Integration of RST/PLT/Sandview Logging for Production Optimization of a Complex Reservoir: A Case Study from a Deep Water Field in Nigeria

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ABSTRACT

The Erha field is located approximately 60 miles offshore Nigeria. The field comprises of stacked deepwater confined channel complex systems with sands of high permeability. The producing wells were often completed with gravel-packed completion for efficient production. This completion in a relatively large borehole along with fresh formation water environment make the understanding of fluid contact and saturation behind the casing a challenging task. Most of the wells have multi-zone completion for higher production but estimation of reservoir performance and pressure under this completion becomes another challenge. One recent well intervention work in Erha field involved Reservoir-Saturation-Tool/Production-Logging-Tool/Sandview (RST/PLT/Sandview) logging and zonal isolation immediately after. A complete dataset was acquired to understand current reservoir pressure, fluid contacts, 3-phase fluid production from different production zones, sand production, and gravel pack quality. Zonal isolation was successfully executed and the well produces 7.4kbd of oil with greatly reduced gas-oil ratio as compared to pre-intervention production. Data collected has also been used to de-risk future drill wells and update reservoir model. Several techniques used to fully understand the reservoir properties and performance and will be discussed in this paper. The combination of PLT and Sandview were used to understand 4 phase (gas, oil, water and sand) zonal contributions. The combination of PLT and RST helped to estimate fluid contact and potential fluid saturation. PLT was performed in three flowrates to understand the performance and pressure of difference reservoirs. RST in silicon activation mode was used to find failed gravel pack intervals.

Key Words:

INTRODUCTION

Background & Objectives

The Erha field is located in deepwater offshore Nigeria, approximately 60 miles southeast of Lagos with a water depth of about 1100 to 1200 meters. The field comprises of stacked deepwater confined channel complex systems with sands of high permeability. The Erha field contains gas, oil and water: the formation water in the interested intervals is relatively fresh with about 14kppm salinity; the API gravity of the oil is about 30.5-32.0°API; and the gas specific gravity is about 0.67. Most of the wells have multi-zone completions across different channel sands, which allowed to achieve high rates from single well. The downside with this completion strategy was the inability to manage unwanted fluid (gas and water) breakthrough from any of the completed intervals due to lack of inflow control devices. A workover would thus need to be required to intervene, acquire necessary data to mitigate risks, and shut-off any interval producing unwanted fluids, like gas or water.

In order to better understand reservoir performance, remaining recoverable hydrocarbons and to de-risk future investments, it became essential to obtain additional static and dynamic data for the Erha field. One project was

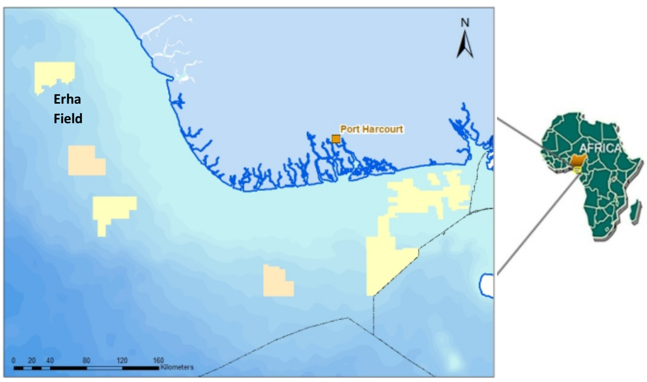

Figure 1: Location of Erha Field.

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proposed in 2018 and executed successfully in 2020 to obtain required data for reservoir characterization and at the same time to improve production volume with idle well restoration using a world class subsea well intervention vessel. This project was the vessel's first project out of shipyard and ExxonMobil's 1st open-water riser based well interventions.

This paper will use one well, Well A, to demonstrate how to integrate RST/PLT/Sandview logging to obtain static and dynamic data and to restore and optimize production. In 2005, Well A was completed as gravel pack oil producer across a 55-meter Zone5, a 38-meter Zone4 and a 17-meter Zone3, as shown in Figure 2(a). Initial rig test showed a much lower production index than expected. The corresponding production logging (PLT) showed 47% of the flow was coming from .17-meter Zone3, suggesting that 93-meter Zone 4 & 5 are impaired; though gravel pack quality log at that time was inconclusive. The well was last tested in 2013 showing high volume of oil production with extremely high gas-oil ratio (GOR) of more than 6000 scf/bbl, as shown in Figure 2(b). The well was cycled due to high GOR and was shut-in in 2013 due to a failed subsea choke. The subsea choke was replaced but the well was left shut-in on suspected sand production. Open-hole log in Figure 2(c) indicated Zone 3, 4, and 5 contained oil originally in 2005 and 4D seismic data in 2014 indicated water in Zone3 and gas in Zone5. Production from the well was supported by gas and water injection in Zone5 and water injection only in Zones 3 & 4.

