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Improving UIS gas drainage in underground coal mines

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IMPROVING UIS GAS DRAINAGE IN UNDERGROUND COAL MINES

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ABSTRACT: Gas drainage is considered one of the most effective controls in preventing coal and gas outbursts. The advances in mining equipment technology over the last 20 years have led to a significant increase in coal mine production, resulting in increased coal mine gas emission during the coal extraction process. High gas emissions, if not effectively managed, may exceed the diluting capability of the mine's ventilation system, potentially exceeding the statutory limit, resulting in gas related production delays. The development of underground to inseam (UIS) gas drainage is discussed. The study is focused on a range of factors which impact gas drainage and proposes actions to improve drainage performance.

INTRODUCTION

Many Australian underground coal mines are progressing toward areas which require the use of gas drainage to reduce seam gas concentrations to below a prescribed Threshold Limit Value (TLV). In a number of cases, these mines will encounter areas where the gas is extremely difficult to drain from the coal, ahead of mining. Where difficult drainage areas are encountered, the mines may be faced with significant production delays while intensive drilling is carried out to reduce the gas concentrations to acceptable levels. To avoid such costly delays, mine management may choose to avoid the area completely, resulting in loss of reserves, loss of potential revenue and ultimately reduced mine life.

This project aims, through an integrated series of site based and laboratory studies to determine the relative impact and significance of a broad range of 'factors' which impact gas drainage in underground mines. A further aspect of this study involves the assessment of a range of actions, based on knowledge of the factors identified in the early stage of the project, which can be taken by the mine operator to improve gas drainage performance, enabling the potentially sterilised areas to be accessed and extracted.

BACKGROUND

This study focuses on gas drainage experience in the Bulli seam which is located in the southern Sydney Basin in New South Wales, Australia. The seam is stratigraphically the uppermost coal seam in the Permian Illawarra Coal Measures. The depth of cover, in the area of study is in the order of 450 to 500 metres with a regional dip of approximately 1.9 degrees, toward the west. The gas composition in the mining domain is variable, ranging from almost pure CH_4 in the east to almost pure CO_2 in the west. Table 1 contains details of the range of coal properties investigated, which are characteristic of the mining area investigated, known as Mine A.

Table 1 - Coal properties investigated in the mining area analysis

Coal Property	Minimum	Maximum
CH4 ratio (CH_4/CH_4+CO_2)	6.5%	97.8%
Gas Content (m^3/t)	5.2 m^3/t	15.72 m^3/t
Permeability (mD)	0.05 mD	6 mD
Seam thickness (m)	2.33 m	3.19 m
Ash content (%)	9.4 %	14.8 %
Moisture content (%)	0.7 %	1.3%
Vitrinite reflectance ($R_{v(max)}$)	1.23	1.36
Vitrinite (%)	28.9%	54.5%
Inertinite (%)	45.51%	71.1%
Mineral matter	1.8%	5.78%
Volatile matter	19.7%	25.25%

The Bulli seam is extremely prone to the occurrence of coal and gas outbursts. During the history of mining in the Bulli seam there have been 12 reported fatalities associated with outbursts, listed in Table 2.

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Table 2 - Fatal outbursts in the Bulli seam (source, Harvey and Singh, 1998)

COLLIERY	DATE	No. KILLED	SIZE (tonnes)	GAS	STRUCTURE
Metropolitan	10 June 1896	3	Unknown	CH4	Dyke and soft fault
Metropolitan	27 July 1926	2	140	CO_2	Fault with 5m throw
Metropolitan	2 December 1954	2	90	CO_2	Normal fault with 0.3m throw
Tahmoor	24 June 1985	1	400	CO_2	Dyke associated with strike-slip movement
South Bulli	25 July 1991	3	300	CO_2 & CH_4	Thrust fault with 0.35m of mylonitic coal and very high gas pressure
West Cliff	25 January 1994	1	350	CO_2	Intersection of 2 strike-slip structures and 0.3m of mylonitic coal

The most effective method of preventing an outburst is through the reduction of seam gas content and gas pressure, Lama (1980), Marshall, Lama and Tomlinson (1982) and Wood (1983). Over the years, many different approaches have been undertaken, by various mine operators, to reduce gas levels and pressures to manageable levels with mixed success.

However, the current advanced gas drainage technology is proving the most effective, Clark et al. (1983). Prior to 1980, gas drainage was achieved through drilling relatively short holes, typically 25 to 40 metres ahead of the working face, using primarily hand-held borers to drill holes of varying diameters, ranging from 43 mm to 100 mm, without any applied suction (Hargraves, 1983). Through advances in equipment technology increased coal production was achieved, however this also resulted in increased gas emissions into the mine airways. In order to prevent these gas emissions from exceeding the diluting capability of the mine's ventilation system, regular, efficient gas drainage programs were required to reduce the gas content of the coal prior to mining, in addition to reducing the outburst risk.

