Petroleum and Coal

Article Open Access

Reservoir Performance Review for Nok Reservoir in Niger Delta

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Received June 11, 2017; Accepted October 4, 2017

Abstract

The review of a reservoir performance helps to identify the basic and unique problems plaguing a reservoir which is ought to be resolved before any reasonable simulation and consequent development. This study investigates the application of reservoir performance review and diagnostics on Nok in the Niger Delta to serve as a prerequisite for its development.

The Nok reservoir is producing at a rate of 3000stb/day for all wells. Well LU1 and well LU2 were discovered to have excessive water production; having a high water cut of 71.5% and 96.6% for well LU1 and well LU2 respectively. From the review, it was discovered that the causes of the high water cut during oil production from the two wells using diagnostic plots of the Water Oil Ratio (WOR) and Water Oil Ratio Derivative (WOR') versus time were water coning at the early stage of production and channeling at the later stage. Re-perforation at a shallower depth was therefore considered as a go forward plan for Nok reservoir which showed a 0% water cut at a test of re-perforation

Keywords: Reservoir performance; water production; faults, diagnostics Plot; water cut.

1. Introduction

Research has disclosed that three barrels of water is produced for every one barrel of oil produced, worst scenarios has gone up to nine times [1]. The produced water will be treated and either disposed or used for water injection projects. The cost of separation, treatment and disposal is enormous [2]. Problem of excessive water production is prominent in mature fields globally and it adversely impacts on the economy of such project development. It is needed to fully understand the different mechanisms that add to unwanted water production to better evaluate existing information, identify additional tests, and design the optimum solution to the problem [3]. To be able to identify and solve unique problems plaguing reservoirs, it is pertinent to conduct a reservoir performance review. This involves the proper coordination and review of the geological data, petrophysical data, dynamic reservoir data and production data for proper evaluation.

Expectations are that water production would increase with the life of the reservoir as production continues but sometimes a sudden increase in water production at an early stage in a reservoir may occur. This is an undesirable condition with respect to field development plan implementation. The excessive water production has associated cost implications on the surface facilities, corrosion, scale problems, water treatment and disposal. Another consequence is the decrease in oil production as more oil is left behind the displacing water front, thereby reducing the performance of the reservoir with respect to oil production. All these along with the decrease in the quantity and quality of the oil produced imply a reduced profitability.

The sources of water include formation water aquifer and injected water. The formation water can originate from water saturated zone within the reservoirs or zones above or below the pay zone. A good number of reservoirs are adjacent to an active aquifer and are subject to bottom or edge water drive. Another source of water is through water injection into the reservoir for the purpose of pressure maintenance and secondary recovery. This constitutes a source of water production problem. No matter the source of water production whether it is from injected water or bottom and edge aquifer, the severity of water production could be described as sweep, good or bad. The magnitude of the problem varies from one form to another [1]. NOK reservoir has a dome shape and it is located in Niger Delta. The geological structure contains 2 sealing faults characterized by sand-to-sand juxtaposition, dividing the reservoir up into 3 distinct fluid-in-place regions, as well as an impermeable horizon in the 6th layer of the reservoir. The phases present in the reservoir are water, oil and gas in the dissolved form produced from 10 producer wells.

2. Reservoir performance plots and analysis for water production

According to Seright *et al.* [4], several methods can be useful in the identification of the source and nature of excess water production. Some of these methods could include simple injectivity and productivity calculations, inter-well tracer studies, reservoir simulation, pressure transient analysis, and various logs interpretations.

