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Concurrent In-Situ Measurement of Permeability, Gas Content and Gas Saturation

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Abstract

Existing ex-situ techniques for measuring the gas content and permeability of coals require collection and laboratory analysis of core samples. In some cases, those samples do not reflect the complex, distributed characteristics of the coal seam being evaluated. In other cases, the analyses are complicated by changes to the samples that may occur during collection.

Gas content measurements

Gas content of coals is typically measured using the Direct Method Analysis (DMA) on freshly cut cores. The problem with the DMA technique is that overall results can be greatly influenced by artefacts of the test apparatus and procedures used by core sample type, sample collection methodology, and analysis conditions. Even if all these factors are precisely controlled, the accuracy of in situ gas content values obtained using the DMA technique can still be greatly compromised through large errors in Q1 values, which can only be predicted, not measured. Compounding this inherent error of the technique is the fact that core desorption is a destructive testing method that cannot be completed twice on the same sample. This means it is not possible to assign error bars on core desorption data, or on the major safety implications of decisions made by using them.

Permeability measurements

It is possible to quantify permeability from tests on whole cores under precisely controlled laboratory conditions. The accuracy of such tests, however, can be impacted by a number of factors including: the method used to capture the cores; the extent of filtrate invasion; damage to cores during retrieval; poor core preservation at the surface; improper re-stressing of cores in the laboratory; re-stress hysteresis of cores; and, scaling effects (core diameter relative to primary, secondary, and tertiary fracture network spacing).

Combined in-situ measurements

A new capability has been developed for simultaneously determining both parameters in-situ. This new combined method provides some advantages; it can be performed more quickly and at a greater density than typical off-situ methods. Its in-situ methodology is, furthermore, well suited to challenging downhole environments such as those containing friable coals, and mixed carbon dioxide and methane gases. Additionally, it can be performed in remote locations without local laboratory support. This new capability has involved the integration of two very different technology platforms that, nevertheless, use reservoir fluid as a key component of their measurement modes. Drill Stem Testing (DST) technology is used to determine flow capacity based on monitoring of fluid behaviour as it is drawn from the coal cleat system.

Reservoir Raman Spectroscopy (RRS) logging technology is used to derive gas content based on measurement of various properties of the extracted fluid.

A description of both enabling technologies, operating principles, and the innovative surface system developed to facilitate concurrent operation of both has been documented in a recent publication by Pope and Morgan (‘A new in-situ method for measuring simultaneously coal seam gas content and permeability’, *Proceedings of 13th Underground Coal Operators Conference*, Wollongong, February 12-14, pp 284-290). In it, the authors show that of the many DST technology platforms, both tubing deployed and wireline deployed, only one - involving the use of tubing pressure to set packers and vertical movement of the work string to manipulate a tester valve - is suited for facilitating simultaneous production and logging of formation fluids. A wireless surface readout formation pressure monitoring system is incorporated between the straddle packers, which use a low-frequency Electromagnetic (EM) signal to propagate formation pressures through the surrounding overburden to the surface. To facilitate concurrent wireline operations and manipulation of the DST system tester valve, a unique load-bearing Wireline Entry Guide (WEG) system was developed, along with a load- bearing quick-union connection system.

The publication by Pope and Morgan also detail a generic test program to showcase the ability to examine produced fluids located in either the wellbore or displaced to the surface under pressure, while simultaneously monitoring the behaviour of fluids still residing in the cleat system. The publication also provides insight into data validation techniques that have been developed to prove self-consistency. Not disclosed, however, are the methods developed to enable the appropriate generation of the adsorption isotherms that are required to accurately calculate gas content from the measured fluid properties. This will be addressed in this paper as part of the case studies review.

This case studies review will also reveal mitigation measures and procedures developed to address the challenges of the new technique. These include the need to manage fluids wisely to ensure representative data and minimise test duration, and the need to use a pragmatic approach in identifying a coal sorptivity that represents a well’s drainage area (versus a single core sample) for each coal intersected.

Field Trial Terms of Reference

A major coal mine operator with an active ongoing exploration program funded testing of their coal seams during a pre-commercialisation beta field trial. Their interest in facilitating this crucial test was driven by the recognition that, if successful, they would then have access to a new technical service yielding immediately actionable data. This availability would, in turn, allow the operator to optimise their future exploration activities, and well spacing and location, and alleviate bottlenecks through existing service channels

Objectives

DST technology has been used extensively by both the coal mining and CSG industries to obtain in situ estimates of bulk permeability to avoid the challenges associated with off-situ analysis of permeability on coal core samples. RRS technology has separately amassed an extensive track record of determining the gas content of coal seams following its commercialisation in 2005. Consequently, the principle objectives established for the field trial were as follows:

1. To confirm the ability to effectively and safely integrate operations of a wireline-deployed RRS logging system with the actuation of a tubing-deployed DST system.
2. To evaluate the robustness of fluid management guidelines, set thresholds, establish decision criteria, and optimise underlying workflow processes.
3. To assess the operational efficiencies achieved in a multi-seam open hole environment.