In 1980, West Cliff Colliery commenced the first routine pre-drainage drilling and gas drainage program, ahead of mining. Since the commencement of underground to inseam (UIS) drilling the equipment has evolved from simple rotary drilling rigs with directional control accuracy of $\pm 15^{o}$ for hole lengths of 400- 600 m (Hebblewhite et al., 1982, Hebblewhite et al., 1983 and Kelly 1983) to technically advanced units incorporating down-hole motors, with in-hole data acquisition tools, capable of drilling distances beyond 1,600 metres with survey accuracy in the order of $\pm 0.5^{o}$ azimuth and $\pm 0.2^{o}$ pitch (Valley Longwall Drilling).

Although aware of the relationship between gas and outburst risk, and the impact of gas drainage on reducing this risk, many operators failed to implement systems to regularly check and assess the outburst risk ahead of future workings.

Following the investigation into the last fatal outburst, which occurred in the Bulli seam at West Cliff Colliery on 25 January 1994, a directive was issued to all Bulli seam coal mine operators, under the authority of the Coal Mines Regulation Act 1982, prescribing threshold limit values (TLV), and other actions, to be implemented to manage risk and prevent future coal and gas outbursts. The Department of Mineral Resources, New South Wales, introduced The Outburst Mining Guideline, MDG 1004, in 1995, which led to the development and implementation of Outburst Management Plans, as part of the mine safety management system. Intensive UIS drilling programs are used to collect coal cores for gas content testing, identify structures ahead of the mine workings, as well as draining gas to below the TLV.

The outburst threshold limit graph which is typical of those introduced at each of the Bulli seam mines, and now forms an integral part of Outburst Management Plans (Figure 1), specifies maximum gas content to which the seam must be drained before approval may be given to mine the area. Given the high gas content throughout the Bulli seam, the introduction of the TLV graph has led to the development and implementation of intensive pre-drainage drilling programs aimed at reducing seam gas contents to below the applicable TLV, to avoid delays to the roadway development and longwall operations.

