Gas Related Modelling of Surface to In-Seam Wells

Ray Williams, Managing Director, GeoGAS Systems Pty. Ltd.
Eugene Yurakov, Senior Gas Reservoir Engineer, GeoGAS Systems Pty. Ltd.

Abstract

This paper describes GeoGAS's approach to the production modelling of MRD wells for both CSM and coal mining applications. MRD wells are normally drilled at relatively shallow depths (200 m to 400 m), with significantly variable gas content and permeability. In these conditions, gas reservoir modelling is seen as being an essential tool for assessment of gas production potential and detailed well planning.

Modelling has been applied to specifying parameters of water pump and gas range capacities, defining when gas desorption will occur during draw down, rates of pore pressure decline, forecast production, gas recovery and gas remaining, and changes in gas quality over time.

Uncertainties in modelling are identified and minimised in the approach adopted.

Introduction

Surface to in-seam, medium radius drilled (MRD) gas production wells have emerged over the past two years as a potentially viable addition or alternative to underground based in-seam drilling in coal mines and vertical well hydro-fracture for coal seam methane (CSM) exploitation. The basic MRD well consists of an inclined, medium radius borehole collared at the surface to tangentially intersect the target coal seam and continue in-seam for up to 1000 m terminating at the intersection of a previously positioned vertical production well (Figure 1). For a detailed description of MRD drilling refer to Mitchell, 2003 (this conference).

MRD is most commonly applied at relatively shallow depths (200 m to 400 m). Within these depths, the gas content and permeability exhibits a wide range of values, with gas content normally increasing and permeability decreasing with depth. It is common throughout the Bowen Basin and in the Hunter Valley for the seams to dip by 3° or more so that contrasting gas reservoir conditions are experienced within the one mining area or CSM play.

In these conditions, gas reservoir modelling has proven to be an essential tool for assessment of gas production potential and detailed design for well planning.

This paper describes GeoGAS's approach to the production modelling of MRD wells for both CSM and coal mining applications.

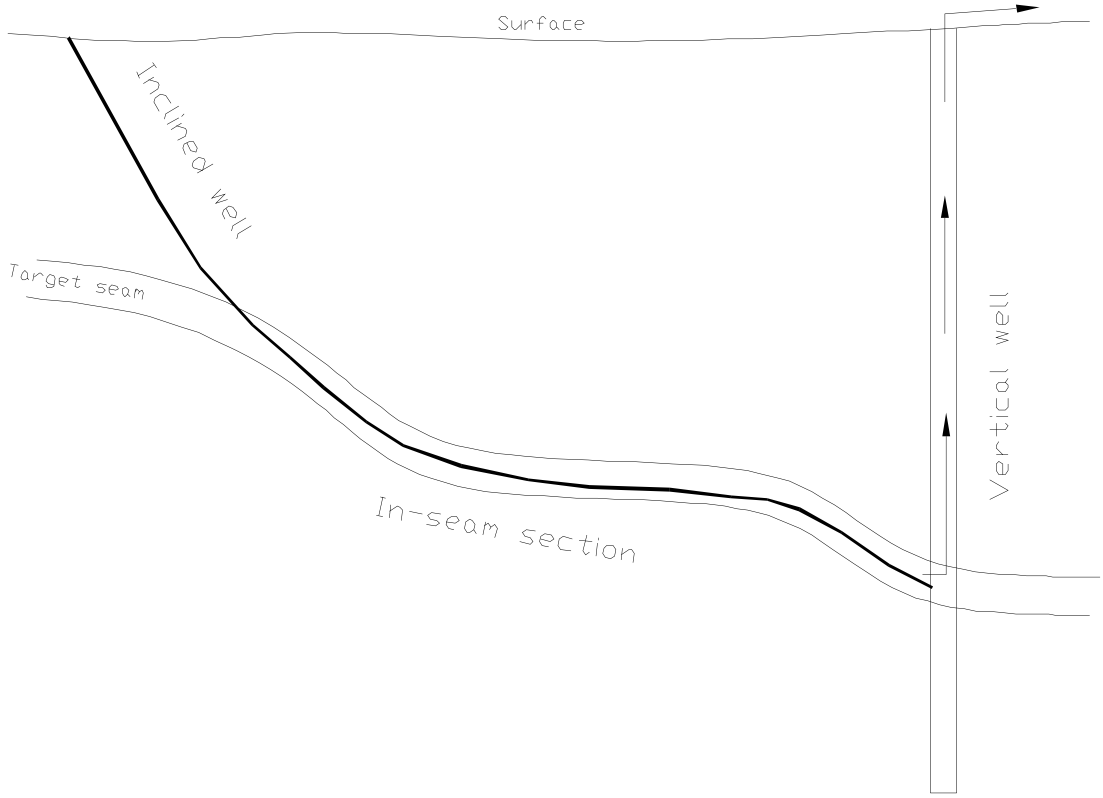

Figure 1 Schematic MRD Well

Gas Reservoir Simulator

GeoGAS currently use the gas reservoir simulator SIMED II, which was developed in Australia by the CSIRO and the University of New South Wales. It provides the framework for specification of gas reservoir properties. In common with other reservoir simulators (eg Eclipse, COMET), it is a two phase (gas and water), three-dimensional, single or dual porosity reservoir simulator. The dual porosity capability is used for coal seams, simulating the slow, concentration gradient driven, desorption from the coal matrix, and the pressure gradient flow of gas through the fracture network.

SIMED has important additional capabilities of being able to concurrently model multi component seam gas (eg CH_4, CO_2, N_2) and flow of gas and water toward mine roadways.

Operational Aspects and Related Modelling

Modelling needs to meet the requirements of operational aspects which include:

- Planning the inclined/in-seam well location, trajectory, orientation, diameter, length and pattern. Pattern variations (hole and row spacings, well geometries) require modelling.

- Specifying vertical well dimensions, casing depths and sizes, and depth of the sump below the target seam (“rat hole”).
- Defining the target drilling horizon in-seam, assessing potential drilling difficulties and determining whether any intra-seam bands might constitute barriers to gas migration. “Roof touches” provide a means of penetrating potentially low transmissibility bands as well as aid in delineation of seam geometry around the borehole. “Floor touches” are possible from a drilling view point, but preclude subsequent lining of the trunk hole.
- Specification of well head equipment, with water pump size and gas reticulation range sizes derived from gas reservoir modelling.
- Drilling the inclined well, intersecting the vertical well and cleaning the well of drilling coal fines.
- Completing the well, involving setting of liner in the trunk in-seam hole and setting up the surface pumps, power and gas/water reticulation.
- Bringing the well into production. Knowledge of when to expect gas desorption is important.

