CONCURRENT IN-SITU MEASUREMENT OF FLOW CAPACITY, GAS CONTENT AND SATURATION

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ABSTRACT

A new core-less testing capability has been developed to provide concurrent measurements of coal seam flow capacity and gas content at in-situ conditions. The fluid-based measurement principles are intended to overcome time constraints, accuracy limitations, and cost implications of discrete measurements attributed to traditional ex-situ measurements on core samples. Details of measurement principles, associated enabling technologies, and generic test procedures have been disclosed in a previous publication.

In 2012 a number of field trials were conducted with this new service for both coal mine operators and CSG operators. This peer-reviewed paper will detail pre-job planning, well site execution, and data analysis for one of these trials, which involved testing several seams across two wells, and will illustrate comparison with data acquired using conventional testing techniques from offset wells. This peer-reviewed paper will also highlight key learnings and overall performance, and explain how the learned lessons can be applied to improve testing efficacy and data quality.

KEYWORDS

Reservoir Raman spectroscopy, RRS logging, drill stem testing, in-situ gas content, in-situ permeability, bulk sorption isotherms, pressure transient analysis (PTA).

INTRODUCTION

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 influenced greatly by artifacts 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 ex-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 (2013). 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 uses 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 also details 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 peer-reviewed 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 insure 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 ex-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 the following six parameters:

1. permeability;
2. skin damage;
3. critical desorption pressure;
4. gas saturation;
5. required pressure drawdown; and,
6. gas content.

An after action review (AAR) aimed at identifying key technical and operational learnings, potential system improvements, projections of additional time savings based on key learnings and system improvements, and a re-evaluation of the value proposition was also conducted.

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 permeabilities 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 desired.

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 evaluation criteria, which are:

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 JOB PLANNING

Once borehole candidate selection was finalised, the Data Centre and Operations immediately engaged the lease holder at multiple levels to ensure proper readiness. The overall aim of the job planning process was geared towards fulfilling field trail deliverables in accordance with the key performance indicators listed in the preceding section. This involved complying with best practices to ensure the supply of fit-for-purpose systems operated by sufficiently competent and experienced personnel in a safe manner. A detailed test the well on paper (TWOP) exercise was also conducted to ensure third-party interfaces were properly identified and addressed, and to familiarise the rig crew, field crew, and company staff with the test program.

FIELD TRIAL EXECUTION

Test execution forms part of an operation process management system (OPMS) to provide a common global system for the planning and execution of installations and tests across the various business units and product lines. This is achieved through strict adherence to prescriptive guidelines that are formalised under the OPMS in the form of process maps. These maps constitute the topmost level of a multi-tiered structure that enables the user to drill down to more extensive written procedures governing each step in the process map and that, in turn, link to very detailed work instructions and associated supporting documentation. The particular process map governing test execution is shown in Figure 1.

Through adherence to OPMS processes, and procedures and work instructions, the tests were completed without incident, with the time breakdown for the tests conducted on the three zones in the second well, presented in Figure 2.

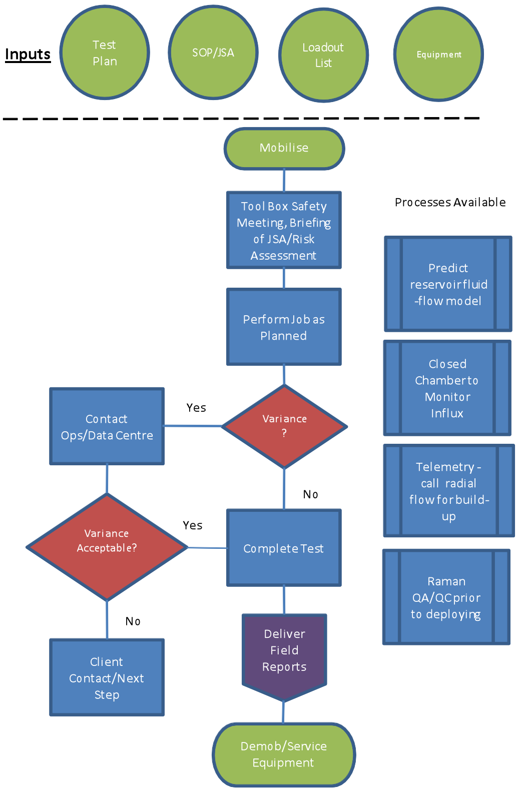

Figure 1. Test execution process.

The primary uncertainty prior to the field trial was related to the amount of time that might be required to obtain representative fluids from the coal seams. Advance analysis indicated that if duration of the test campaign per well exceeded seven days, the tests would not be acceptable, operationally or financially. Heightening the concern was the fact that the wells to be tested were to be drilled with standard muds, increasing the possibility that skin damage or invasion would preclude production of representative fluids.

Instead, field observations showed that the coal fluids cleaned-up almost immediately, and representative fluid was obtained within one to two work string volumes.

FIELD TRIAL SUMMARY

Two wells were selected, with three seams targeted in each for testing; 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 the two boreholes, along with estimates of gas and reservoir parameters derived for each seam are shown in Figures 3 and 4, and in Tables 1 and 2. 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