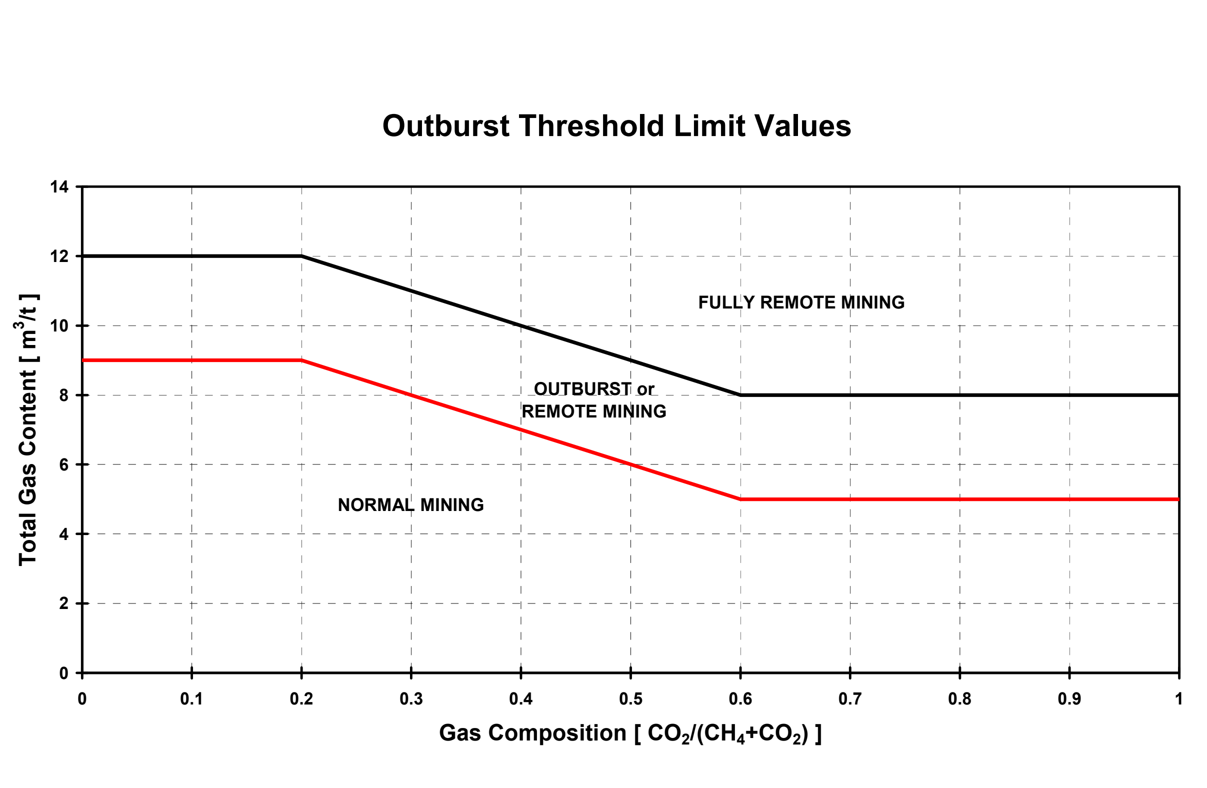

Figure 1 - Typical outburst Threshold Limit Value (TLV) graph

Many of the Bulli seam mines now employ extensive gas drainage programs with greater than 100,000 metres of underground to inseam (UIS) pre-drainage boreholes being drilled annually. However, even with the application of such intensive UIS drilling, there are a number of mining areas, past, present and future, which will experience difficulty reducing the gas content to below the TLV. This poor drainage is caused by a variety of geological conditions and operational factors which adversely impact drainage performance.

A number of inter-related projects are now being undertaken at the University of Wollongong to quantify the factors that impact gas drainage and to evaluate suitable drainage improvement initiatives that mat be implemented by mine operators to address the poor drainage zones.

Project Outline & Objectives

The objective of this project is to develop an understanding of the factors which impact gas drainage and to determine suitable actions that may be implemented to successfully treat the identified difficult drainage zones, ahead of mining, enabling these zones to be accessed and extracted, without incurring any unacceptable gas drainage related production delays. The process to achieve this objective, summarised in Figure 2, involves both site-based and laboratory testing and analysis. The initial work programme focussed on determining the factors which have most impact on gas drainage, based on the collection and analysis of the following:

- gas flow data from UIS drill holes;
- coal core gas and quality data; and
- collect and test coal samples to determine properties and characteristics.

The second phase involves the investigation, evaluation and possible trial of a range of potential drainage improvement techniques, to improve gas drainage effectiveness.