MRD drilling is a new technology. Experience is being gained with every new well drilled and the optimum ways of operating are in an early stage of evolution. In the absence of such experience, the following sections provide the author’s current views on aspects of design and operation.

Water Pump Specification

Gas reservoir modelling provides a basis for specifying water pump sizes. SIMED can model water production, simulating the effect of running a pump at a constant peak rate. Water production modelling in higher permeability coal is sensitive to fracture porosity (Figure 2), which is not a readily measured parameter.

Experience from modelling of 14 wells that have been brought on line is that the pump size has tended to have been overstated. Problems in practice arise where the same pump is not able to handle the full range of flows the well will experience.

Water production from the onset of gas desorption may be less than forecast, depending upon the gas/water relative permeability relationship. A lower pump capacity can be modelled, which has the effect of delaying gas production (Figure 3). In mining applications the tendency has been one of wanting to get the gas out as quickly as possible, ie favouring faster draw down from higher pump rates. That requirement is less pressing in CSM applications, but an unnecessarily long draw down is not desirable from a commercial viewpoint.

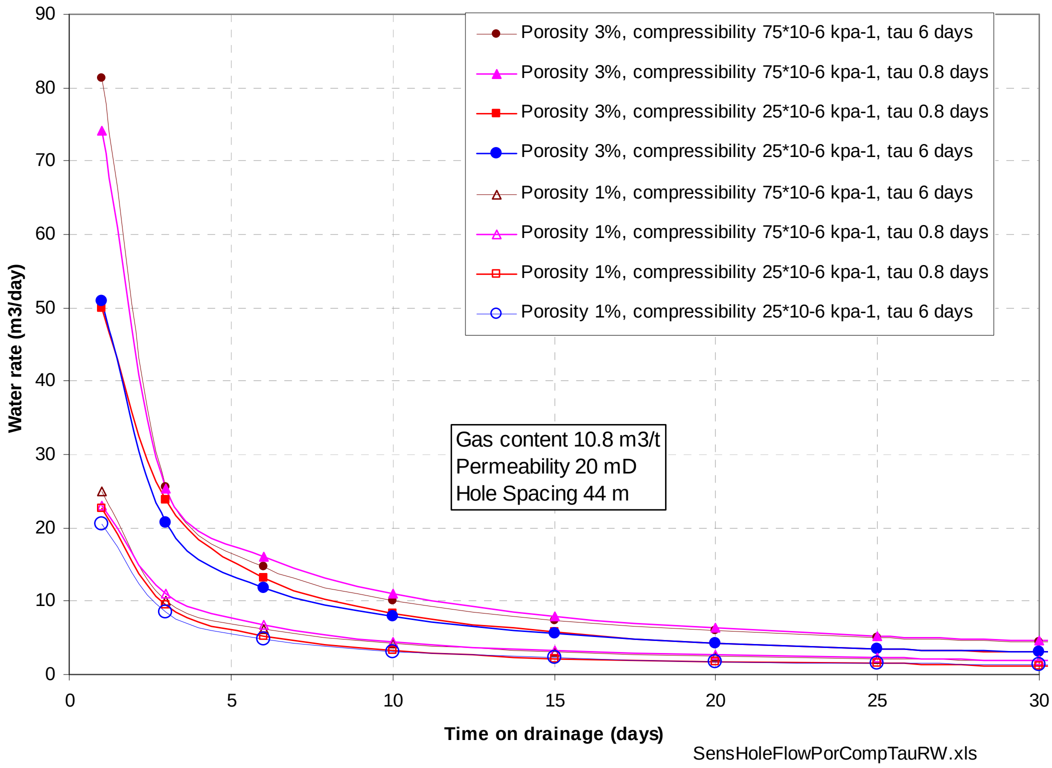

Figure 2 Sensitivity of Porosity and Compressibility to Water Production

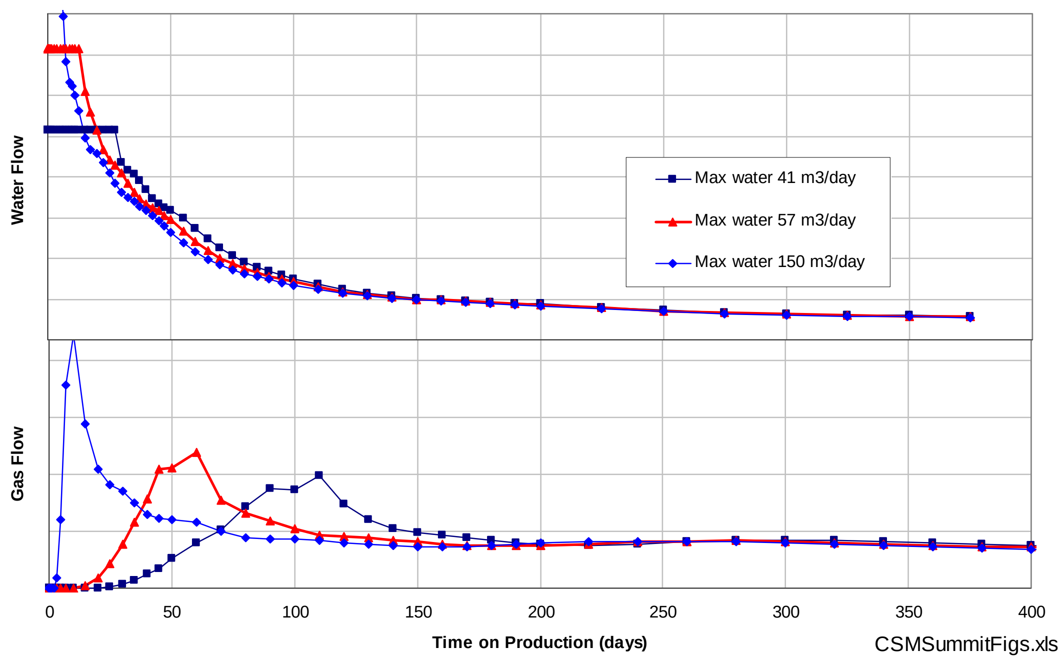

Figure 3 Effect of Fixed Maximum Water Production Rate on Gas Production

Gas Desorption Pressure

For under saturated reservoirs (which are a majority in the author's experience), pore pressure reduction is gradual and uniform before reaching the gas desorption pressure. At gas desorption pressure, in MRD wells, a lot of coal is affected at about the same time, resulting in a potentially violent process. The suddenly desorbing gas carries coal particles through the fracture network to the well bore. If the pressure is reduced too quickly, a large area around the well bore will be affected at the one time. The pressure reduction driving desorption rate and gas flow toward the borehole will be greater, causing movement of a lot of coal fines with the potential for blocking up the flow paths around the well bore.