The objectives of the work included the: evaluation of gravel pack quality; determination of sand entry interval and sand production inside tubing; confirmation of gas/oil/water entry intervals and gas/oil/water production inside tubing; understand formation fluid of each zone behind casing; obtain current reservoir pressure of each zone; propose depth for zonal isolation.

METHODOLOGY

Logging Tools and Program

One key objective is to evaluate gravel pack quality. Gavel pack logging from RST silicon activation mode uses a high energy neutron source to activate the silicon outside the screen, which in turn emit gamma rays. One gamma ray detector could be placed above RST tool to measure this induced gamma ray after activation, which is compared to gamma ray before activation to get gravel pack efficient. This technique has been applied in deep water unconsolidated reservoir East coast of India (Dhar, 2012), offshore unconsolidated reservoir East Malaysia (Amin, 2015), and also in this project.

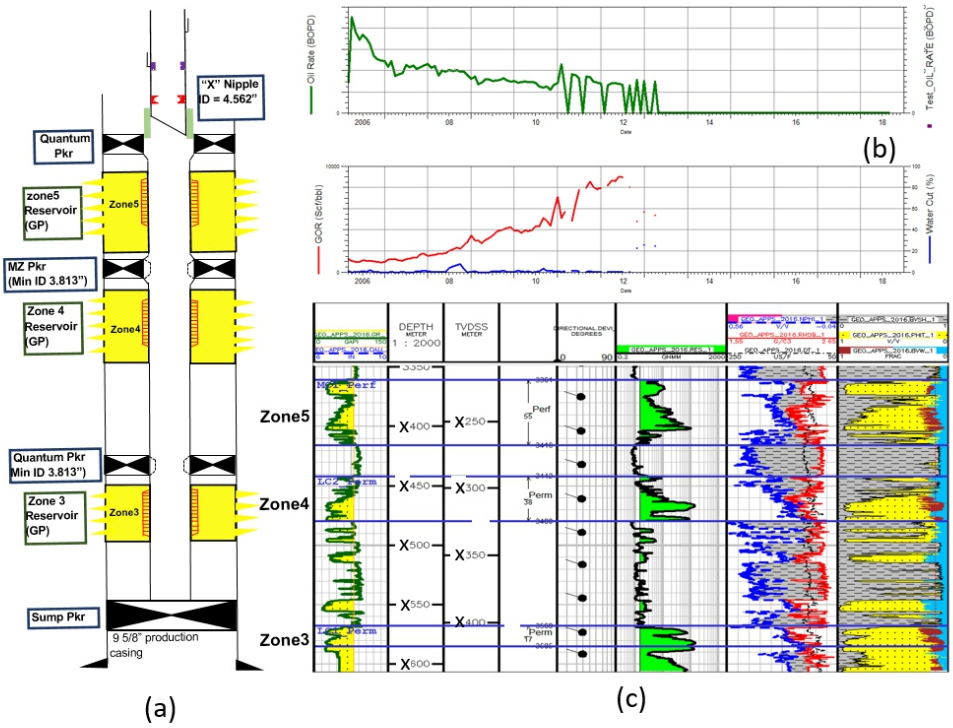

Figure2: Introduction of the well. (a) Completion schematic;(b) Performance history; (c) Open-hole log.

The accurate real-time quantitative sand-particle evaluation is also one of the key objectives. The latest wireline downhole sand measurement tool has been successfully applied in Southeast Asia to quantify sand inflow from heterogeneous stacked reservoirs (Swarnanto, 2018). The sand measurement tool—Sandview—was brought into Nigeria to have its first try in-country. Sandview was combined with array PLT tools like array gas/liquid holdup tool, array water/hydrocarbon hold up tool for downhole gas-oil-water-sand (4-phase) inflow measurements to interpret 4-phase entry intervals and productions inside the tubing.

Understanding formation fluid and saturation behind casing could be challenging considering gravel pack completion in a relatively large borehole along with relatively fresh formation water in the interested intervals. If formation water is relatively fresh, RST Sigma mode is used to understand gas/liquid behind casing and RST inelastic carbon (IC) mode for carbon/oxygen (C/O) logging is used to understand hydrocarbon/water and saturation behind casing. RST tool featured a laboratory characterized C/O database for open holes, standard cased holes, and gravel-packed cased holes. Laboratory measurements in the absence of gravel showed that tool response was significantly different than with gravel (Wanjau, 1999). Also the gravel introduces a porous medium into the borehole sector filled with fluid impacted by both borehole and formation fluid. Overall the introduction of a gravel-pack in the wellbore environment significantly complicates evaluation of formation fluids. In this project, RST measurements along with PLT measurements together were used to understand borehole fluid.