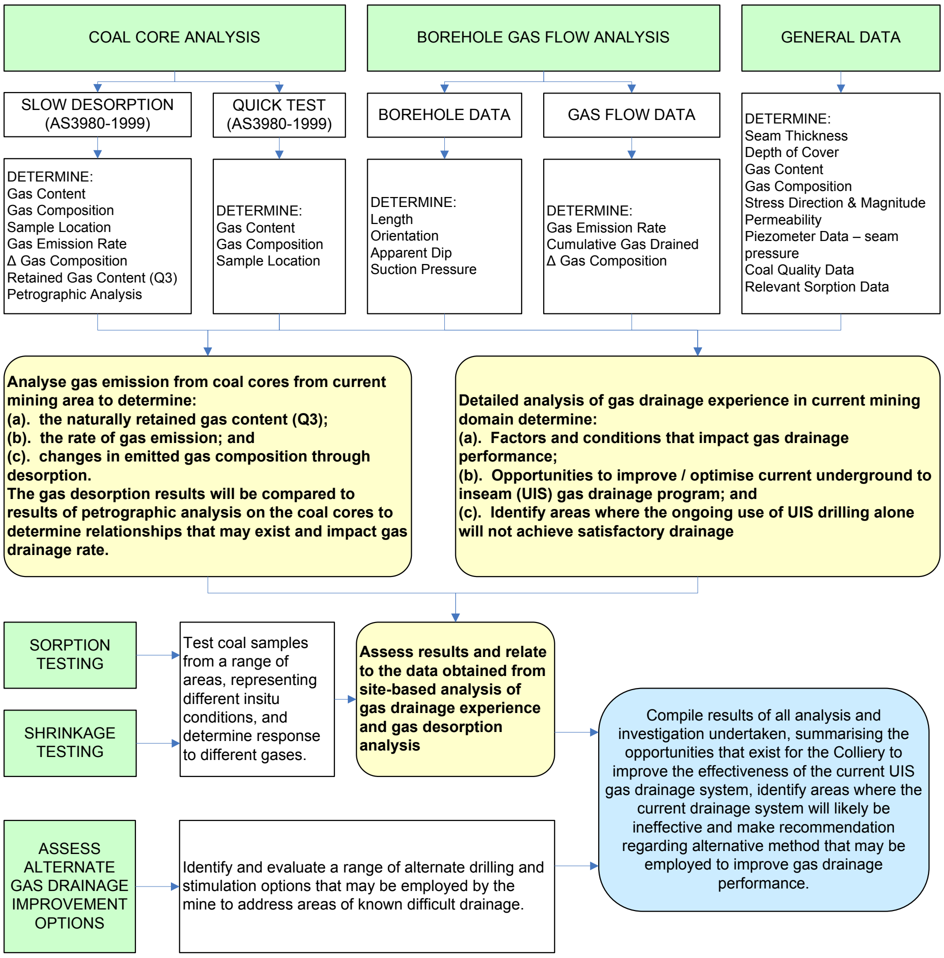

Figure 2 - Project flowchart

Mine Site Analysis

Gas flow data has been collected from 306 UIS boreholes, covering an area which encompasses four separate longwall panels in a local mine (Mine A). The location of the boreholes and coal cores analysed during this study are shown in Figure 3.

A review of the entire dataset identified that 118 holes (38.5 % of the total holes) were compromised in some way, either through blockage or flooding, overlapping with adjacent boreholes, or very short life. These holes were excluded from the dataset as the flow data was deemed to be questionable and not representative of reasonable conditions. Gas flow data from the remaining 188 boreholes form the basis of the analysis. Table 3 lists the panels and number of boreholes from each which were included in the overall borehole flow analysis.

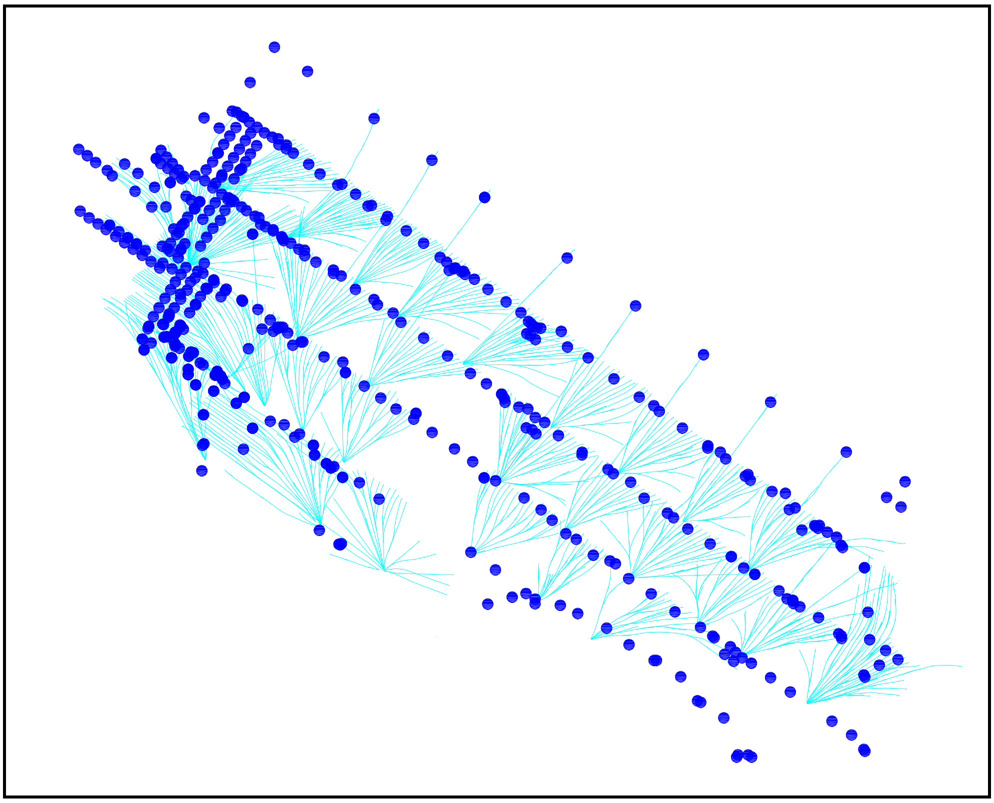

Figure 3 - UIS borehole and coal core locations analysed (Mine A)

Table 3 - Borehole number and location analysed in Mine A

UIS Borehole Gas Flow Analysis Time on Suction	PANEL											
	516		517		518		519		520		TOTAL	
	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%
Drill Stubs Recorded	3		8		11		10		1		33	
Total holes in drill stub	33		68		117		84		4		306	
No. holes <100 days	14	42.4%	17	25.0%	20	17.1%	0	0.0%	0	0.0%	51	16.7%
No. holes <50 days	8	24.2%	14	20.6%	12	10.3%	0	0.0%	0	0.0%	34	11.1%
Total holes included in analysis (after short life holes {<30 days}, obvious failed holes {blocked & flooded} and overlapping holes removed from dataset)	**13**	39.4%	**39**	57.4%	**67**	57.3%	**69**	82.1%	**0**	0.0%	188	61.4%

Figure 4 shows the distribution of total gas production of all 188 boreholes included in the dataset.

