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Unlocking Opportunities for Gas Lift Well Surveillance - Building the Framework for Consolidated Data Capture and Processing

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Abstract

Gas lift operations are highly dependent on data quality and team competence to operate the asset efficiently. Traditional methods for gas lift well surveillance and diagnostics rely on wireline services, a method with growing constraints to adapt to constantly evolving well and operational challenges. The Well Intervention-less Tracer Surveillance System (WITSS) provides a cost effective, comprehensive approach to well surveillance without the reliance on tools entering the well. This results in reduced HSE risks and no associated deferred production.

This paper describes a pilot implementation to evaluate the adequacy and accuracy of this technology in the context of ADNOC Onshore gas lift producers. The objective is to evaluate its performance against conventional method data sets and assess the reproducibility of data where no reference existed. The 10 well pilot included both accessible and obstructed wells. Data from the custom designed modular portable kit used for executing the surveillance activities, was analyzed and compared against conventional flowing gradient surveys with full data consumption in well models for comprehensive nodal analysis and opportunity identification.

For this pilot, ten wells were surveyed twice using the WITSS method. Results were compared to traditional methods acquired through wireline surveys for accessible wells, and against established multi-phase flow correlations for obstructed wells. The pilot confirmed the WITSS method is as accurate as conventional gauge measurements in mapping pressure and temperature profiles in gas lifted wells.

The WITSS method provided additional insight on accurate gas consumption based on the assessment of total gas lift utilization per well and allowed comprehensive model calibration and well performance definition. It also identified potential integrity issues via identification of primary injection at designed stations and secondary unwanted injection sites. Continuous compositional gas analysis of both injected and produced gas streams provided additional verification for analyzing gas lift injection performance. It also highlighted a change in fluid compositional analysis opening discussions for material selection review of the assets.

Production uplift identified from 50% of wells was compliant with the reservoir management strategy. The value proposals of flow stabilization through gas lift valve re-calibrations and replacements, adjustment of injection flow rate and further controls on injection pressure management are under process for implementation. Full field scale up scenario is under preparation.

INTRODUCTION

Within the industry, the challenge of insufficient gas supply for gas lift operated fields is discussed extensively along with its impact on field surveillance and optimization. This is not the topic of this paper, rather the challenge stems from lack of accuracy in physical measurements to allow for proper optimization of a growing gas lifted field under an accelerated gas lift conversion drive. Optimization in the context of gas lift is simply put - the optimum allocation of available injected gas for maximum production returns from the field. The challenge being addressed in this paper is the core fundamental data set required to make informed optimization decisions. Over-engineering during initial design of instrumentation, metering and control equipment presents a challenge to the ability to accurately meter and control the allocation of injected gas for artificial lift. This is a concern for a growing field of more than 100 gas lift producers with development plans for triple that well count over the next five years.

These core inefficiencies are affected by the low quantity and low quality of wireline intervention methodologies, such as flowing gradient surveys, to support well monitoring and diagnostics. Increasing scale deposition or deformation in the tubing of gas lifted wells, further limits conventional wireline surveillance efforts to be deployed in the field.

As a result of these issues, the authors of this paper sought to identify an intervention-less solution that could provide the extent of data on each producer required to support comprehensive analysis for individual, as well as collective gas lift optimization. This was delivered in the form of a compact multi-method approach that combined and enhanced monitoring technologies such as acoustic surveys, tracer fingerprint analysis, compositional profiling coupled with independent temperature and gas rate measurement. This comprises the Well Intervention-less Tracer Surveillance Survey (WITSS) solution. The technology allowed for injection point verification, surface and downhole gas lift rate measurement along with full compositional profiling of injected and produced gases. All this data was processed in a physics-based well model. Nodal analysis performed to replicate well behavior in accordance with production well test, gas lift performance curves generated to establish and define the operating envelope and low-lying optimization opportunities.

STATEMENT OF THEORY AND DEFINITIONS

For more than thirty years, the industry has discussed the use of tracers in gas lift surveillance activities. However only in recent years has the technology advanced to support comprehensive diagnostics. Based on these advancements in technology and collaborations with key industry and research giants, the WITSS method has been developed. The method comprises a set of portable equipment and a mathematical model for the propagation of a tracer gas in gas lifted wells. Additional studies were conducted regarding the mixing and propagation properties of different tracer gases, combined with sensitivity analysis of the model for a range of inputs.

The studies concluded that the main challenge is matching the measured tracer concentration as a function of time (fingerprint) to the lifting depths in the well. By developing a unique method for gas lift measurements, annulus temperature profiling and continuous compositional analysis, the accuracy of this fingerprint matching was maximized and provided an additional set of valuable data for the operator.

WITSS service is divided into three main categories and linked to the pilot objectives:

1. Metering:

   - Real time, continuous compositional analysis of injected and produced gases
   - Gas lift rate measurements
   - Pressure and temperature gradients in production annulus
   - Depth of gas-liquid interface in production annulus
   - Depth of lift-gas injection (single/multi-pointing)
   - Net gas produced and total produced gas rate
   - Gas lift propagation time and velocity in annulus and tubing
2. Troubleshooting:
   - Identify lifting depths and potential tubing integrity issues (leak depths)
   - Identify poor lift-gas metering
   - Identify restricted or eroded gas lift valves
   - Identify leaks and leak rates in gas-lift valves during inflow leak test of production annulus
   - Identify and investigate sustained casing pressure (SCP) in intermediate casing
3. Optimization:
   - Gas-lift simulations
   - Gas-lift performance curve definition
   - Gas-lift redesign / potential uplift

The WITSS method comprises injecting a tracer medium into the well's gas lift supply, while monitoring compositional variations of the injected and produced gas streams downstream the injection point. The compositional data collected, together with surface pressures, temperatures and acoustic response, is further processed in a proprietary software, tuning production parameters and identifying the integrity status of the well.

Considering the objectives and the logistics of the pilot, Nitrogen (N_2) gas was selected as the tracer medium in place of commonly used Carbon Dioxide (CO_2). Primarily, the need for reliable, direct gas lift rate measurement was considered, although additional properties of N_2 tracer were found superior compared to CO_2. N_2 is a widely available, inert gas used everywhere in the oil field. With extremely low solubility and a very low critical temperature, it is always a gas, it is easy to model, and is thus a very good candidate for tracing and dilution of pressurized gas streams. It provides better accuracy when interpreting the results of its propagation, even in multiphase streams. Additionally, there is no environmental impact or corrosive solutions generated.

CO_2 is a high-density gas that is liquefied at 35bar under standard conditions. CO_2 is highly soluble in water producing a corrosive solution. It is associated with global warming and negative environmental impact. It is difficult to model as a tracer in a gas lifted well as it undergoes a phase change from liquid to super-critical upon injection. Due to its mixing and thermodynamic properties, simple mass balance dilution equations cannot be applied when diluting gas lift streams with CO_2.

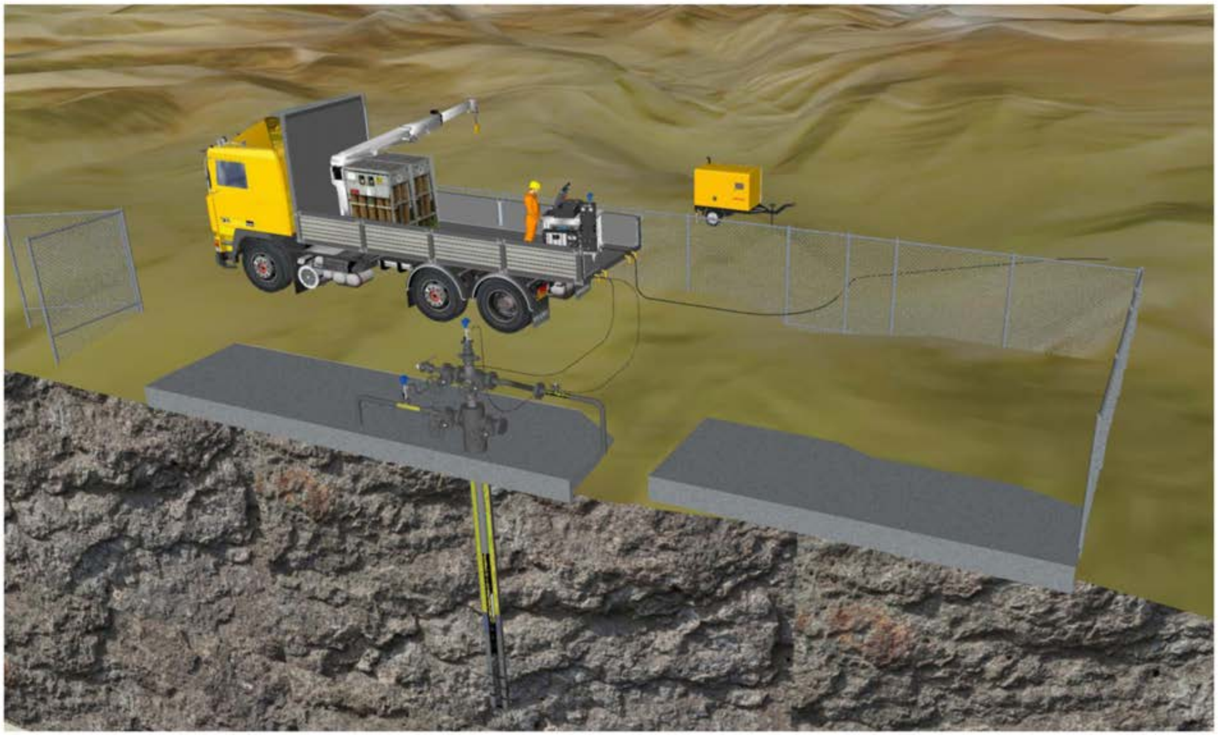

Figure 1—WITSS onshore application overview

Modeling strategy

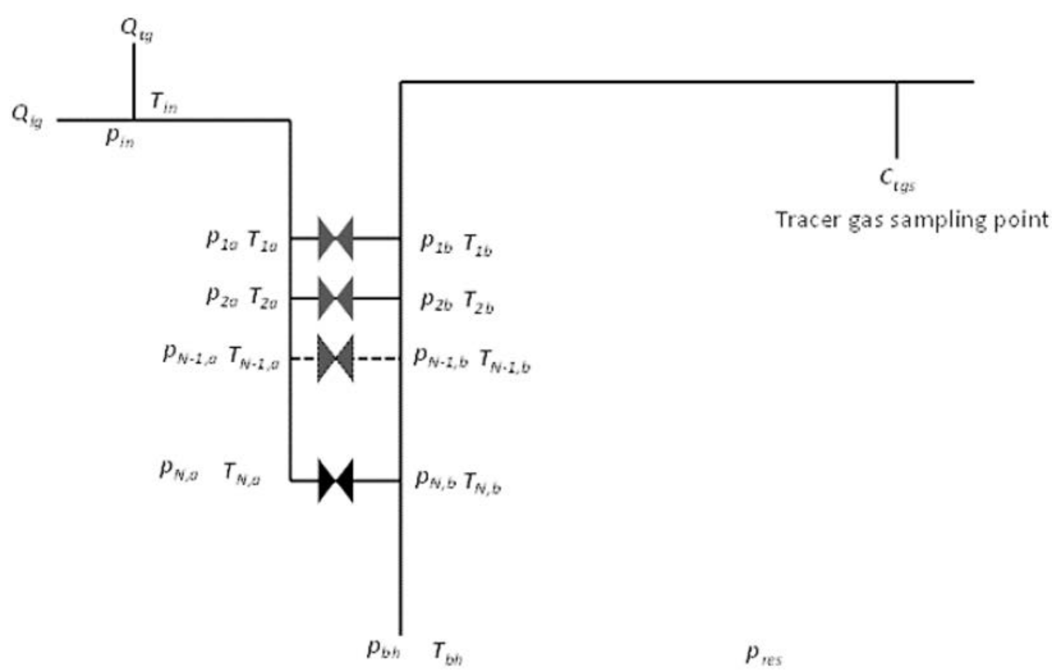

Figure 2—Mass flow computation concept

The WITSS model calculates the transport of a tracer gas in the annulus from the injection point to the gas lift valves. The solution is found by dividing the annulus volume into a given number of grid boxes, and solving the mass and momentum conservation equations iteratively for each box.

- Lift gas injection and gas production mass rates are measured using a tracer dilution method and mass balance equations.
- Annulus temperature gradient is derived from advanced proprietary acoustic methodology.
- Annulus and tubing head pressure, composition and surface temperature are logged throughout the survey.
- Tracer gas is measured when injected into the well, and the simulation is tuned based on survey results.