This damage near the well bore is modelled in SIMED as a skin factor, which has a large effect on gas production (Figure 4). History matching production wells has required initial skin factors from 0 to 30, the former occurring in relatively low permeability coal. The reservoir appears to be more forgiving in low permeability ground, where coal particle movement is not induced to the same extent as in high permeability coal. Over time, the wells "clean up".

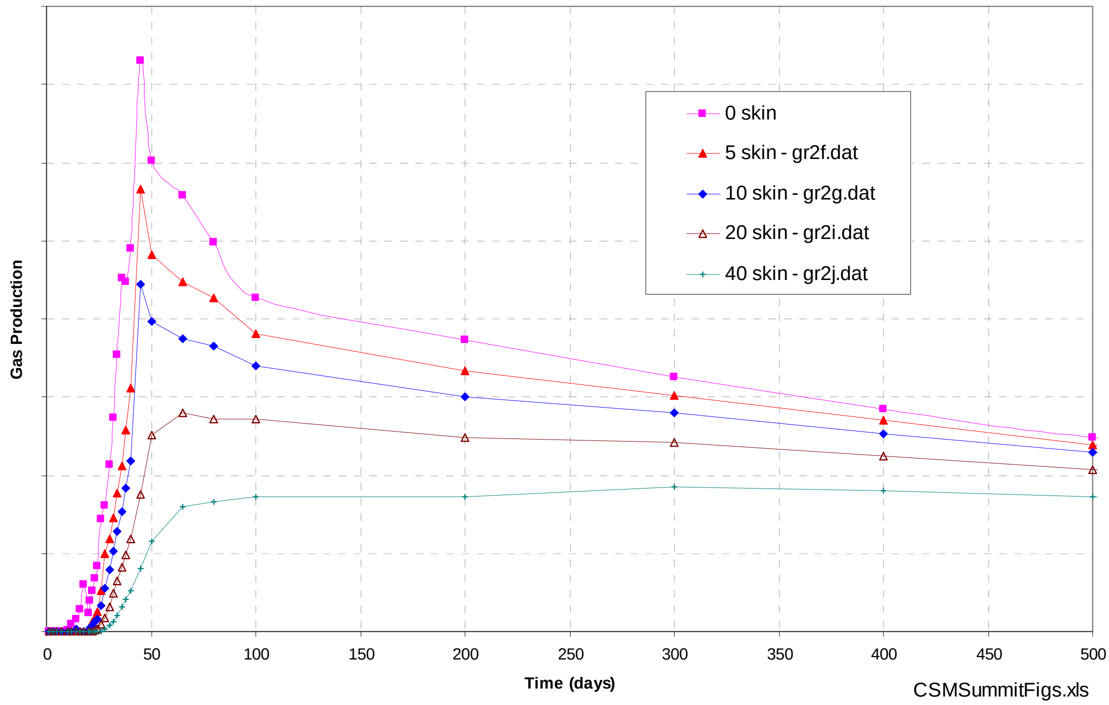

Figure 4 Effect of Skin on Gas Production

Forewarning of when gas desorption will be initiated is critical, as the behaviour of the well undergoes rapid changes in casing pressure and water height. Water pump rate and casing pressure need to be adjusted to permit a gradual reduction in pore pressure with minimum negative effect on skin.

The combination of gas content and the sorption isotherm defines the level of gas saturation and the pressure at which the gas will begin to desorb from the coal on reduction of pore pressure. It is one of the most critical elements to get right, as errors in either or both the gas content and sorption isotherm can result in inadvertently running through gas desorption during well draw down, and large differences in modelled gas production rates.

Validation of gas desorption pressures has been significantly aided by field determined desorption pressures obtained by multiphase well testing (Multiphase Technologies Pty. Ltd.). This is additionally confirmed where MRD wells have been pumped down to gas desorption (Figures 5). In this case, field desorption pressures occur over a range of 360 kPa.

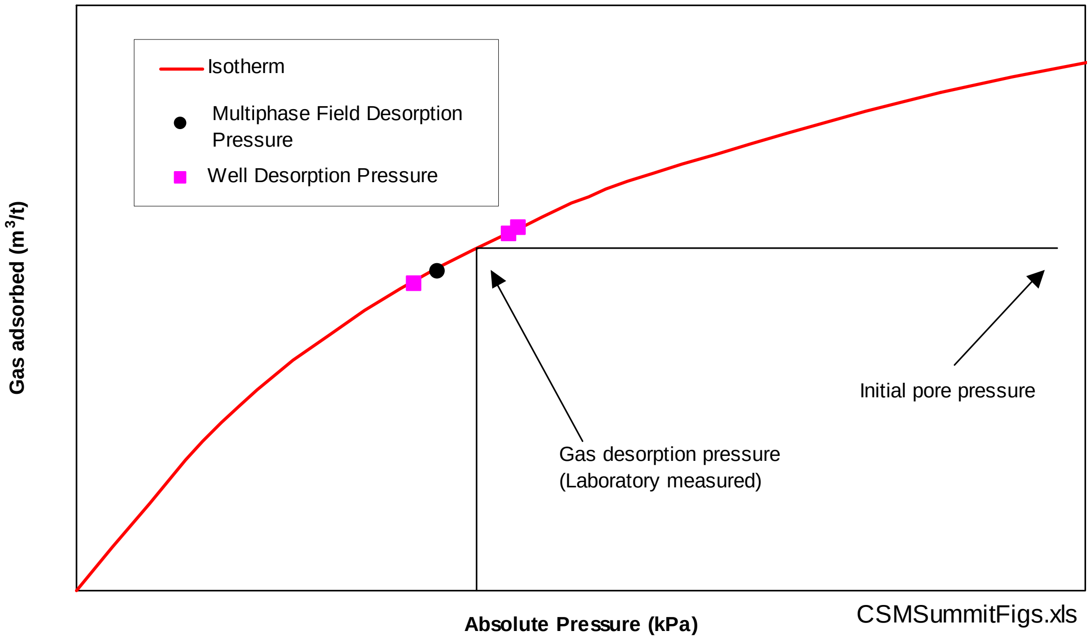

Figure 5 Field and Laboratory Gas Desorption Pressures

While field and laboratory desorption pressures are normally closer than in this example some large mismatches have occurred (Figure 6). In the example where the laboratory desorption pressure is 65% higher than the field desorption pressure, permeability is very low, making field identification of the desorption pressure less certain. That said, in this instance it was still not possible to reconcile the two data sources.

There are a number of contributors to uncertainty in defining gas desorption pressure:

- Using inappropriate coal density in the isotherm test. The calculation is highly sensitive to density.
- Uncertainty in correcting gas content values to absolute zero pressure.
- Errors in correcting gas content and isotherms to a common reservoir temperature and mineral matter content.