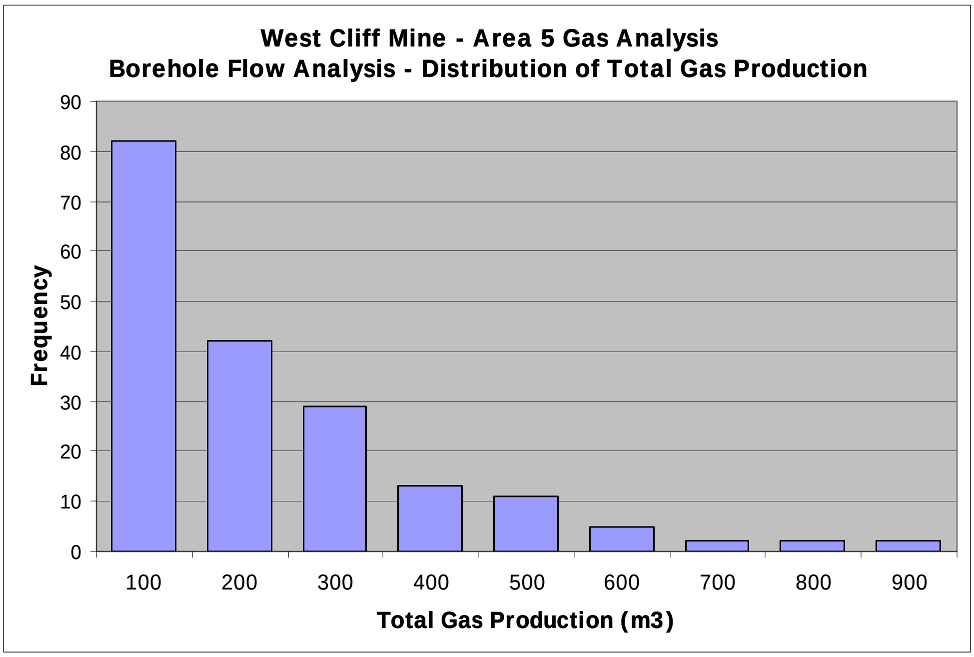

Figure 4 - Distribution of total gas production from UIS boreholes

Table 4 lists the variables which were considered to have an impact on total gas production.

Table 4 - Factors initially considered to impact gas drainage

Borehole length	Seam thickness
Borehole orientation to cleat (100/280)	Moisture content
Borehole orientation to stress	Reflectance Rv(max)
Borehole apparent dip	Permeability (mD)
Gas content (m3/t)	Ash content
Gas composition (%CH4)	Intertinite component
Time on suction (days)	Vitrinite component
Suction pressure (kPa) - median	Mineral component

RESULTS AND DISCUSSION

A detailed statistical analysis was performed on the dataset from which the correlations, shown in Table 5, were determined. The table is split into the factors which are considered naturally occurring and therefore not controllable and those on the right which the operator has a certain degree of control over.

Table 5 - Statistical correlation results from complete dataset analysis

Factor assessed for correlation	R^2	Factor assessed for correlation	R^2
Gas composition (%CH4)	42	Time on suction (days)	18
Gas content (m3/t)	32	Suction pressure (kPa) - median	10.2
Seam thickness	25	Borehole orientation to stress	6
Permeability (mD)	19	Borehole length	3.9
Reflectance Rv(max)	17	Borehole orientation to cleat (100/280)	1.1
Intertinite component	17	Borehole apparent dip	0
Vitrinite component	16		
Mineral component	8		
Ash content	6		

Note: R^2 represents the percentage variation of the variable relative to the regression model for the dataset. The higher the R^2, the better the regression model fits the data.

Using statistical analysis, virtually no correlation was found between total gas production and the following variables; borehole orientation to cleat, borehole orientation to stress, and apparent dip, yet a review of the data distribution indicated ranges where greater gas production was achieved. Figure 5 shows the distribution of gas production data for these three variables.