Gas Liquid Contact in the Production Annulus:

Measured using a portable acoustic logging system connected to the annulus wing valve at surface. The system records reflections from an acoustic pulse generated at surface, and the instrument measures the gas-liquid contact in the production annulus and quantifies the gas volume. It shows all changes in cross-sectional diameter in the annulus, thereby making it possible to identify wellbore components and anomalies.

Figure 3—Portable acoustic logging system

Lift Gas Rate / Produced Gas Rate / Net Gas Produced Measurements:

These measurements are obtained by injecting a known concentration of tracer at a constant rate into an upstream location of the flow stream. The tracer becomes mixed and diluted, and after steady-state conditions are achieved, the diluted volume fraction of the tracer is measured at a downstream location. The increase in the tracer component concentration at the sampling location, is directly proportional to the flow stream's volumetric rate transferring the tracer to the sampling location.

Lift Gas Composition

Online real-time gas analyser performs continuous gas analysis of produced and injected gases. This includes per second measurement of the mol% of methane, ethane, propane, iso-butane, n-butane, iso-pentane, n-pentane, hexane, N_2, CO_2 and H_2S.

Pressure-Temperature Profile in Production Annulus:

Pressure and temperature gradient in the production annulus are critical for accurate determination of lifting depths using the tracer method. The pressure and temperature gradient are calculated from the acoustic velocity profile in the wellbore, the gas composition, and the surface pressure. The measured P/T profile is then tuned based on comparison to the simulated P/T gradients using Hasan-Kabir correlation.

Figure 4—Shkorin Gas Analyser (SGA)

Measured Lift Gas Propagation / Determination of Lifting Depth(s):
A tracer gas is injected with the lift gas using the tracer injection module. The tracer injection module is equipped with a Coriolis flowmeter and quantifies mass, pressure and the temperature of the injected tracer. The tracer travels down the production annulus with the lift gas and returns to surface with the produced fluids. A tracer detection system is connected to the flow line at surface and records the tracer returns in real-time. The lifting depth is determined based on the round-trip travel time of the tracer gas. The area underneath the return peak of the tracer is used to determine the amount of tracer returning from one or more lifting depths (Figure 5: Simulated vs measured travel time and corresponding area underneath each peak). Any loss of tracer is detected by considering the mass balance of the system.

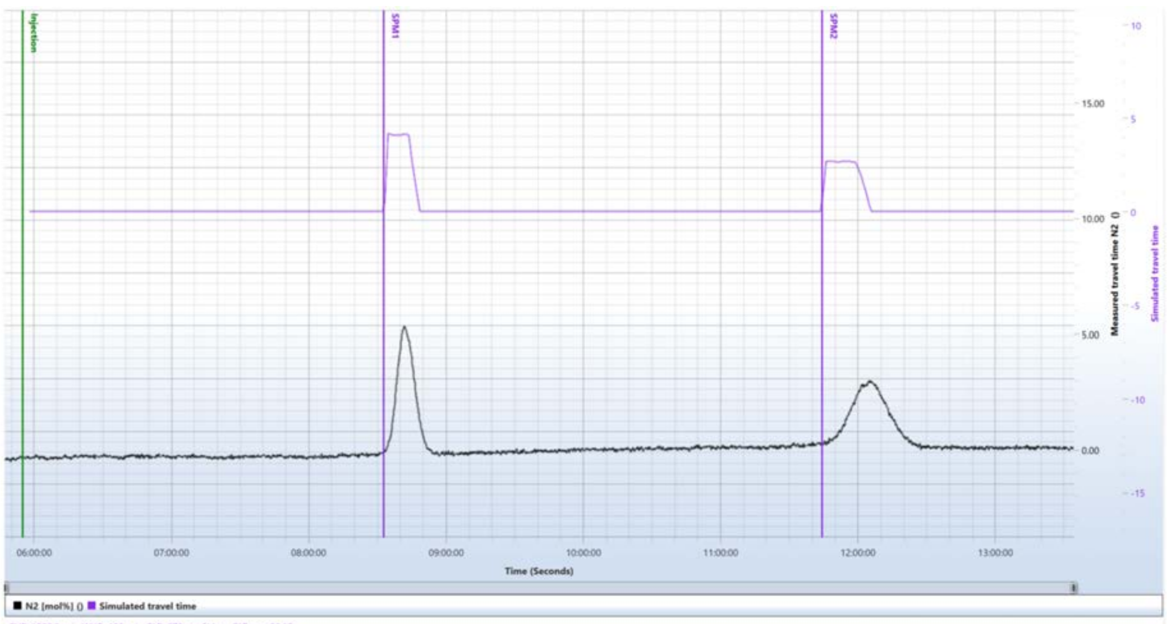

Figure 5—Simulated vs measured travel time and corresponding area underneath each peak

DESCRIPTION AND APPLICATION OF EQUIPMENT AND PROCESSES EQUIPMENT:

A set of customized equipment for onshore logistics in a hazardous environment was prepared for the pilot:

- Gas analyzers for online analysis of produced gas including C_1-C_6 components, CO_2, N_2 and H_2S.
- Dedicated hoses, conditioning system including gas liquid separator and effluent containment system.

- Pressure and temperature gauges installed at injection and sampling manifolds.
- Ex certified generator for powering the equipment
- Additional instrumentation was also used including ultra-sonic clamp-on flowmeter, Coriolis flowmeter, thermal mass flowmeters and acoustic logging equipment.

An Ex certified SCADA system with dedicated software for logging and data interpretation was used to conduct the test and evaluate the results in the field. Five custom software applications were used to interpret the data:

1. Logging software for recording the data from all the sensors.
2. Acoustic software for recording and interpreting acoustic signals, computing the depth of liquid level and temperature gradient in the A annulus.
3. Gas lift metering software for calculating gas lift volumetric rate from tracer dilution and applying mass balance equations on the measured tracer returns.
4. Tracer metering software with a dynamic well model for calculating the tracer round trip travel time and to convert the time of each tracer return to the representative lifting depth.
5. Software for generating the survey reports.

N_2 tracer gas was supplied in a standard 300 bar rack on a truck. The pressure in rack was sufficient to inject N_2 into the gas lift supply without additional boosting requirements.

STEPWISE EXECUTION:

1. **Rig-up**
   Rig-up was performed on site by connecting the injection and detection manifolds to dedicated points on the gas lift supply, annulus wing valve and top-cap. Analysed sample gas was directed to an effluent containment system located at a safe distance from the work area and secured with gas detectors.
2. **Acoustic measurements**
   A pressure pulse was generated from the acoustic gun into the A annulus to determine the liquid level and temperature gradient. Liquid level and downhole temperature are determined by logging the roundtrip travel time of the pressure wave traveling at the speed of sound from the acoustic gun and reflected typically from side pockets mandrels, safety valves, liquid level or any other sudden change in the diameter in the path of the propagation (Figure 7: Acoustic response). The temperature gradient is determined based on the gas composition, pressure and temperature measured at site, combined with the travel time to each reference point (typically SPM) downhole (Figure 8: Acoustic temperature profile).
3. **Gas lift dilution measurements**
   Gas lift injection rate was measured by continuously injecting N_2 at gas lift supply (Point of injection 1, Figure 6: Rig-up schematic), while measuring the compositional response downstream (Point of detection 2, Figure 6: Rig-up schematic) with the online gas analyzer. The gas lift injection rate was then calculated from the mass balance dilution equation.
4. **N2 pulse injection**
   Approximately 20 kg of N_2 was injected into each well to determine the lifting depth(s). Injected N_2 tracer mixes with the well's gas lift supply and propagates downhole. The lift gas will penetrate the production tubing at each point of communication between annulus and tubing and then return to the surface with the produced fluids. A sample of the produced fluids (Point of detection 3, Figure 6: Rig-up schematic) is continuously conditioned and analysed, recording the compositional changes in the

produced fluid due to the injected tracer (Figure 11: N_2 pulse injection fingerprint). Surface pressure and temperature are logged throughout the survey.

5. **Data analysis and reporting**

The data gathered during the survey is processed and analysed to calculate well's gas lift injection rate and lifting depth(s). It also provides data for evaluation of the casing and tubing integrity and provides detailed compositional analysis of the produced and injected gasses including corrosive and toxic components such as H_2S and CO_2.

