Realtime Surface Mudlogging / Data Acquisition; Uncertainties and the Way Forward

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ABSTRACT

Acquisition and accurate quantifications of gas-in-mud and gas-in-rock that is entrained into the drilling mud stream while drilling oil and gas wells is crucial in the search of hydrocarbons and well monitoring. This paper discusses the challenges and uncertainties inherent in mudloging techniques which could have great impacts on the acquired data and thus lead to erroneous interpretations. In this study, we analyzed mud gas using continuous gas extraction and analysis methodology from selected wells. This methodology involves extraction of gas from a circulating drilling fluid for quantitative and compositional analysis using surface logging equipment - gas extractor, gas lines, and gas analyzer. Potential uncertainties such as shift-in-the gas analysis window, misaligned gas data and gas-in-mud underestimation (volume and component) were observed in some of the wells drilled. The erroneous data introduced by these uncertainties can adversely impact real-time decision making and cascading effect on the geological models built with the data. We identified potential sources of the above-mentioned uncertainties to the following: (a) drop in sample pressure or moisture in the gas line, (b) leakage along the gas line, (c) positioning of the gas trap, (d) real-time transmission of gas-in-mud data in bit depth instead of lagged depth, and (e) poor calibrations of gas analyzer. A systematic approach was developed to minimize the above-mentioned uncertainties- use of constant volume surface gas extractor, periodic blow back of gas lines, multiple-point gas calibrations, detailed gas analyzer calibrations, and so on. The above remedial procedures were deployed in subsequent wells resulting in significant improvement in data quality and decision making in the recently drilled wells across the assets and helped prevent potential losses of over $21 million from drilling challenges like wellbore collapse and well control. It also improved formation evaluation activities during the well drilling.

Keywords: Mud gas, Calibrations, Uncertainties, Gas volume, analysis window, Drill cuttings. Lag depth, Drilling fluid, Gas extraction.

INTRODUCTION

Surface mud logging, a technique by which the natural gas that entrains into the drilling mud stream can be obtained and measured, is very important while drilling oil and gas wells. The technique uses three important processes ((1) Continuous Gas Extraction, (2) Continuous Gas Transportation and (3) Continuous Gas Analysis) to provide qualitative and quantitative gas information from a circulating drilling fluid and drill cuttings. Accessory equipment such as surface gas trap, gas lines and gas analyzer are required during the processes.

Mud gas Acquisition Concept: Drilling fluid, drill cuttings and gas counts are critical in terms of real-time surface mud log data acquisition. Drill cuttings (small pieces of the formation rock cut by the drill bit) and mud gas circulate upwards with the drilling mud during well drilling (Fig. 1). The formation fluids are continuously liberated during the drilling process and mixed with the mud. The fluid is preserved within the mud during its transportation from bottom hole to the surface. The continuous sample becomes available at the surface at a specific lag time or when the annulus volume is circulated out. Lag time is simply defined as the time taken by drilling mud, gas, drill cuttings or other materials to rise from the bottom of well to the surface. It depends on the annular volume and fluid flow rate. The drilling fluid (mud) carrying hydrocarbon (HC) is stirred or agitated with a high rotation per minute (RPM) in the extraction chamber using the sensor gas trap or gas extractor. The trapped HC plus air mix is sucked by a suction pump of the analyzer and transported to the mudlogging unit through gas lines. The analyzer in the mud logging unit analyzes this mixture as “Gas in Air” and gives results as a

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concentration of methane equivalent hydrocarbons in the air. It is important to state that some of the hydrocarbons circulated out remains entrapped in the drilling mud column and re-circulated (recycled Gas), thus, only part of the gas contained in the mud can be extracted due to limitation of the extraction efficiency and the gas/liquid equilibrium. Meanwhile, the cuttings that circulate upwards with the drilling mud are collected at the shale shaker and examined under the microscope in the mud logging unit.

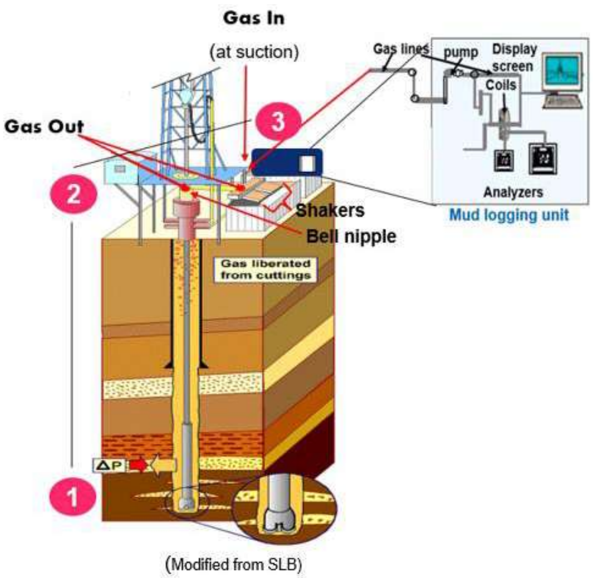

Figure 1: Realtime Surface Mud Logging Conceptual Model.

