was largely determined by the CO₂ penalty and the electricity price. They also demonstrated that well costs were the largest cost component of an ECMM project (except for potential CO₂ penalties). Furthermore, well costs can vary considerably based on reservoir geology, rig availability, economic climate, and other factors. Based on these findings, the economic parameters described by Monte Carlo simulation in this analysis are

- CO₂ penalty
- electricity price
- well costs

To enable meaningful probability distributions to be derived for the reservoir properties, a wide range of data sources were used and encompass data measured predominantly in the Sydney Basin, NSW and the Bowen Basin, QLD. Thus, stochastic treatment of the economics is representative of these regions. The number of realisations for the Monte Carlo simulation is defined as 1000. This is based on a similar analysis performed by Sander (2014) which used 500 simulation runs. The larger number of 1000 runs was selected to ensure representative output distributions are obtained.

The operational scenario to which Monte Carlo simulation is applied is enhanced mine drainage using flue gas injection. Based on an analysis presented in Sander and Connell (2012), the injection of an artificial flue

Download English Version:

<https://daneshyari.com/en/article/1753031>

Download Persian Version:

<https://daneshyari.com/article/1753031>

[Daneshyari.com](https://daneshyari.com)