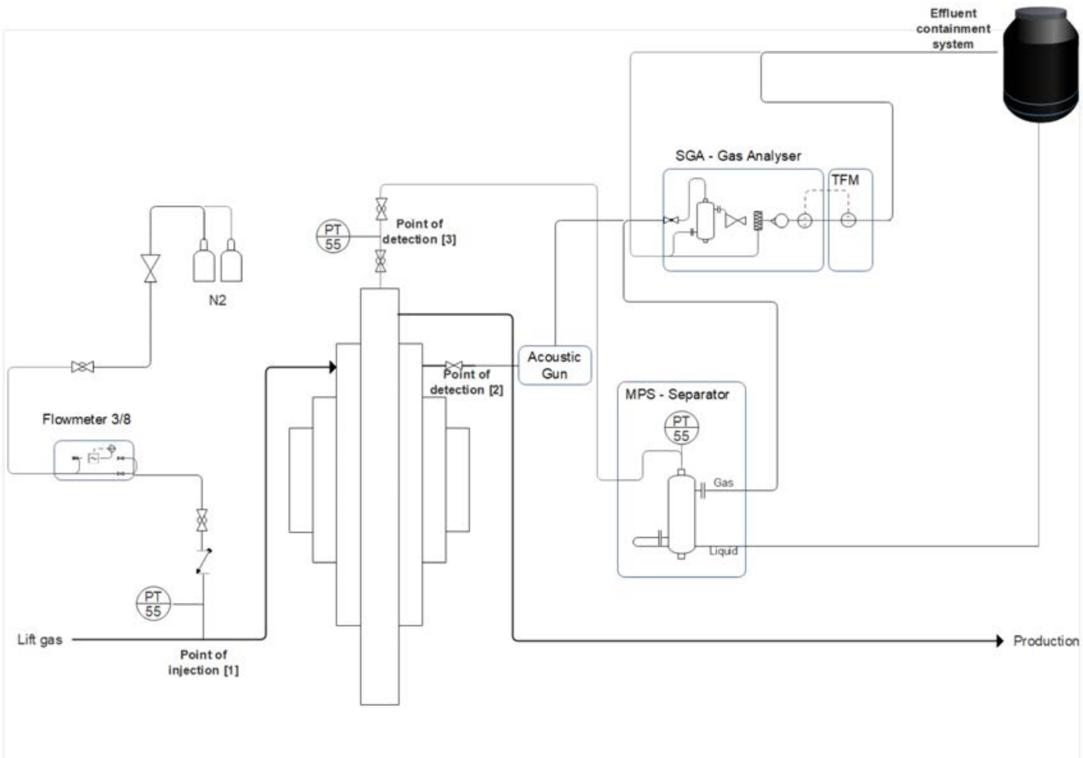

Figure 6—Rig-up schematic

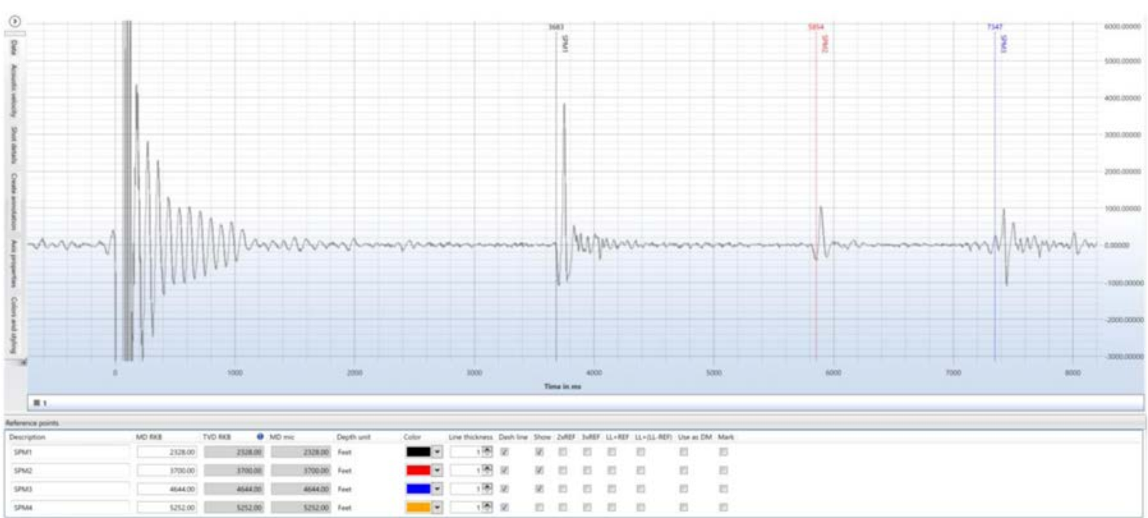

Figure 7—Acoustic response

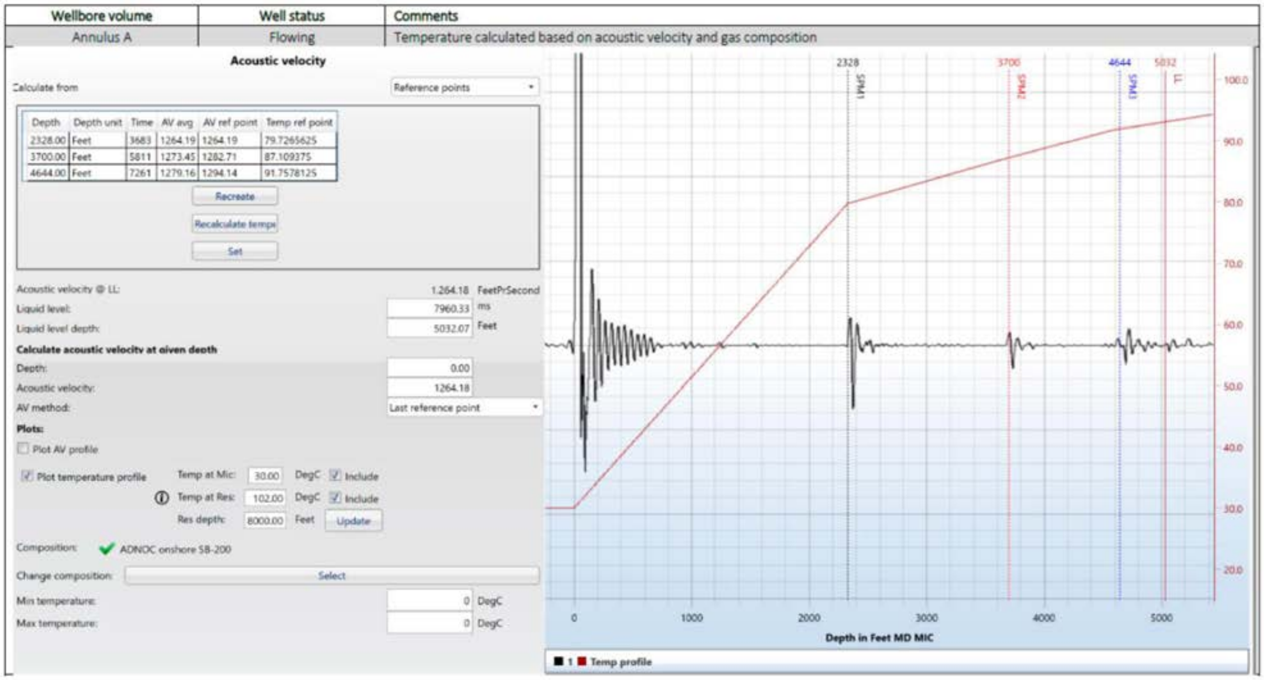

Figure 8—Acoustic temperature profile

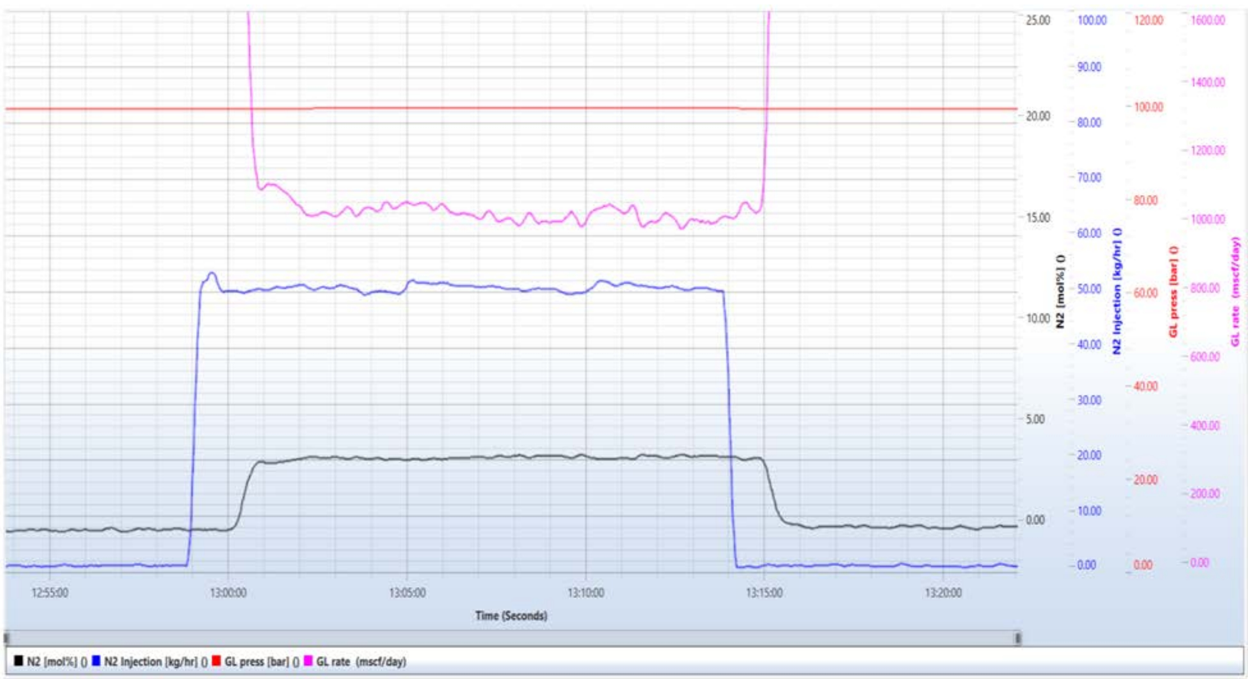

Figure 9—Gas lift dilution measurement

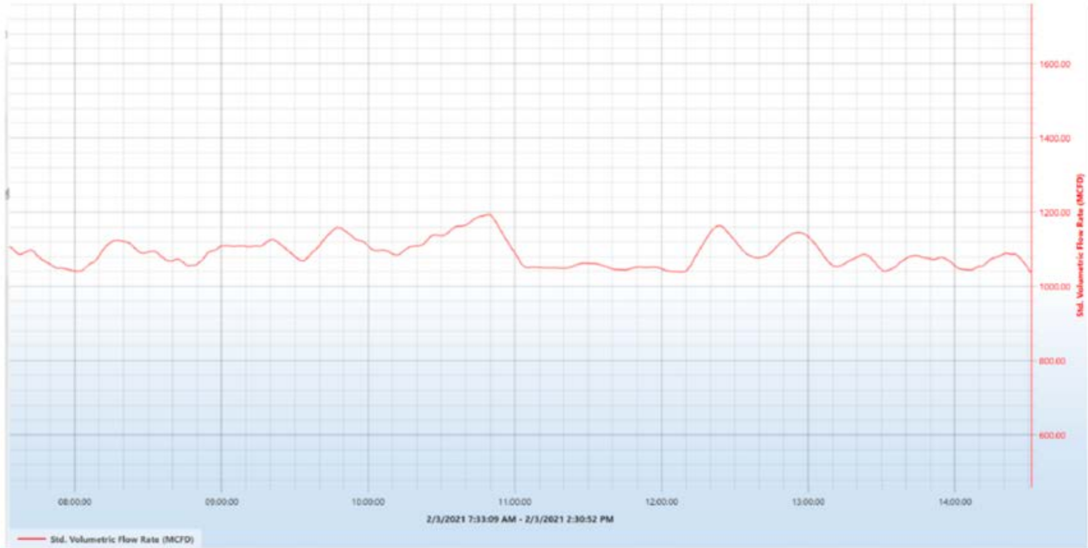

Figure 10—Gas lift ultra-sonic trend

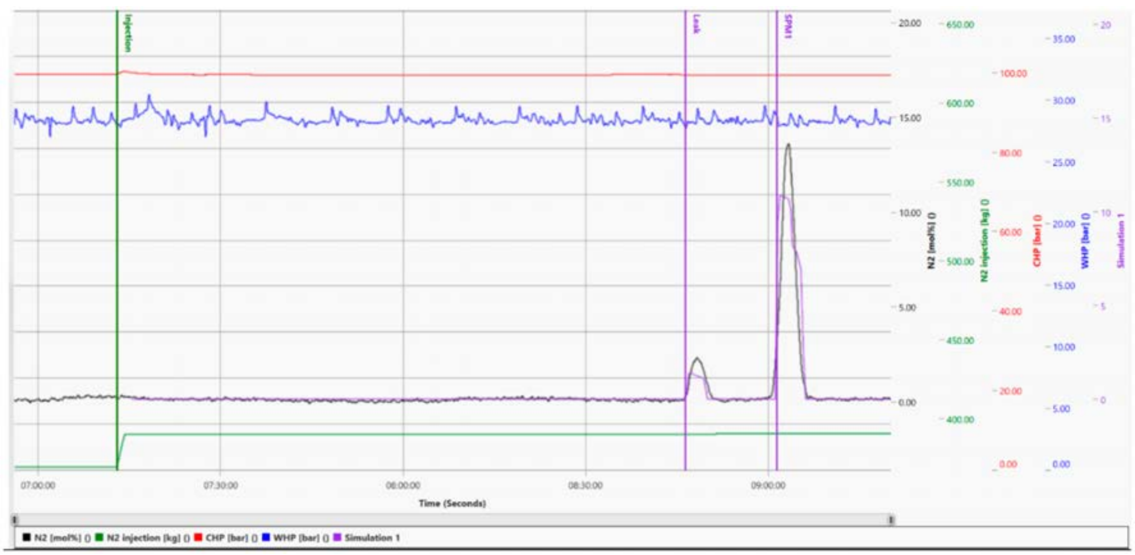

Figure 11—N2 pulse injection fingerprint

DATA PROCESSING:

Acoustic Data:

The recorded data is filtered and processed using proprietary software to measure the pulse travel time to each downhole reference point. This time is converted to a representative depth using the acoustic velocity profile. Acoustic velocity is calculated using known reference points, such as a side pocket mandrel from the well schematic diagram and verified using Peng Robinson EoS model - considering measured surface pressure, temperature, and gas composition.

The acoustic response is also used to calculate average temperature at each reference point/SPM in the gas lifted volume using EoS model. The calculation requires pressure, temperature and gas composition measured at the surface as input values along with the acoustic velocity.

Gas lift dilution measurement:

The total rate of gas Q_{gs} at Point of detection 2 (Figure 6: Rig-up schematic) is calculated using the equation below using the measured concentration of tracer gas, background gas composition and the known mass of injected tracer gas upstream (Figure 6: Rig-up schematic).

$$M_{tr,i} = \int_{t_{d1}}^{t_{d2}} m_{tr}(t)dt = \int_{t_{d1}}^{t_{d2}} m_{g,d}(t)\left[c_{tr,d}(t) - c_{tr2,d}\right]dt$$

$$M_{tr,i} = \rho_{gs}\int_{t_{d1}}^{t_{d2}} Q_{gs,d}(t)\left[c_{tr,d}(t) - c_{tr2,d}\right]dt$$

$$Q_{gs,d} = Q_{gs} = \frac{M_{tr,i}}{\rho_{gs}\int_{t_{d1}}^{t_{d2}}\left[c_{tr,d}(t) - c_{tr2,d}\right]dt}$$

Where:

$M_{tr,i}$ – mass of injected tracer

m_{tr} – mass rate of injected tracer

$c_{tr,d}$ – tracer component concentration at the detection location

$c_{tr2,d}$ – tracer component concentration prior the injection (base line)

ρ_{gs} – standard density of flow stream (lift gas)

$m_{g,d}$ – mass flow rate at the detection location (lift gas mass rate)

$Q_{gs,d}$ – volumetric flow rate at the detection location (lift gas vol. flow)

An ultra-sonic meter was used to trend the gas lift rate throughout the survey. Uncertainty related to pipe thickness and accurate gas composition cause deviation in standalone ultra-sonic measurement. By using the gas lift rate obtained from the dilution measurement as a point of calibration for ultra-sonic readings, this uncertainty was eliminated. Accurate gas lift trend throughout the survey was obtained by combining those two independent methods. (Figure 10: Gas lift ultra-sonic trend).