It is important to note that gas data typically acquired while drilling comes from different sources which include, liberated gas (gas that is released when the drill bit crushes the rock), produced gas (gas inflow caused by borehole pressure lower than hydrostatic), atmospheric gas (O_2, N_2, Ar), and recycled gas (Onyeji, J.A. *et al* 2020).

Key Deliverables and Uses: Mud gas data are underused due to this widely accepted presumption that it is unreliable and unrepresentative especially when it comes to formation evaluation (Kandel et al., 2001). However, the scientific value of mud gas data acquisition/ monitoring while drilling cannot be overemphasized. The key deliverables include:

(1) Daily Geological report- It contains the following information, lithology description and formation gas volume breakdown of the formation drilled, volume of drilling fluid loss to the formation and quantity of the metal fillings recovered within 24 hours of drilling operations.

(2) Daily Drilling Activity Report- This captures the drilling activities (tripping etc.) in real time with real time comments. The report serves as a reference material during incidence investigation.

(3) Mudlog ASCII- Cuttings sample descriptions and gas ASCII can be imported into any well data management platform like Techlog for robust formation evaluation and interpretation.

(4) Drilling Log- Contains drilling mechanical parameters and lithology vs depth which is useful in the evaluation of bit performance via rate of penetration (ROP) at certain depth interval. Drilling log data can be used to optimize new drills based on the drilling efficiency as seen in the ROP in the logs and the combination of drilling mechanics parameters ranges used.

(5) Mudlog Masterlog- Contains more information such as, well deviation information, mud properties, lithology, gas data and the gas ratios (wetness, balance and character) as well as annotation of important event on the log. Gas event - swab gas, Pipe connection and Formation gas.

(6) Cuttings Sample- Small pieces of rock that are chipped away by the drilling bit while a well is being drilled. Cuttings are transported via the mud-stream from the bit to the surface where they can be "caught" and analyzed. Drill cuttings provides useful information required in Geomechanics, Biostratigraphy, Sedimentology, Anti-collision and so on (Fig. 2 and 3).

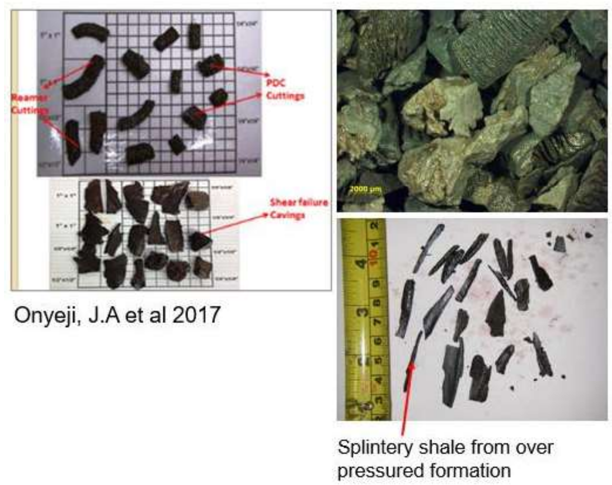

Figure 2: Drill cuttings showing useful information required for Geomechanics (After Onyeji J. A, *et al.,* 2017).

Figure 3: Drill cuttings showing Anti-collision well tracking capabilities of mudlog data.

In this study, potential uncertainties (shift-in-the gas analysis window, misaligned gas data and gas-in-mud underestimation (volume and component)) that associate with gas-in-mud and in- rock acquisition are presented. Also, sources of the uncertainties, and the way forward to acquire highly accurate gas-in-mud and in-rock data are shared.

Geological Setting: The study area is in the western area of the Niger Delta oil field, Nigeria. The field was deposited within 25 to 30 feet of water depth (Fig. 4). It is a complex, mature oil and gas field with large reserves. Over forty-five wells have been drilled in the field, resulting in the discovery of variety of hydrocarbon bearing reservoirs namely, non-associated gas reservoirs, under-saturated oil reservoirs, and saturated oil reservoirs.

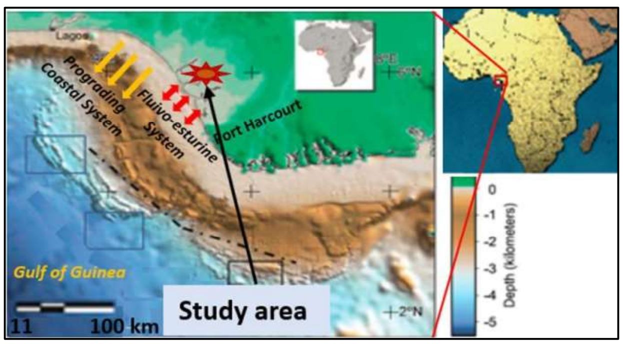

Figure 4: Location map showing study area.

Uncertainties Associated with Mud gas Data Acquisition

Causes for varying gas concentrations in the mud gas data are difficult to assess. This is because drilling mud gas is a function of the in-situ gas composition, physical and chemical properties of the formation and the drilling mud, and the drilling operation (Ablard et al., 2012, Erzinger ***et al.,*** 2006, Hammerschmidt et al., 2014). However, the unreliability of mud gas data may be attributed to the uncertainties associated with its acquisition coupled with strong influence from drilling parameters such as rate-of-penetration, formation pressure, mud weight, mud type, mud flow rate, bit and borehole diameter, gas-trap position in the shaker, and mud-out temperatures (Hammerschmidt et al., 2014). Some uncertainties have been observed during the process of acquiring gas-in-mud and in-rock data, these includes- gas contamination and recycled gas, shift-in-the gas analysis window, gas-in-mud underestimation (volume and component) and misaligned gas data (Fig. 5).
The erroneous data introduced by these uncertainties can adversely impact real-time decision making and cascading effect on the geological models built with the data.