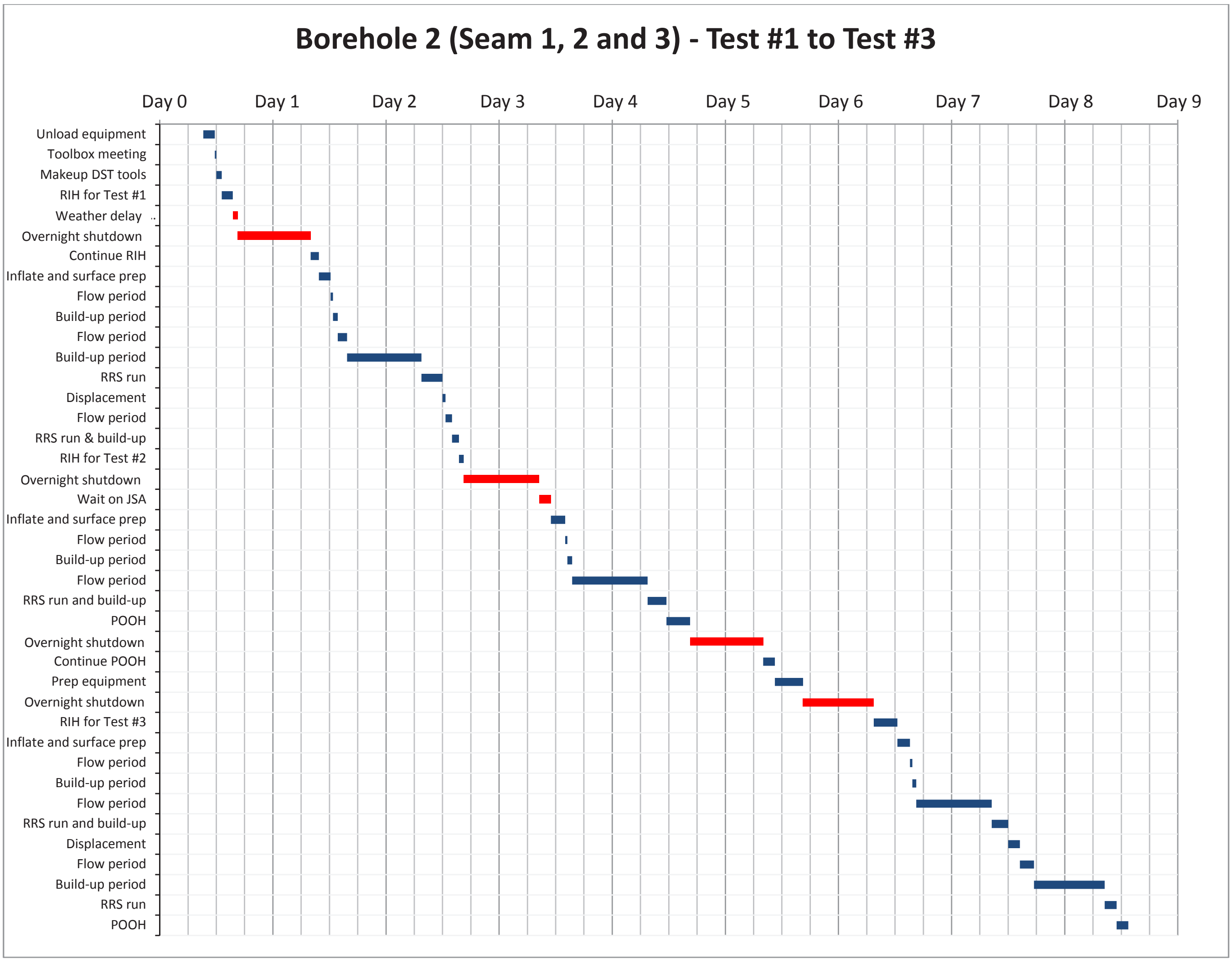

Figure 2. Time breakdown Gantt chart.

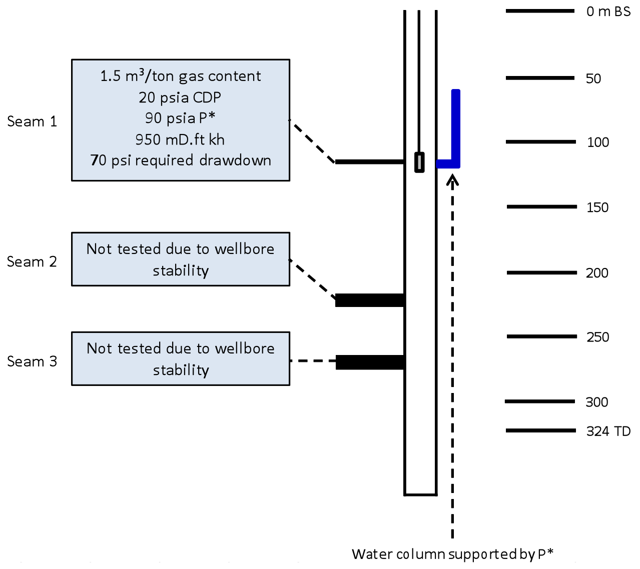

Figure 3. Borehole 1.

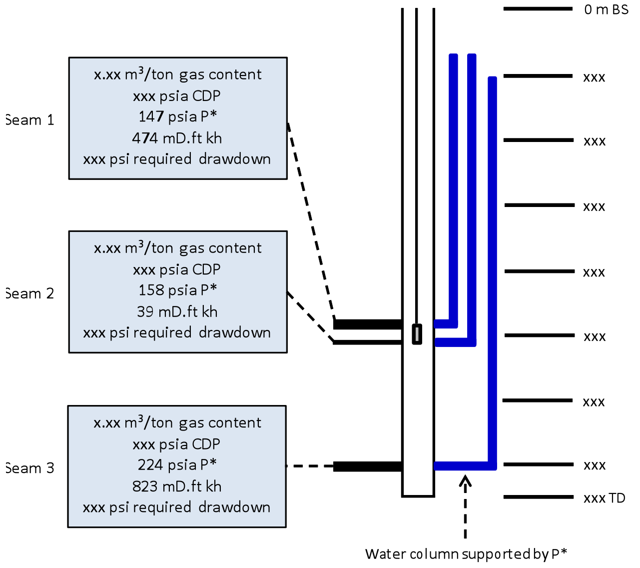

Figure 4. Borehole 2.

Table 1. Borehole 1. See nomenclature for list of abbreviations.