Tracer Pulse Injection:

Continuous compositional analysis of the produced gas is performed to record the signature of the tracer when returned to the surface. The data is used to determine the round-trip travel time of the gas lift via each point of communication between the annulus and tubing. This time is converted to relative depth using a WITTS dynamic well model that simulates the transport of injected and produced fluids in both the annulus and production tubing of a gas lifted well.

Annulus model. The model calculates transport of lift gas and tracer gas in annulus from the injection point to the gas lift valves / leak points. The solution of the mass and momentum conservation equations is found by dividing the annulus volume into a given number of grid boxes and solving sequentially for each box. Injection pressure and rate are known, so the transport of fluids during a given time step is first calculated for the uppermost box below the injection point. Then, the output of each box (pressure, velocity, mass balance including a gas identification number) is the input for solving the next box. When the gas mixture reaches the intermediate gas lift valves, a fraction of the gas mass is injected in the tubing, the remaining gas will be displaced further down the annulus.

The calculation is repeated until the tracer gas reaches the lowermost gas lift valve.

Tubing model. The tubing model is a two-fluid model with distinct velocities for the liquid phase and the gas phase. The relationship between the liquid and gas velocities is given by a closure law (drift-flux model). The boundary condition is the well-head pressure. The reservoir production is assumed to be constant initially. The production index is calculated from the given produced oil rate, water cut, GOR, reservoir pressure, and initial downhole pressure. Mass and momentum equations are solved by numerical integration from bottom to top.

The tubing model is coupled with the annulus model and determines at each time step the mass of lift gas and/or tracer gas that is injected in the tubing through the gas lift valves or leak points. The downhole tubing pressure calculated at each time step is then used to calculate the produced rate in the next time step.

PRESENTATION OF DATA AND RESULTS

The pilot comprised of a ten (10) well sample set of which five (5) were fully accessible to wireline and five (5) were not accessible to wireline due to inorganic scale obstructions in tubing (Figure 12: Candidate wells).

WELL TYPE	WELL NAME
ACCESSIBLE	W-0001A
	W-0002A
	W-0003A
	W-0004A
	W-0005A
OBSTRUCTED	W-0006o
	W-0007o
	W-0008o
	W-0009o
	W-0010o

Figure 12—Candidate wells

The results and reports from WITSS surveys were uploaded to a cloud portal - Figure 13: Summary of results (WITSS). The platform was customized, and the following metadata was extracted into representative columns (Table 1: WITSS metadata):

Date	Well	Report	WHP (Psig)	WHT (DegC)	CHP (Psig)	GLR (Mscf...	PGR (Mscf...	CLL (ft MD)	BHFP (Psig)	SIBHP (Psig)	BHRD (ft MD)	PLPD (ft MD)	PLPP (%)	PLPN (text)	SLPD (ft MD)	SLPP (%)	SLPN (text)	TLPD (ft MD)	TLPP (%)	TLPN (text)	H2S (ppm)	CO2 (mol%)
09.03.2021	S...		406	83.8	1321	700	1134	4009	2624	3292	8001/...	1800	80	tubin...	4009	20	SPM2	NA	NA	NA	60	4.17
27.02.2021	S...		376	77	1454	820	1174	4324	2914	3754	7974/...	3293	100	SPM2	NA	NA	NA	NA	NA	NA	98	4.21
27.02.2021	S...		386	88	1573	1000	1260	4890	2755	NA	8042	4187	100	SPM2	NA	NA	NA	NA	NA	NA	44	4.29
22.02.2021	S...		387	85.5	1426	650	1616	4273	2666	3771	7959/...	4273	90	SPM3	2119	SPM1	NA	NA	NA	NA	34	4.33
17.02.2021	S...		382	76.7	1049	1900	2561	3760	2746	NA	8069	3762	100	tubin...	NA	NA	NA	NA	NA	NA	NA	4.2
15.02.2021	S...		406	80	1586	620	878	4004	3210	3813	8036	2031	52	SPM1	3293	40	SPM2	4004	8	tubin...	NA	4.15
10.02.2021	S...		385	84	1330	1200	2243	4604	2754	NA	8089	2234	80	SPM1	NA	NA	NA	NA	NA	NA	High ...	4.1
01.02.2021	S...		412	86	1444	1155	2339	4544	2676	NA	8119	2329	80	SPM1	2020	8	tubin...	3700	12	SPM2	NA	4.2
01.02.2021	S...		447	73	1537	750	1974	4782	2437	NA	8083	4418	100	SPM2	NA	NA	NA	NA	NA	NA	NA	4.38
26.01.2021	S...		418	48.7	1479	1800	4017	4700	2566	NA	8114	2271	80	SPM1	4700	18	SPM3	1750	2	tubin...	NA	4.12

Figure 13—Summary of results (WITSS)

Table 1—WITSS metadata

Well-head pressure (WHP)	Primary lifting point percentage (PLPP)
Well-head temperature (WHT)	Primary lifting point name (PLPN)
Casing-head pressure (CHP)	Secondary lifting point depth (SLPD)
Gas lift rate (GLR)	Secondary lifting point percentage (SLPP)
Production gas rate (PGR)	Secondary lifting point name (SLPN)
Casing liquid level (CLL)	Tertiary lifting point depth (TLPD)
Bottom-hole flowing pressure (BHFP)	Tertiary lifting point percentage (TLPP)
Shut-in bottom-hole pressure (SIBHP)	Tertiary lifting point name (TLPN)
Bottom-hole reference depth (BHRD)	H2S
Primary lifting point depth (PLPD)	CO2

The metadata shown in Table 1: WITSS metadata was extracted from the final reports in the cloud-based system and can be directly imported into the client's internal database.

Timeline

The pilot execution was originally planned in 2020. Unexpected issues related to COVID-19 outbreak caused some delays and final execution took place in Q12021 (Figure 14: Timeline).

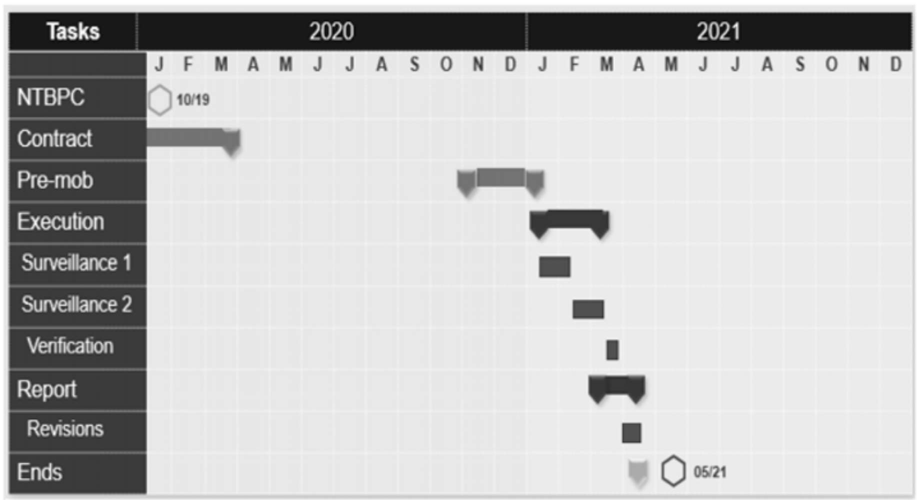

Figure 14—Timeline

Workflow and data-analysis

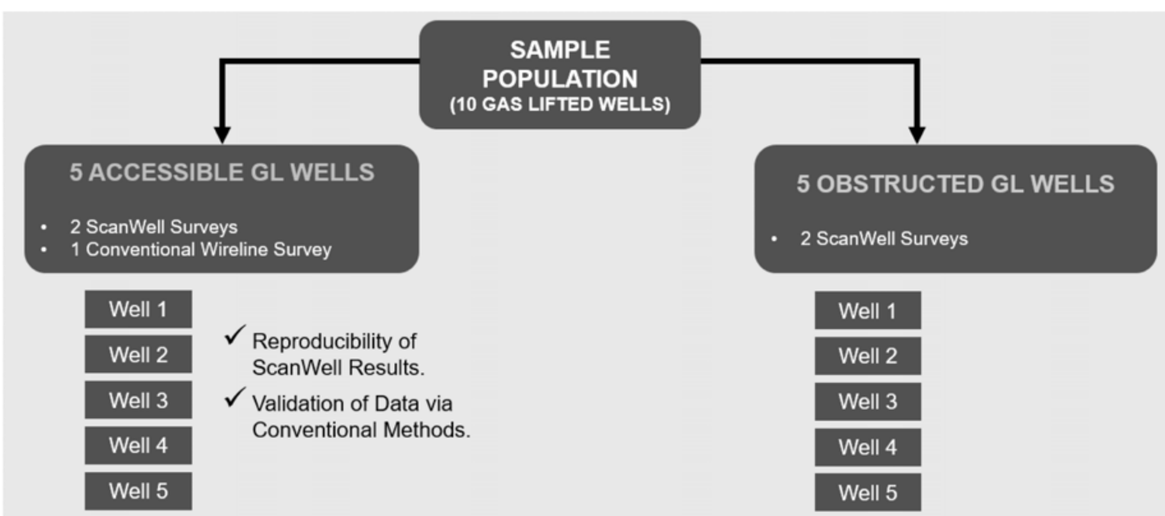

Figure 15—Sample population

WITSS survey was followed by conventional production test using test separator and wireline Flowing Gradient Survey (FGS) (Figure 16: Workflow).

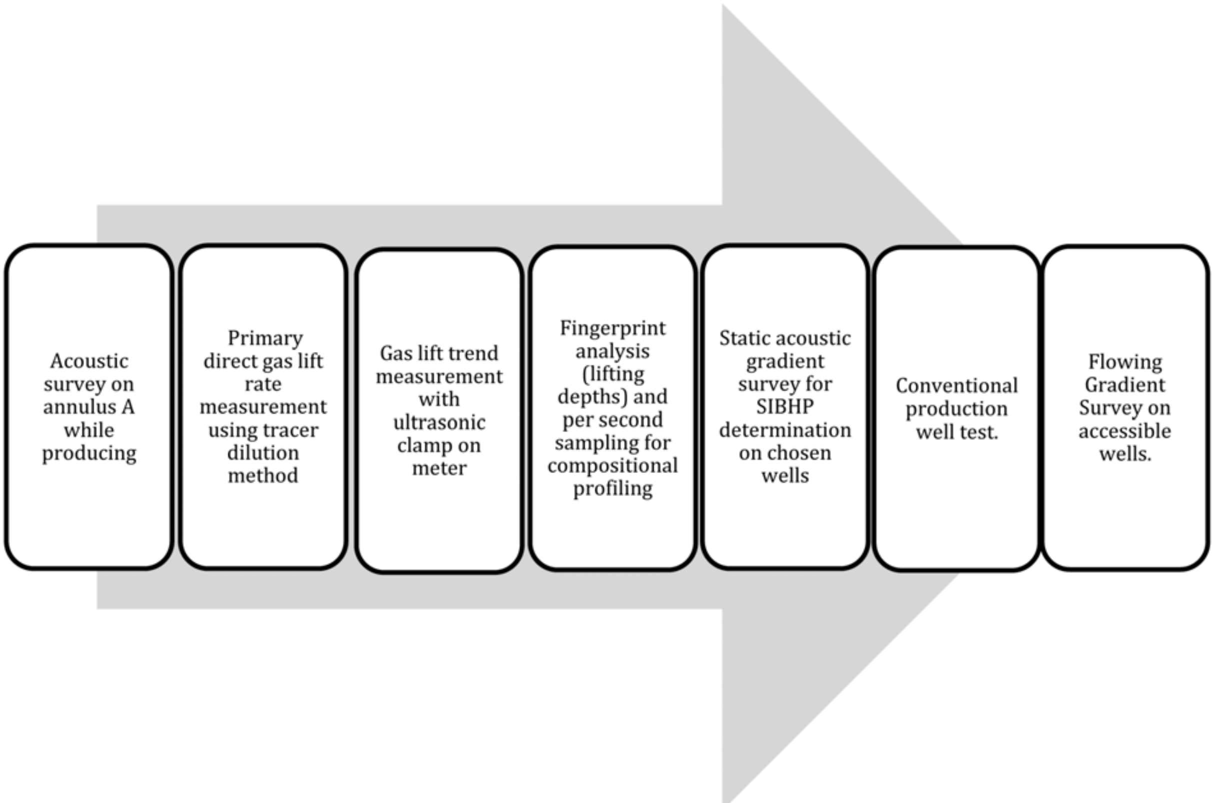

Figure 16—Workflow

The method utilized for validation of the WITSS surveys were comparisons of pressure and temperature profiles to wireline measurements on the accessible wells. WITSS surveys were also conducted twice on each well to evaluate repeatability of results.