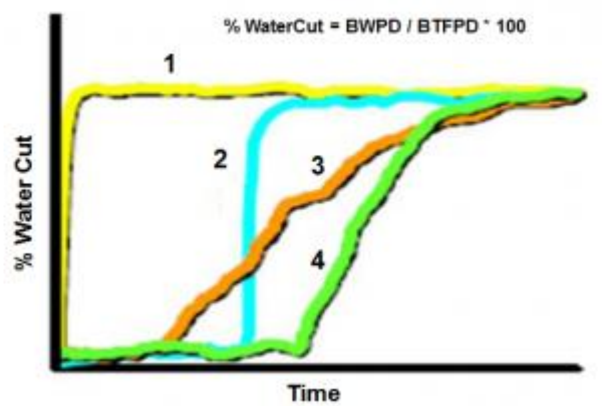
Kikani [5] itemized the following plots for the analysis of both production and injection wells. The following plots were identified for producing wells:

1. Decline Curve Analysis
2. Log of water cut or oil cut versus cumulative production
3. Fetkovich type curves
4. Omoriegie-Ershaghi Plot (X plot)
5. Dowell-Schlumberger log(WOR) Diagnostic Plot

According to Chan [6], the above plots could be useful to evaluate production efficiency, but they do not reveal any detail on reservoir flow behaviours. Although, some of the plots could show reservoir characteristics, they do not shed any clue on the timing of the layer breakthrough. Therefore, the need for the diagnostic plot was proposed by Chan. Diagnostic plot reveals detailed reservoir flow behaviours, the timing of the layer breakthrough and the relationship between the rates of change of the Water–Oil-Ratio (WOR) with the excessive water production mechanism.

2.1. Diagnostic plots

According to Chan [6], the log-log plots of WOR versus time or GOR (Gas-Oil Ratio) versus time show different characteristic trends for different mechanisms. The time derivatives of WOR and GOR were found to be capable of differentiating whether the well is experiencing water and gas coning, high-permeability layer breakthrough or near wellbore channelling. Chan identified three most noticeable water production mechanisms namely water coning, near well-bore problems and multi-layer l. Based on the plot of production trend in figure 1 it is easy to identify the type of water related problem. Chan suggested the use of diagnostic plot to identify the type of problem.



- Casing Leaks (1)(2)
- Flow behind casing (1)
- Conning or cresting (3)(4)
- Channel from injector (4)
- High permeability streak (4)
- Completion near a water zone (1)(2)
- Fracturing job went to water (1)(2)
  Watered-out zone (3)(4)

Figure 1. Conformance problems associated with water cut trends [6]

A dynamic reservoir simulation with ECLIPSE Black oil model, which has the ability to simulate the field development and generate results, based on the reservoir characteristics and production schedule was set in place.

3. Data organization

The primary data was obtained from the Niger Delta, the data obtained for the purpose of this work are: PVT laboratory data; Reservoir data; Production data.

The relative permeability data was generated using Special Core Analysis program in the simulator as a secondary data as shown in Table 1 (gas saturation) and Table 2 (oil saturation).

Table 1. Gas saturation function

Sg	Krg	Pc (psia)	Sg	Krg	Pc (psia)
0	0	0	0.45	0.354	1.5
0.05	0	0.03	0.54	0.465	2.1
0.09	0.032	0.1	0.63	0.586	2.8
0.18	0.089	0.3	0.72	0.716	3.6
0.27	0.164	0.6	0.81	0.854	4.5
0.36	0.253	1	0.9	1	5.5

Table 2. Oil saturation function

So	Krow	Krowg	So	Krow	Krowg
0.3	0	0	0.66	0.465	0.216
0.36	0.032	0.001	0.72	0.586	0.343
0.42	0.089	0.008	0.78	0.716	0.512
0.48	0.164	0.0275	0.84	0.854	0.729
0.54	0.253	0.064	0.9	1	1
0.6	0.354	0.125	0.66	0.465	0.216

3.1. Field model description

Table 3 shows the data used in developing the reservoir model. This model simulates live oil through a heterogeneous reservoir divided into 2400 cells built on a grid dimension of 20 x 15 x 8 using Cartesian grid defined with corner point geometry.

Table 3. Model description

Grid dimensions	20 x 15 x 8
Reservoir size	19000ft x 16000ft
Depth of reservoir top	6900ft
Porosity range	0.16 - 0.34
Permeability range	4.2 - 2783.2mD

Coarse grid model was used to capture all the producers instead of using grid refinement for single well. The phases present in the reservoir were water, oil and gas in the dissolved form. The geological structure contains 2 sealing faults, dividing the reservoir up into 3 distinct fluid-in-place regions, as well as an impermeable horizon in layer 6. The field was investigated to find out the source of water production, since there is an aquifer at the edge of the reservoir. The contribution of the aquifer was investigated with analytical aquifer model for edge water drive.