Selective flow performance (SIP) method was used to interpretation reservoir pressure. Borehole pressure was measured when well was in shut-in condition and different flowing conditions, to predict formation pressure for Zone 5, Zone 4 and Zone 3.

Two logging strings were designed to meet the objectives discussed above. The first logging string - RST toolstring-1 - consisted of RST along with several other sensors like gamma ray (GR), casing collar locator (CCL), borehole temperature, borehole pressure, and borehole fluid density. The RST was designed to run in three different modes when well in shut-in condition: silicon activation mode for gravel pack quality; sigma mode for gas vs. liquid of Zone3, 4, and 5; IC mode for possible oil water contact and saturation of Zone3. Other sensors were used to collect basic information inside tubing to understand temperature, pressure, and fluid inside tubing. RST toolsting1 is shown in Figure 3(a) and the objective of using it is shown in Table 1.

The second logging tool sting—Sandview/PLT toolstring-2—consisted array gas/liquid holdup tool, array water/hydrocarbon hold up tool, sand detection tool, in-line and full-bore spinner, X-Y caliper, along with several sensors like GR, CCL, borehole temperature, borehole pressure, and borehole fluid density. The tool was designed to determine 4-phase (gas, oil, water, sand) entry points and production rates at shut-in condition and

Tool	Tool Description	OD	Wt	Len	Acc len
Drawing		in	lbs	m	m
	PEH-EFA: Logging head	1.375	9.39	0.72	18.01
	AH-38: Adapter	1.688	2.00	0.09	17.29
	ERS-E: Electrical Release	1.688	15.00	0.49	17.20
	SAH-G: Swivel	1.688	11.99	0.40	16.71
	EQF-43: Weight bar	1.688	74.00	1.83	16.31
	EQF-43: Weight bar	1.688	74.00	1.83	14.48
	EQF-43: Weight bar	1.688	74.00	1.83	12.65
	PBMS-A: Temperature, Pressure, GR	1.688	49.50	2.52	10.82
	PGMC-B: Gradio Manomenter (Well fluid Density)	1.688	32.60	1.45	8.30
	GHOST-A Gas Hold Up Tool	1.688	29.00	2.18	6.85
	PSDT-B: Sand Detection Tool (SandView)	1.690	18.47	1.12	4.67
	TTG-F: Centralizer	1.688	13.21	1.21	3.55
	PILS-A: inline Spinner	1.688	15.00	0.77	2.34
	PFCS-A: Flowrate and Caliper Sonde	1.688	18.70	1.57	1.57
	Total Weight (lbs)		436.86		

Tool	Tool Description	OD	Wt	Len	Acc len
Drawing		in	lbs	m	m
	PEH-EFA: Logging head	1.375	9.39	0.850	18.82
	AH-38: Adapter	1.688	2.00	0.084	17.97
	ERS-E: Electrical Release	1.688	15.00	0.400	17.89
	SAH-G: Swivel	1.688	11.99	1.827	17.49
	EQF-43: Weight bar	1.688	74.00	1.827	15.66
	EQF-43: Weight bar	1.688	74.00	1.825	13.84
	EQF-43: Weight bar	1.688	74.00	2.520	12.01
	PBMS-A: Temperature, Pressure, GR	1.688	49.50	1.446	9.49
	PGMC-B: Gradio Manomenter (Well fluid Density)	1.688	32.60	0.940	8.04
	ILE-C: Eccentralizer	1.688	22.99	7.014	7.10
	RST-C	1.720	19.71	0.045	0.09
	Bottom Nose	1.688	2.00	0.045	0.05
	Total Weight (lbs)		387.19		

Figure 3: Proposed logging tool strings.(a) RST Toolstring1. (b) Sandview/PLT Toolstring 2

multiple flowing conditions. The reason to run Sandview/PLT toolstring2 in multiple flow conditions was to obtain reservoir pressure using SIP method, and also to understand reservoir performance and potential of different zones. RST toolsting2 is shown in Figure 3(b) and the objective of using it is shown in Table 2.

The second logging tool sting—Sandview/PLT toolstring-2—consisted array gas/liquid holdup tool, array water/hydrocarbon hold up tool, sand detection tool, in-line and full-bore spinner, X-Y caliper, along with several sensors like GR, CCL, borehole temperature, borehole pressure, and borehole fluid density. The tool was designed to determine 4-phase (gas, oil, water, sand) entry points and production rates at shut-in condition and multiple flowing conditions. The reason to run Sandview/PLT toolstring2 in multiple flow conditions was to obtain reservoir pressure using SIP method, and also to understand reservoir performance and potential of different zones. RST toolsting2 is shown in Figure 3(b) and the objective of using it is shown in Table 2.