A further aim of the field trial was to benchmark analyses of acquired data with results obtained from traditional core laboratory studies and permeability tests using alternative DST technology and testing techniques.

Field trial deliverables

The wireline-deployed RRS and tubing-deployed DST systems incorporate a variety of different sensor types to continuously monitor in-situ fluid properties and behaviour during the testing of each coal seam. Additional sensors are included to aid diagnosis of the mechanical and seal integrity of the hardware testing platforms, and to monitor system health. A variety of reports could, therefore, be generated, encompassing various treatments of measured data, data validation results, pressure transient analyses, and RRS analyses. The key deliverables specified for the field trial were derivation of permeability, skin damage, critical desorption pressure, gas saturation, required pressure drawdown and gas content.

Field trial scope

To fully evaluate the capabilities of this new service, it was decided to test multiple seams in multiple wells exhibiting a wide range of permeability and gas contents. Candidate well selection was based on following criteria:

1. Boreholes needed to be newly drilled to limit borehole instability risk and minimise uptake of wellbore fluids by the coal seams.
2. Boreholes needed to be PQ (122.6 mm) size or larger to accommodate the downhole equipment footprint.
3. Close proximity to other boreholes that had been previously cored and tested for gas content and permeability was undesirable.

Field trial evaluation criteria

To assess the merits of the newly integrated service, the success of the field trial was to be judged based on the following evaluation criteria:

1. accuracy of acquired data
2. veracity of data analyses
3. test expediency
4. extent of operational support requirements; and,
5. comparison of testing and operational costs with alternative techniques.

Field Trial Summary

Two wells were selected for testing, with three seams targeted in each; however, due to geomechanical instability problems, only one seam was ultimately tested in the first borehole. No such problems were encountered in the second borehole, with tests conducted on all three target seams. Depictions of borehole 2, along with estimates of gas and reservoir parameters derived for each seam tested in the borehole are shown in Figure 1. Gas data from the second borehole has been withheld to respect client confidentiality, with scaling applied to other data revealed for this borehole.

Key deliverables were met on all four seams tested across the two boreholes. Furthermore, computed gas contents were found to closely match those derived from fast desorption tests on cores, with comparison results for Borehole 2 shown in Figure 2. Permeability data was found to be self-consistent, but differed with values obtained through earlier DSTs in neighbouring boreholes. Several possible reasons have been attributed to account for the difference. One reason identified from the after action review process is the potential impact of surging while running in hole.

DST No.	Interval Name	Interval (m BS)	Flow Capacity (mD-ft)	Skin	Pressure (psia)	CDP (psia)	Std. Dev. (%) Spectra (No.)	V_L (m3/ton) L_P (psia)	G_c (m3/ton)	G_s (m3/ton)	G_c/G_s (%)	Drainage dP (psi)	$P_{abandon}$ (psia)	Recovery (m3/ton)	R.F. (%)
1	Seam 1	xxx.x – xxx.x	474	3.8	147	xxx	11.1 / 135	23.53 / 364	x.xx	xx.xx	33	xxx	10	xx.xx	82
2	Seam 2	xxx.x – xxx.x	39	2.0	158	xxx	5.4 / 64	24.28 / 387	x.xx	xx.xx	47	xxx	10	xx.xx	88
3	Seam 3	xxx.x – xxx.x	823	25.3	224	xxx	6.5 / 77	24.20 / 410	x.xx	xx.xx	47	xxx	10	xx.xx	90