DST no.	1
Interval name	Seam 1
Interval (m BS)	114.6–118.2
Flow capacity (mD-ft)	950
Skin	3.8
Pressure (psia)	90
CDP (psia)	20
Std. Dev (%) spectra (no.)	12.5/25
V_L (m³/ton) / L_p (psia)	23.11/289.0
G_C (m³/ton)	1.5
G_S (m³/ton)	5.49
G_C/G_S (%)	27
Drainage dP (psi)	70
$P_{abandon}$ (psia)	10
Recovery (m³/ton)	0.72
R.F. (%)	48

Table 2. Borehole 2. See nomenclature for list of abbreviations.

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

in Figure 5. 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 AAR process is the potential impact of surging while running in hole. This is discussed later in this peer-reviewed paper.

DETAILED DISCUSSION

Synthesis of bulk sorption isotherms

RRS technology measures the concentration of solubilised gases in the water drawn from the cleat system. This is equated to a partial pressure for each gas, including methane, using an appropriate solubility law such as Henry's law. The partial pressure of methane in the cleats is the same as the partial pressure of methane occupying the micropores and coal matrix itself. It is also the same as the critical desorption pressure (CDP) of methane adsorbed to the coal structure. While, however, partial pressure of solubilised methane in the water and CDP of methane adsorbed to the coal are the same, the concentrations—as determined by Henry's law and an adsorption isotherm, respectively—are different. It is thus necessary to reference a suitable sorption isotherm for the coal to compute a gas content.

The advantage of the RRS measurement technique is that the measured partial pressure, and consequently CDP, is not impacted by geological heterogeneity. Its validity, therefore, extends some distance away from the wellbore. Furthermore, with the spacing of the DST straddle packers chosen to induce flow from the cleat system spanning the entire thickness of the target seam, the technique effectively yields a bulk averaged value of methane partial pressure that is applicable to the entire region of constant CDP, and which can then be used to calculate a gas content that likewise is applicable to the entire coal. In an optimised dewatering or pre-drainage strategy, this region would represent the accessible drainage volume for each well.

With the spectrometer exhibiting little sampling or measurement error, the uncertainty in computed gas content

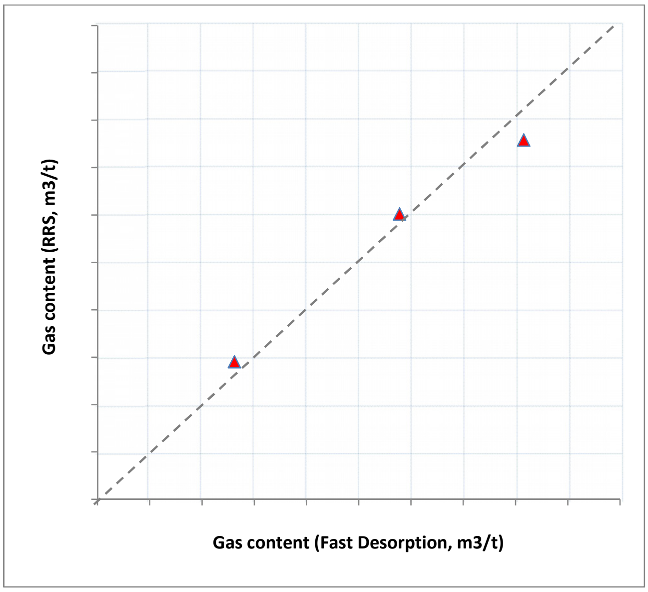

Figure 5. RRS versus fast desorption gas content comparison.

values is thus dominated by the errors accumulated in synthesising a suitable bulk sorption isotherm. This isotherm must be representative of the coal sorptivity in the drainage area of the well. At a minimum, its construct is also corrected for differences between average near wellbore ash content and ash content in the individual samples used to determine Langmuir pressure and volume. If appropriate, the synthesised sorption isotherm can also be corrected for differences between coal seam temperature and bath temperature used to quantify coal sorptivity. The same approach can be applied to correct for differences between average seam moisture content, if known, and moisture content of the coal sample used to determine the sorption isotherm.

A statistical approach is used to analyse dry-ash free Langmuir volumes and ash contents to separate variations in sorptivity from variations in ash content. The process developed to perform this analysis involves the following seven steps:

1. Evaluate available isotherm data of coal samples similar to the target seam being tested (i.e., similar depth, temperature, etc.) for variation in underlying sorptivity (reflecting variations in coalification or chemical/maceral content).
2. Investigate any outliers individually, and identify a representative Langmuir pressure with a statistical measure of deviation.
3. Derive dry-ash free adsorption isotherm values (i.e., correct Langmuir volume to ash-free basis), and check the consistency of similar coals.
4. Establish the density to ash correlation.
5. Determine the average density of the target seam from an evaluation of the density log using appropriate cut-off values.
6. Customize Langmuir volume for the target coal seam based on average ash content.
7. Identify and correct for temperature effects to derive new Langmuir pressure and Langmuir volume.

If the mean moisture content for the target seam is known then steps 3–7 can be conducted on a dry, ash-free (DAF) basis. In addition, the results of these analyses can be rigorously evaluated for statistical variation, providing an indication of how representative they are for the coal in question.

An example of pre- and post-processed Langmuir volumes from the first two steps is shown in Figure 6, with an established ash correlation as a function of coal density from step 4 shown in Figure 7. The synthesised value for the Langmuir volume derived for the target coal seam from steps 5–7 is shown in Table 3.