RESULTS

- Gravel Pack Quality Log

In this work, silicon activation mode from RST logging was used to detect gravel pack quality. When well was in shut-in condition, RST toolstring1 was run in hole to the bottom of the logging zone. With RST minitron off, log up and record GR from GR sensor above RST tool. This is the GR log before silicon activation. After that, turn on RST tool in silicon activation mode, and log down to record GR again after activation. The difference between two GRs (before and after silicon activation) was used to

Table 1: RST Toolstring 1.

Logging Toolstring	Logging Tools	Objective
RST Toolstring 1	PBMS: GR + CCL + Borehole Temperature + Borehole Pressure	GR: correlate to open hole logs CCL: completion alignment Borehole temperature: potential fluid entry and fluid behavior behind the casing (for both perforation zone and non-perforation zone) Borehole pressure: to understand pressure in borehole. Derivative of borehole pressure is borehole fluid density
	PGMS: Borehole fluid density	To understand potential oil and water holdup in the wellbore (holdup is the percentage of fluid in the cross section of well borehole. Different from oil cut or water cut.)
	RST	RST in silicon activation mode: gravel pack quality RST in Sigma mode: understand gas/oil contact. Understand oil/water contact for saline formation water (not feasible for Nigeria fresh formation water environment) RST in IC mode: main application in Nigeria to understand oil/water contact and possible oil saturation. It is a challenging task with gravel pack completion

Table 2: Sandview/PLT Toolstring 2.

Logging Toolstring	Logging Tools	Objective
Sandview/PLT Toolstring2	PBMS: GR + CCL + Borehole Temperature + Borehole Pressure	GR: correlate to open hole logs CCL: completion alignment Borehole temperature: potential fluid entry and fluid behavior behind the casing (for both perforation zone and non-perforation zone) Borehole pressure: to understand pressure in borehole. Derivative of borehole pressure is borehole fluid density
	PGMS: Borehole fluid density	To understand potential oil and water holdup in the wellbore (holdup is the percentage of fluid in the cross section of well borehole. Different from oil cut or water cut.)
	Ghost: • 4 array gas sensors for gas hold up	Each gas sensor will provide gas holdup. Average of 4 sensors (or sensors with good quality data) will provide final gas hold up
	PSDT: Sandview	Sandview tool will see produced sand/solid from production zone, not the static sand/solid in the borehole accumulated with time. This is the advantage of the tool.
	PILS: Inline spinner	Understand fluid flow in the wellbore. With proper calibration, can get fluid velocity.
	PFCS: • 4 assay electrical sensors for water hold up • Fullbore spinner • X-Y caliper	Each electrical sensor will provide water holdup. Average of 4 sensors (or sensors with good quality data) will provide final water hold up Fullbore spinner to understand fluid flow in the wellbore. With proper calibration, can get fluid velocity. X-Y caliper can provide internal diameter

calculate gravel pack efficiency for interpretation of gravel pack quality. Logging speed was optimized to allow strong signal strength from activation to GR sensor, as shown in Table 3.

Table 3: Logging speed for gravel pack quality Log.

Logging Toolstring	GR–Minitron Spacing	Wait time	Logging Speed	Logging Direction
Toolstring1 (PMBS-PGMS-RST)	~6.6 m	199 seconds	2.0 m/min	Down

- Sand Production

One key objective is to find out the zones of suspected sand production. Sandview tool was selected considering several advantages: the tool will only detect sands hitting the sensor from the side to determine sand entry points and production rate, not the sands that are already in the tubing; the tool has high sensitivity to detect single particles as small as 0.1mm; the tool is immune from background noise such as fluid, gas jetting, tool motion etc.