Gas contamination and recycled gas: Nowadays drilling muds are built with several components such as esters,

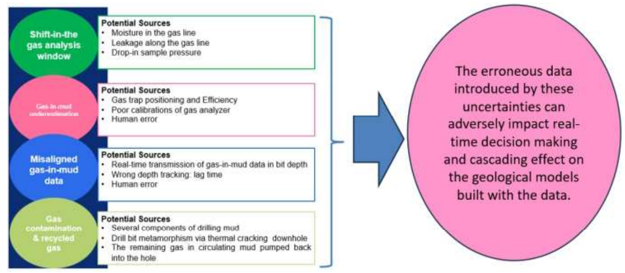

Figure 5: Uncertainties Associated with Mud gas Data Acquisition.

olefins, paraffins, ethers, alkylbenzenes etc. It is observed that these components are liberated from mud in the mud logging degasser, and it appears as C4 - C5 contamination, thus affecting C4 and C5 gas readings (Fig. 6). Drill bit metamorphism (high temperature caused by bit - typically PDC - friction) via thermal cracking downhole may directly contaminate C2 measurements and benzene especially on the fast response chromatographs.

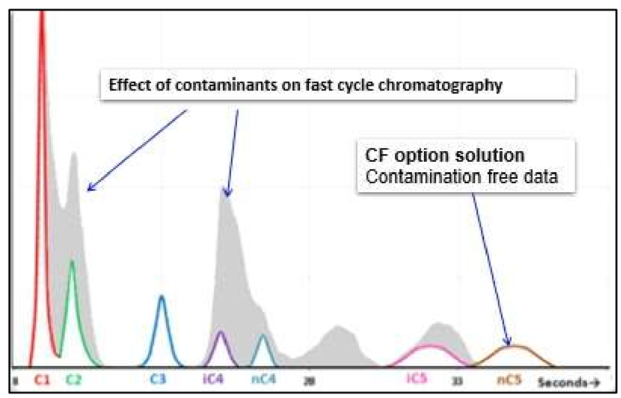

Figure 6: Effect of gas contamination.

Also, it is important to note that surface degasser does not completely remove hydrocarbons/ gas contained in the drilling mud. The remaining gas will be pumped back into the hole with the circulating mud, and it will reappear at surface after one cycle time. Recycled gas can be detected and corrected using Gas In signal (Fig. 7).

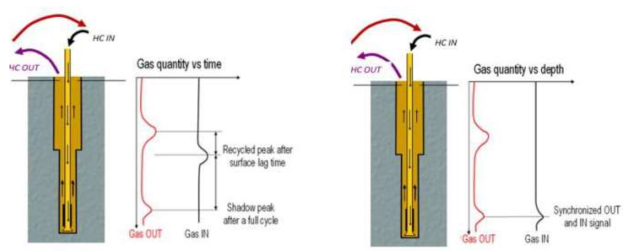

Figure 7: Recycled gas detection and correction.

Shift-in-the gas analysis window: This is a situation where real-time gas component appear outside the set known calibration gas windows. Generally, gas window shift occurs when there is a change in gas elusion/ retention time which does not coincide with the calibrated elusion/retention time in the gas system. Retention time is defined as the time it takes for each of the gas components to exit the analysis chamber. Typically, all the gas components (C1 to C5) are analysed within the system at the same time under constant sample pressure, oven temperature and sample flowrate. The gas components analysed leave the analysis chamber based on weight and known retention time set during calibration, in that lighter components exit first before heavy components. But when there is drop in sampling pressure or moisture/blockage in the gas line, a delay is observed which adversely affects the travel time for the gas component to exit, thus zero will be recorded against the gas component within that window (Fig. 8).

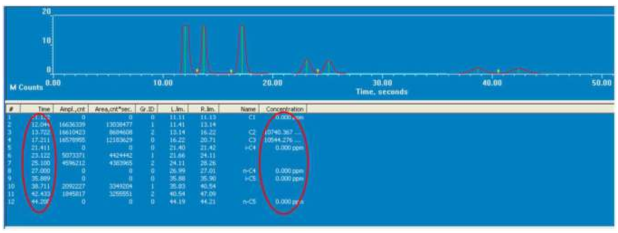

Figure 8A: Shift-in-the gas analysis window. Here only C2 and C3 had values, others appeared as 0.00ppm due to change in retention time.

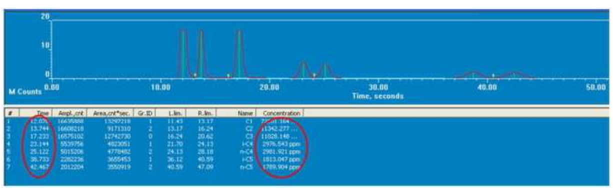

Figure 8B: Gas analysis window with correct retention time. Here C1 to C5 had values, thus no shift.