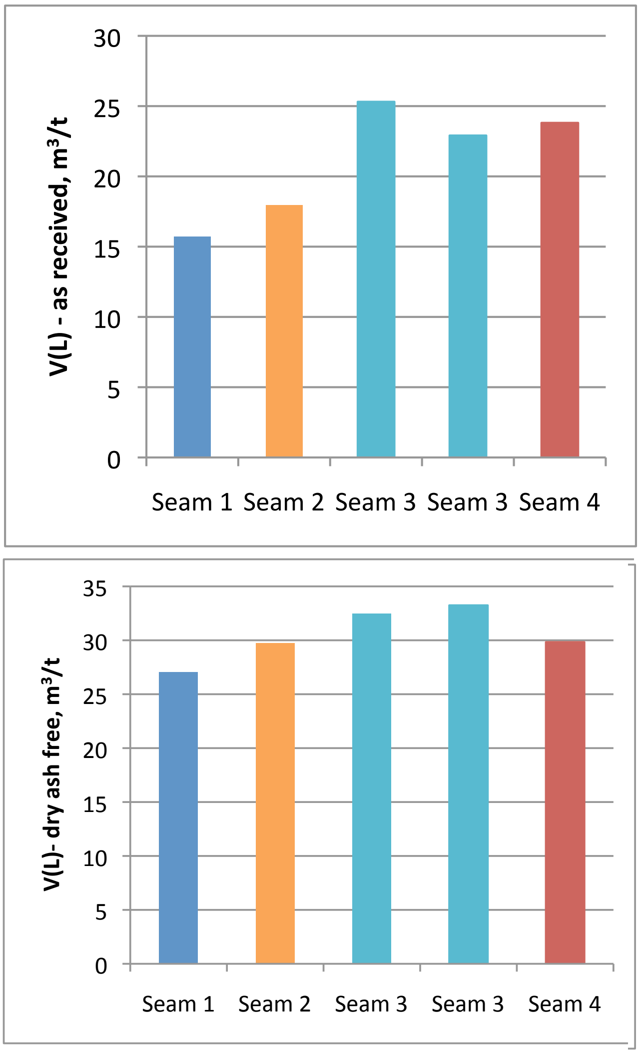

Figure 6. Example pre- and post-processed Langmuir volumes.

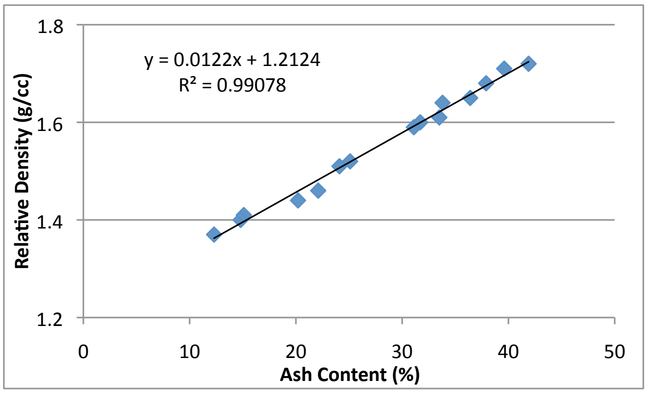

Figure 7. Example density-ash correlation.

Table 3. Example synthesised Langmuir volumes for the target coal seams.

Seam no.	Average density (g/cc)	Average ash (%)	V(L)—DAF (psi)	Synthetic V(L)—AR (psi)
Seam 1	1.57	29	27.06	19.21
Seam 2	1.63	34	29.74	19.65
Seam 3	1.50	23	32.87	25.17
Seam 4	1.62	33	29.84	19.93

Fluid management

Determining CSG content using the RRS logging technique involves drawing water from the cleat system until under-saturated conditions are observed on the RRS logs. These conditions need to extend for more than a certain minimum fluid column height in the work string to ensure self-consistency. Depending on the extent, if any, of drilling fluid invasion prior to testing the seam, the hydrostatic head of the overall fluid height attained could approach reservoir pressure; however, this would violate the criteria established for the maximum permissible fluid height that can be tolerated. This threshold is set to ensure that a sufficiently large pressure transient is induced during the subsequent build-up period to accurately compute coal seam permeability. Under this circumstance the well would be shut-in once the fluid height in the work string reaches this threshold. At the end of the build-up period, the work string contents are reversed out, with the coal seam then allowed to produce additional fluid into the work string. RRS logging operations are then repeated, and possibly alternated with inflow of additional fluid from the coal seam, until the specified acceptance criteria are achieved.

This is just one of a number of scenarios impacting fluid management. The following is a list of all six scenarios that need to be accommodated through development and implementation of a suitable fluid management decision tree and associated contingencies:

1. Permeability and gas content are required. Extensive fluid invasion has occurred.
2. Permeability and gas content are required. Minimal fluid invasion has occurred.
3. Only gas content is required. Extensive fluid invasion has occurred.
4. Only gas content is required. Minimal fluid invasion has occurred.
5. Coal seam permeability is very low.
6. Coal seam pressure is very low.

An examination of the fifth scenario will illustrate the robustness of the processes and procedures developed to manage fluid ingress and displacement. Coals with low permeability would be referred to the decision tree shown in Figure 8. This uses a prediction for work string fill time as an evaluation criterion, with results of an example study shown in Figure 9.

Data validation

Validation of data acquired by the various measurement systems integrated into both the DST system and RRS logging system is deemed essential. This process should be conducted prior to conducting any data analysis and, if possible, prior to leaving the well site. This is true of any data acquisition and analysis program. Data acquired using this new integrated testing capability is conducted on multiple levels:

1. Cross-referencing data sets.
2. Comparison with absolute references.
3. Independent verification.

DST PRESSURE GAUGE DATA

Data acquired by the various pressure sensors is validated by comparing pre- and post-test atmospheric readings, and through comparison with each other, with results of such a comparison from the second test in the second borehole shown in Figures 10 and 11. Figure 10 shows that all three gauges accurately measured the atmospheric pressure prior to being installed in the DST string. Figure 11 shows that the difference in coal seam pressures recorded by the two gauges placed between the two packers was very small. Most importantly, the plot shows that the pressure difference was constant during the build-up periods. A similar plot (not shown) was created that compared the difference in pressures recorded by the third gauge, which was positioned above the tester valve, and one of the two formation gauges. This plot showed that during the flow periods the pressure difference between the two gauges was also constant. Collectively, these observations provide conclusive proof that all three gauges functioned correctly, and that the data from all three is, therefore, valid.