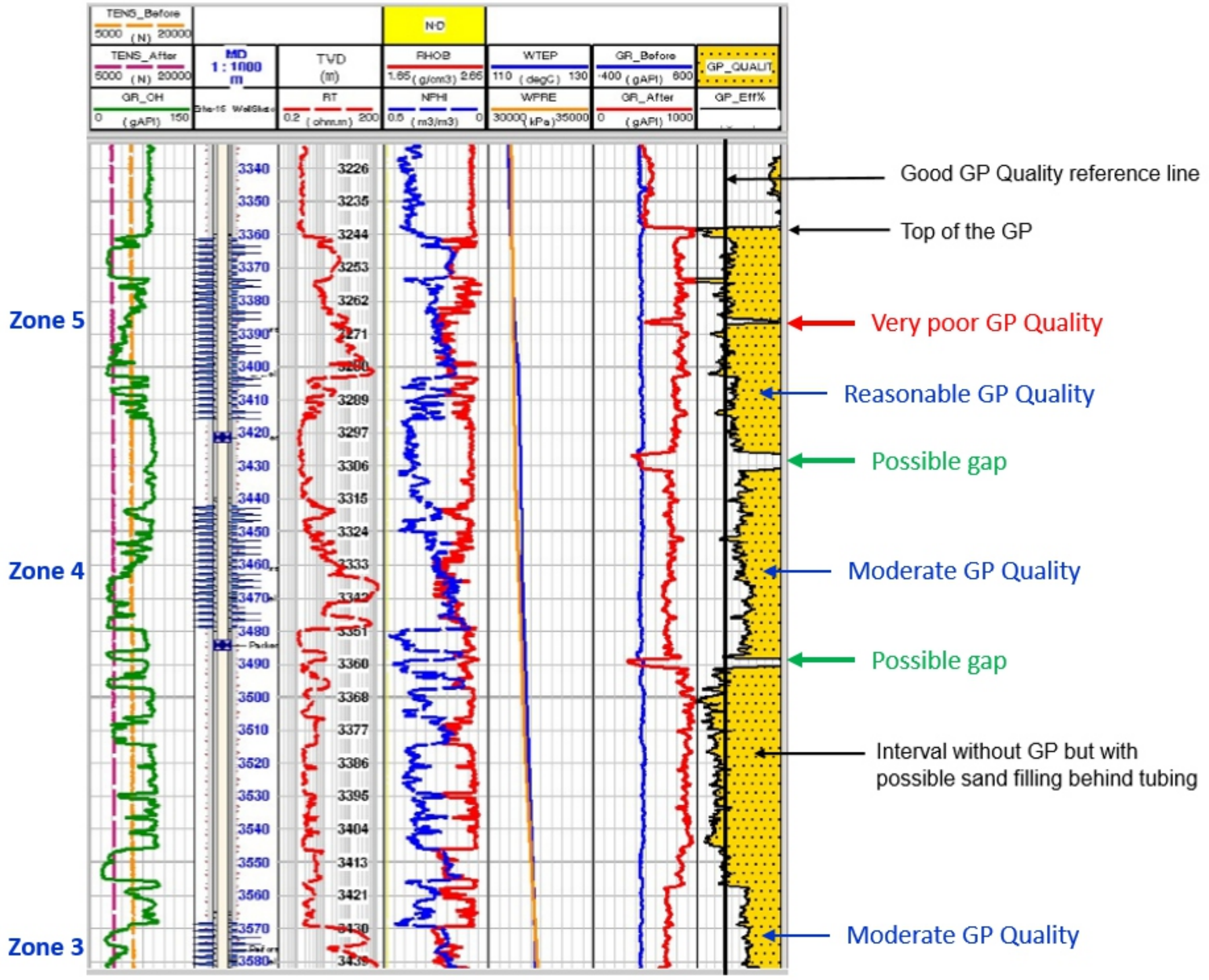

Figure 4: Gravel pack (GP) quality from RST silicon activation mode Second last track: gamma ray before and after activation; Last track: gravel pack efficiency indicator.

The last track of Figure 4 shows gravel pack efficiency indicator which is used to interpret gravel pack quality. Top of the gravel pack is at the top of zone 5. In the middle of zone 5 exists a 2-meter very poor gravel pack quality zone indicating a possible gravel pack damage; other than that, zone 5 has reasonable gravel pack quality. Zone 4 & 3 have moderate gravel pack quality. One interesting interval between zone 3 and 4 shows a possible sand filling behind tubing from original completion.

In Figure 5, the last four tracks to the right show output from Sandview tools. A clear sand production zone was distinguished in the middle of Zone 5. The detection repeated on all logging passes and the sand entry interval was matching the very poor gravel pack quality interval shown in the third track of Figure 4 and last track of Figure 4. Another support for the sand view interpretation was the clogging happened to spinner during stationary measurement across this interval. Spinner data in the second track indicates extremely fluid entry in this thin interval.

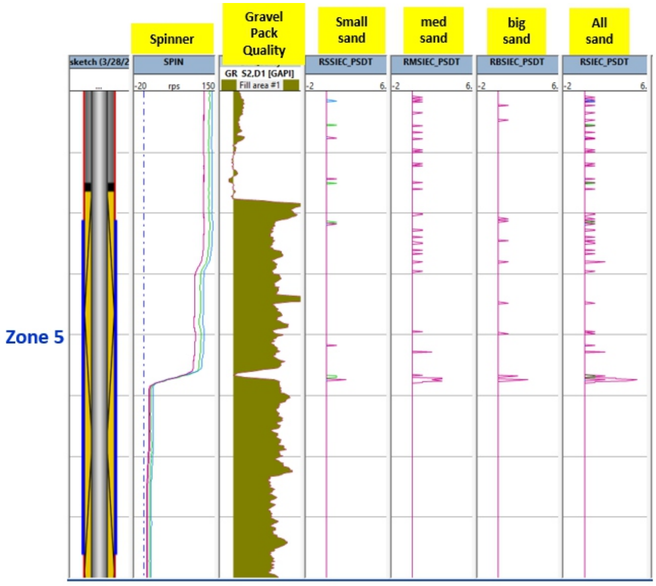

Figure 5: Detection of Sand Production.