- Effects of moisture on gas sorption capacity. For low to high volatile bituminous coals at least, it appears more appropriate to conduct isotherm tests on an "as received" moisture basis than at equilibrium 'bed" moisture[1].

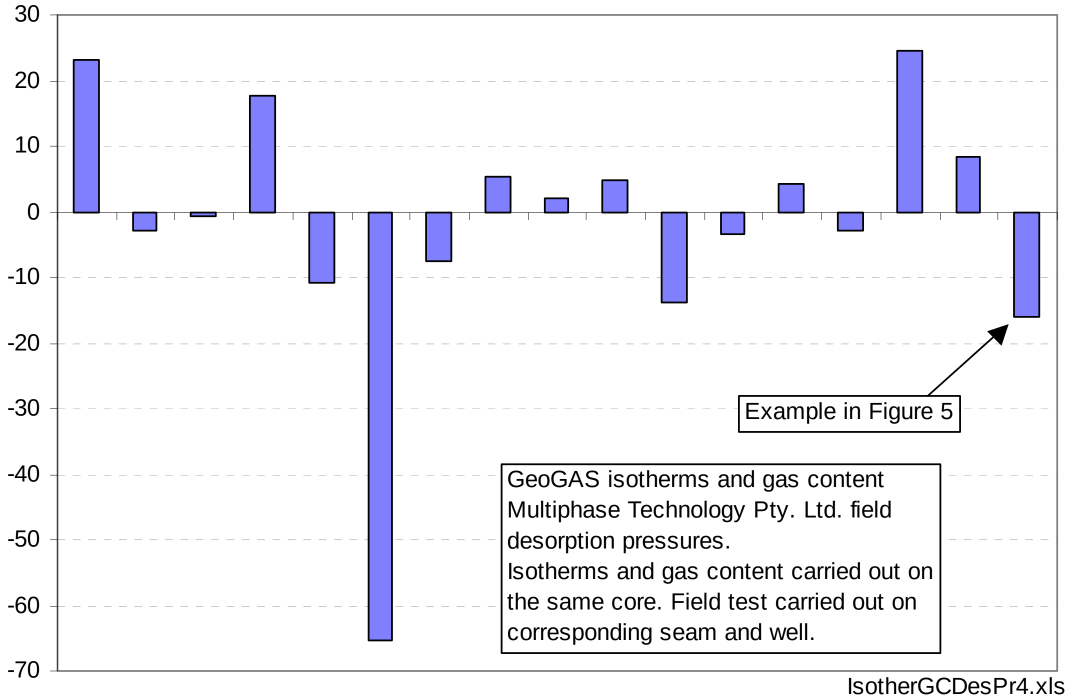

Figure 6 Percentage Difference Between Field and Laboratory Desorption Pressures

Provided the water height is reduced gradually, gas desorption pressures are readily recognisable in MRD wells, where a sudden change in the water height results from the combined effects of a relative permeability reduction to water and desorbed gas helping to push down the water column (Figure 7).

Well Continuity and Monitoring

Production modelling assumes the well bore remains open along its length. Major branching of boreholes can produce significant additional gas flows at a low cost – in theory. Unless the coal is particularly hard and devoid of potentially unstable clay bands, the authors do not recommend branching, other than for roof touches and to increase the likelihood of gas flow across intra seam bands. Branched holes cannot be readily lined, and there is increased potential for collapse at the branch point.

Although non lined boreholes have been successful, the borehole should be lined to ensure continuity over the life of the well. That said, a liner will preclude re-entering the borehole to clear a blockage. The debris that collects on the liner over time can be periodically flushed away.

[1] Comparative studies with James Cook University through ACARP project C10008

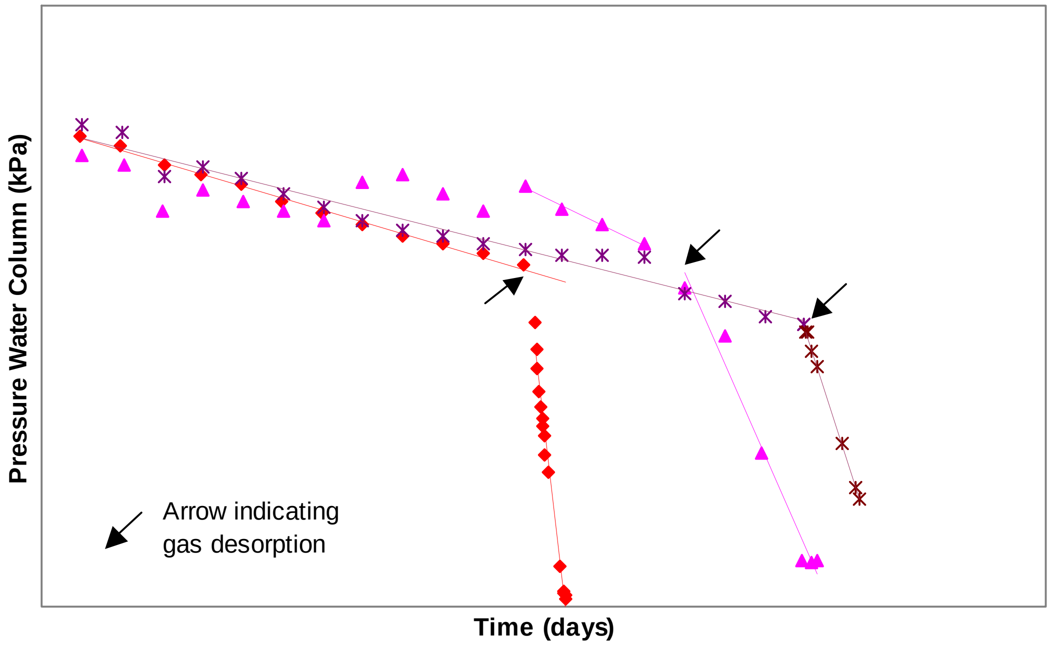

Figure 7 Gas Desorption Pressure Identification, MRD Wells (with permission of CH_4 Pty. Ltd.)

It is a good practice to chart the pressure reduction in both the inclined and vertical wells. If there is connection, the two should follow each other and be of similar magnitude. It can be indicative of excessive pressure loss along the well, where the two track each other, but differ in magnitude – perhaps indicating time for maintenance.

As a general rule, it should known how each in-seam well (or arm of the well where two or more horizontal wells are drilled into a vertical well) is performing. A further problem with branching is that it is not possible to know if a particular branch is functioning.

In the fullness of time, more elaborate drilling patterns will probably prevail, but for now, an understanding of the processes governing production is regarded as being highly important to defining optimum future development.