In this case #2 study, methane (C1) and heavy gas components (C4 and C5) were recorded in the absence of some light gas components (C2 and C3). These were observed after drilling through a long column of sandstone reservoir intercalated with shale units without blowing back and flushing the gas lines of moisture prior to drilling through the reservoir (Table 1.0).

Table 1.0: Gas Data: A shift in the gas analysis window

MD-DHDE	TVD	TVDSS	TGAS	C1	C2	C3	IC4	nC4	IC5	NC5
11381	7244.7	7158.7	222	35604	2032	649	104	159	38	34
11382	7244.7	7158.7	225	37062	2086	658	106	165	49	36
11383	7244.7	7158.7	222	36287	2065	659	104	161	54	35
11384	7244.7	7158.7	215	36275	1768	525	76	125	20	14
11385	7244.7	7158.7	215	36052	1743	519	74	123	19	16
11386	7244.7	7158.7	217	36131	0	516	75	120	0	16
11387	7244.7	7158.7	214	35646	0	494	77	116	0	19
11388	7244.7	7158.7	214	36295	0	500	78	117	0	20
11389	7244.7	7158.7	213	35419	0	0	78	116	0	19
11390	7244.7	7158.7	213	35214	0	0	77	113	0	19
11391	7244.7	7158.7	214	35817	0	0	70	110	0	20
11392	7244.7	7158.7	213	35591	0	0	71	112	0	20
11393	7244.7	7158.7	221	36960	0	0	74	116	0	22
11394	7244.7	7158.7	215	35518	0	0	71	114	0	32
11395	7244.7	7158.7	225	37468	0	0	75	119	0	33
11396	7244.7	7158.7	231	39370	0	0	80	124	0	28
11397	7244.7	7158.7	229	38548	0	0	78	122	0	28
11398	7244.7	7158.7	231	39657	0	0	80	126	0	17
11399	7244.7	7158.7	233	38894	0	0	80	124	0	22
11400	7244.7	7158.7	241	41372	0	0	83	131	0	20
11401	7244.7	7158.7	456	77787	0	0	134	195	0	49

Gas-in-mud underestimation: Another potential uncertainty in gas-in-mud and in-rock acquisition emanate from surface gas system (gas analyzers) calibration. Typical example can be seen in one of the recent wells drilled in the studied area. The gas composition and volume recorded across the target reservoirs K-4 and M-1 were suspected to be underestimated. This is based on the previous mud gas data acquired across the reservoirs in the field and based on the behaviour of gas chromatograph (Table 2.0).

Table 2.0: Overview of mud gas data acquired in #-43H.

MD-DEPTH	TVD-DEPTH	TVDSS	TOTAL-GAS	C1	C2	C3	IC4	NC4	C5	Reservoir
7678	6920.51	6834.51	14	2408	336	0	0	0	0	K-4
7679	6921.25	6835.25	18	3096	432	0	0	0	0	
7680	6921.99	6835.99	16	2752	384	0	0	0	0	
7681	6922.74	6836.74	15	2580	360	0	0	0	0	
7780	6997.24	6911.24	19	3168	1100	0	0	0	0	L-2
7781	6997.99	6911.99	20	2720	1000	200	0	0	0	
7782	6998.75	6912.75	21	2856	1050	210	0	0	0	
8037	7177.49	7091.49	35	5110	1820	0	0	0	0	
8038	7178.18	7092.18	32	5256	1872	0	0	0	0	
8156	7259.6	7173.6	26	3796	1352	0	0	0	0	M-1
8157	7260.29	7174.29	26	3796	1352	0	0	0	0	
8158	7260.98	7174.98	25	3650	1300	0	0	0	0	
8159	7261.68	7175.68	24	3504	1248	0	0	0	0	
8160	7262.37	7176.37	25	3650	1300	0	0	0	0	
8161	7263.06	7177.06	26	3796	1352	0	0	0	0	
8162	7263.75	7177.75	24	3504	1248	0	0	0	0	
8163	7264.44	7178.44	26	3796	1352	0	0	0	0	
8164	7265.13	7179.13	24	3504	1248	0	0	0	0	
8165	7265.82	7179.82	25	3650	1300	0	0	0	0	
8166	7266.51	7180.51	26	3796	1352	0	0	0	0	
8167	7267.2	7181.2	27	3942	1404	0	0	0	0	
8168	7267.89	7181.89	26	3796	1352	0	0	0	0	
8169	7268.58	7182.58	24	3504	1248	0	0	0	0	
8170	7269.27	7183.27	25	3650	1300	0	0	0	0	

Total-Gas is in units while C1 to C5 is in parts per a million (ppm).

Further study revealed that these uncertainties were because of poor calibrations of gas analyzers, as well as human error/ inexperience personnel issues. Typically, the gas acquisition system utilized requires 15 - 20psi sample pressure for good calibration to be achieved, however the contractor used wrong sample pressure (less than 15psi). This is not up to the required pressure to carry out the calibration (Fig. 9).