- Fluid Entry and Production Rate

PLT/Sandview logging was run to understand sand/gas/oil/water entry and production rate. Three flowing surveys with 40%, 30% and 50% of choke size were conducted to understand the performance of three reservoirs also obtain the reservoir pressure. Figure 6 shows the interpretation of three flowing surveys.

Summary for 40% choke size

- Zone 5 contributed to 92% production
    - Zone 5 has three production intervals.
    - Top interval produced gas.
    - Middle interval was matching the sand entry interval also the very poor gravel pack quality interval. This thin interval contributed to ~68% production with a lot of gas and some oil. The high production in this zone could related to the damage of the gravel.
    - Bottom interval produced mostly oil
- Zone 4 contributed to 7% production with oil and water
- Zone 3 almost no production

Summary for 30% choke size

- Zone5 contributed to almost 100% production
- Zone 5 has three production intervals.
    - Top interval produced gas.
    - Middle interval also the very poor gravel pack interval contributed to ~76% production with a lot of gas and some oil.
    - Bottom interval produced mostly oil
- Zone 4 almost no production
- Zone 3 almost no production

Summary for 50% choke size

- Zone 5 was not logged considering possible very high rate of gas production to break the spinner
- Zone 4 produced oil, water and solution gas. Oil production is higher comparing to 40% choke condition.
- Zone 3 started producing produces water

- Formation Fluid

RST Sigma mode is used to understand gas/liquid behind casing and RST inelastic carbon (IC) mode for carbon/oxygen (C/O) logging is used to understand water/hydrocarbon and saturation behind casing.

Borehole fluid density measurement indicated borehole is filled with gas in Zone5, oil in Zone4, and water in Zone3. RST in sigma mode shows for Zone4, formation fluid is liquid, as shown in Figure 7(b); for Zone5, formation fluid contains injected gas from a close by gas injector though how deep this injected gas filled down to is not very certain, as shown in Figure 7(a). Combining the information from PLT, the top and middle part of Zone5 were mostly filled with injected gas, the very bottom part of Zone5 still contains oil in the formation, and Zone4 contains oil in the formation.

Figure 8 shows near carbon oxygen ratio (NCOR) vs. far carbon oxygen ratio (FCOR) from RST IC mode. Figure 8(a) shows C/O ratio plot without gravel pack was significantly different than with gravel pack (Wanjau, 1999), so selection of interpretation model could impact the results. In Figure 8(a), four corners of each situation represent WW-water in borehole and formation, OW-Oil in borehole and water in formation, OO- oil in borehole and formation, and WO – water in borehole and oil in formation.

Figure 8(b) shows C/O ratio plot for Zone3, indicating gravel pack may trap some oil, and formation fluid contains large amount of water. PLT shows that Zone3 produced water. Combining RST and PLT measurements, Zone3 contains water in the formation.

- Reservoir Pressure

Selective flow performance (SIP) method was used to interpretation reservoir pressure of Zone5, Zone4 and Zone3 from pressure measurements of different flowing surveys, as shown in Figure 9.