RRS LOGGING DATA

The pressure and temperature data acquired by the RRS logging string is compared with the data acquired by the DST pressure gauges. The conductivity sensor readings are compared with measurements obtained by using a precise, handheld instrument on samples of produced fluids after reverse circulation to the surface. The accuracy of solubilised gas concentrations obtained with the spectrometer are verified through post-test calibration verification. RRS log data for the second test in the second borehole is presented in Figure 12. Note that the measured bubble point of gas in the fluid column is not equivalent to that of the coal seam due to differences in physical conditions between the coal seam and the fluid column measurement point, and due to the super-saturation of gas in the fluid column. Measurement of gas under sub-saturated conditions, therefore, is required for accurate results.

PRESSURE TRANSIENT ANALYSIS (PTA) DATA

As with any modelling study, it is imperative that model inputs are validated to avoid the rubbish-in-rubbish-out trap. Succeeding in this best practice involves close collaboration with the lease holder engineers, applying extensive due diligence and independent peer-review. For PTA analyses, flow-rate computation errors are one of the most common sources of discrepancy. To ensure consistency, two flow-rate data sets are generated using data from two different DST pressure gauges. Both sets are then cross-referenced with an independent, single point estimate of flow rate. To limit flow-rate uncertainties, rolling averaging techniques are used.

To validate the permeability values derived from PTA, the values are cross-referenced with results from proprietary quasi-pseudo steady state analyses, as shown in Figure 13 for the first zone in the second borehole.

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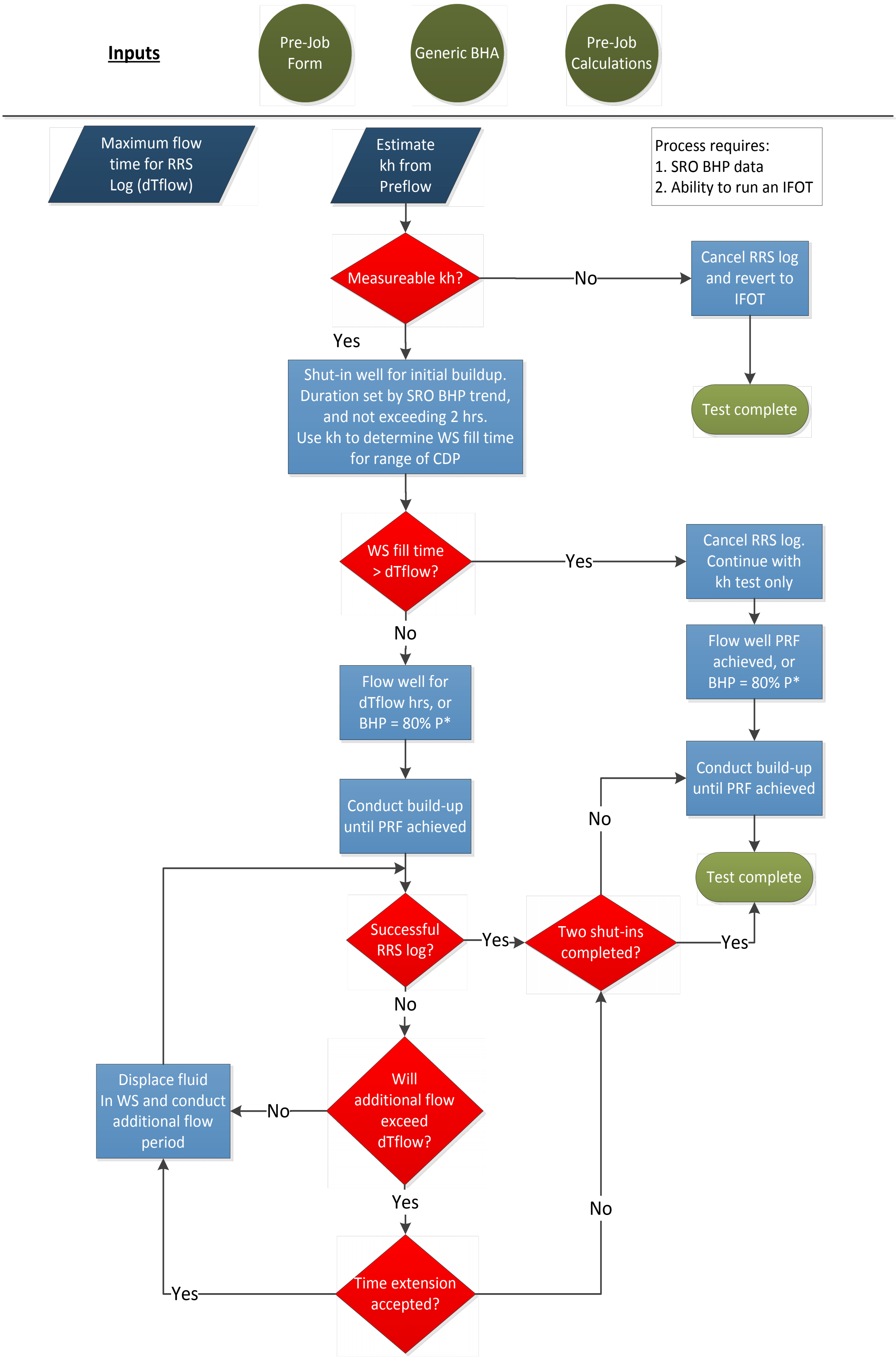


Figure 8. Low permeability fluid management decision tree.