As illustrated above (Figure 17: Data analysis methodology), all collected data was consumed and processed in a physics based well model and nodal analysis delivered a calibrated model from which opportunities can be identified.

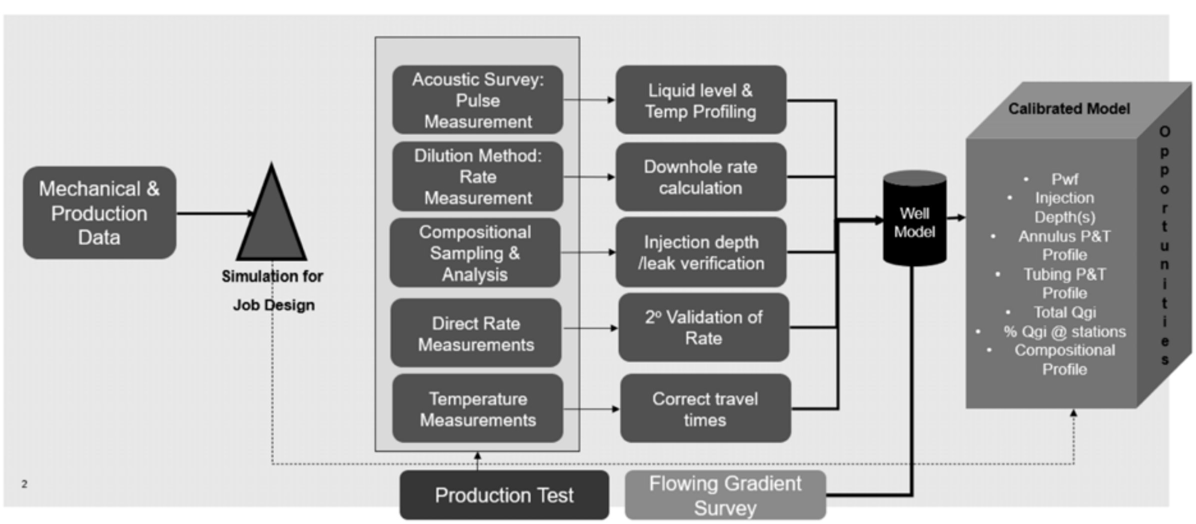

Figure 17—Data analysis methodology

Example: Accessible Well W-003A

There are 4 SPMs in this well at depths: 2329, 3700, 4644, 5252 ftMD. The acoustic survey identified the liquid level in the annulus at 4644', confirming that the first and second side pocket mandrels (SPM) are uncovered and that the fourth and deepest SPM at 5252' is not supporting injection (Figure 18: Acoustic survey, Well W-003A). This was further verified using tracer pulse survey.

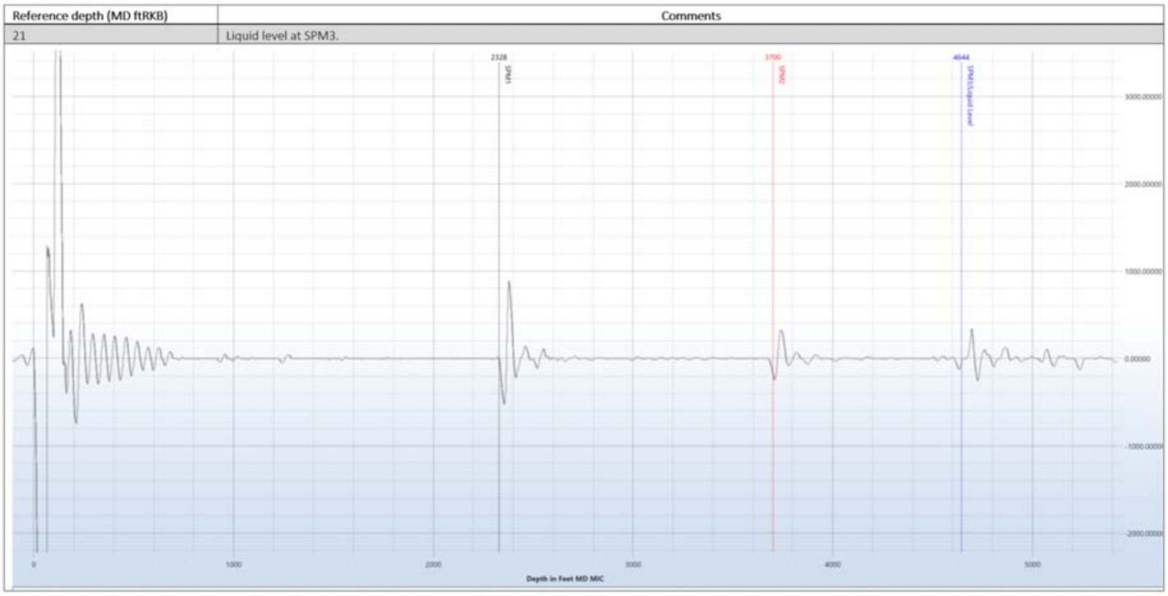

Figure 18—Acoustic survey, Well W-003A

The N_2 tracer fingerprint (Figure 19: N2 fingerprint vs simulated results) indicated a leak above the first SPM at 2020' passing 8% of the total injected gas lift rate. 82% of gas was being injected at SPM1 at 2329'. Based on mass balance calculations from tracer survey and liquid level measurements from acoustic survey the remaining 10% was concluded as passing through SPM2 at 3700'.

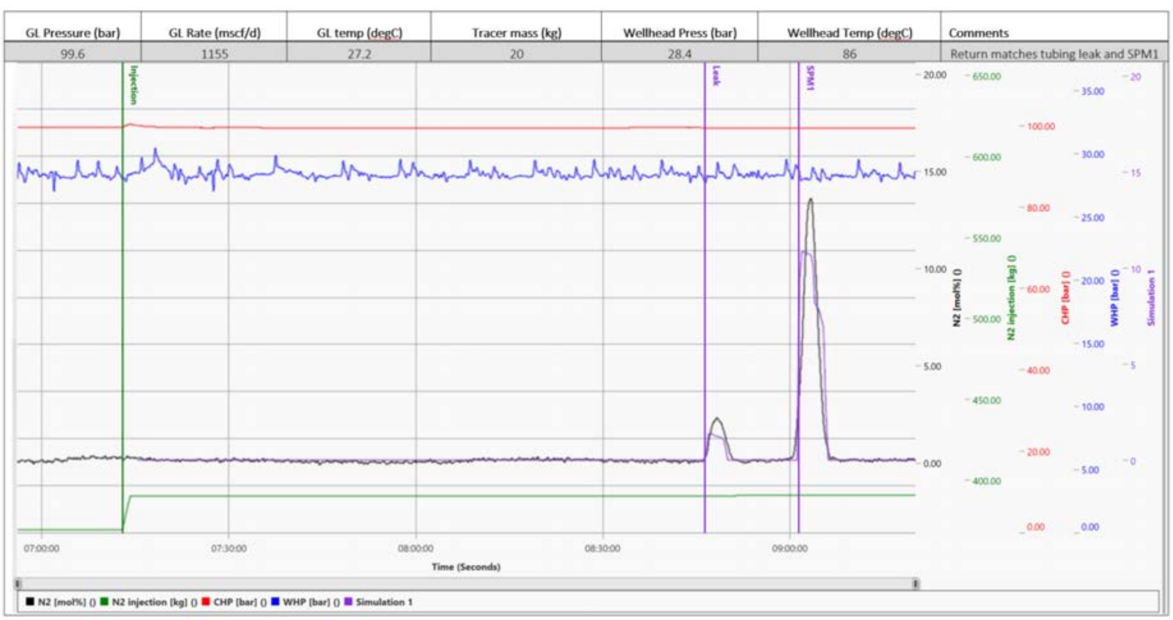

Figure 19—N2 fingerprint vs simulated results

The tracer dilution method and ultrasonic flowmeter determined the gas lift injection rate on this well to be 1.125MMscf/d (Figure 20: Tracer dilution results) and 1.155MMscf/d (Figure 21: Ultra-sonic trend) respectively. The gas lift injection rate measured by field gas lift meter was 0.5MMscf/d.

Figure 20—Tracer dilution results

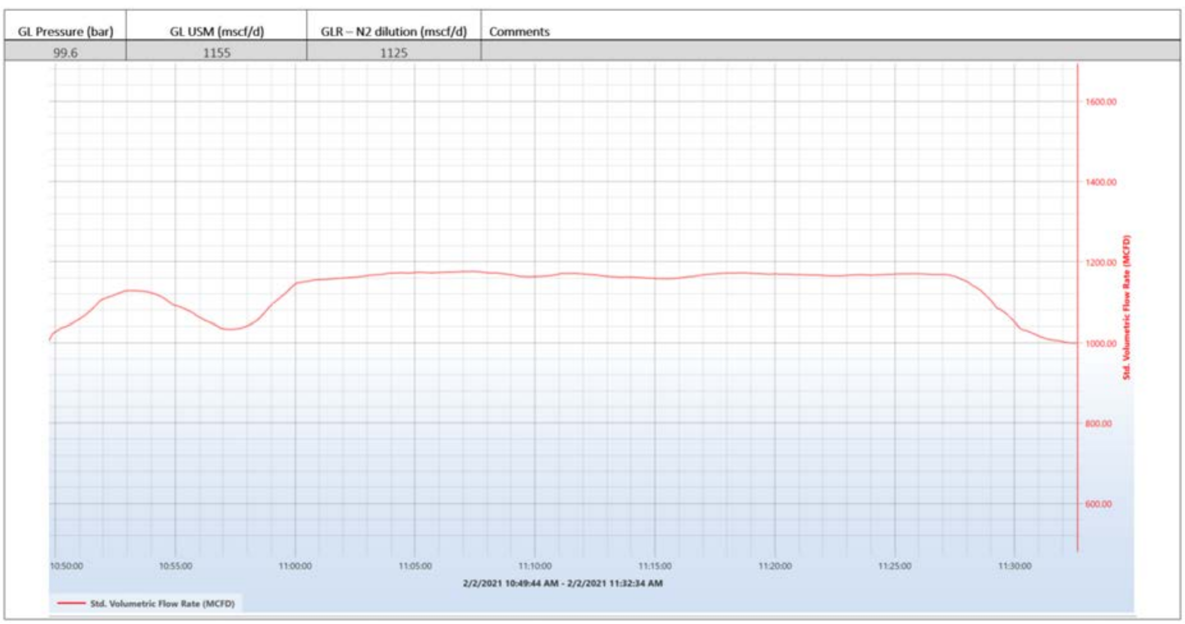

Figure 21—Ultra-sonic trend

The total produced gas measurement from the WITSS method was consistent with values reported at the test separator. This supported the verification of the injected gas rate and allowed the correction of gas lift rate in the well model for nodal analysis.