- Well Test after Intervention

Considering fluid and sand production along with gravel

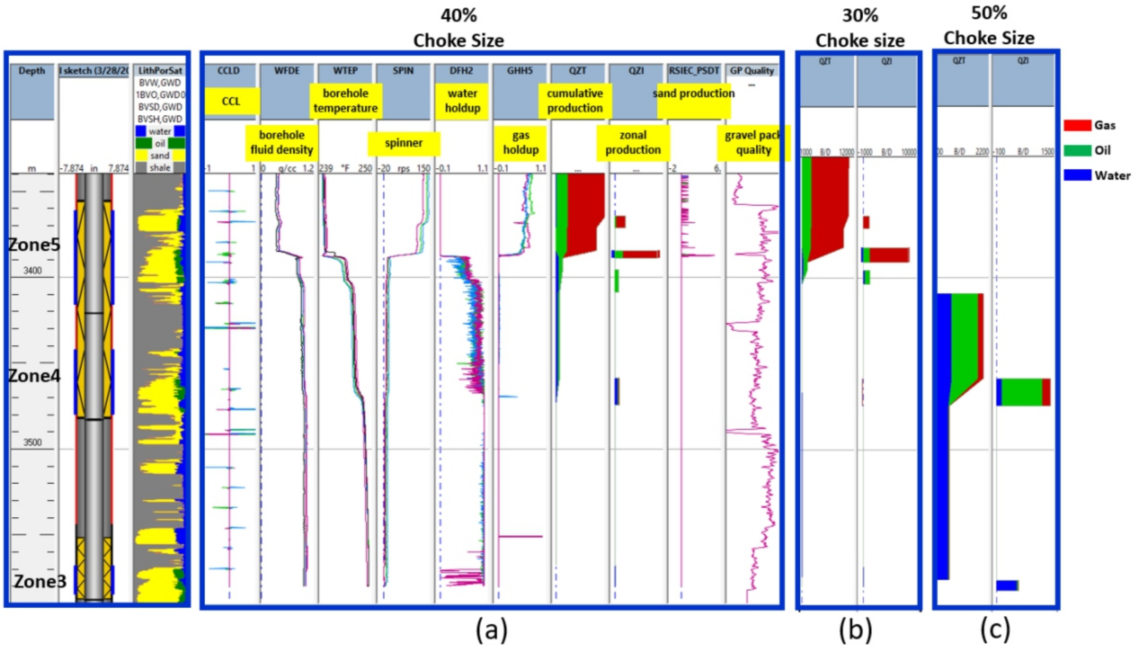

Figure 6: Fluid entry and production in three flowing surveys (a) 40% Choke size; (b) 30% Choke size; (c) 50% Choke size.

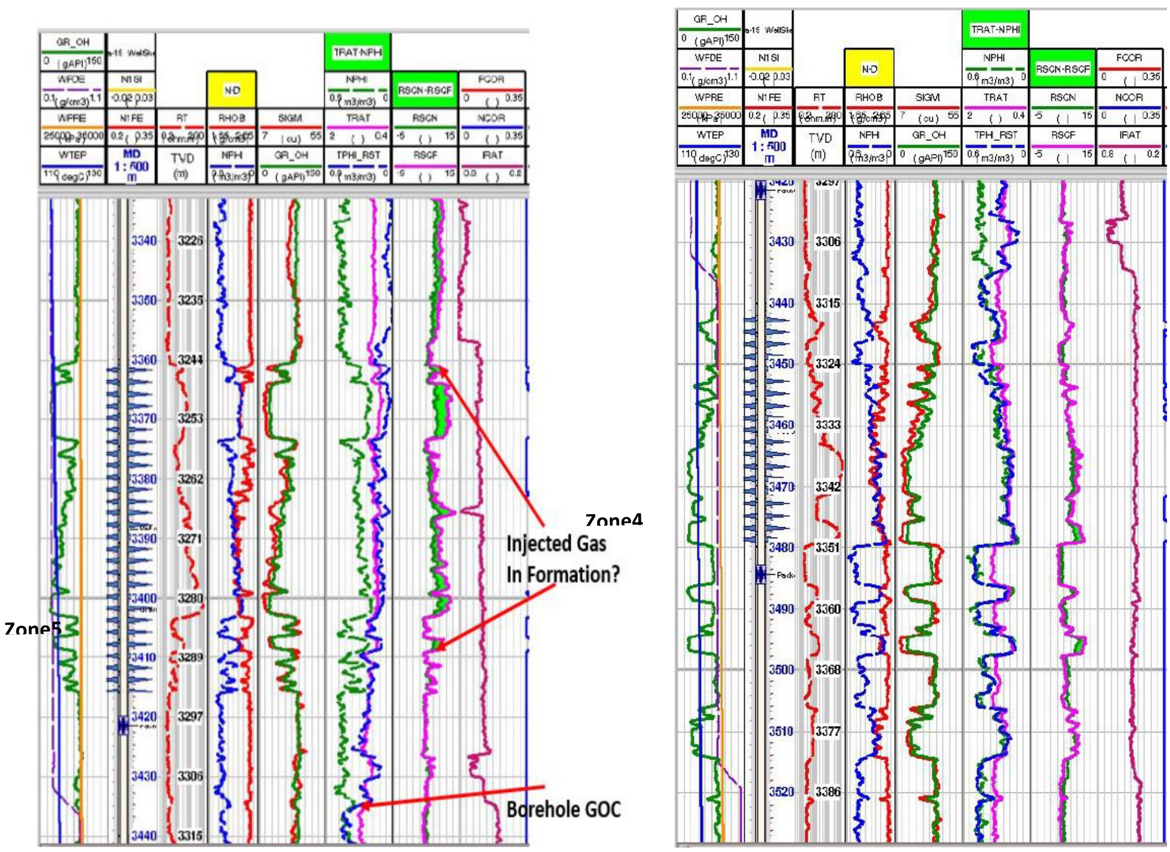

Figure 7: RST Sigma Mode Measurements (a)Zone5; (b) Zone4.