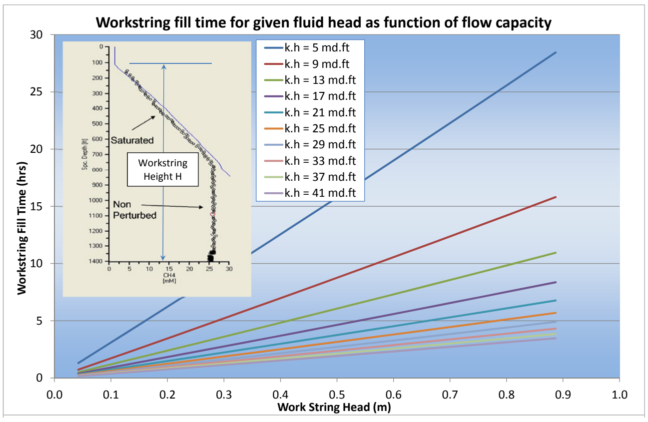
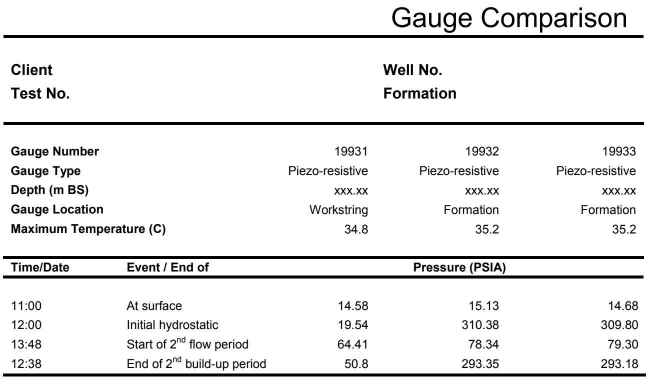


Figure 9. Example work string fill time calculator.



Gauge Comparison

Client		**Well No.**	
Test No.		**Formation**	

Gauge Number	19931	19932	19933
Gauge Type	Piezo-resistive	Piezo-resistive	Piezo-resistive
Depth (m BS)	xxx.xx	xxx.xx	xxx.xx
Gauge Location	Workstring	Formation	Formation
Maximum Temperature (C)	34.8	35.2	35.2

Time/Date	**Event / End of**	**Pressure (PSIA)**		
11:00	At surface	14.58	15.13	14.68
12:00	Initial hydrostatic	19.54	310.38	309.80
13:48	Start of 2nd flow period	64.41	78.34	79.30
12:38	End of 2nd build-up period	50.8	293.35	293.18

Figure 10. Borehole 2, Zone 2 gauge comparison table.

AFTER ACTION REVIEW (AAR) WORKSHOP

The aim of this review process is to analyse what happened, why it happened, and how it can be done better by the participants and those responsible for the project. Each task executed, from the start of job planning through to the submission of final data analysis reports, requires determination of the following:

1. Does a standard operating procedure (SOP) exist?
2. If so, were any departures from the SOP required and approved?
3. If so, determine the underlying reasons for the departures.
4. Ascertain whether the outcome from each SOP was successful.
5. If not, why, and was any non-productive time (NPT) incurred?
6. Does a risk assessment covering work encompassed by the SOP exist?
7. Did any health, safety and environment (HSE) incidents occur? If so, why, and were they adequately covered by existing risk assessments?

The AAR workshop is also intended to be an opportunity to propose modifications or improvements to the DST and RRS technologies aimed at:

1. improving reliability;
2. boosting robustness;
3. expanding the system operations envelope;
4. compressing test schedules; and,
5. simplifying operations.

An AAR workshop was conducted with the field crew following the completion of the second well field trial. Findings from the review of each step were captured and rigorously analysed. One such finding was that surging while running in hole could affect (increase) permeability of the coals. This led to a formal opportunity for improvement (OFI) being implemented, involv-