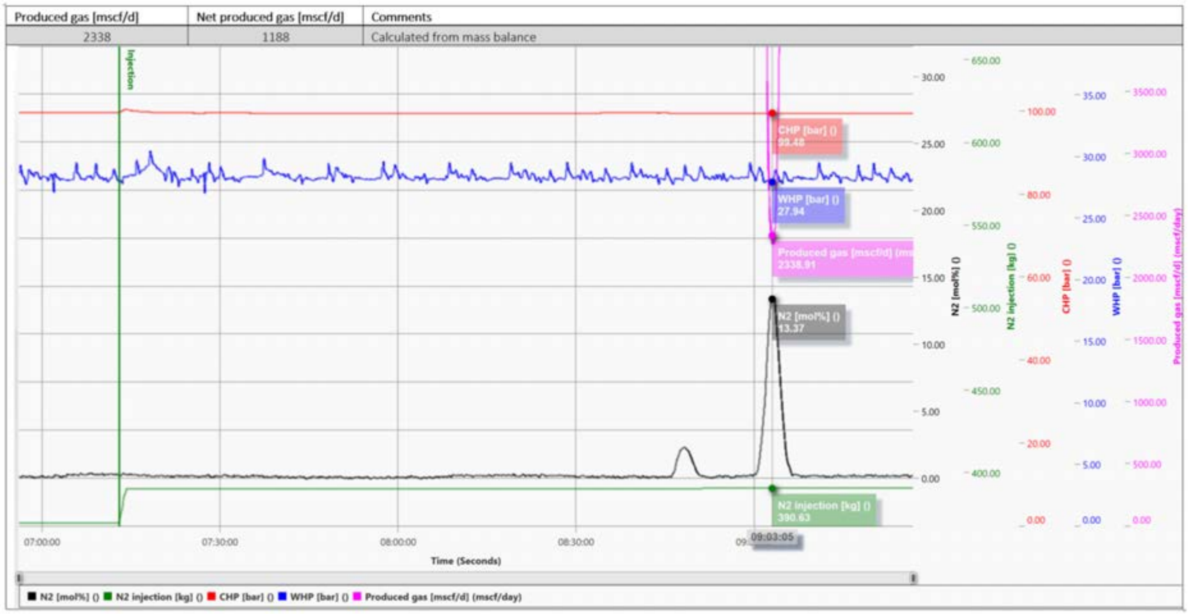

Figure 22—Fingerprint analysis

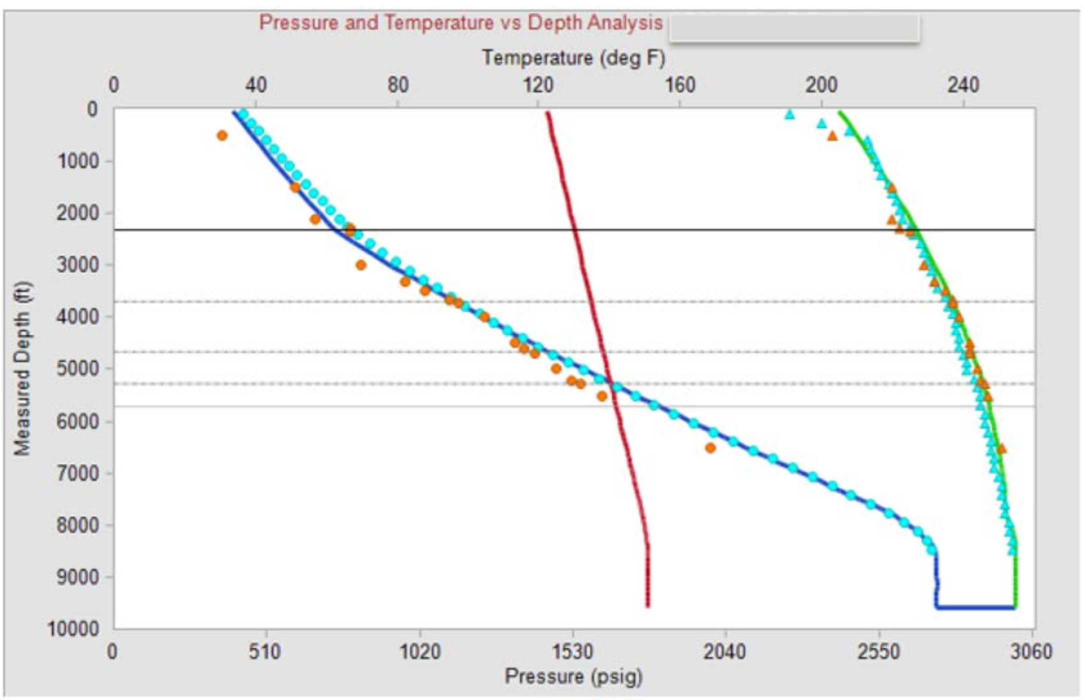

Figure 23—Nodal analysis WITSS vs FGS

Orange dots: Wireline Pressure Data
Orange triangles: Wireline Temperature Data
Blue dots: WITSS Pressure Data
Blue triangles: WITSS Temperature Data

Wireline flowing gradient survey data and WITSS results corroborated the main injection point at SPM-1 with a calculated delta-pressure of 135psi. Additionally, a distinct cooling effect was observed studying wireline FGS data at approximately 2020' - a phenomenon which would go undetected by the conventional method due to SOP which limits the number of stops for each survey using wireline. There was significant value obtained by having the ability to update the FGS based on observations from first WITSS run.

The gas lift injection rate was verified by analysis in the model through the ability to match the production test rate following correction of the gas-oil-ratio, GOR. Based on the analysis the variance between the measured (by wireline FGS) and calculated (WITSS) bottomhole flowing pressure was 7% and the variance of the calculated BHFP (WITSS) compared to the calculated BHFP from multiphase flow correlation was 1.5%. The liquid loading analysis also validated the gas lift injection rate as the model confirmed an inability to deliver the reported liquid rates at 0.5MMScfd injection at 50.9% water cut.

The analysis of WITSS and wireline data supported the following findings and recommendations on well W-003A;

- Static acoustic investigation should be performed on the annulus as well as the tubing to verify the leak point at 2020’
- Based on the above, the healthy CHP suggests an opportunity exists to lower the injection point to SMP4.
- Potential production gain +400bopd can be achieved with GLR adjustment to 1.5MMScfd
- 7% variance in measured vs calculated P_{wf} and measured gas lift rate is 124% higher than reported.
- Variance between MPF correlation and WITSS for FBHP result was 1.5%.
- Gas lift valve change out program required to shift injection point to SPM4. Dummy to be installed in SPM1 and GLV at SPM 3 to be replaced to avoid multipointing.

Example: Obstructed Well-0009-o

The acoustic survey on Well-0009-o identified the liquid level in the annulus at 4009’ (SPM2) suggesting that injection at the time of the survey could be through SPM 1, SPM 2 or a secondary leak point in the tubing string.

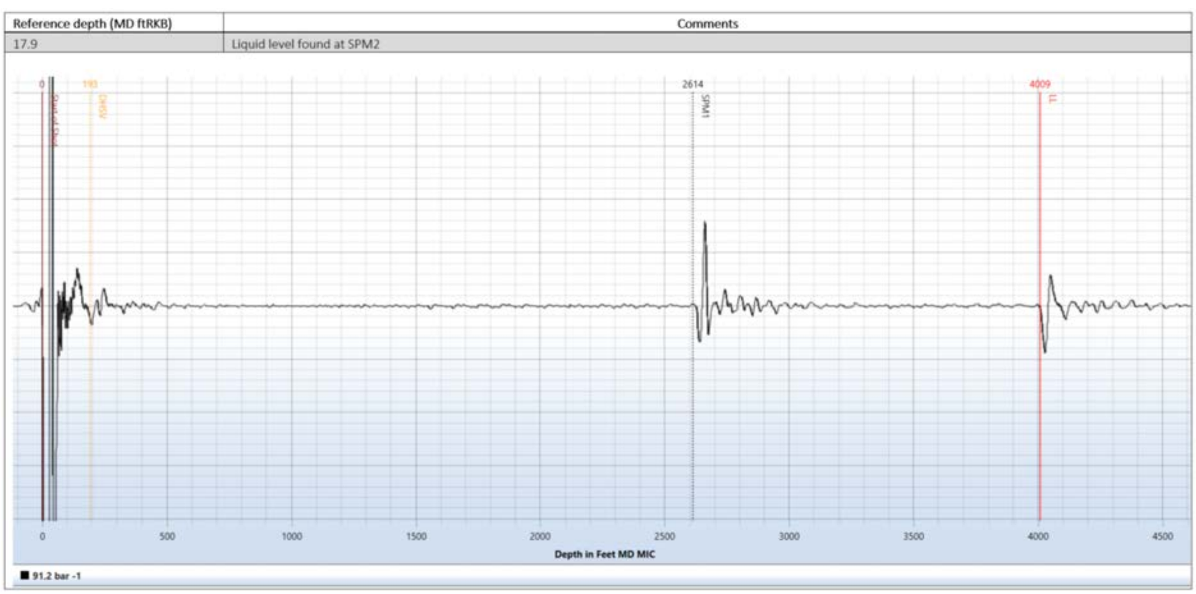

Figure 24—Acoustic survey results

The tracer fingerprint confirmed that 100% of lift gas was entering the tubing via a shallow leak above SPM1 at 1800’. SPM1 is located at 2614’. Tubing obstruction from wireline field reports occurred at approximately 4400’.

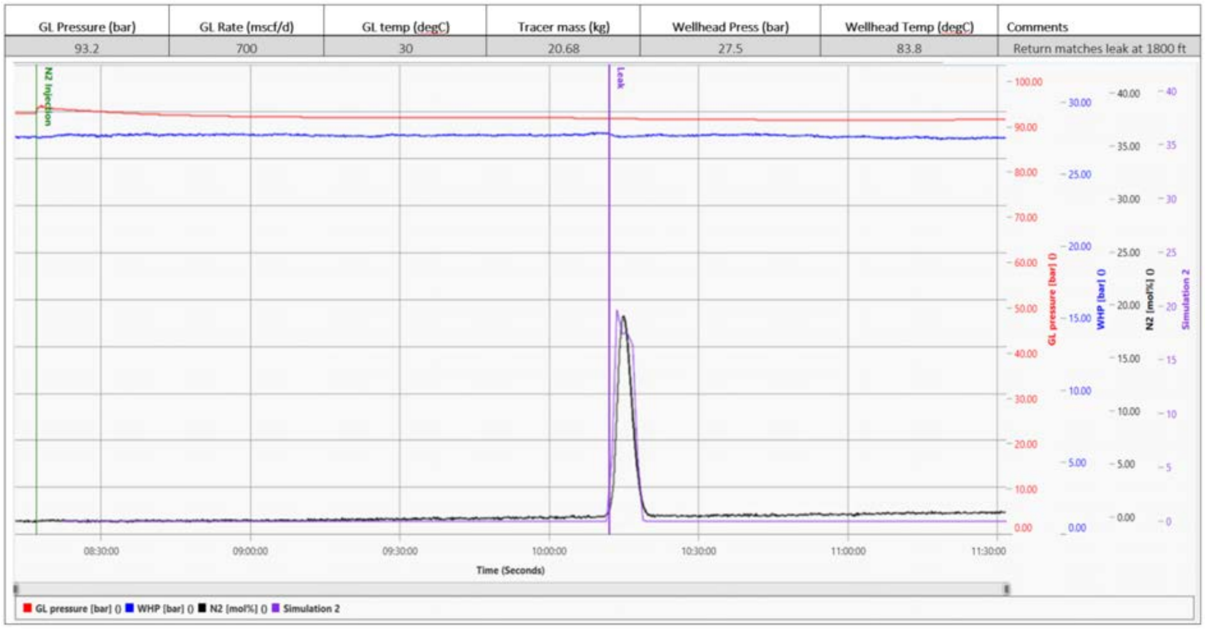

Figure 25—Fingerprint analysis

Based on the above findings an additional acoustic survey was performed on the tubing side to verify the leak depth. After shut-in, an acoustic shot confirmed the leak point at the same depth detected by the annulus survey. The suppression of liquid in the tubing also provided the opportunity to verify the liquid level and allow calculations of the static BHP in the well.