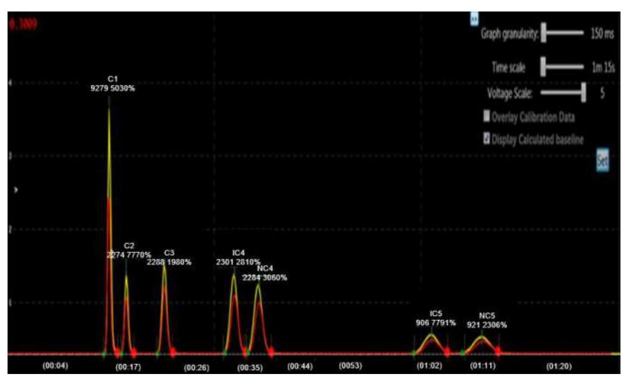

Figure 9: Gas analysis window showing (a) Yellow graph- good calibration already set in the system, and (b) Red graph- poor calibration conducted while drilling the well.

Misaligned gas data: Depth tracking/measurement errors is one of the major challenges in surface mud logging. It was observed that gas values acquired misaligned with the resistivity readings of the reservoir being drilled. This study showed that this uncertainty resulted from real-time transmission of gas-in-mud data in bit depth instead of lagged depth. The calibration is very good, but it has lag depth transmission issues (Fig. 10).

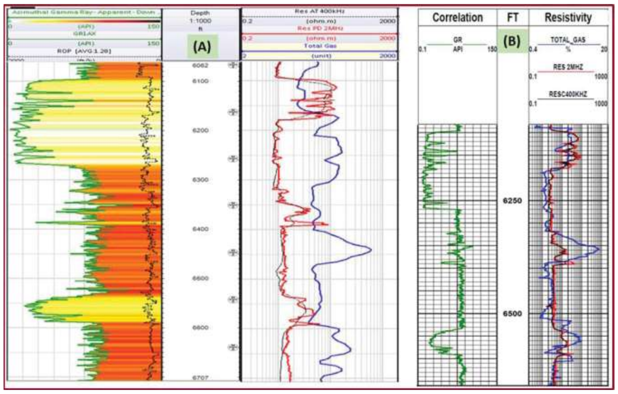

Figure 10: Well log showing; (A) Misaligned gas data with the resistivity readings, and (B) Corrected gas data at the base office during the study.

The Way Forward- Systematic approach

Given the aforementioned challenges and impact on decision making while drilling oil and gas wells, it becomes imperative to minimize these uncertainties to obtain accurate gas-in-mud and in-rock that truly represent the reservoir being drilled. However, gas-in-mud data acquisition technique discussed in this paper involves continuous gas extraction and analysis from a circulating drilling fluid for quantity and composition using surface gas trap, gas lines and gas analyzer. Thus, the way forward described in this paper relies on the systematic use of a constant-volume surface gas trap/ extractor linked to the gas analyzers, flame ionization (FID) total hydrocarbon detector (THA) and gas chromatograph/ mass spectrometry.

Gas Trap: Gas sampling or extraction from the drilling mud stream is done using gas trap or gas extractor positioned at the shale shaker box or possum belly, in some cases at the bell nipple or off the mud return line to minimize losses to the atmosphere. It can also be situated at the mud suction line or mud pit to monitor recycle gas content of the mud. There are various designs of gas extractors but all with the same primary objective of liberating as much gas as possible from the drilling fluid (mud) and making them available for measurement and analysis. The driving force of a conventional gas trap is the agitator. Optimal release of gas from the mud is a function of the design and power of the agitator amongst others. The improved efficiency of these traps means that the gas sample delivered to the mud logging unit is increasingly representative of the true gas content of the drilling mud and therefore of the gas associated with the formation fluid.

Remedial measures: Air powered gas traps were deployed in this project. It requires the use of oilers to lubricate the agitator bearing to avoid stalling. Thus, care was taken to ensure that air source could supply enough air to rotate the agitator. Agitator blade agitates and liberates gas from the circulating drilling fluid, hence constant inspection is recommended to ensure its in place and functioning. Periodic checks/cleaning was adopted on Gas exit vent; this is to ensure vents are not blocked by either moisture or mud cake. Also, constant contact/flow of mud through the trap is maintained for effective gas liberation.

Gas Lines: These are channels through which the liberated gases travel from the trap to the gas analyzers. Lines, pumps, and filters enable the transport of a dry-gas sample to the gas detector/ analyzer in the mud logging unit.

Remedial measures: Appropriate gas line management must be in place while drilling oil and gas wells. These channels must be kept free of moisture, cracks, drilling mud and any other substance capable of impeding the free flow of gas. Loop and joints elimination is vital to avoid collection of moisture in loops and disconnections at joints respectively. Periodic blow backs were carried out to remove moisture from the gas lines using moisture free air compressor. Secondary gas line was in place during blow back. During the process, controlled blow back pressure is recommended to avoid creating cracks/disconnections at joints along the gas line. This can also be done prior to drilling through the reservoirs. After extraction, gas analysis may be performed at the sampling location (Brumboiu et al., 2000) or, more routinely, the gas is continuously transferred via a vacuum line to the logging unit where it passes through the manifold of analytical instruments and may be captured for laboratory-based analysis (Ellis et al., 1999).