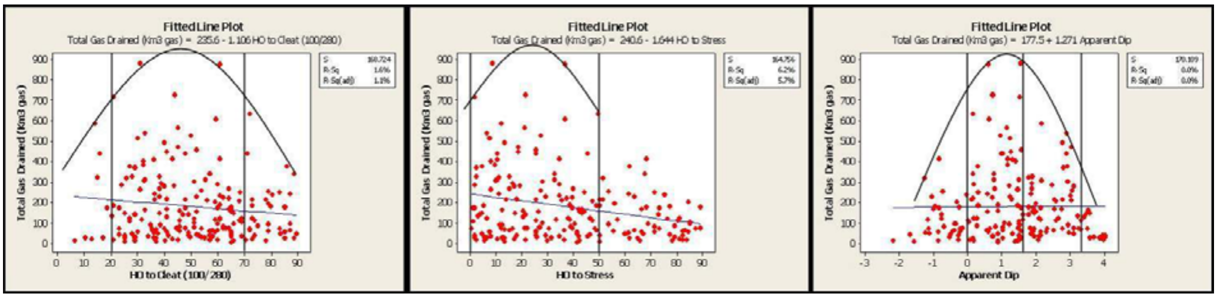

Figure 5: -Gas production data distribution relative to borehole orientation and apparent dip

The dataset was refined to include only those meeting all three of the criteria listed below. Further analysis was undertaken on the refined dataset to include:

- Borehole orientation to cleat (100/280) – 20 to 70 degrees;
- Borehole orientation to stress – 0 to 50 degrees; and
- Borehole apparent dip – 0 to +1.6 degrees.

Table 6 shows the results of the statistical analysis on the dataset which satisfied the above listed criteria.

Table 6 - Correlation results for data fitting borehole orientation and apparent dip criteria

Factor assessed for correlation	R^2	Factor assessed for correlation	R^2
Gas content (m3/t)	30.0	Time on suction (days)	32.0
Gas composition (%CH4)	29.0	Borehole length	2.0
Reflectance Rv(max)	20.9	Suction pressure (kPa) - median	1.8
Seam thickness	20.8	*Borehole orientation to stress*	*0.0*
Permeability (mD)	13.7	*Borehole orientation to cleat (100/280)*	*0.0*
Mineral component	10.6	*Borehole apparent dip*	*0.0*
Intertinite component	5.9		
Moisture content	5.8		
Ash content	5.7		
Vitrinite component	5.2		

Note: R^2 represents the percentage variation of the variable relative to the regression model for the dataset. The higher the R^2, the better the regression model fits the data.

As expected, there was no correlation between gas production and the three variables used to refine the dataset. The controllable variable, 'time on suction', maintained the strongest correlation with total gas production.

Given the relatively narrow range of apparent dip (0 to +1.6 degrees) the dataset was expanded to cover an increased apparent dip range, considered to provide greater flexibility for mine site deployment. The results of the statistical analysis on the dataset satisfying the criteria, listed below, are provided in Table 7.

- Borehole orientation to cleat (100/280) – 20 to 70 degrees
- Borehole orientation to stress – 0 to 50 degrees; and
- Borehole apparent dip – 0 to +3.25 degrees.

Table 7 - Correlation results for data fitting borehole orientation and apparent dip criteria

Factor assessed for correlation	R^2	Factor assessed for correlation	R^2
Gas composition (%CH4)	33.0	Time on suction (days)	20.0
Gas content (m3/t)	30.0	Borehole length	6.7
Reflectance Rv(max)	21.0	*Borehole apparent dip*	*3.0*
Seam thickness	21.0	Suction pressure (kPa) - median	2.0
Permeability (mD)	14.0	*Borehole orientation to stress*	*1.3*
Mineral component	11.0	*Borehole orientation to cleat (100/280)*	*1.0*
Intertinite component	6.0		
Ash content	6.0		
Moisture content	5.0		
Vitrinite component	5.0		

Note: R^2 represents the percentage variation of the variable relative to the regression model for the dataset. The higher the R^2, the better the regression model fits the data.

The results show the controllable variable, 'time on suction', continues to maintain the strongest correlation with total gas production.

As shown in the results of the statistical analysis above, of all the non-controllable factors considered, both gas composition and gas content have the strongest correlation with total gas production. Figure 7 shows the distribution of total gas production relative to both gas composition and gas content.

