

Enhanced Gas Drainage from Undersaturated Coalbed Methane Reservoirs

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Keywords: Coal; Methane; Gas; Drainage; Enhancement; Saturation; Permeability.

Abstract

Traditional methods of coal seam gas drainage rely on the use of reservoir pressure reduction to promote gas desorption from the coal matrix. Studies in coal mining gas drainage operations, particularly in coal seams that are deeply undersaturated and have low permeability, found the rate of reservoir pressure reduction was prohibitively slow. In such conditions, lengthy production delays have been experienced while additional gas drainage drilling is undertaken in an attempt to reduce seam gas content below specified threshold limits. Such drilling represents a high additional operating cost and yields low total gas production whilst adversely impacting the mine's gas drainage drilling schedule. In extreme cases known zones of difficult to drain coal are avoided resulting in a loss of potentially recoverable coal and gas reserves.

An alternative method for enhancing coal seam production which does not rely on reservoir pressure reduction has been identified. This method, known as the cyclic inert gas injection method, involving the injection of nitrogen, has potential application in deeply undersaturated and low permeability coal seams enabling seam gas to be removed and permeability increased without the need to reduce reservoir pressure to the critical desorption point. The cyclic inert gas injection method is presented and discussed.

1. Introduction

Gas drainage is an integral part of many underground coal mines with efficient and effective gas management required to support safe and productive mine operations. In gassy mines, such as those operating in the Bulli seam, located in the Southern Sydney Basin, Australia, there has been a reliance on underground to in-seam (UIS) drilling to pre-drain the coal seam to reduce the gas content below prescribed threshold limits ahead of mine development. Figure 1 illustrates a typical UIS drilling pattern showing boreholes drilled in a fan pattern, from an open roadway across a longwall block to drain the adjacent roadway, prior to the development of that roadway.

A detailed investigation was conducted at a Bulli seam mine that had encountered an area of the coal seam that proved extremely difficult to drain. Conventional UIS drainage was generally unsuccessful in reducing the gas content below threshold limits within the available drainage window i.e. the time between completing drilling and planned mining of the area. This resulted in lengthy production delays and increased cost associated with drilling the additional gas drainage boreholes in

an attempt to achieve mining compliance. Ultimately the mine plan was revised to exclude the area of difficult-to-drain coal which amounted to shortening all of the planned future longwall panels reducing the mine's planned recoverable coal reserves by 3.0 million tonnes.

Throughout the mine, regardless of location, gas production from UIS boreholes was highly variable, as indicated in Figure 2, with 45% of 279 boreholes achieving less than 100,000 m³ total gas production.

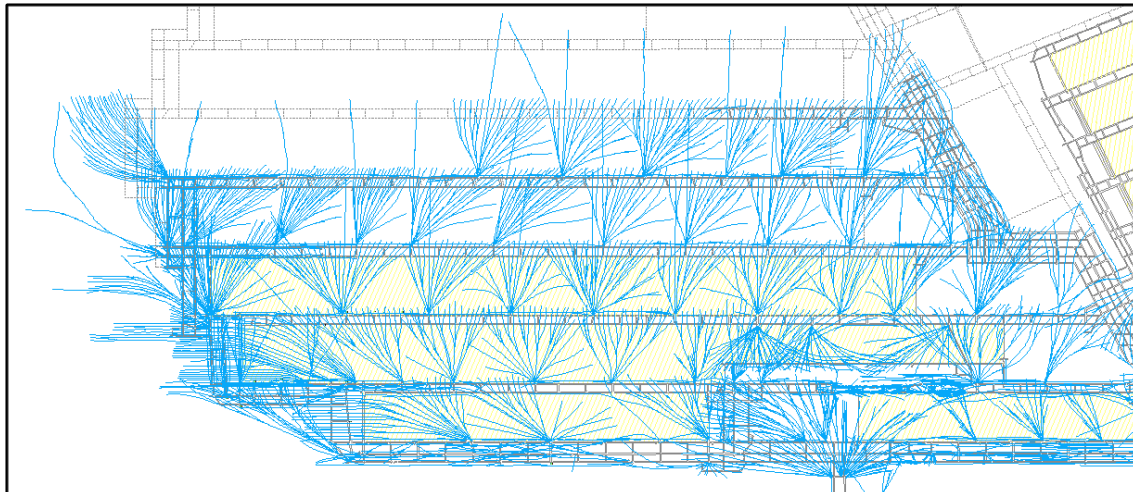


Figure 1: Typical drilling pattern used for pre-mining gas drainage of the Bulli seam.