Approach to Modelling

For both CSM and coal mine modelling the following approach is taken:

- Collection and validation of reservoir parameters
- Consideration of well design and operation parameters that need to be included in the model.
- Conceptual modelling primarily to gain a feel for the well spacings required
- Detailed production modelling simulating specific planned wells
- History matching well performance

For CSM applications, the conceptual and detailed modelling also includes determination of gas recoveries. Coal mining applications are more concerned with remaining gas content at the time of mining. Additional modelling is undertaken to define the effect of this remaining gas content on mine gas emission.

While slow reduction in well pressure is conducive to minimum skin, it is important that the final operating well pressures are reduced to the lowest practical value. For CSM, both gas production and percentage recovery are affected by well pressures, so that ultimately, the well should operate at a low pressure (eg 202 kPa abs), perhaps not so low as to create issues with oxygen ingress to the system. In coal mining, it is critical at the time of mining, to have the well pressure at, or lower than the ambient atmospheric pressure of adjacent mine workings, otherwise gas will flow from the borehole to the workings.

Reservoir and Operation Parameters

In any modelling exercise, some parameters will be known and others will need to be estimated. Ranges of parameters, both measured and estimated need to be defined and included in sensitivity modelling. Early in a project, uncertainty in modelling is relatively high and experience of the modeller is certainly important in setting up the most appropriate models and interpretation.

It is difficult to be categorical about the sensitivity of parameter combinations. The potential combinations are vast and to make the process manageable requires subjectivity in setting up of parameter matrices. GeoGAS is currently investigating parameter sensitivity under an ACARP project[2]. The ratings in Tables 1 and 2 are to be interpreted as follows:

- Low – impact less than 10%
- Middle – impact 10% to 20%
- High – impact greater then 20%

These tables should be viewed as “an instance” of sensitivity modelling. The number of models run in creating them (200) is a small fraction of the possible combinations. Other researchers will likely place different emphasis on these effects.

The low permeability case is 3 mD, the moderate to high case is 20 mD.

[2] Project C10008 Improved Application of Gas Reservoir Parameters

Table 1 Impact of Input Parameters – Low Permeability Case

Input Parameter	Low Permeability Case, Impact Input Parameters On				
	Remaining Gas Content	Borehole Flow Rate Peak	Borehole Cumulative Flow	Rib Emission Peak	Cumulative Rib Emission
Initial Gas Content	High	High	High	High	High
Permeability In Hole Direction	Middle	Middle	Low	Low	Middle
Permeability at ⊥ To Hole Direction	High	Middle	Middle	Low	Middle
Ash (Isotherrn)	Middle	High	Middle	High	Middle
Relative Permeability Curve	Middle	Middle	Low	Low	Low
Hole Spacing	High	Low	High	Low	High
Porosity	Middle	High	Middle	High	Middle
Coal Compres-sibility	High	High	High	High	High
Tau	Low	Middle	Low	High	Low

While gas content is a readily measurable parameter at high frequency, there are almost always fewer permeability measurements than would be desired. Porosity, compressibility and tau (desorption time constant) become particularly sensitive at higher permeabilities. In the course of undertaking interference testing for directional permeability, it is possible to back out results for porosity and compressibility[3]. As these measurements are relatively costly and infrequently carried out, values used are initially “industry standards”, but modified as better history match data are obtained.

For history matching, MRD wells are much better monitored than underground in-seam boreholes, flow data from the latter being confined to gas and mostly affected by environmental conditions. Compliance core testing in coal mines in conjunction with MRD monitoring provides an excellent opportunity for history matching parameters such as directional permeability.

[3] David Casey, pers comm..

Table 2 Impact of Input Parameters – Moderate to High Permeability Case

Input Parameter	Moderate-High Permeability Case, Impact Input Parameters On				
	Remaining Gas Content	Borehole Flow Rate Peak	Borehole Cumulative Flow	Rib Emission Peak	Cumulative Rib Emission
Initial Gas Content	High	High	High	High	High
Permeability In Hole Direction	Middle	Middle	Middle	Low	Low
Permeability at ⊥ To Hole Direction	High	Middle	Middle	Low	Low
Ash (Isotherm)	Middle	High	Middle	High	Middle
Relative Permeability Curve	Middle	Middle	Low	Low	Low
Hole Spacing	High	Middle	High	Low	High
Porosity	High	High	Middle	High	Middle
Coal Compres-sibility	High	High	High	High	High
Tau	High	High	High	High	High

For MRD wells, transmissibility across intra seam bands (to 0.15 m thick) is normally modelled as "fully transmissible" provided the bands can be perforated by roof touches. Gas content testing of cores taken through the seam once the well has been on line for a defined period, will aid in developing improved modelling treatment.

The rate of pressure draw down is an important design parameter for modelling. SIMED can model any rate of draw down, but it cannot inherently model the resulting impacts on "skin". The authors believe the rate of pressure draw down should be tied to an acceptable borehole flow per unit length value. In high gas content and/or high permeability coal, the flow per unit is relatively high and consequently, the pressure draw down will be low. In low permeability coal, the draw down can be relatively fast.

Included in considerations on draw down rate is the effect on economics. For coal mining, a result has to be achieved to permit mining by a certain date. Wells need to be drilled sufficiently in advance of mining to allow time for optimum draw down rate according to skin minimisation. Similarly for CSM, wells need to be drilled and brought on line to meet the project gas production needs and address the issue of minimising well bore damage.

Modelling

For coal mining applications, varying borehole spacings are conceptually modelled using typical parameters to obtain a feel for the time required to reduce the gas content to a target value (Figure 8). Spacings are limited to gate road widths in the short term and multiples of longwall pillar widths in the longer term.

For CSM, varying spacings can be modelled (parameters Table 3) and the outcomes of initial production rate, cumulative production and recovery assessed against an economic cut off.

At first glance, a 3.5 m thick seam with a gas content of 12 m^3/t would seem to have potential. At a permeability of 5 mD, gas production is for the most part below 250 MCFD (Figure 9). A close spacing (130 m) gives a more acceptable production, but the well is short lived. Recoveries are also relatively low for a given gas rate, economic cut off (< 60%, Figure 10). Sensitivity analyses can be undertaken with the less certain parameters of porosity and compressibility. At low permeabilities, these differences are usually not so pronounced.