3.2. Geological model (Grid/Rock data)

The basic geometry of the simulation grid and various rock properties (porosity, absolute permeability) in each grid cell are specified in the grid section. The varying rock properties which include different values of porosity and permeability were generated for the model using the calculator program in the utility option of the grid section of the simulator. The distribution and allocation of porosity and permeability values used in the study are show in figures 1 and 2. Blue colour shows areas with low porosity while red depicts areas with high porosity. Similarly, low permeability is denoted with blue colour and high value with red as illustrated in the figures below. An aquifer was attached to the reservoir to understand the drive mechanism and diagnoize the source of water. Carter Tracy's model in Eclipse 100 was used for the analysis.

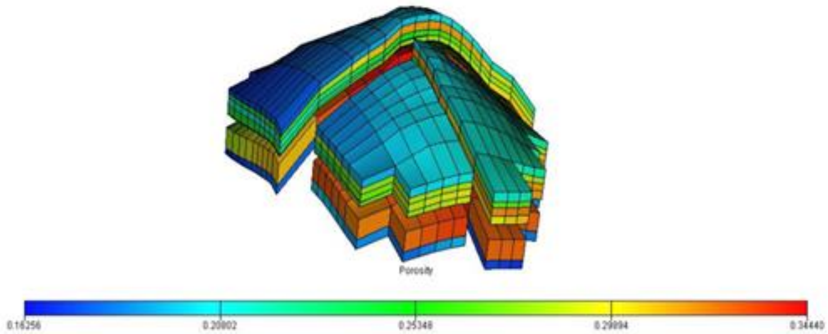


Figure 2. Porosity Distribution

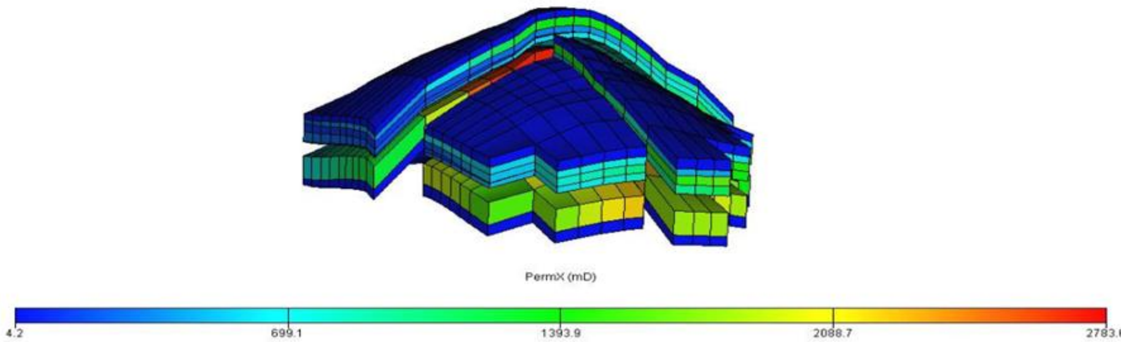


Figure 3. Permeability distribution

3.3. PVT section

The PVT Section gives an accurate description of the hydrocarbon system and its properties. Options relating to the PVT Sections were selected at this stage. PVTi was used to characterize the phase behaviour of the reservoir fluids. Tables 4 through 6 show the PVT properties of oil, gas and water. PVT data was imported from INCLUDE files generated by PVTi to Eclipse Black oil simulator.