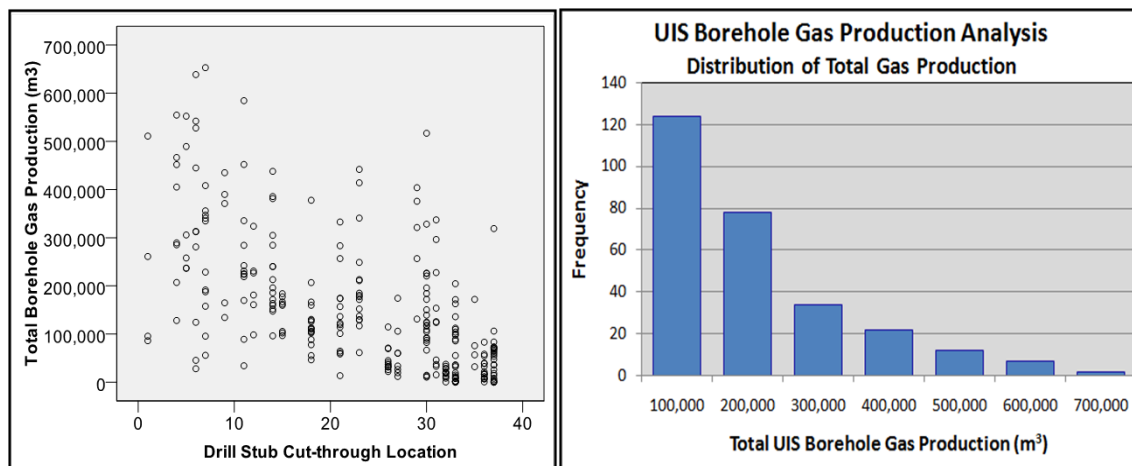


Figure 2: Distribution of total gas production from 279 UIS Bulli seam pre-drainage boreholes.

With the continual increase in production capacity of modern mining machinery the available drainage window is reducing, placing increased pressure on UIS gas drainage methods to achieve optimum performance. Sub-optimal gas production is therefore unsustainable in modern high capacity longwall mines. However the mechanisms that control and influence coal seam gas drainage are generally not well understood which is the reason why many coal mine gas drainage programs achieve less than optimum performance. A variety of geological properties and operational factors were investigated to determine the relative impact on gas production performance from UIS boreholes used to pre-drain the Bulli seam at this mine (Black and Aziz, 2010). Geological factors, in particular the total gas in place and degree of saturation (DoS) along with permeability were indicated to have a dominant impact on gas drainage effectiveness, with gas drainage found to be most difficult from deeply undersaturated and low permeability coal. The prevailing geological conditions tend to cap total gas drainage potential while the operational factors, such as drainage time and borehole

orientation to cleat and stress, were found to affect the ability of coal seam gas drainage programs to achieve the potential maximum gas production performance. Figure 3 shows reasonably strong correlations between (a) total gas production and total gas in place and (b) total gas production to day 50 relative to degree of saturation.

Surface-based gas drainage has significant potential to assist in the drainage of gas ahead of mining. Techniques such as vertical hydraulically fractured wells and medium-radius drilling (MRD) are becoming more common.

Conventional gas drainage methods do however rely on decreasing reservoir pressure to stimulate gas desorption in accordance with the sorption isotherm condition for the given coal / gas mix (Durucan and Shi, 2009), as indicated in Figure 4. Such methods, although relatively simple are not efficient as reduction in reservoir pressure also corresponds to a reduction in the rate of gas production from the borehole (Puri and Stein, 1989). Total coal seam gas production using conventional pressure depletion methods rarely achieve greater than 50% recovery of the initial sorbed gas volume (Stevenson *et al.*, 1993).