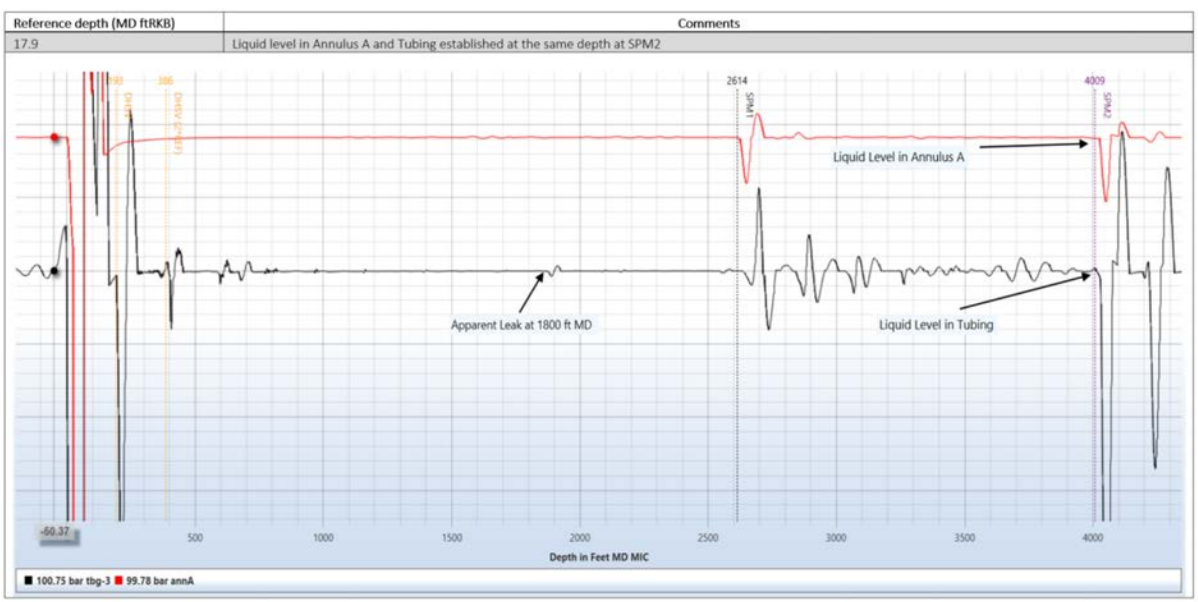

Figure 26—Sut-in acoustic survey on tubing

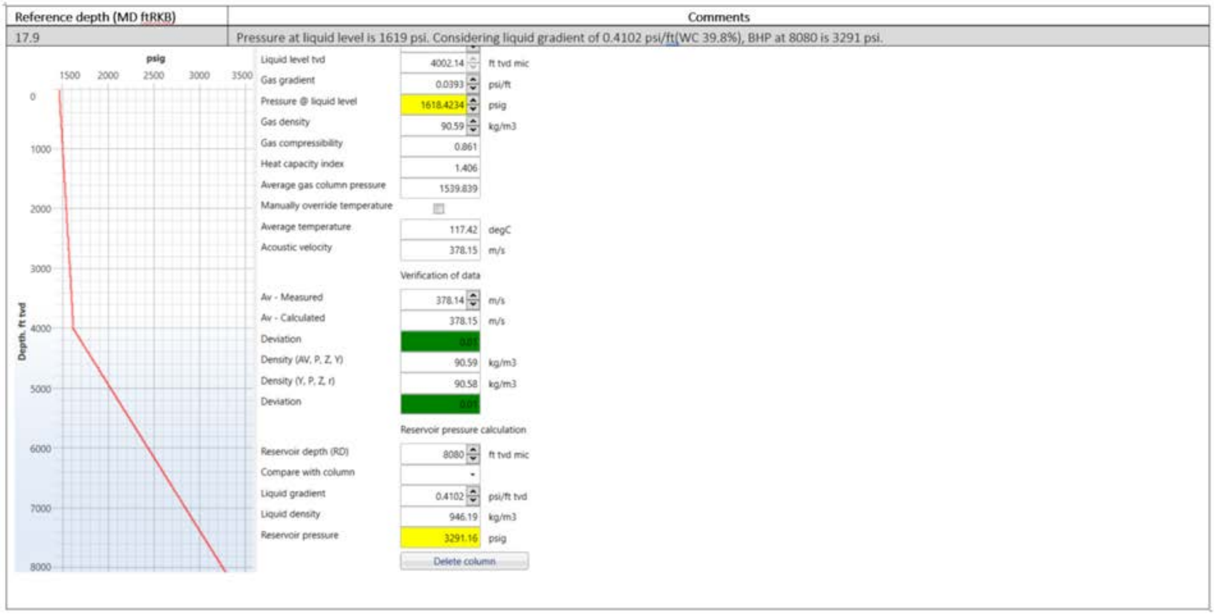

Figure 27—shut-in BHP acoustic analysis

Tracer dilution method consistently verified the Qgi at 0.7MMscf/d (Figure 28: Gas lift dilution results) compared to the 0.4MMscf/d reported by the inline gas lift meter. The survey also showed fluctuations in the lift gas supply (Figure 29: Gas lift ultra-sonic trend) which is expected due to the absence of injection rate control on this well.

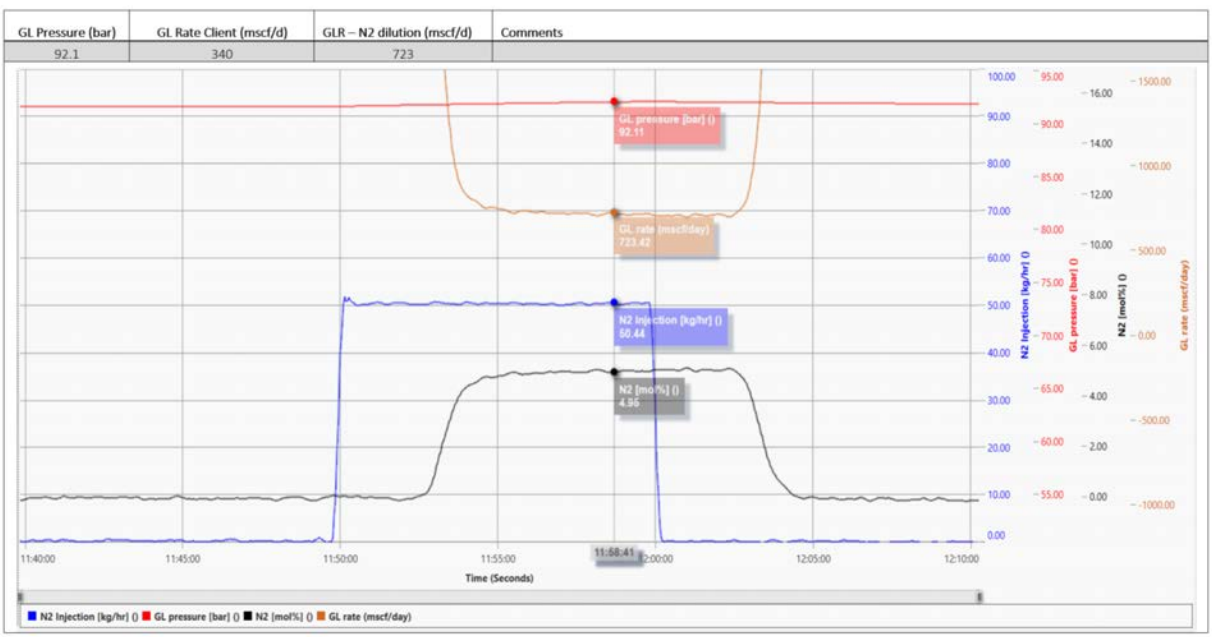

Figure 28—Gas lift dilution results

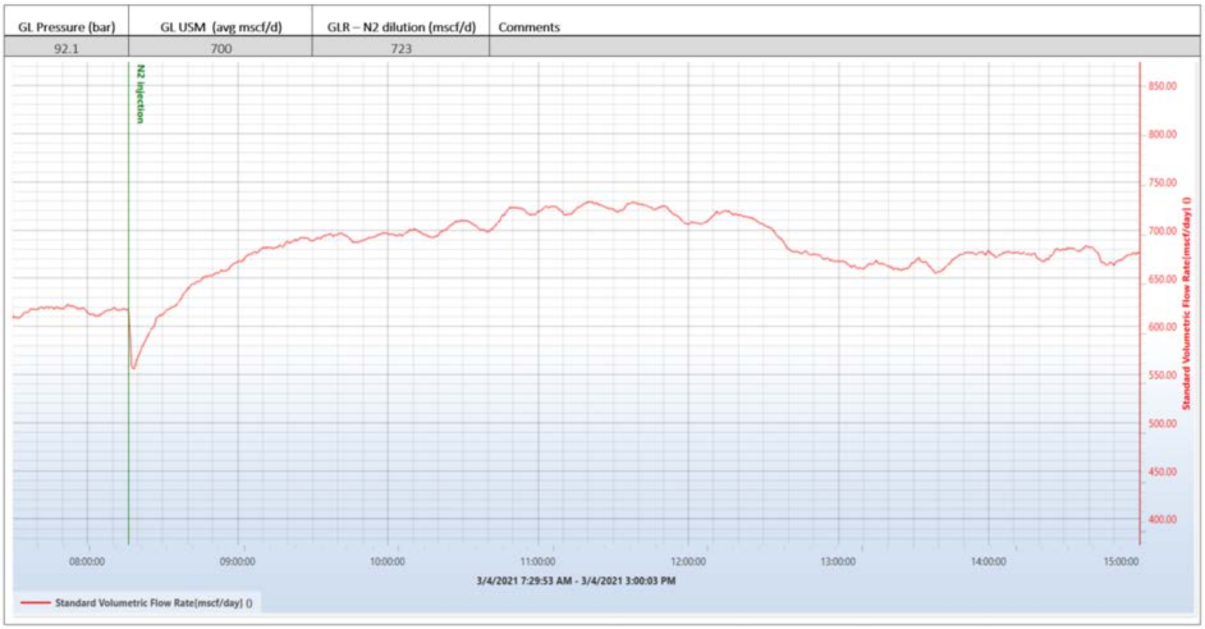

Figure 29—Gas lift ultra-sonic trend

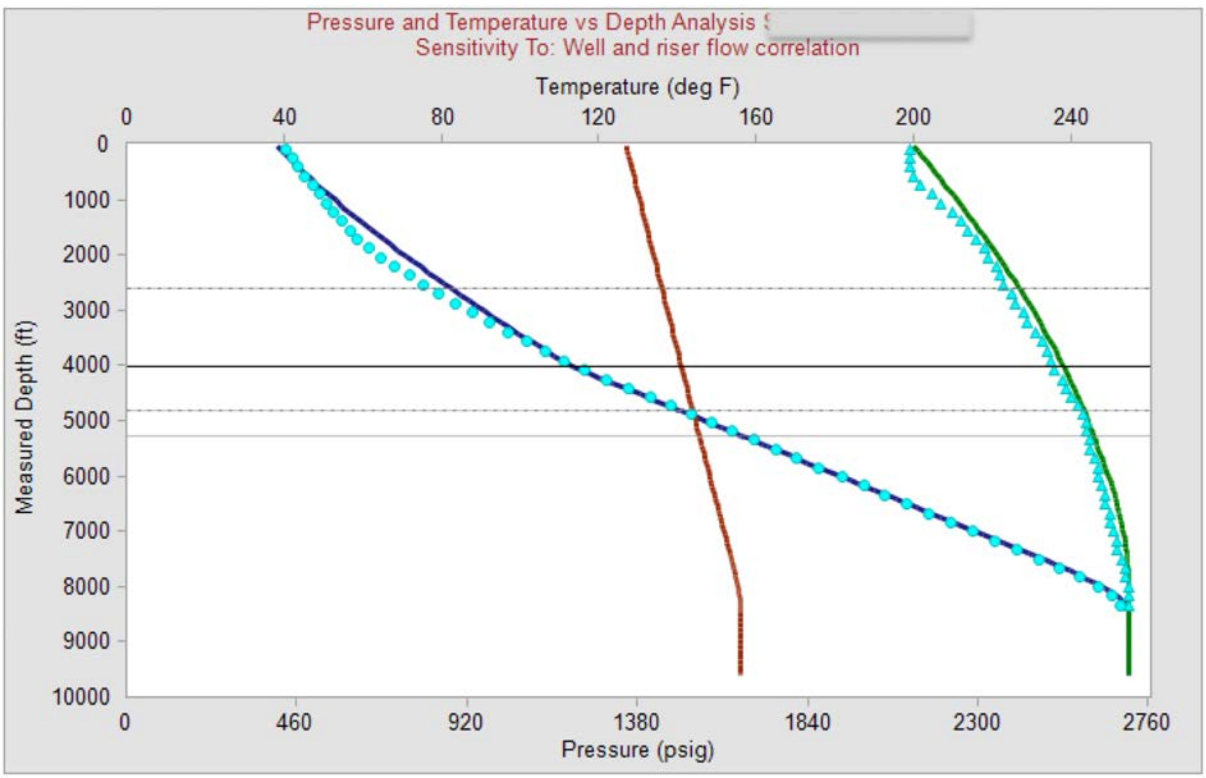

Figure 30—Nodal analysis WITSS data

In the absence of advanced surveillance, it would be impossible to know that an integrity breach existed in this well. The WITSS method was able to confirm the unwanted injection point at 1800' that was considerably reducing the wells production rate. The analysis supports improved production, by deepening the injection point to SPM2 at 4009', with stable injection at higher rates, once the leak is addressed. Further liquid loading analysis confirms stable production and incremental production of 900STB/d by increasing Qgi to 1.2MMscf/d.