Gas Detector: Total hydrocarbon analyzer (THA) which measures continuously the volume of gas liberated from the drilling mud throughout the entire drilling time, and Gas Chromatograph (GC) which measures gas composition with improved resolution (C1- C5 in less than 1 minute), were utilized in this project.

Gas System Calibration: Gas calibration is simply the setting up of gas system (gas analyzers and accessories) to respond accurately to a known gas concentration. It is key to having representative gas data when the gas system is deployed for gas measurements and quantification. Calibrating the system for high resolution measurements requires the use of multiple calibration points. Multiple calibration points imply the use of a range of calibration gasses from the lowest available and readable by the system (0.1%) to a maximum (say 100%)- though individual gas system saturation points are a factor in this case. While carrying out gas calibrations or setting up gas system, one must be careful due to "garbage in garbage out". Therefore, it is advisable that data engineers or wellsite geologists ensure that the gas-detector/analyzers calibration procedures are respected. Also, watch out for possible changes in the mud system or drilling conditions before any interpretation can be made. This is to minimize uncertainties and the risk of interpretational errors.

In this project, three-point calibrations- 0.1%, 5% and 10% concentrations were the minimum standard used while four-point calibrations- 0.1%, 1%, 5% and 10% were also utilized in our recent wells drilled (Fig.11 and Table 3.0). For good gas system calibration, these points must fall along or close to the correlation line with correlation coefficient in the range of 0.85 to 0.95.

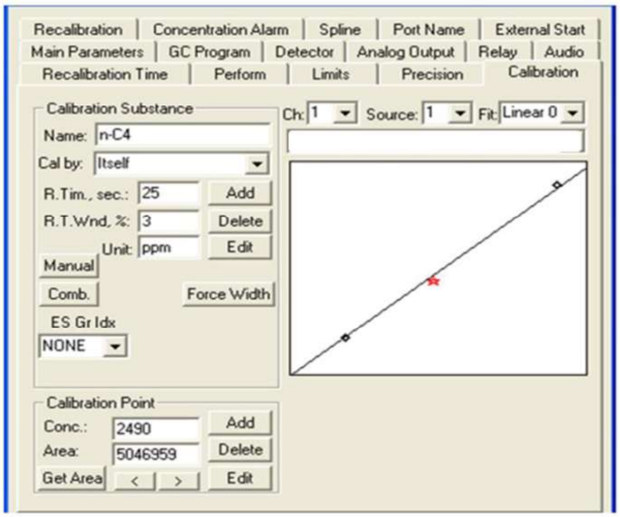

Figure 11: A three-point calibration result conducted in-44H.

RESULTS AND DISCUSSIONS

Systematic approach utilized in mud gas interpretation involves three steps, namely- (1) Gas measurement and quantification, (2) Formation fluid composition and (3) Fluid composition interpretation.

Step 1(Gas measurement and quantification): It involves gas in-mud and in-rock extraction, and quality control of gas extraction processes.
Step 2: (Formation fluid composition): It requires surface to downhole data, thus data at bit depth synchronization, correction of hydrocarbon sources other than formation fluids, and down hole fluid composition determination are crucial at this step.
Step 3 (Fluid composition interpretation): It involves the extrapolation of fluid composition to fluid type, and the integration of fluid logging information to reservoir study.

Considering the uncertainties and the systematic approach used for mud gas interpretation, three-point (3-P) gas calibration/ checks were conducted using 0.1%, 5% and 10% concentrations. The gas system calibrations

Table 3.0: The result of A three-point calibration conducted in-44H.

0.1% C1 - nC5

GAS	BOTTLE CONC (PPM)	CHROM (PPM) R1	CHROM (PPM) R2	AVERAGE	DIFF (Units)	DIFF (PPM)	% ERROR
C1	1000	986	984	985	0.08	15	1.50
C2	990	983	987	985	0.03	5	0.51
C3	1010	1002	1001	1001.5	0.04	8.5	0.84
iC4	990	988	989	988.5	0.01	1.5	0.15
nC4	1000	997	999	998	0.01	2	0.20
iC5	1000	1001	1001	1001	-0.01	-1	-0.10
nC5	1000	1004	1002	1003	-0.02	-3	-0.30

1% C1 - nC5

GAS	BOTTLE CONC (PPM)	CHROM (PPM) R1	CHROM (PPM) R2	AVERAGE	DIFF (Units)	DIFF (PPM)	% ERROR
C1	10030	10031	10031	10031	-0.01	-1	-0.01
C2	10000	9978	9977	9978	0.11	22.5	0.21
C3	10030	10008	10004	10006	0.12	24	0.24
iC4	5030	5029	5027	5028	0.01	2	0.04
nC4	5020	5029	5027	5028	-0.04	-8	-0.16
iC5	2510	2508	2506	2507	0.02	3	0.12
nC5	2500	2506	2504	2505	-0.03	-5	-0.20

10% C1 - nC5

GAS	BOTTLE CONC (PPM)	CHROM (PPM) R1	CHROM (PPM) R2	AVERAGE	DIFF (Units)	DIFF (PPM)	% ERROR
C1	101580	100936	101045	100990.5	2.55	589.5	0.58
C2	10050	10048	10053	10051	0.00	-0.5	0.00
C3	10020	10009	10001	10005	0.08	15	0.15
iC4	2490	2495	2498	2496.5	-0.03	-6.5	-0.26
nC4	2490	2496	2499	2498	-0.04	-7.5	-0.30
iC5	1500	1505	1506	1506	-0.03	-5.5	-0.37
nC5	1500	1507	1506	1507	-0.03	-6.5	-0.43