New drainage methods must therefore be identified and developed to support continued safe and productive underground coal mine operations.

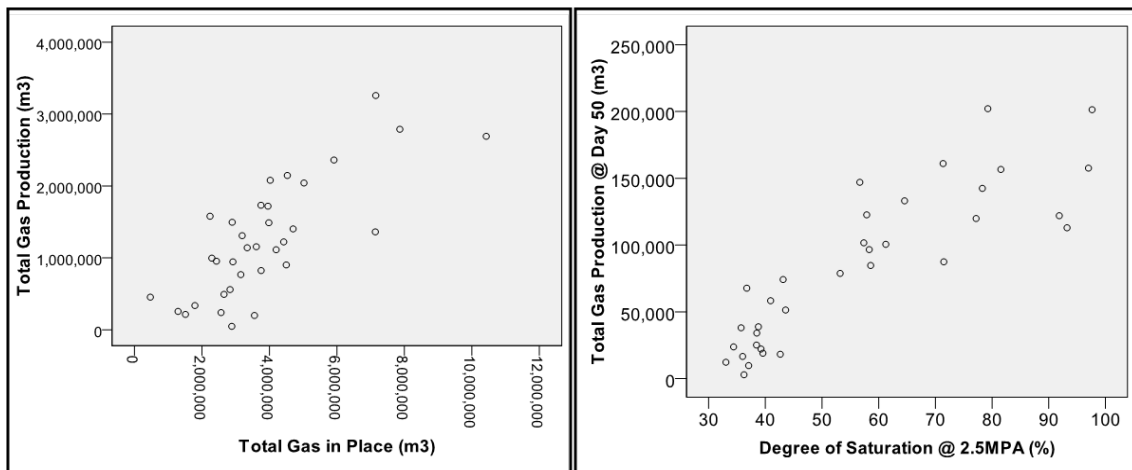


Figure 3: Total gas production relative to total gas in place and degree of saturation.

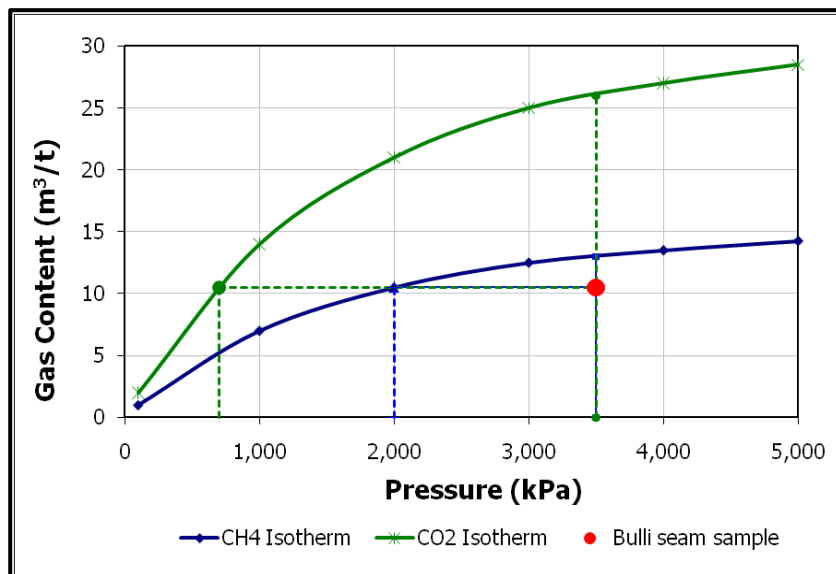


Figure 4: Typical Bulli seam gas content and reservoir pressure condition relative to CH4 and CO2 isotherms

2. Enhanced Coalbed Methane Drainage

Enhanced coalbed methane (ECBM) is a drainage enhancement technique that involves the injection of an inert gas, typically CO₂ and/or N₂, into a coal seam to stimulate gas desorption and increase total coal seam gas production (Stevenson *et al.*, 1993 and Durucan and Shi, 2009). The use of ECBM to enhance coal seam gas production was first trialled in 1993 in a small scale N₂-ECBM pilot project in the Fruitland formation, San Juan Basin and CO₂-ECBM pilot project in the Manville formation, Alberta (Ham and Kantzas, 2008 and Saghafi, 2009). A typical ECBM drilling pattern consists of a central gas injection borehole surrounded by a number of dedicated gas production boreholes, used to extract the seam gas / injected gas mixture from the coal seam.