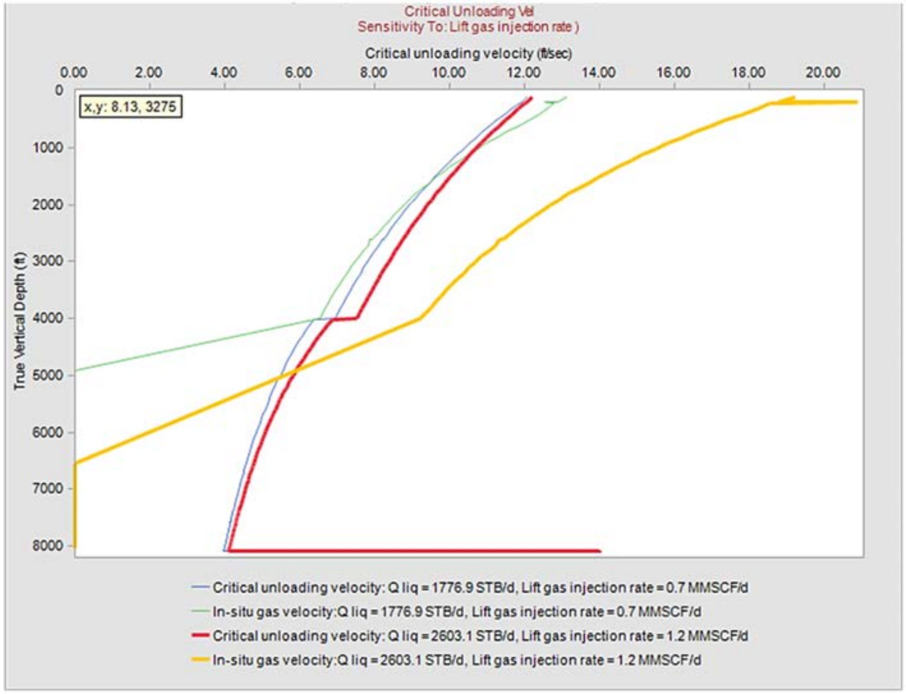

Figure 31—Liquid loading analysis of current and recommended condition

The gas-lift injection rate measured by tracer dilution method was verified by matching the production test rate after correction of gas-oil-ratio (GOR). Based on this analysis the variance of the calculated BHFP compared to the calculated BHFP from multiphase flow correlation was 1.5%. The liquid loading analysis also validated the gas-lift injection rate as the model confirmed that the well would not be able to deliver the modelled liquid rates with a 0.7MMScfd gas injection rate.

The analysis supported the following findings and recommendations on well W-0009o:

- Tracer survey confirmed single injection at a leak point in tubing at 1800' above SPM 1.
- Gas lift injection rate calculated using dilution method was 75% more than that reported from the field meters.
- Workover recommended to address tubing leak and restore well to stable single injection at SPM2 at 4009'
- Potential for production uplift of 900STB/d by increasing Qgi from 0.7MMscf/d to 1.2MMscf/d

SUMMARY:

Bottom Hole Flowing Pressure:

The overall results demonstrate high accuracy in the determination of gas lifted well BHFP by WITSS as a calculated output compared to the measured value by conventional wireline gauge run. For the ten (10) wells in the pilot, both methods gave very similar results for the five (5) accessible wells. For the five (5) obstructed wells, WITSS and MPFC also showed similar and consistent results. The key performance indicator for the evaluation was less than or equal to 10% variance between measured and calculated values.

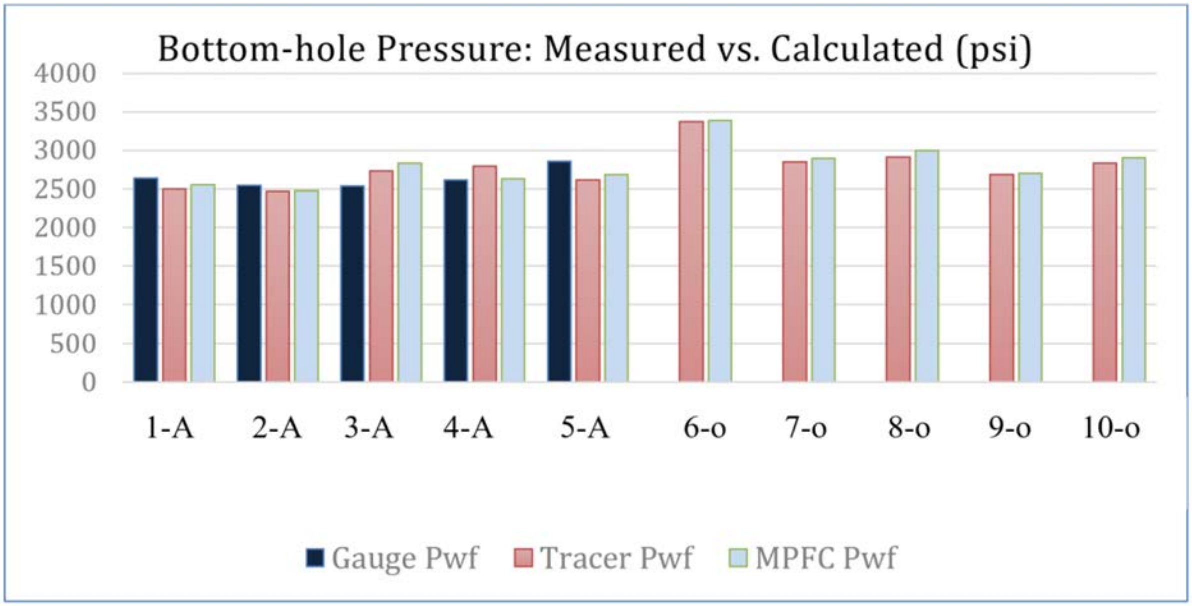

Figure 32—Variance between measured and calculated flowing bottom-hole pressures records <10%

Injection Gas Rate:

A known challenge prior to embarking on this pilot was the error in Qgi measurements because of field equipment overengineering. The pilot showed that for all ten wells, the reported injection rates from previous production tests were significantly lower than that measured in situ. In all cases the correction of GOR and Qgi in the models allowed for matching the production rate and confirming the injection depths. An accurate in situ gas lift measurement should be used to quantify in field meter measurement errors and allow improved data correction strategy.

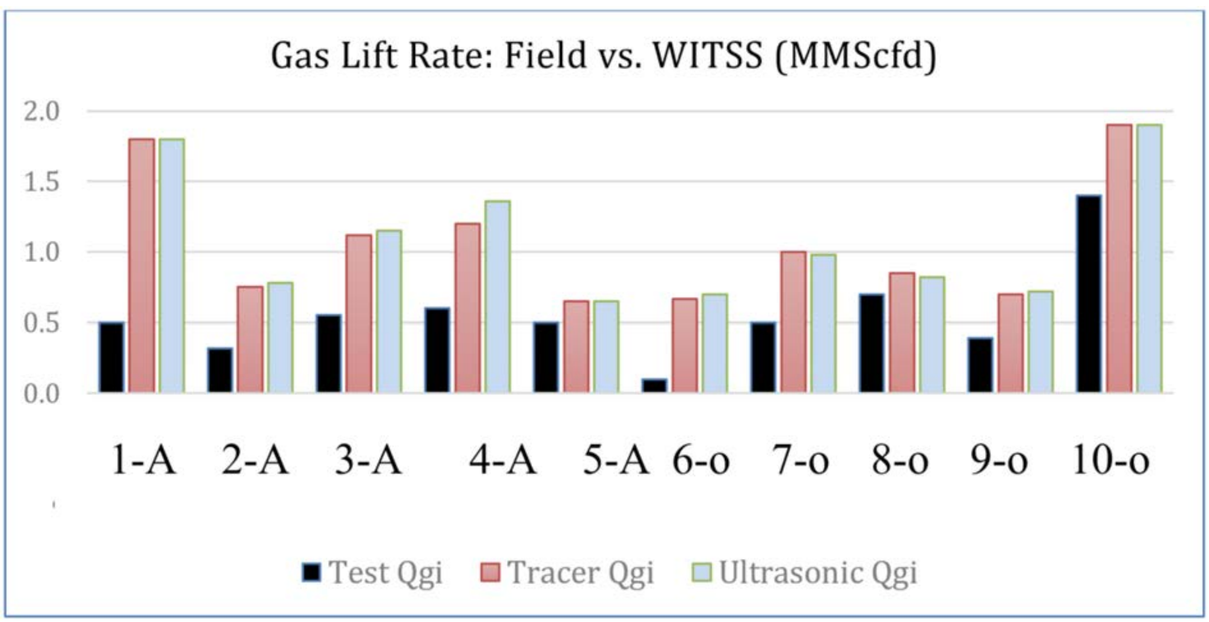

Figure 33—Gas lift injection rate error

Compositional Fluid Profiling:

Consistent compositional fluid profiles were observed on the injection gas side as all wells are fed from the same source. Differences were observed in produced gas composition and H_2S content. From a completion material selection point of view, this observation was flagged as significant.

Table 2—Compositional analysis of injected and produced gases

Measurement Principle	Well status	Comments	
Spectrometry	Flowing	The values are averaged and normalised	
Produced gas	03.03.2021 09:00:00 – 10:00:00	Lift gas	03.03.2021 16:46:00 – 17:02:00
H2S	60 ppm	H2S	39 ppm
Nitrogen N2	0.01	Nitrogen N2	0.0
Carbon dioxide CO2	4.17	Carbon dioxide CO2	4.22
Methane CH4	66.77	Methane CH4	69.65
Ethane C2H6	12.5	Ethane C2H6	12.54
Propane C3H8	8.86	Propane C3H8	8.08
iso-Butane i-C4H10	1.75	iso-Butane i-C4H10	1.32
n-Butane n-C4H10	4.61	n-Butane n-C4H10	3.13
iso-Pentane i-C5H12	0.65	iso-Pentane i-C5H12	0.55
n-Pentane n-C5H12	0.51	n-Pentane n-C5H12	0.35
Hexane C6	0.16	Hexane C6	0.15
Sum	100	Sum	100

Acid Gas Measurement:

Table 3—H2S measurement verified by independent laboratory

Well	WITSS measurement of H_2S concentration in lift gas into Annulus A (ppm).	LAB measurement of H_2S concentration in lift gas into Annulus A (ppm).
W-0005A	39	45
W-0008o	41	40
W-0007o	42	42
W-0009o	39	46

For wells where H_2S measurements were available, this data, when cross referenced with independent lab measurements, were comparable and consistent. This confirmed the confidence of H_2S measurements using WITSS method for future surveillance and acid gas mapping.

KEY TAKE-AWAY:

- All wells were confirmed as producing above reservoir management requirement of Pb+100psi.
- Actual gas lift injection rates were validated by two (2) independent methods with greater than 95% agreement.
- Quantification of measurement error in in-line gas lift rate measurement was achieved.
- Potential well integrity issues were identified allowing for proactive corrective measures to be executed.
- A comprehensive assessment of measured versus calculated flowing bottom-hole pressure was achieved.

- Full compositional profiling, including acid gas measurement, was achieved and can support the development of a method for proactive leak detection under scale-up scenario with a larger well population.

LESSONS LEARNT:

Table 4—Lessons learnt

Item	Category	Lessons Learnt
1	Operations	• Improved procedure based on pilot experience in order to optimize survey duration. • When a tubing leak is detected, perform leak investigation including direct leak metering and static acoustic survey. • Measure pressure at B annulus while performing the survey. If SCP detected, perform direct leak investigation on B annulus. • Performing shut-in BHP analysis on chosen wells.
2	Logistics	• Dedicated customized truck with built in equipment and hose drums for faster rig-up and rig down, shortening survey duration. • Considering operating equipment on 24 VDC battery packs from truck, removing generator as weak link and minimizing stand by time. • Customized scaffolding/ladder for easy top cap access. • Improved solution for catching and removal of effluents.
3	Data & Reporting	• Establish database with all requirement input data for initial modelling prior to job execution. • Create customized solution for direct data migration to client's software.

CONCLUSIONS

In the current environment with increased focus on well integrity and HSE in GL operations, and the need for improved surveillance mechanisms, an innovative approach combining several methodologies to improve well performance visibility and reduce HSE impact - is the new frontier. The WITSS system provides a platform for enhancing the quality and quantity of data for granular well diagnostics. The method supports the consolidation of metering and monitoring activities without negative production impact for proactive surveillance.

The system accurately identified the current unloading status of each well, clearly indicating the depth at which gas lift was operating. With accurate down-hole lift gas rate measurements, and indications of unwanted secondary injection points, proactive measures to correct integrity elements in the completion is possible. Significant cost avoidance was achieved through improved utilization of existing wireline units, avoiding any increased requirement with the ongoing acceleration of gas lift conversions. Economically, the pilot was very successful due to the production uplift delivered whilst having properly calibrated well models validated by wireline pressure and temperature data.

The value of implementing the WITSS technology as a primary surveillance method for gas lifted wells is as follows:

- Demonstrated capacity to manage an increasing number of gas lifted wells without increasing wireline resources.
- Demonstrated synergy with company's digital growth processes by providing high quality data in customized cloud-based solution.
- No deferred production associated with the survey.
- Reduced HSE and operational risk as well as reduced logistical footprint.
- Reduced CO_2 emissions of approximately 400T/year.
- Increased team competence and efficient gas lift operation.
- Conservative production gain of 75BOPD per well based on well optimization potential.
- Significant NPV gains for total OPEX input.

The performance of the WITSS method has proven both robust and successful. No HSE or Lost Time incidents, while a comprehensive diagnostic was achieved on all wells.

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