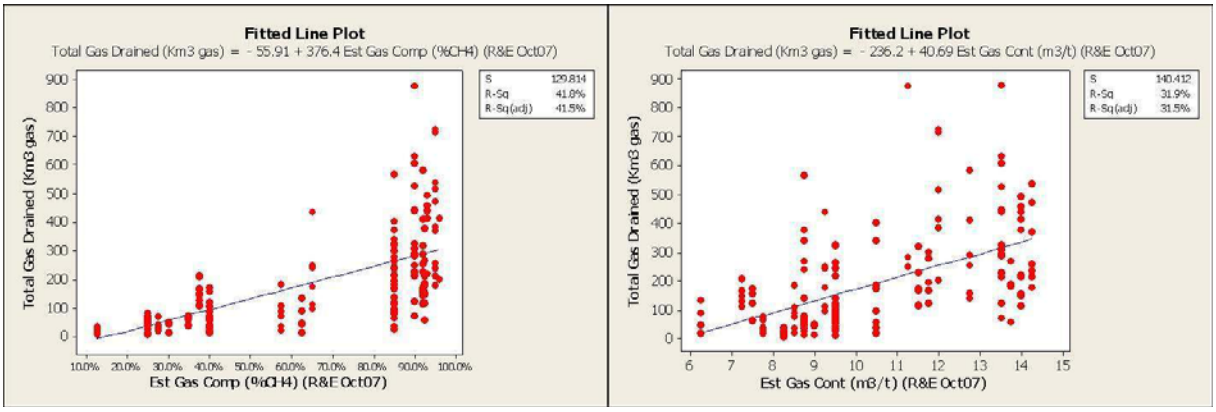

Figure 7 - Distribution of gas production data relative to gas composition and content

Although both graphs show increasing total gas production with increasing composition and content, the gas composition appears to be the most dominant. In areas where CO_2 is the dominant gas, the total gas production is generally low, typically less than 200,000 m^3. In the areas where CH_4 is the dominant gas, far greater total gas production is achieved, particularly where the CH_4 composition is greater than 80%. It must however be recognised that although it is possible to achieve very high gas production in the high CH_4 zones, there are also a significant number of very poor producing boreholes.

The dataset was refined on the basis of boreholes whose gas composition ranged between 0 and 40 % CH_4. Table 8 shows the results of the statistical analysis on this dataset. It can be seen that 'time on suction' continues to maintain the strongest correlation to total gas production of all the controllable factors considered. Suction pressure also has a far greater correlation to total gas production in the high CO_2 zones.
The results also show increased correlation between a number of the non-controllable factors and total gas production, in particular 'permeability' and 'moisture content'.

Table 8 - Correlation results for data fitting the high CO_2 criteria (0–40% CH_4)

Factor assessed for correlation	R^2	Factor assessed for correlation	R^2
Permeability (mD)	77.0	Time on suction (days)	54.0
Gas composition (%CH4)	43.0	Suction pressure (kPa) - median	42.0
Moisture content	36.0	Borehole apparent dip	9.0
Mineral component	26.0	Borehole length	0.0
Gas content (m3/t)	22.0	Borehole orientation to stress	0.0
Vitrinite component	21.0	Borehole orientation to cleat (100/280)	0.0
Reflectance Rv(max)	20.0		
Seam thickness	16.0		
Intertinite component	13.0		
Ash content	5.0		

Note: R^2 represents the percentage variation of the variable relative to the regression model for the dataset. The higher the R^2, the better the regression model fits the data.

A similar analysis was conducted on a refined dataset covering all borehole data within the gas composition range of 70 to 100 % CH_4. Table 9 shows the results of the statistical analysis on this dataset. Similar to the previous analysis, 'time on suction' continues to maintain the strongest correlation to total gas production of all the controllable variables considered. There is generally low correlation between all of the non-controllable factors and total gas production which is due to the high degree of variability in the total gas production of the boreholes in the high CH_4 zones.

Table 9 - Correlation results for data fitting the high CH_4 criteria (70–100% CH_4)

Factor assessed for correlation	R^2	Factor assessed for correlation	R^2
Gas composition (%CH4)	8.0	Time on suction (days)	29.0
Reflectance Rv(max)	8.0	Borehole orientation to stress	14.0
Moisture content	6.3	Borehole orientation to cleat (100/280)	12.0
Gas content (m3/t)	4.2	Borehole apparent dip	2.0
Seam thickness	0.6	Suction pressure (kPa) - median	1.0
Permeability (mD)	0.0	Borehole length	0.0
Mineral component	0.0		
Vitrinite component	0.0		
Intertinite component	0.0		
Ash content	0.0		

Note: R^2 represents the percentage variation of the variable relative to the regression model for the dataset. The higher the R^2, the better the regression model fits the data.

Capability assessment was then undertaken to determine statistically the impact on total gas production which may be expected through optimising the UIS gas drainage program, based on the results of the gas data analysis. The two areas where improvement and optimisation were considered possible are:

- Borehole orientation; and
- Gas drainage system maintenance.