The injection of CO₂ or N₂ into the coal seam, referred to as inert gas stripping, reduces the partial pressure of CH₄ in the free gas phase stimulating the desorption of CH₄ from the coal matrix (Brown *et al.*, 1996 and Durucan and Shi, 2009). The movement of gas through the coal seam 'sweeps' the desorbed seam gas toward the production borehole(s).

The effectiveness of ECBM is highly dependent on prevailing geological conditions, the properties of the coal seam gas reservoir, the layout of the injection and production boreholes and the design of the injection program. To be effective the injected inert gas must be in contact with the coal matrix for sufficient time to stimulate desorption and sweep seam gas from a large area of the coal seam. In cases where the face cleat and geological structures align sub-parallel to the path between the injection and production boreholes the injected gas is more likely to take a direct path toward the production borehole resulting in low sweep efficiency and reduced effectiveness of the ECBM method.

The concept of injecting CO₂ through an injection borehole into a coal seam, at a pressure greater than reservoir pressure and less than fracture initiation pressure, to promote CH₄ desorption into the injected fluid, with the CO₂/CH₄ gas mix being extracted through separate production wells was first introduced in the mid-1970's (Every and Dell'Osso, 1977). The injection of other inert gases such as N₂, He, Ar and air into the coal seam through a dedicated injection to strip and remove CH₄ through separate production boreholes without reducing reservoir pressure was proposed by Puri and Stein (1989). Prior to the development of the coalbed methane industry a similar technique involving the injection of heated gases into oil sand strata to increase oil production from adjacent well was proposed by Steffen (1948).

Battino and Hargraves (1982) suggested the use of inert gas injection to enhance UIS pre-drainage performance through injection of compressed air into CO₂ rich coal and N₂ into CH₄ rich coal through a central borehole to accelerate gas production from adjacent producer boreholes.

As coal has a strong affinity for CO₂ adsorption some of the CO₂ injected into the coal seam during CO₂-ECBM will compete with CH₄ for sorption sites displacing CH₄ from the coal matrix (Mazumder and Wolf, 2008). The process of CO₂ adsorption does however induce swelling of the coal matrix which can reduce permeability and have a detrimental impact on the ability to inject additional gas into the coal seam. During CO₂-ECBM at the Allison Unit pilot project in the San Juan Basin a reduction in permeability of more than two orders of magnitude was experienced as a result of sorption induced swelling (Durucan and Shi, 2009).

N₂ is considered a superior gas for use in ECBM injection for methane production as it achieves greater sweep efficiency and is less likely to induce sorption related permeability reduction (Oudinot *et al.*, 2007 and Durucan and Shi, 2009). Injection of N₂ following CO₂ at the Tiffany ECBM pilot in the San Juan basin not only reversed the permeability reduction caused by the previous CO₂ injection but enhanced the rate of N₂ injection into the coal seam (Oudinot *et al.*, 2007 and Durucan and Shi, 2009).

Injecting gas into the formation at elevated temperature has been reported to have a positive effect in increasing gas desorption and total gas production through ECBM, stimulating the movement of gas molecules and reducing the sorption capacity of coal (Every and Dell’Osso, 1977; Puri and Stein, 1989 and Levine, 1992).

3. Cyclic Inert Gas Injection

A modified technique to enhance gas production from coal is proposed. The technique, known as cyclic inert gas injection (CIGI), builds on ECBM and incorporates aspects of past research to offer increased total gas production and permeability enhancement (Black *et al.*, 2010). CIGI involves injecting a heated inert gas, such as N₂, into a coal seam through a dual purpose injection-production borehole at a pressure greater than reservoir pressure and less than fracture initiation pressure to penetrate the cleat and flood the coal structure surrounding the injection borehole. Upon completion of the injection phase the borehole is shut-in for a period to encourage desorption of CH₄ from the coal matrix. After sufficient hold time the borehole is opened to produce a mixture of desorbed CH₄ and inert gas. The cycle of inject-hold-produce is repeated multiple times, each cycle increasing the total area affected by the stimulation treatment. Figure 5 illustrates the major components of a CIGI project and the progressive increase in volume of coal treated during a five cycle coal seam stimulation treatment.