Table 4. Dry gas PVT properties

Pressure (psia)	Formation volume factor (rb/Mscf)	Viscosity (cP)	Pressure (psia)	Formation volume factor (rb /Mscf)	Viscosity (cP)
1214.7	13.947	0.0124	2614.7	1.638	0.0148
1414.7	7.028	0.0125	3014.7	1.282	0.0161
1614.7	4.657	0.0128	3414.7	1.052	0.0173
1814.7	3.453	0.0130	3814.7	0.890	0.0187
2214.7	2.240	0.0139			

Table 5. Live oil PVT properties

Rs (MSCF/STB)	Pressure bub (psia)	FVF (rb/stb)	Visc (cP)
0.137	1214.7	1.172	1.97
0.195	1414.7	1.2	1.556
0.241	1614.7	1.221	1.397
0.288	1814.7	1.242	1.28
0.375	2214.7	1.278	1.095
0.465	2614.7	1.32	0.967
0.558	3014.7	1.36	0.848
0.661	3414.7	1.402	0.762
0.77	3814.7	1.447	0.691
	4214.7	1.4405	0.694
	4614.7	1.434	0.697

Table 6. Water PVT properties

Reference Pressure(Pref)	3814.7 Psia
Water FVF at Pref	1.0231 rb/stb
Water compressibility	3.1E-6 1/psi
Water viscosity at Pref	0.94 CP
Water viscosibility	0 1/psi

Table 7. Fluid gravities at surface conditions

Oil API gravity	35
Water specific gravity (w.r.t. pure water)	1.0096
Gas gravity (w.r.t. air)	0.75

3.4. Initialization of model

The model is composed of three regions with different equilibration specifications. The first equilibration region is at a datum depth of 7100ft with pressure at datum as 3814.7psia while the second and third regions are at a datum depth of 8000ft with datum pressure as 4145.39psia. The summary of the equilibration regions and fluid in place (FIP) reports of the field are shown in the Tables 8 and 9. A reference pressure of 3814.7 psia was used to initialize the reservoir.

Table 8. Data Used for Equilibration Specification

Equilibration region	Datum depth (ft)	Pressure (psia) at depth	WOC depth (ft)	GOC depth (ft)
Region 1	7100	3814.7	7500	7100
Region 2	8000	4145.39	7550	7000
Region 3	8000	4145.39	7600	7000

Table 9. Details of the fluids-in-place report

Region	Oil (stb)	Water (stb)	Gas (Mscf)	Dis Gas (Mscf)	Mobile oil wrt water (stb)	Mobile oil wrt gas (stb)
Field	5.6330272E+8	2.354596E+9	4.6154332E+8	4.3377823E+8	3.4833198E+8	3.2436177E+8
1	3.8830317E+8	1.3179173E+9	3.2679367E+8	2.9902858E+8	2.4955781E+8	2.2962918E+8
2	97902295	6.10198E+8	75384767	75384767	48300853	52162948
3	77097253	4.2648068E+8	59364885	59364885	50473315	42569636

3.5. Wells and production schedule

Schedule as an interactive program was used to prepare, validate and integrate production and completion data for use in the reservoir simulator. From the results of history matching (Figures 4 and 5) the model can be used to evaluate the performance of the well in the reservoir.

Schedule was used to handle all the main categories of production data necessary for simulation. These took the form of well surveys, production, and completion data.