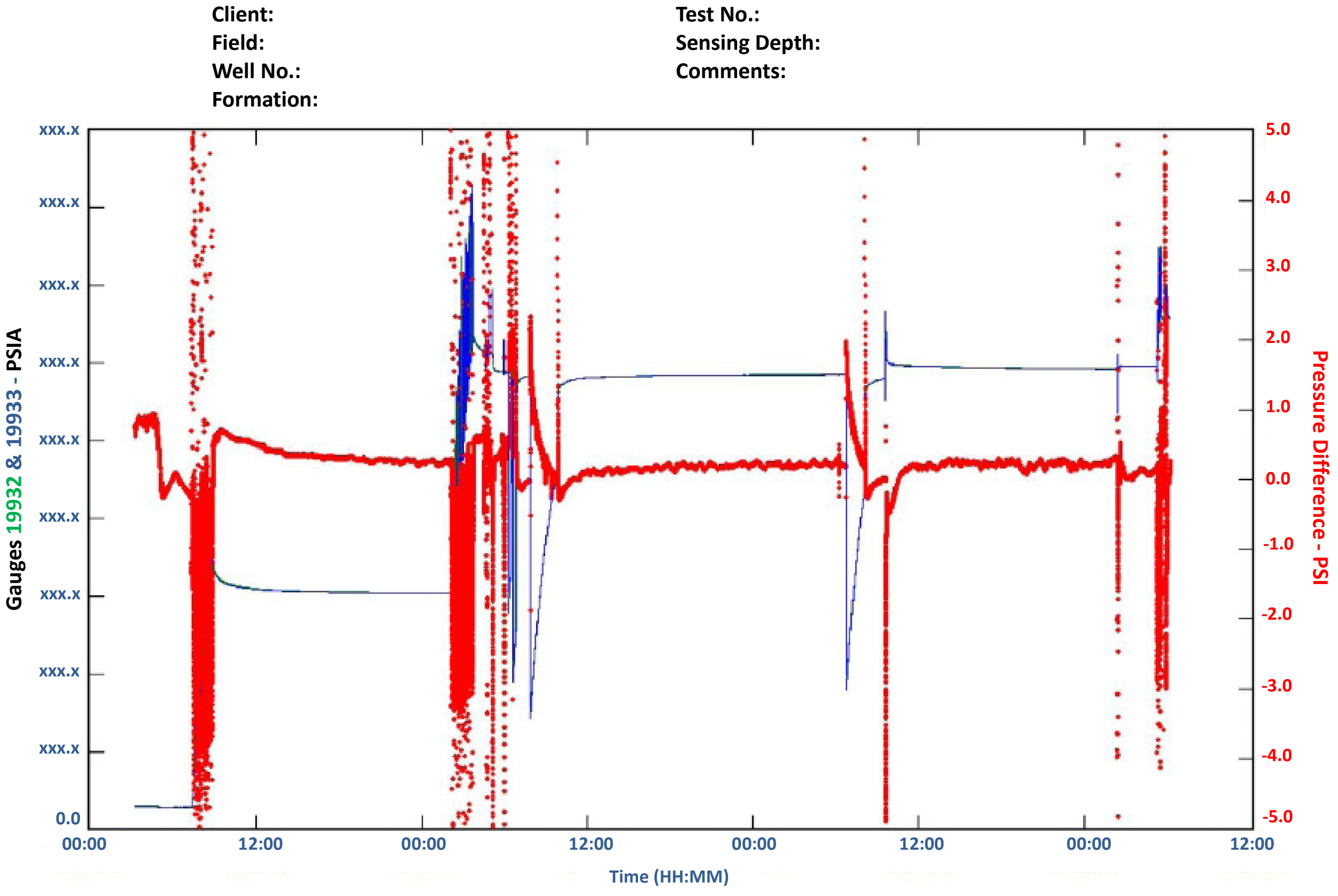


Figure 11. Borehole 2, Zone 2 gauge difference plot.

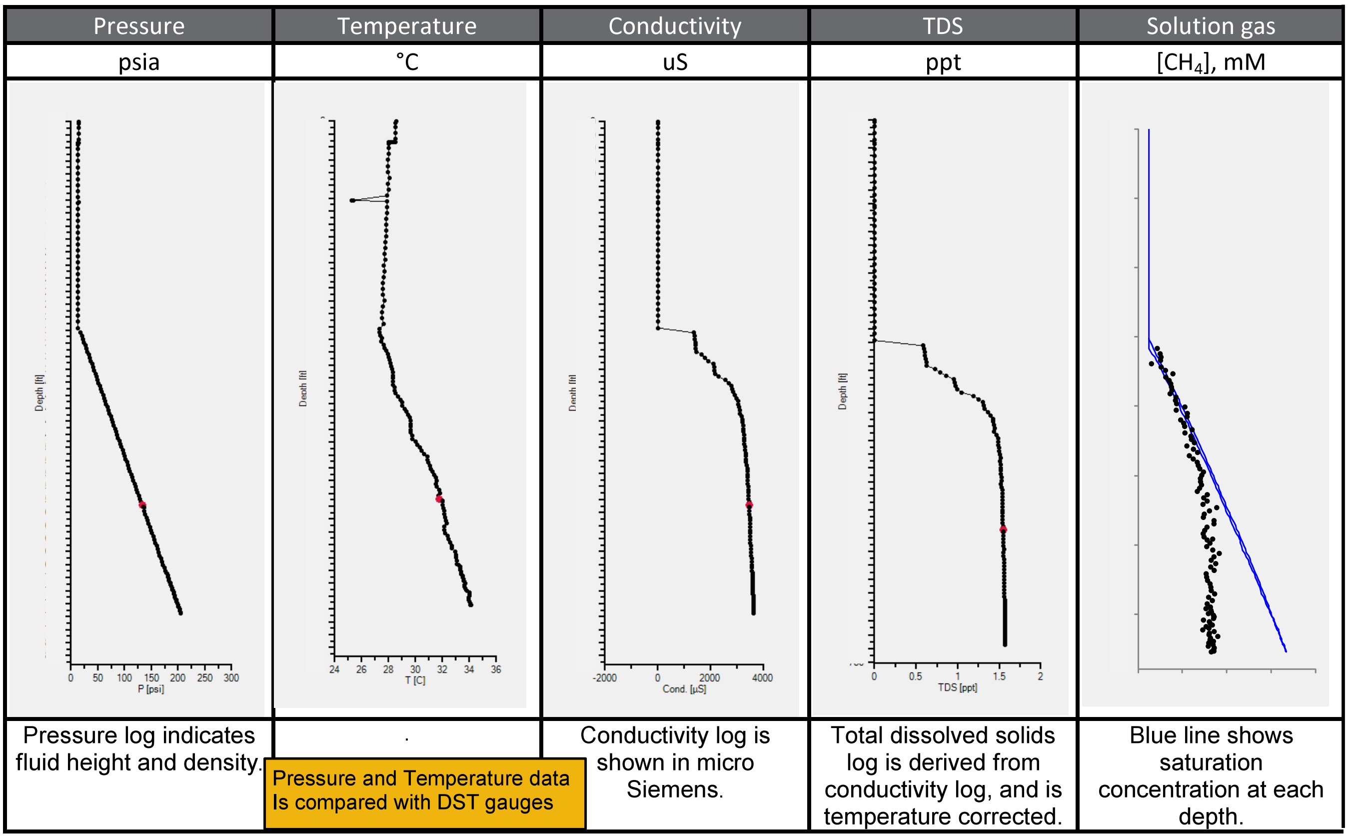


Figure 12. Borehole 2, Zone 1 RRS log.

ing a change to SOP that limits tripping speed during deployment of the DST string.

The AAR also resulted in a number of system refinements and improvements being identified, some of which were incorporated prior to official product launch, such as the integration of a wireless real-time surface readout monitoring system. Other suggestions were placed with the sustaining engineering function to help ensure that the integrated service is matured. Ideas requiring development of new subsystems were referred to the Stage-Gate ideation management process. This includes the top-drive wireline entry guide (WEG) system referred to in the publication by Pope and Morgan (2013), and shown in Figure 14.

KEY LEARNINGS

Following the AAR, a separate review was conducted with the lease holder 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 and completion techniques do 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 non-reservoir 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.