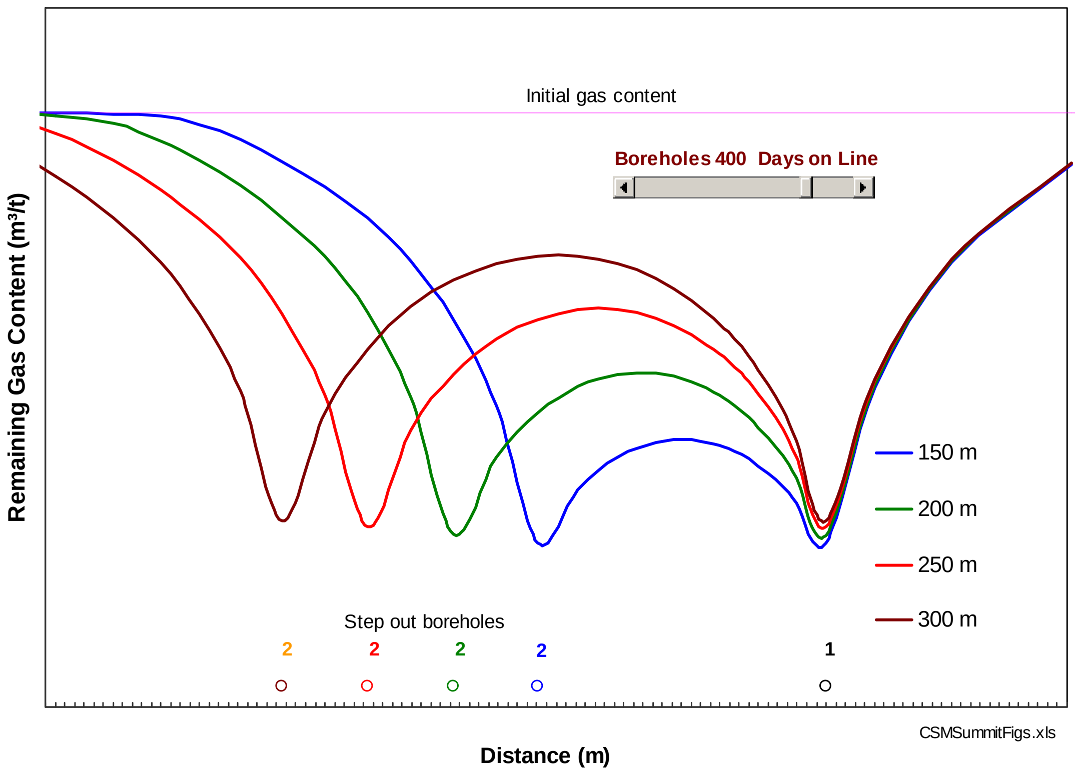

Figure 8 Conceptual Modelling Borehole Spacings Gate Road Protection

Table 3 MRD CSM Wells Conceptual Modelling Parameters

Parameter	Value
Depth (m)	350
Reservoir Temperature	45
Porosity (%)	1
Seam Thickness (m)	3.5
Coal Compressibility (kPa^-1)	4.85E-05
Qm (m3/t) @ seam ash & temp & 1013 hPa	13
Qm (m3/t) @ seam ash & temp, to 1013 hPa	1.07
Permeability XY (mD)	5
Permeability Z (mD)	1
Relative Density (g/cc)	1.46
Desorption Time Constant (days)	4
LV @ seam ash & temp & abs P (m3/t)	22.39
LP (kPa abs)	2012.03
Field Desorption Pressure (kPa abs)	3045.13
Pore Pressure As Input (kPa abs)	3300
Skin	0
Row to row spacing (m)	200
Borehole length in seam (m)	750
Borehole Dia (mm)	110
BHP after 100 days (kPa abs)	200