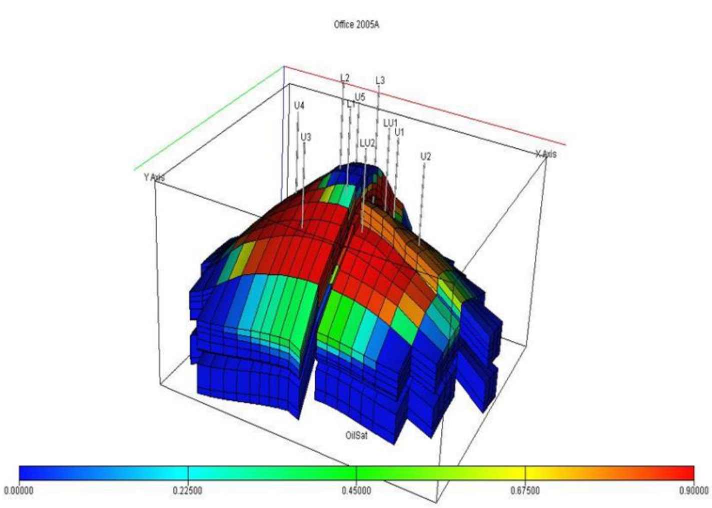


Figure 4. Field well locations, designs and architecture

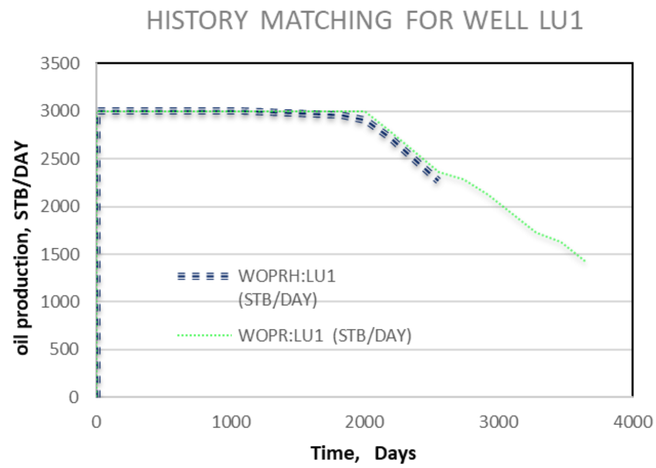


Figure 5. History matching of production data with simulated date for well LU1

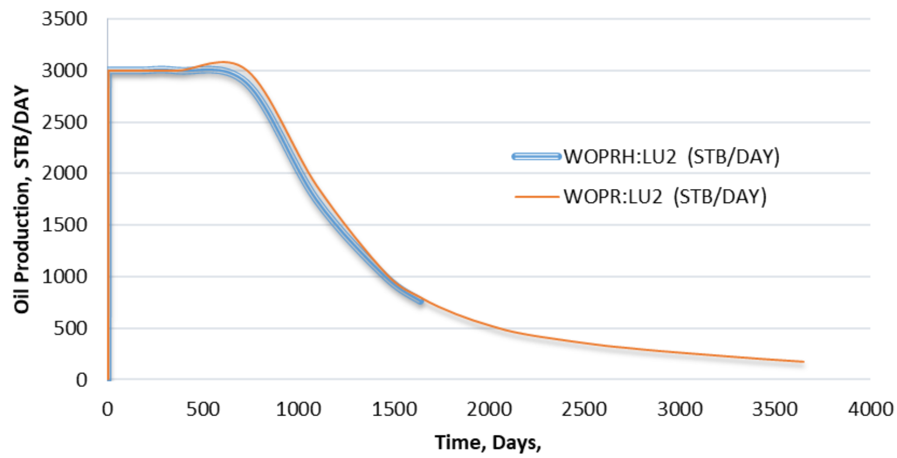


Figure 6. History matching of production data with simulated date for well LU2

3.5.1. Completion strategies

The drilling campaign for the field is strategic for the actualization of the field development plan, at the intended date of first oil and the intended rate for production.

It involved the drilling of 10 wells (producers); all of which are assumed to be ready before production commences. Each well is set to start producing at a peak production rate of 3000stb/d. To optimize production, a vertical well configuration is used for all the producers. The wells are completed across layers 2 to 5 for the producer wells. The well locations are shown in the figure 4.

3.5.2. Production schedule

The summary of the well production data used in the simulation is shown in the table below. In the schedule section the wells were connected to the layers. The wells were scheduled to produce based on the data in Table 10. Initial bottom-hole pressure of 3814.7psia was constrained to 500 psia to end the production.