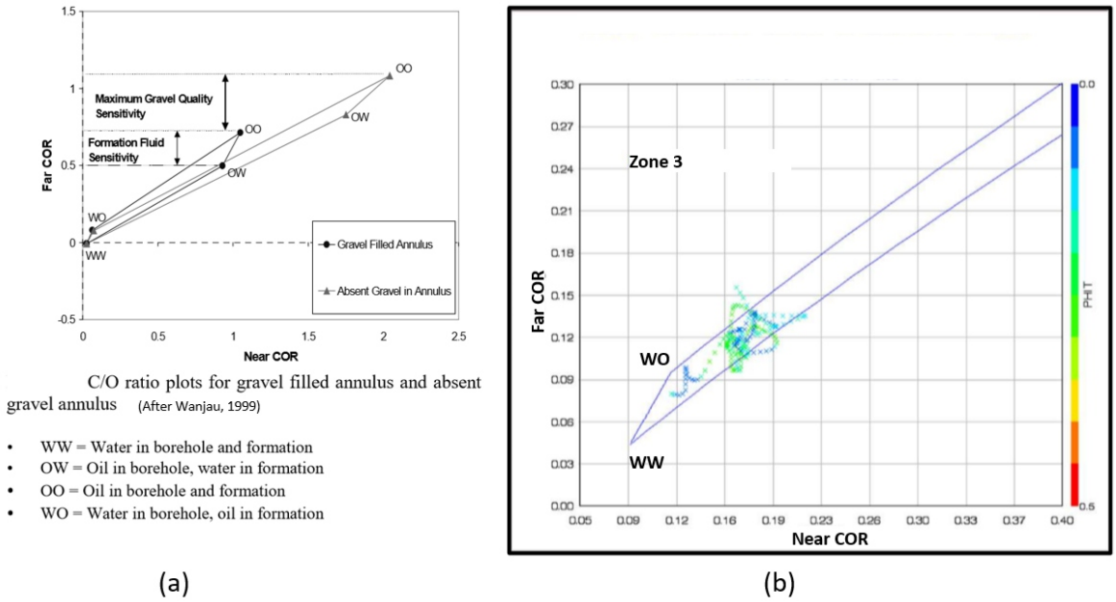

Figure 8: Near C/O Ratio (NCOR) vs. Far C/O Ratio (FCOR) (a) C/O ratio plot with gravel pack vs. no gravel pack (Wanjau, 1999) (b) C/O ratio plot for Zone3.

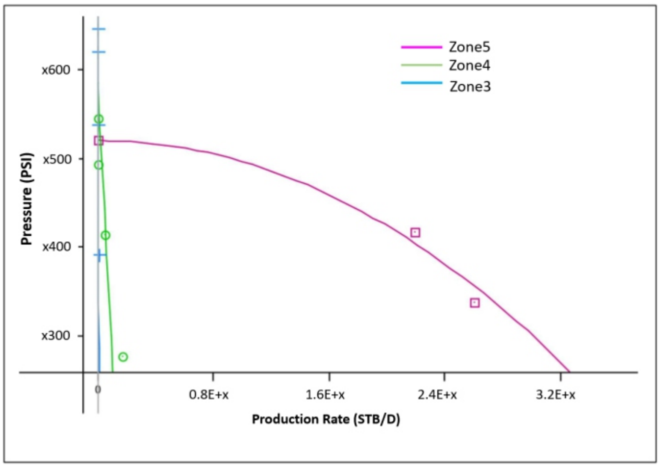

Figure 9: Interpretation of Reservoir Pressures from SIP Method.

pack quality, partial of Zone5 was decided to be isolated to block the top and middle production intervals in the Zone5. Considering water production, the entire Zone3 was decided to be isolated. Zonal isolation was successfully executed and the well produces 7.4kbd of oil with greatly reduced gas oil ratio as compared to pre-intervention production.

CONCLUSIONS

Several techniques has been discussed in this paper using RST/PLT/Sandview logging to meet the objectives of the work: evaluate gravel pack quality; determine sand entry interval and sand production inside tubing; confirm gas/oil/water entry interval and gas/oil/water production inside tubing; understand formation fluid of each zone behind casing; obtain current reservoir pressure of each zone; propose depth for zonal isolation. Well intervention was executed successfully to restore oil production.

Valuable static and dynamic data were collected for Erha field: to understand reservoir performance and remaining recoverable hydrocarbon potential; to evaluate flood conformance, depletion efficiency and multi-zone well completion efficiency at flow unit scale; to calibrate reservoir model, re-evaluate field potential, refine depletion plan to optimize production in each channel, and de-risk future drill wells.

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