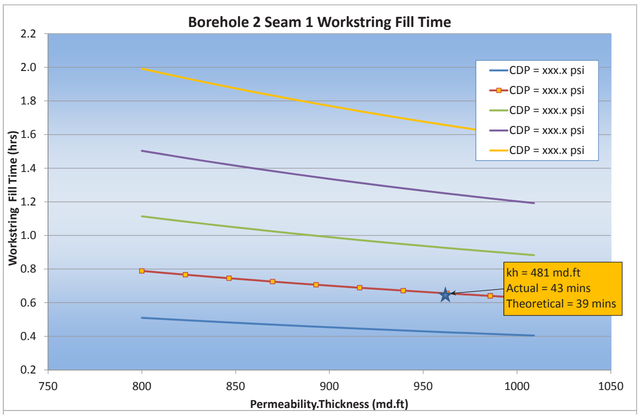


Figure 13. Borehole 2, Zone 1 permeability verification.

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 subsequent wells.

Revised test duration projections that demonstrate the significant reduction in overall test schedules that can potentially be achieved through the proposed changes to SOPs and refinements to test equipment, based on the key learnings from the field trial, have been developed. This is illustrated in Figure 15, covering 12-hour rig operations.

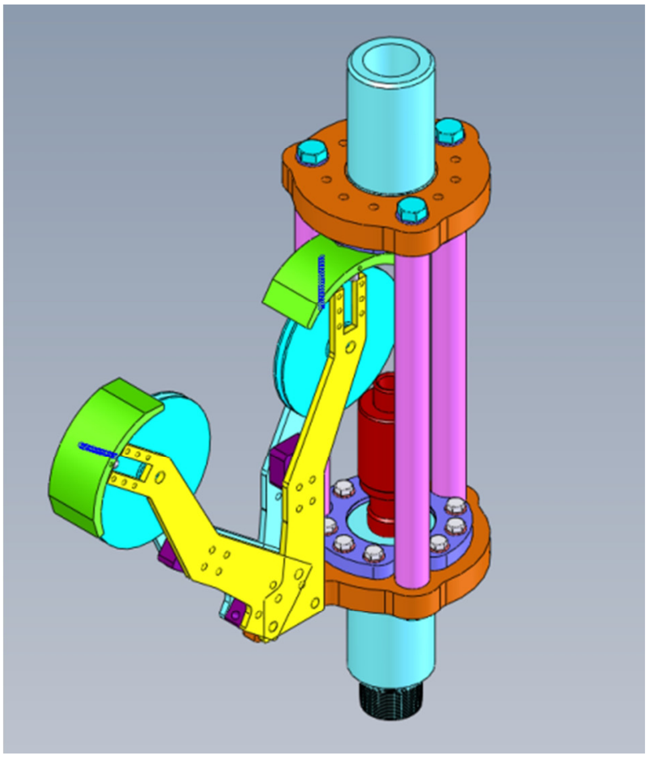


Figure 14. Top drive wireline entry guide.

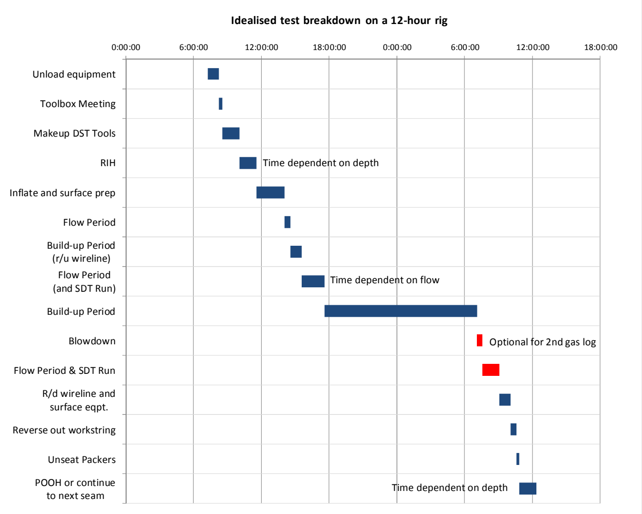


Figure 15. Projected test schedule for 12-hour rig operations.

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.

REFERENCES

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NOMENCLATURE

BHP	Bottom hole pressure
CDP	Critical desorption pressure
Drainage dP	Difference between original coal seam pressure (P*) and CDP
G_c	Gas content
G_s	Gas saturation
IFOT	Injection fall off test
kh	Permeability.thickness product
P*	Original coal seam pressure
$P_{abandon}$	Coal seam abandonment pressure
PRF	Pseudo radial flow
R.F.	Recovery factor
V_L	Langmuir volume
WS	Work string

Authors' biographies next page.

THE AUTHORS

Quentin Morgan holds an honours degree in nuclear engineering (1982) and a masters degree in petroleum engineering (1983), and is chief technology officer at WellDog. Prior to joining the company in 2011, he spent 28 years working for a number of major international oil and gas service companies, involving permanent secondments to six continents. After a variety of roles in operations, country management, and technology development, Quentin joined Weatherford in 2002, where he held positions as region product line manager for intelligent completions, and then region business unit leader for sandface completions. This culminated in the appointment to technical director for subsurface engineering in 2009.

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John Pope, PhD, is president and CEO of WellDog, which he founded in 1999 to apply a new offshore chemical sniffer to geochemical sensing of coal seams. He was appointed by the Governor of Wyoming to the Wyoming CBM Water Use Task Force from 2005–2007, and to the US Interstate Oil and Gas Compact Commission in 2006. John holds a PhD in physical chemistry from the University of Wyoming, and a BS in physics from the University of Missouri-Rolla. He has worked at Monsanto Chemical Company, and at Tokyo University of Agriculture and Technology. John holds several issued patents, and has published dozens of technical papers. He presently splits time between Wyoming and Queensland.

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Peter Ramsay is data centre manager at WellDog. He holds a diploma in natural gas and petroleum (1972). Prior to joining the company, Peter spent 35 years working for a major international service company. Progressing through a variety of roles, he was appointed as technical services manager for the open hole DST product line. In this capacity, Peter was responsible for quality control/quality assurance of test data, and the education of internal staff and clients on the aspects of conducting a successful DST.

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APPEA

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