Table 10. Production well control data

Oil rate	3000 stb/d
Liquid rate	5000 stb/d
Bottom hole pressure target	500 psia

4. Reservoir production performance evaluation

Reservoir performance evaluation was carried out to detect the problem in the reservoir represented in the model. This involved plots of the field production data to determine how well the reservoir is producing based on the oil, gas and water production rates, water oil ratio and water oil ratio derivative, pressure and water cut with cumulative production and time. The plots considered here are:

i. Oil, gas and water production rates with time
ii. Water cut with cumulative production
iii. Log-log plot of water oil ratio, (WOR)
iv. Log-log plot of water oil ratio derivative, (WOR)' with time

where: Water Oil Ratio (WOR) is given as; $WOR = \frac{\text{Water rate}, q_w}{\text{Oil rate}, q_o}$;

the equation for Water Cut calculation is; $\text{Water cut}, f_w = \frac{\text{Water rate}}{\text{Total liquid rate}} = \frac{q_w}{q_L}$;

and Water-Oil-Ratio derivative is given as; $WOR'_n = \frac{WOR_{n+1} - WOR_{n-1}}{t_{n+1} - t_{n-1}}$

The WOR and the WOR derivative (WOR') plots were used in combination to diagnose the related water production mechanism prevailing in the Nok reservoir. An upward sloping of the WOR plot with time indicates increased water production. It also considers that the upward sloping of the WOR derivative indicates multilayer channelling while the downward sloping indicates water coning. For the purpose of this work, the centre difference first order derivative approach is used to determine the WOR'.

5. Results and discussion

5.1. Performance review of wells

Considering well production rates against time (about 10years), the performance review on the wells indicated a high water cut for well LU1 and well LU2 having values of 71.5% and 96.6% respectively as against the expected water cut of 50% as the economic limit. The other wells present in the reservoir had a relatively constant oil production rate and relatively very little water production. A plot of field pressure depletion shows constant pressure drop for about 5.5 years and thereafter the decline rate changed. This agreed with the constant oil production rate seen in figure 7 for 5.5 years.

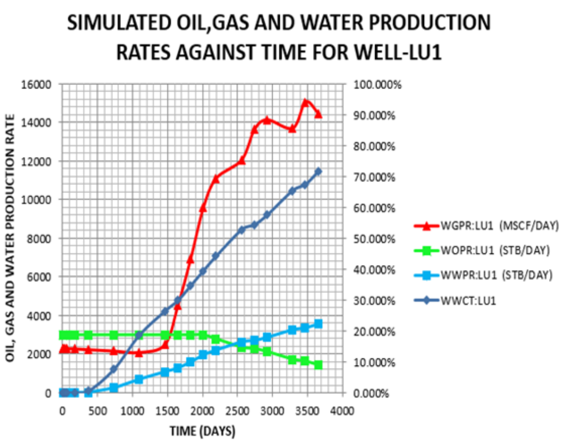


Figure 7. Simulated Well production rates for Well LU1

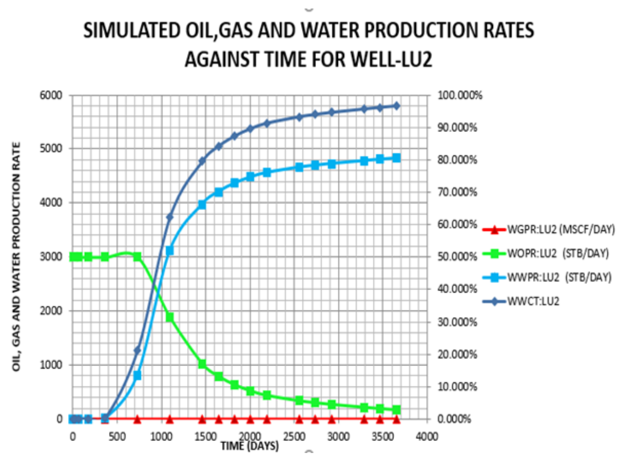


Figure 8. Simulated Well production rates for Well LU2

Oil production rate continued to drop as oil, water and gas compete to flow through the pore space showing reduction in the relative permeability to oil. As water cut increased with time oil production dropped in Well LU1. At 6.6 years of pro-duction, the water- oil ratio (WOR) became 1.0 and from then water production continued to increase while oil production declined. By the end of the well's life at 10.14 years, total liquid production became 71.7%

water and 28.3% oil. Gas can pass through a little passage hence permeability to gas was not much affected. At end of the simulation time the oil production rate reduced to 1600 bbl/day

Well LU2 experienced a more grievous situation. Water production started at about 1 year after the commencement of production but the rate of water production was high from 320 days till 1100 days and the rate increased slowly from 3000 days to 3600 days. Constant oil production rate occurred from initial production time to about 720 at 3000 bbl/day. Production decline commenced from 720 days with a rapid decline due to high water production. The proportion of water production is relate the loss in oil production. It is worthy to note that the drive mechanism is entirely water-drive as gas production is zero.