As discussed previously, the gas production data indicates an optimum borehole trajectory exists in relation to cleat direction, stress direction and apparent dip. Statistical capability analysis determined that a 54.88 % increase in average total gas production may be achieved by maintaining all UIS boreholes to within the following criteria:

- Borehole orientation to cleat (100/280) – 20 to 70 degrees
- Borehole orientation to stress – 0 to 50 degrees; and
- Borehole apparent dip – 0 to +1.6 degrees.

Where the range of the apparent dip is increased to cover the range 0 to 3.25 degrees the capability assessment concluded that a 26.34 % increase in average total gas production may be achieved. Also, some 82 boreholes (26.8 % of the total boreholes), achieved low total gas production, less than 100,000m^3.

However, the statistical analysis did not find any relationship between the factors considered and poor production. Although not analysed in this study, regular problems with UIS boreholes were reported which included; 'borehole blocked', 'borehole full of water' and 'no suction'. It is believed that through focussed system management, which includes regular assessment of borehole flow performance that holes which perform below expectation may be quickly identified and appropriate corrective action may be taken to improve drainage.

Statistical capability assessment was used to assess the impact on average total gas production by addressing the boreholes producing less than 100,000 m^3. The impact was determined through eliminating the low producing holes from the dataset. The result was a 56.28 % increase in average total gas production. At an estimated cost of $20,000 for each installed UIS drainage borehole, significant financial benefit and gas drainage effectiveness (m^3/$) could be realised through implementing measures to avoid failed and poor producing holes. Table 10 lists the results of this statistical capability assessment.

Table 10 - Results of statistical capability assessment of UIS borehole gas production dataset

Capability assessment - Total Gas Production (m^3)	No. of samples	Mean Total Gas Production (m3)	Average production increase (%)
ALL Data	188	179,183	Status Quo
Data fitting the Orientation & Dip condition	53	277,524	154.88%
Data outsite the Orientation & Dip condition	135	140,573	
Data fitting the Orientation condition, Dip range increase to (0^o-3.25^o)	106	226,385	126.34%
Data outside the Orientation condition, Dip range increase to (0^o-3.25^o)	82	118,163	
Data greater than 100,000m^3 total gas production	106	280,026	156.28%
Data less than 100,000m^3 total gas production	82	48, 822	
Data fitting the Orientation & Dip condition & >100Km^3 production	38	368,996	205.93%
Data fitting the Orientation condition, Dip range (0^o-3.25^o) and >100Km^3 total production	72	308,426	172.13%

CONCLUSIONS

This study identified that a significant portion of the drilling effort yields little benefit to the overall gas drainage effort. Of the 306 UIS boreholes studied, 118 (38.5%) were found to be either blocked, flooded or had an effective drainage life of less than 30 days prior to being intersected by compliance drilling or roadway development. A further 82 (26.8%) achieved total gas production of less that 100,000m^3.

Of the six controllable factors, listed below, which were included in the analysis, 'time on suction' consistently recorded the highest correlation to total gas production. The other factors in the order of correlation significance include:

- Suction pressure
- Borehole orientation relative to cleat
- Borehole orientation relative to stress
- Borehole apparent dip
- Borehole length

In high CO_2 zones, the gas production achieved was typically low, at less than 200,000 m^3.

In the high CH_4 zones, there was significant variation in the total gas production, ranging from extremely poor (~0 m^3) through to extremely high (~900,000 m^3). However, there was strong correlation between total gas production and 'time on suction' and borehole trajectory.

Borehole orientation and apparent dip have a significant influence on total gas drainage. Boreholes oriented 20 to 75 degrees relative to the dominant cleat, and 0 to 50 degrees relative to the major horizontal stress and with an apparent dip in the range of 0 to +1.6 degrees were found to have an average total gas production 54 % greater than the complete dataset and 97 % greater than those holes outside this range.

Also, by eliminating the poor producing holes (those achieving less than 100,000 m^3), implementing systems and measures to improve borehole integrity, and ongoing borehole and gas drainage system management, issues such as blockages, flooding and short lead times could be prevented. By improving the management and maintenance of the entire system, to reduce or eliminate the number of failed and poor producing boreholes, has the potential to increase the average total borehole gas production by up to 56 %.

Combining both optimised borehole trajectory and improved system management it may be possible to more than double the average borehole total gas production capability.

Although gas production in high CO_2 zones is impacted more by non-controllable factors than in the high CH_4 zones, however, finite improvement in gas production from UIS boreholes can be achieved by;

- Borehole maintenance, to avoid blockages, etc.;
- Optimise borehole trajectory – relative to cleat, stress and apparent dip;
- Maximise drainage time; and
- Maintain high suction pressures

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