1% METHANE

GAS	BOTTLE CONC (PPM)	CHROM (PPM) R1	CHROM (PPM) R2	AVERAGE	DIFF (Units)	DIFF (PPM)	% ERROR
C1	10000	10021	10020	10020.5	-0.10	-20.5	-0.21

were conducted prior to the drilling of the intermediate and production hole sections of the new drill (#44H). The correlation coefficient (R) of the calibration is 0.951, while the calibration conducted in the previous well drilled (#43H) was poor with R of 0.542 due to personnel inexperience on gas system (Fig. 12).

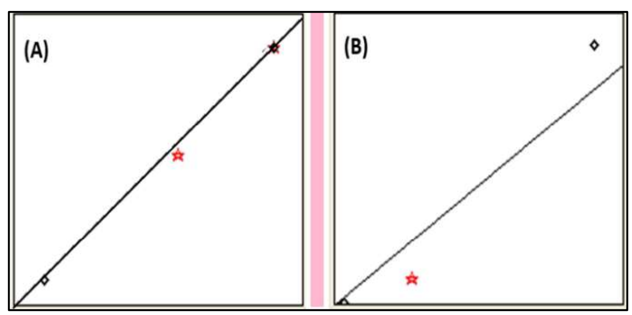

Figure 12: A three-point calibration graphs showing; (A) good three-point calibration conducted while drilling #44H, and (B) poor calibration at #43H.

Other remedial measures carried out to minimize the uncertainties discussed in the previous section includes periodic checks on the gas trap to ensure it is in constant contact with the drilling mud, and the agitator blade are functioning accordingly. The gas lines were also cleared of moisture prior to the drilling through the target reservoirs. Gas samples extracted from the drilling mud while drilling production hole section were analyzed for hydrocarbon

Table 4.0: Comparison of the results of mud gas data acquired from K-4 sand in wells.

43H										44H										
MD-DEPTH	TVD-DEPTH	TVDSS	TOTAL-GAS	C1	C2	C3	IC4	NC4	C5	MD-DHDEP	TVD	TVDSS	TGAS	C1	C2	C3	IC4	nC4	IC5	NC5
7678	6920.51	6834.51	14	2408	336	0	0	0	0	7310	6938.4	6852.4	37	6522	249	67	0	0	0	0
7679	6921.25	6835.25	18	3096	432	0	0	0	0	7311	6938.7	6852.7	39	6935	264	72	0	0	0	0
7680	6921.99	6835.99	16	2752	384	0	0	0	0	7312	6939.1	6853.1	40	7024	273	73	0	0	0	0
7681	6922.74	6836.74	15	2580	360	0	0	0	0	7313	6939.5	6853.5	42	7509	277	75	0	0	0	0
7682	6923.48	6837.48	16	2752	384	0	0	0	0	7314	6939.8	6853.8	27	4715	181	44	0	0	0	0
7683	6924.23	6838.23	14	2408	336	0	0	0	0	7315	6940.2	6854.2	16	2293	271	107	0	0	0	0
7684	6924.97	6838.97	14	2408	336	0	0	0	0	7316	6940.5	6854.5	16	2205	260	105	0	0	0	0
7685	6925.72	6839.72	13	2236	312	0	0	0	0	7317	6940.9	6854.9	18	2501	293	118	0	0	0	0
7686	6926.46	6840.46	15	2580	360	0	0	0	0	7318	6941.3	6855.3	16	2250	266	106	0	0	0	0
7687	6927.21	6841.21	18	3096	432	0	0	0	0	7319	6941.6	6855.6	15	2910	0	0	0	0	0	0
7688	6927.95	6841.95	15	2580	360	0	0	0	0	7320	6942.0	6856.0	31	6100	0	0	0	0	0	0
7689	6928.7	6842.7	20	3440	480	0	0	0	0	7321	6942.4	6856.4	43	8243	0	0	0	0	0	0
7690	6929.44	6843.44	18	3096	432	0	0	0	0	7322	6942.7	6856.7	43	8448	0	0	0	0	0	0
7691	6930.18	6844.18	18	3096	432	0	0	0	0	7323	6943.1	6857.1	46	8784	0	0	0	0	0	0
7692	6930.93	6844.93	15	2580	360	0	0	0	0	7324	6943.4	6857.4	45	7580	385	105	0	0	0	0
7693	6931.67	6845.67	16	2752	384	0	0	0	0	7325	6943.8	6857.8	61	10824	448	119	0	0	0	0

Table 5.0: Comparison of the results of mud gas data acquired from M-1 sand in wells.