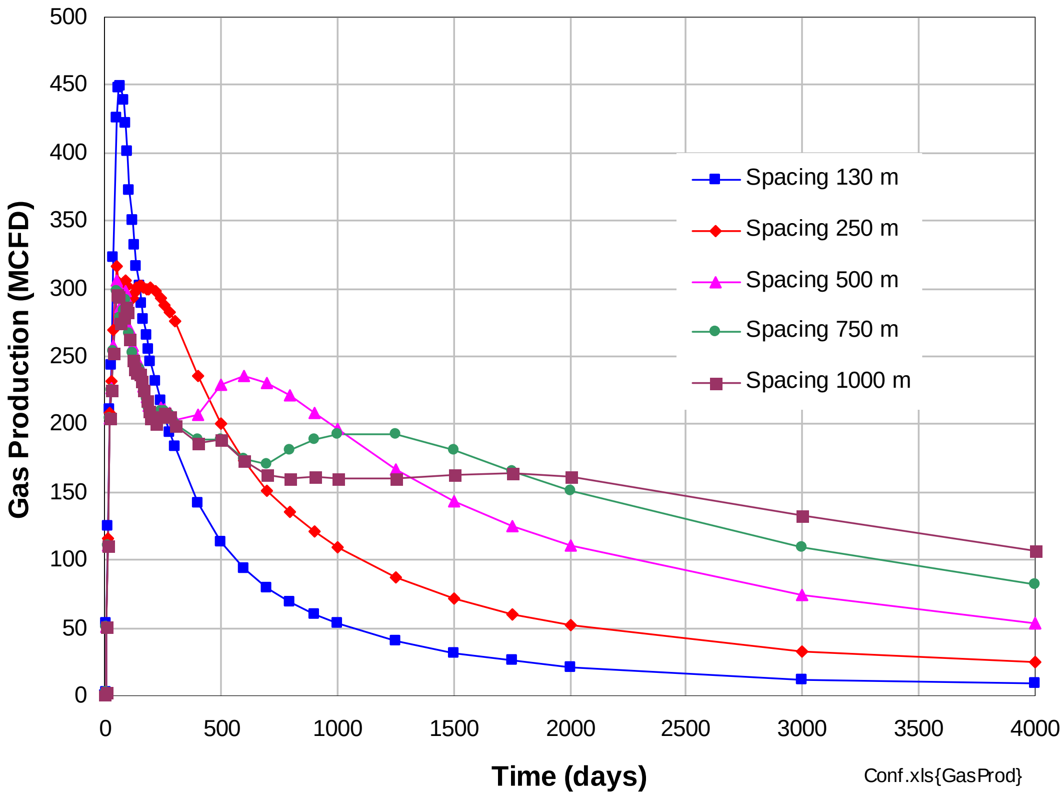

Figure 9 Conceptual Modelling Borehole Spacings CSM 5 mD Permeability

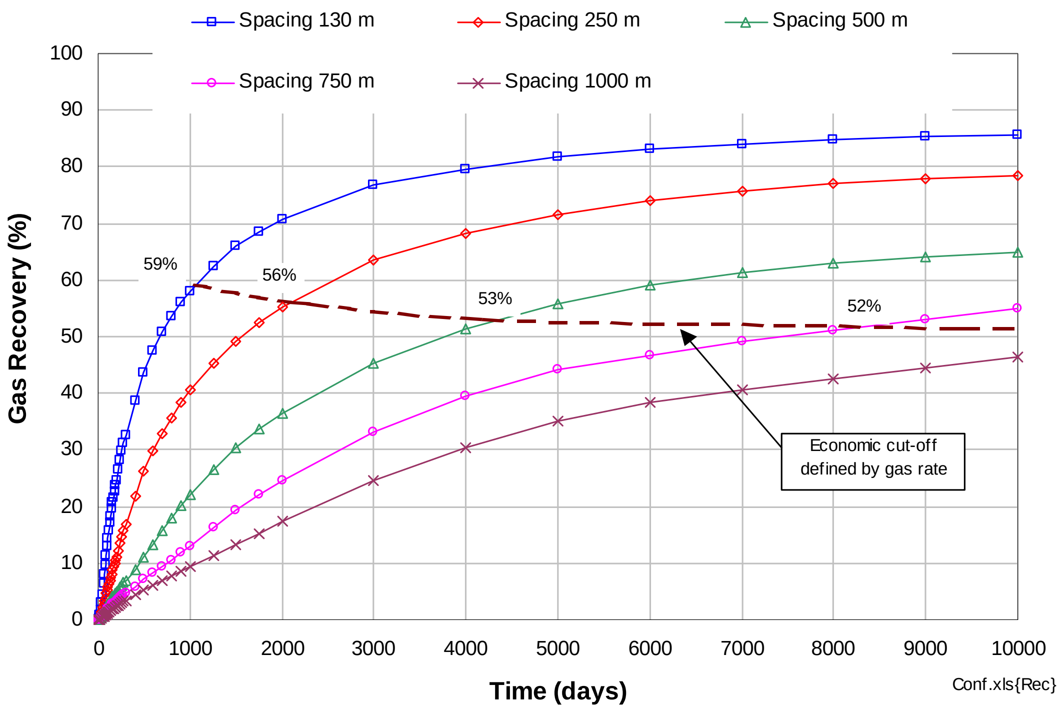

Figure 10 Conceptual Modelling Recovery CSM 5 mD Permeability

While recoveries are likely to remain modest, acceptable rates of production can be achieved from relatively low permeability coal providing the seam has good thickness (5 m+) and there are a lot of metres drilled in-seam, either by drilling longer boreholes (1000 m+) or by closing up spacings (< 250 m). Minimisation of drilling costs is clearly important.

Modelling the previous example at high permeability (30 mD) produces a completely different outcome, with gas production peaking above 1100 MCFD for all spacings (Figure 11) and gas recoveries ranging from 74% to 81% (Figure 12).