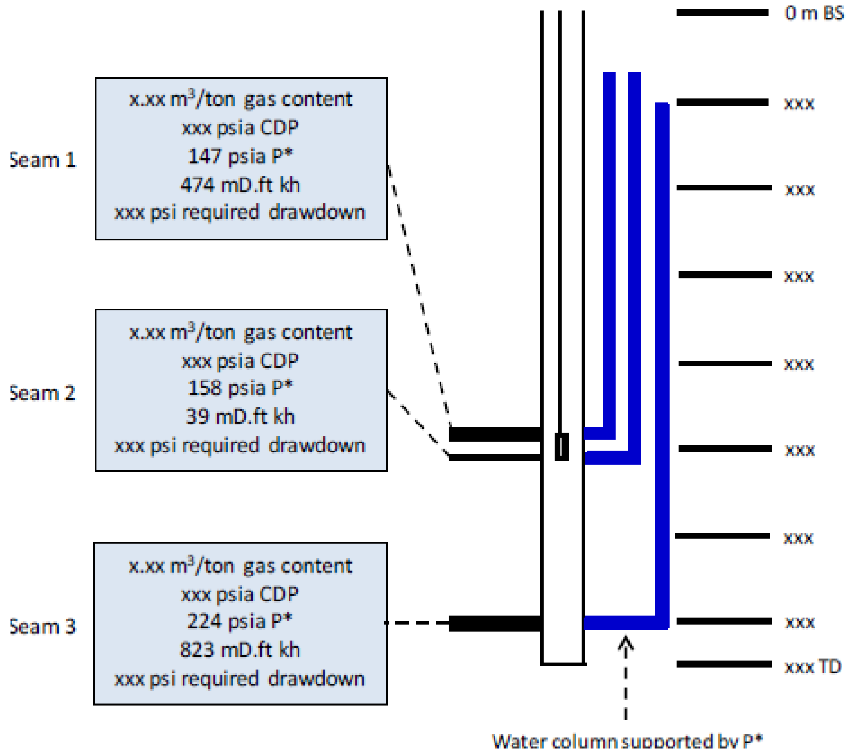

Figure 1: Borehole 2.

Key Findings

A review was conducted with the leaseholder to assess the performance of the new in situ permeability and gas content measurement service. The evaluation criteria listed previously were used to assign key performance indicators, with key findings as follows:

1. Standard well design does not conflict with RRS and DST testing methods.
2. It is possible to quickly retrieve reservoir fluids from coal seams isolated in open holes, with all seams tested to date having flow capacities ranging from 39–1,646 mD.ft.

3. The RRS logging technique can readily distinguish between reservoir and nonreservoir fluids.
4. The design of the surface pressure and flow control system can safely manage methane-laden fluids at the rig floor.
5. The RRS system has a wide dynamic range, with all seams tested to date having gas contents ranging from 1.5-13.3 m^3/t. The limit of detection (LOD) of existing generation RRS logging systems equates to around 0.8 m^3/t, with a new high sensitivity instrument presently being developed by research and development to lower LOD to around ± 0.1 m^3/t.
6. The DST and RRS systems both provide early indications of hole instability.
7. It is possible to obtain data needed to quantify gas content and permeability for a target coal seam in less than 24 hours.
8. The field trial proved the DST system's ability to facilitate multiple individual tests in separate seams in a single trip, saving test time.
9. The inflatable straddle packer system can successfully pack- off coal seams without inducing hole instability in wells that have been left unsupported for two or more months.
10. Testing time can be compressed significantly by certain equipment refinements, which have been verified on sub- sequent wells.

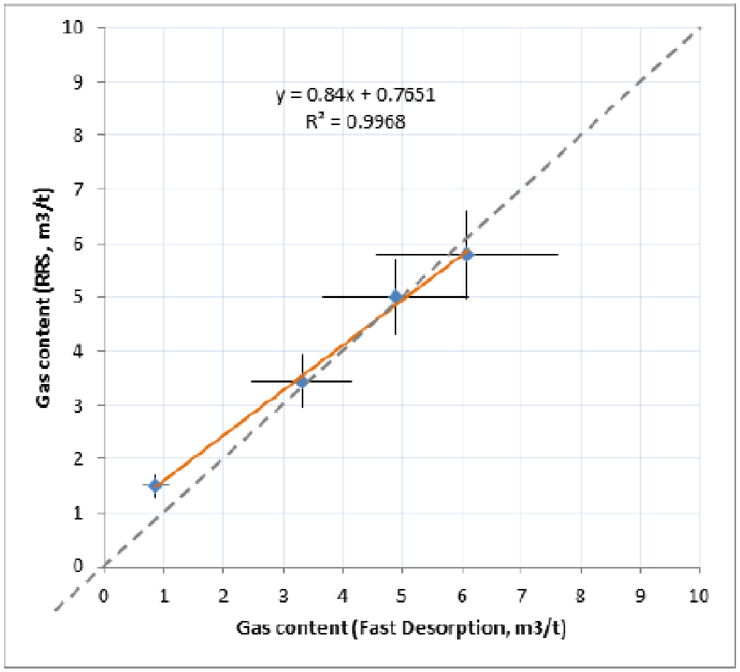

Figure 2: RRS versus fast desorption gas content comparison.

Conclusions

1. A new core-less testing capability has been developed to provide concurrent measurements of coal seam permeability and gas content at in situ conditions.
2. The testing capability involves the integration of DST technology and a proprietary Raman spectroscopy logging system, both using reservoir fluid as a key component of their measurement modes.
3. The testing methodology involves the extraction and examination of fluids from the coal clear structure, with sufficient pressure budget kept in reserve for pressure build-up surveys. Effective fluid management is, therefore, crucial to achieving accurate representative results.
4. The analyses of fluid behaviour and properties yield bulk averaged values of permeability and gas content applicable to the accessible drainage volume of the seam being tested.
5. Operation of this integrated service has been successfully demonstrated in a field trial involving tests on multiple coal seams in two multi-zone wells.
6. All key deliverables established for the field trial were met, with computed gas contents found to be closely matching those derived from fast desorption tests on cores