43H										44H										
MD-DEPTH	TVD-DEPTH	TVDSS	TOTAL-GAS	C1	C2	C3	IC4	NC4	C5	MD-DHDEP	TVD	TVDSS	TGAS	C1	C2	C3	IC4	nC4	IC5	NC5
7678	6920.51	6834.51	14	2408	336	0	0	0	0	7310	6938.4	6852.4	37	6522	249	67	0	0	0	0
7679	6921.25	6835.25	18	3096	432	0	0	0	0	7311	6938.7	6852.7	39	6935	264	72	0	0	0	0
7680	6921.99	6835.99	16	2752	384	0	0	0	0	7312	6939.1	6853.1	40	7024	273	73	0	0	0	0
7681	6922.74	6836.74	15	2580	360	0	0	0	0	7313	6939.5	6853.5	42	7509	277	75	0	0	0	0
7682	6923.48	6837.48	16	2752	384	0	0	0	0	7314	6939.8	6853.8	27	4715	181	44	0	0	0	0
7683	6924.23	6838.23	14	2408	336	0	0	0	0	7315	6940.2	6854.2	16	2293	271	107	0	0	0	0
7684	6924.97	6838.97	14	2408	336	0	0	0	0	7316	6940.5	6854.5	16	2205	260	105	0	0	0	0
7685	6925.72	6839.72	13	2236	312	0	0	0	0	7317	6940.9	6854.9	18	2501	293	118	0	0	0	0
7686	6926.46	6840.46	15	2580	360	0	0	0	0	7318	6941.3	6855.3	16	2250	266	106	0	0	0	0
7687	6927.21	6841.21	18	3096	432	0	0	0	0	7319	6941.6	6855.6	15	2910	0	0	0	0	0	0
7688	6927.95	6841.95	15	2580	360	0	0	0	0	7320	6942.0	6856.0	31	6100	0	0	0	0	0	0
7689	6928.7	6842.7	20	3440	480	0	0	0	0	7321	6942.4	6856.4	43	8243	0	0	0	0	0	0
7690	6929.44	6843.44	18	3096	432	0	0	0	0	7322	6942.7	6856.7	43	8448	0	0	0	0	0	0
7691	6930.18	6844.18	18	3096	432	0	0	0	0	7323	6943.1	6857.1	46	8784	0	0	0	0	0	0
7692	6930.93	6844.93	15	2580	360	0	0	0	0	7324	6943.4	6857.4	45	7580	385	105	0	0	0	0
7693	6931.67	6845.67	16	2752	384	0	0	0	0	7325	6943.8	6857.8	61	10824	448	119	0	0	0	0
7694	6932.42	6846.42	14	2408	336	0	0	0	0	7326	6944.2	6858.2	104	17722	670	175	18	36	0	0
7695	6933.16	6847.16	15	2580	360	0	0	0	0	7327	6944.5	6858.5	107	18849	706	183	18	37	0	0
7696	6933.91	6847.91	17	2924	408	0	0	0	0	7328	6944.9	6858.9	109	18677	701	185	18	37	0	0
7697	6934.65	6848.65	15	2580	360	0	0	0	0	7329	6945.3	6859.3	109	19654	643	153	0	22	0	0
7698	6935.4	6849.4	19	3268	456	0	0	0	0	7330	6945.6	6859.6	109	19227	627	152	0	22	0	0
7699	6936.14	6850.14	21	3612	504	0	0	0	0	7331	6946.0	6860.0	99	17371	559	135	0	19	0	0
7700	6936.89	6850.89	14	1904	700	0	0	0	0	7332	6946.3	6860.3	94	16614	529	128	0	19	0	0
7701	6937.63	6851.63	18	2448	900	0	0	0	0	7333	6946.7	6860.7	91	16140	526	127	0	18	0	0
7702	6938.37	6852.37	19	2584	950	0	0	0	0	7334	6947.0	6861.0	89	15630	504	123	0	18	0	0
7703	6939.12	6853.12	15	2040	750	0	0	0	0	7335	6947.3	6861.3	80	14411	436	109	8	15	0	0
7704	6939.86	6853.86	16	2176	800	0	0	0	0	7336	6947.6	6861.6	78	13702	414	104	7	15	0	0
7705	6940.61	6854.61	20	2720	1000	0	0	0	0	7337	6947.9	6861.9	66	11791	351	88	6	13	0	0

gas content with total gas analyzer (THA) and a gas chromatograph (GC). While the THA only detected methane (C1), the GC allowed the identification and quantification of higher hydrocarbons in addition to methane, i.e. ethane, propane, i- and n- butane, and i-and n- penthane (C1, C2, C3, C4- and C5). These concentrations are then compared to the gas measurements obtained within the same reservoirs (K-4 and M-1) in the offset well gas data (#43H). It is important to state that both gas measurements and quantifications were done using the same gas system spec under the same drilling conditions; same drilling fluid properties, rheology, mud weight, and bottom hole assembly (BHA) configuration. Well-43H is about 200m away from well-44H within the same fault block.

During the drilling operation of well-44H, the gas-in-mud data recorded in #44H were significantly higher in absolute hydrocarbon gas concentrations than the previous well drilled (43H) as shown in Tables 4.0 and 5.0 below. The gas-in-mud data underestimation recorded in well-43H with lower gas recovery are likely due to the technical issues and human error as narrated earlier.

CONCLUSIONS

The systematic methodology proffered by this study led to improvement in data quality and decision making in the recently drilled wells across the assets and helped prevent potential losses of over $21 million from drilling challenges like wellbore collapse and well control. It also improved formation evaluation activities during the well drilling.

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