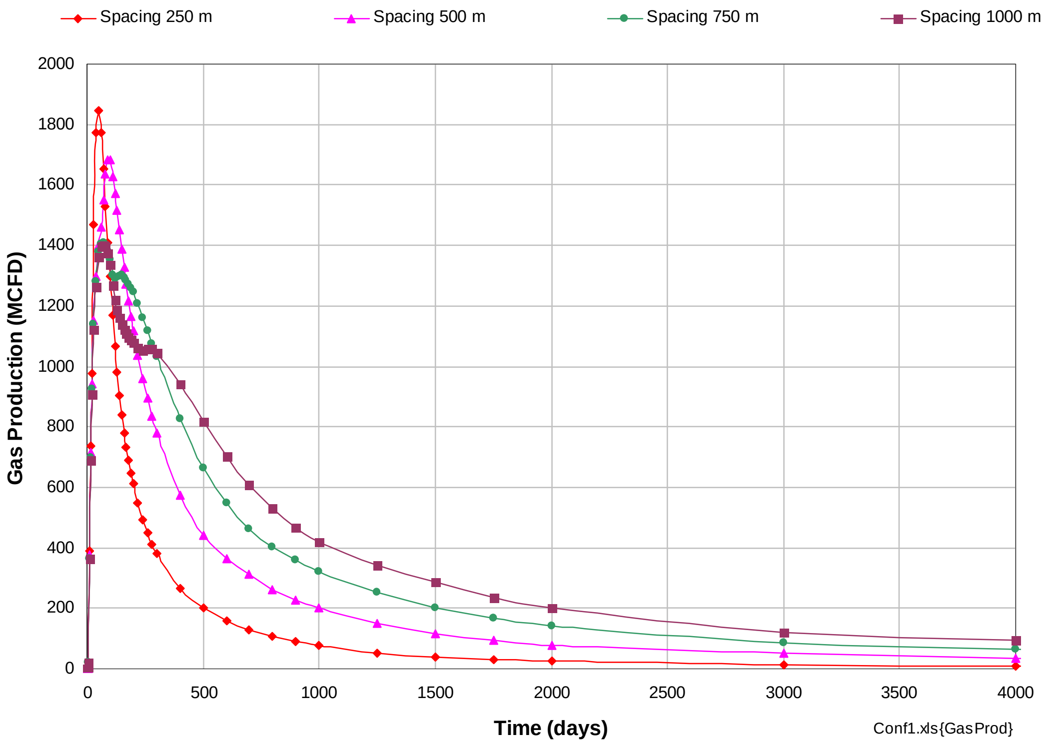

Figure 11 Conceptual Modelling Borehole Spacings CSM 30 mD Permeability

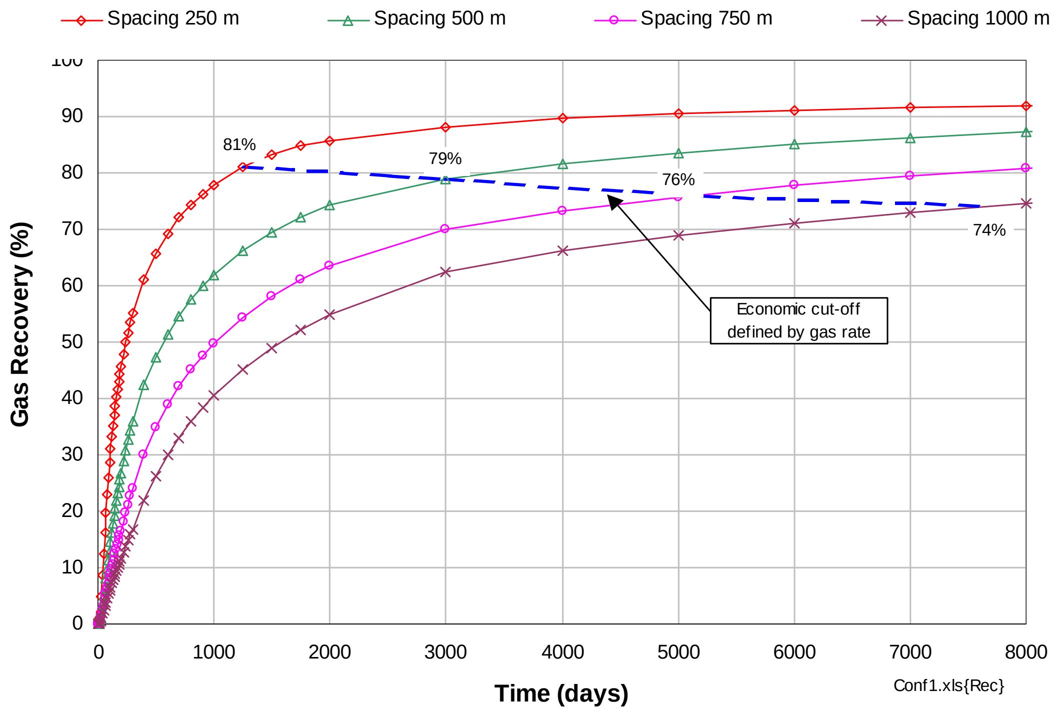

Figure 12 Conceptual Modelling Recovery CSM 30 mD Permeability

Coal mine applications are additionally complicated by the presence of the mine workings, involving the following additional considerations:

- Modelling the effect on gas drainage production when the mine workings progress to the region of the MRD well (Figure 11).
  Initial modelling of pore pressure reduction resulting from existing mine workings prior to gas drainage modelling
- Modelling the resultant effect the MRD well on mine gas emissions (Williams et al, 2001).

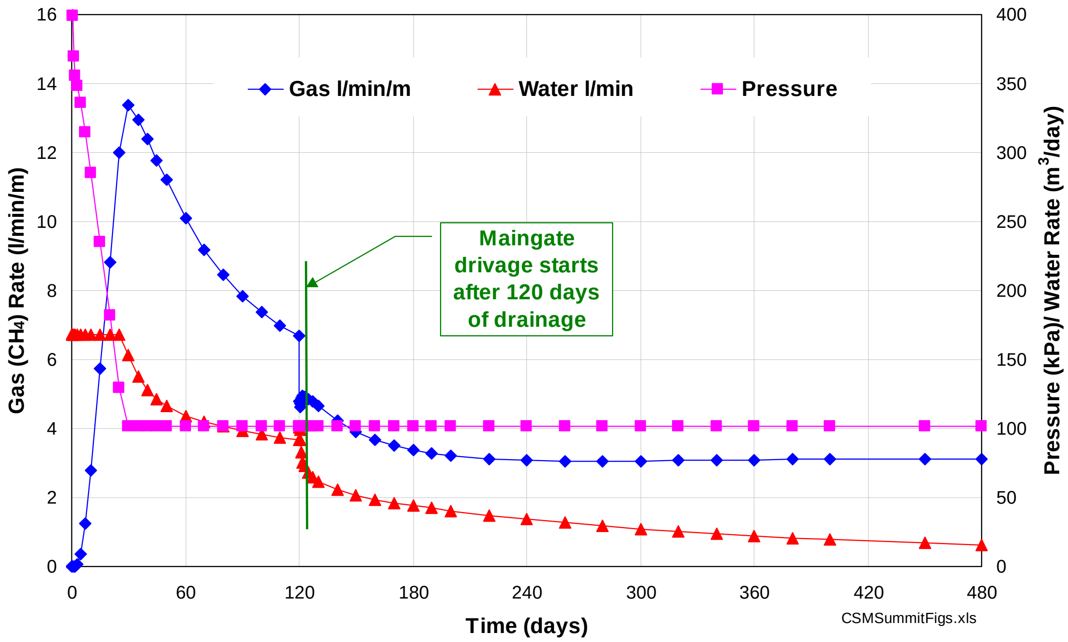

Figure 11 MRD Production Before and After Mine Workings Come into Its Vicinity

Conclusions

MRD wells have the following advantages over other forms of drilling:

- Relatively high production from low permeability coal due to the high level of contact via the long, in-seam boreholes.
- High gas recoveries (eg 80%) resulting from accurate drilling to a predetermined pattern.
- The absolute predictability of the drilling pattern improves the reliability (bank ability) of modelling outcomes.
- For coal mining specifically:
    - Higher purity gas (potentially pipeline specification).
    - The ability to segregate the gas drainage from mine operations and take advantage of long lead times with resulting reduced cost/m^3 drained.
    - A significant bonus in exploring well ahead of mine development for geological structures.

    - Improved stability of gas drainage boreholes during both drilling and drainage due to drilling above gas desorption pressure. Most in-seam collared predrainage is conducted at desorption pressure.

There are potential disadvantages which can mostly be overcome with appropriate management:

- Because of the extent of contact with the coal seam, a large region is affected during the onset of gas desorption, the resulting violence promoting hole collapse, hole blockage and reduction in permeability around the well bore.
- For coal mining:
    - Inadvertent mining into a pressurised borehole or nearby pressurised well creating emission into workings.
    - Leaving drill steels in seam.
    - Oxygen ingress to goafs from subsequent longwall mining if boreholes are not isolated.

Because well bore damage has such a significant effect on well performance, care in both drilling and in bringing wells on line is emphasised. Each well should have a formal plan for bringing on line, that includes when to expect gas desorption pressure and an acceptable window for reduction in pore pressure. For the higher permeability coals, damage caused by transmission of drilling fluids into the formation can be minimised by under-balanced drilling (Thomson et al., 2003), but not under-balanced to the extent of letting gas desorption commence during drilling.

Although rig capacity and directional drilling steerage and navigation allow the drilling of quite long (+1000 m) boreholes with and without major (700 m) branches, at this early stage in the application of MRD, the authors recommend simple geometries (one in-seam hole per inclined well collar, no branches (other than “roof touches”) and lined boreholes.

Gas reservoir modelling has the flexibility to handle a wide range of gas reservoir conditions and operating options. If diligently applied, this will produce the most effective outcome for the least time and expense. Internal consistency of data and history matching against a comprehensive range of measured parameters is essential for modelling to evolve and become more accurate.

Cross checking of field and laboratory desorption pressures is an example of internal data consistency applied to a critical modelling parameters (in this case, gas content, sorption capacity). In general, too few measurements of sorption isotherms are undertaken and a better basis for mineral matter and temperature correction is required.

The difficulty in directly measuring parameters such as relative permeability, directional permeability, porosity and compressibility can be somewhat compensated by history matching that contains a range of “redundant” data. For example, in additional to using pore pressure decline and gas and water production, the uniqueness of the parameter set can be enhanced by checking history match outputs against discretely measured pore pressures and gas contents surrounding the well.

Acknowledgements

Part of the work in this paper was carried out with the aid of a grant from the Australian Coal Association Research Program (ACARP).

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