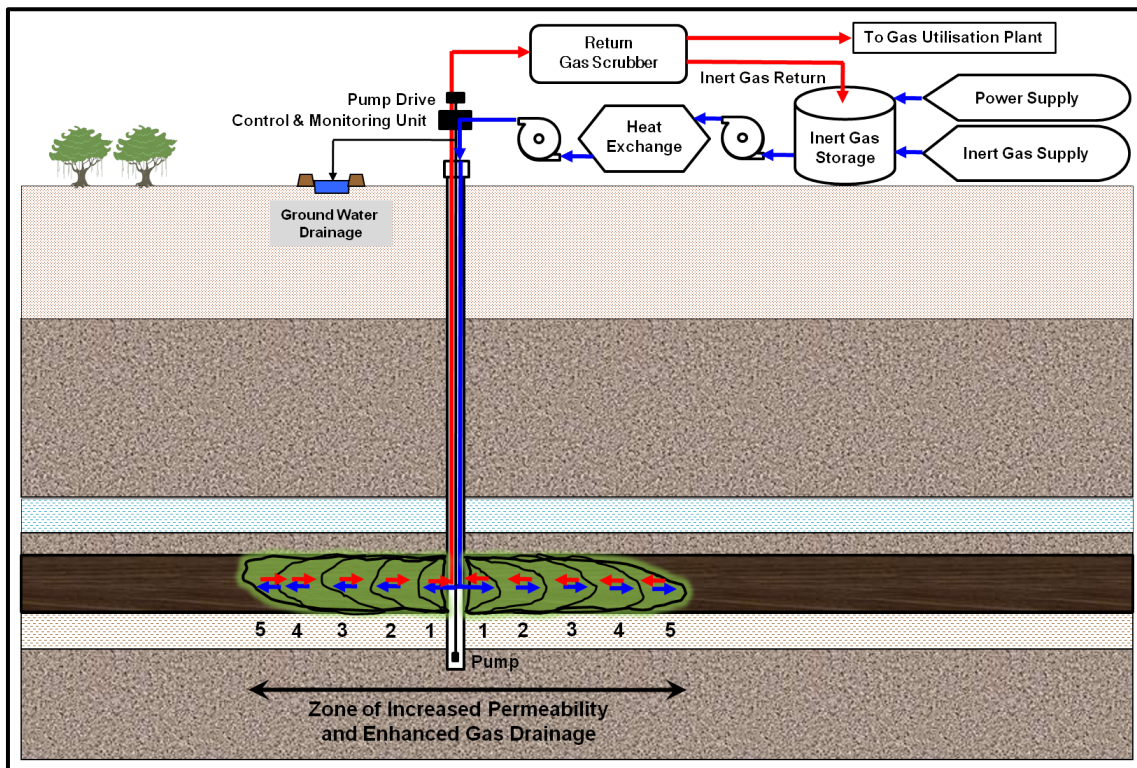


Figure 5 – Illustration of the Cyclic Inert Gas Injection Process to enhance coal seam gas drainage

The individual aspects of the CIGI method that in combination deliver a potentially superior ECBM treatment to stimulate coal seam gas production are listed below:

- Gas injection into the coal seam at a pressure greater than reservoir pressure and less than fracture initiation pressure forces inert gas into the coal seam, opening the cleat and penetrating deep into the formation;
- The presence of fractures and geological discontinuities are not detrimental as they provide additional paths for inert gas penetration into the coal seam;
- Reduced partial pressure of the inert gas within the cleat and fracture network of the coal promotes CH₄ desorption from the coal matrix;
- Heat transfer from injected gas increases the temperature of the coal seam, energising the CH₄ gas molecules and increasing the rate of movement out of the coal matrix;
- Increasing the temperature reduces the sorption capacity of coal which in turn increases the relative degree of saturation of the CH₄ / inert gas mix.
- The sorption isotherm of a CH₄/N₂ gas mix is lower than for pure CH₄, therefore for a given gas content, injecting N₂ will also serve to increase the relative degree of saturation; and
- During the gas production phase a reduction in pressure within the cleat and fracture network will cause the coal matrix to swell having an adverse effect on permeability. However this effect will be counteracted by the matrix shrinkage resulting from CH₄ desorption. After having been subjected to multiple inject-hold-produce cycles the CH₄ content is expected to have been substantially reduced and the resulting shrinkage of the coal matrix will deliver a net increase in effective permeability.

Recent laboratory studies at the University of Wollongong (UoW) examined the effect of displacing adsorbed gases in coal using N₂ injection. The work involved injection of N₂ into coal samples saturated with binary CO₂/CH₄ gas in a high pressure triaxial gas chamber to a pressure of 3.0 MPa. Results indicate the injection of N₂ caused both gases to be displaced from coal, with a 20% increase in CH₄ production. The study also recorded strain changes occurring both perpendicular and parallel to coal layering/bedding, with potential to increase coal permeability.

Given the relatively high cost and potentially limited availability of sufficient quantities of pure N₂, alternatives such as compressed air (78% N₂) are being considered as a low cost, readily available alternative gas for use in the CIGI treatment.

The next stage in the development of the CIGI technique is to conduct a field demonstration in a suitably undersaturated, low permeability coal seam to quantify the degree of gas production and permeability enhancement able to be achieved and to quantify and refine the treatment parameters.

The CIGI technique has the potential to significantly enhance gas production, particularly from coal seams that have low permeability and are deeply undersaturated in gas, offering the following benefits:

- Increased coal seam gas extraction prior to mining, which can be efficiently treated or utilised, thereby reducing the total annual greenhouse gas emission (MtCO_{2-e}) from mine operations; and
- Reduced residual gas content of coal to minimal level limits, thereby reducing inherent safety risks associated with elevated seam gas emission during mining such as outburst, explosion and fire and the management of high concentrations of ventilation air methane (VAM).

4. Conclusion

There are many factors, both controllable and uncontrollable, that impact the ability of mine operators to drain coal seam gas to reduce gas content prior to mining. A detailed study conducted at an operating Bulli seam coal mine investigated the impact of various geological properties and operating factors on coal seam gas drainage. Geological properties were found to have a controlling impact on gas production potential while operating factors impacted the ability of the gas drainage

program to achieve optimum performance within the constraints imposed by the prevailing geological properties.

Gas drainage was found to be particularly difficult from coal with low permeability and undersaturated in gas. In such conditions conventional UIS and surface-based drainage methods that rely on reservoir pressure reduction to promote gas desorption achieve low productivity and may be incapable of achieving sufficient gas content reduction within the available drainage time.

A new technique to enhance coal seam gas production is proposed which involves the cyclic injection of an inert gas into the coal seam through a common injection/production borehole. The use of a single dual-purpose (injection/production) well eliminates the risk of bypass and low sweep efficiency that exists with conventional ECBM methods. The proposed cyclic inert gas injection technique utilises a combination of three independently proven processes (i) matrix swelling and shrinkage in response to adsorption/desorption, (ii) gas diffusion from the coal matrix in response to gas concentration gradient, and (iii) gas flow from the treated coal seam to the injection/production well due to pressure gradient upon completion of each *inject-hold-release* cycle. Cyclic inert gas injection proposes to increase the *in situ* gas condition, raising the mixed gas content and gas pressure, thereby raising the energy state of the seam gas surrounding the injection borehole. Through injection of inert gas, such as N₂, the isotherm of the mixed gas would be reduced while the gas content (mixed gas) increased, thereby increasing the degree of saturation and reducing the reservoir pressure reduction required to reach the critical desorption point on the isotherm.

It is expected that cyclic inert gas injection has the potential to become an integral part of coal mine pre-drainage programs offering potentially significant improvement to gas drainage performance from gassy and low permeability seams.

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