5.2. Diagnosis of problem

Chan [6] as shown in figure 9 demonstrated that a positive slope of the plot of water cut versus time reveals water channelling through high permeability streaks, rise of the oil-water contact, leaks behind casing. The criteria for choosing water breakthrough mechanism [7] are given as:

- when WOR slope is positive and WOR' is positive, the reason for water production is channelling;
- when WOR slope is positive and WOR' is negative, the problem is caused by coning;
- when the WOR slope is positive linear slope and the WOR' show a horizontal line the problem is rising water oil contact.

Using the above criteria, the slopes of Figures 4.4 (a and b) satisfies the conditions for coning and channelling.

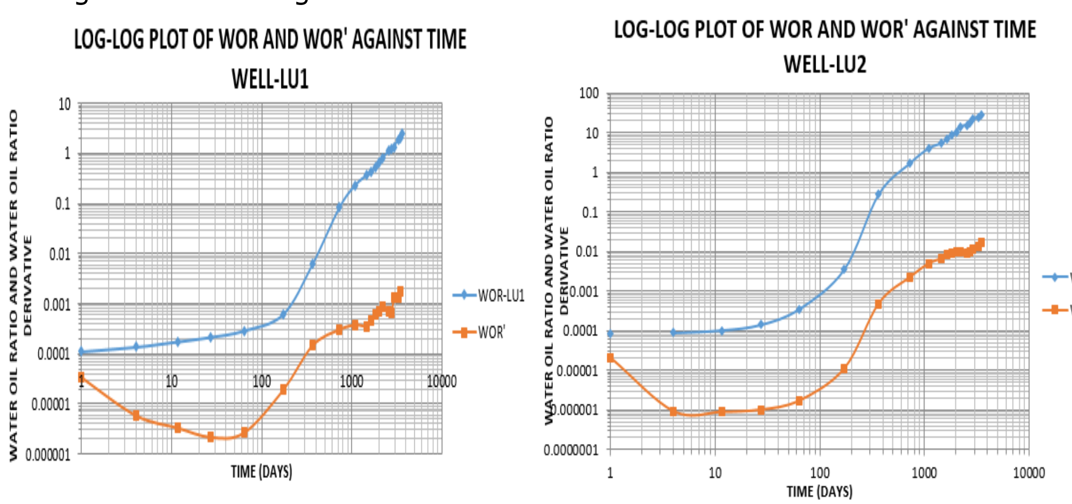


Figure 9. a) Log-log plot of water oil ratio and derivative of water oil ratio for Well LU 1 b) Log-log plot of WOR and WOR derivative for Well LU 2.

Further diagnostic analysis indicated that at the early stage of production, water conning could have resulted in early water production and at later stage water production resulted from channelling from the edge water as a result of high permeability streaks in the perforated zone. This water conning may be due to perforations near the oil-water contact, which was also confirmed by water oil ratio derivative curve (negative slope indicates conning while positive slope indicates channelling). In Well LU1the plot of WOR' indicated a negative slope followed by a positive slope. Well LU2 WOR derivative plot can be divided to three zones negative slope, horizontal line and positive slope indicating that the well experienced coning, rising water-oil contact and channelling.

5.3. Inferred solutions to identified problem

The next step is to proffer solution to the water problems. A work over operation was simulated where the initial perforations were plugged and the wells were re-completed at shallow layers. The result of the simulation shown in figure 10 gave a zero percent (0%) water cut. Re-completion was adopted as an appropriate solution for the wells. The wells are presently completed in layer 1 through layer 3.

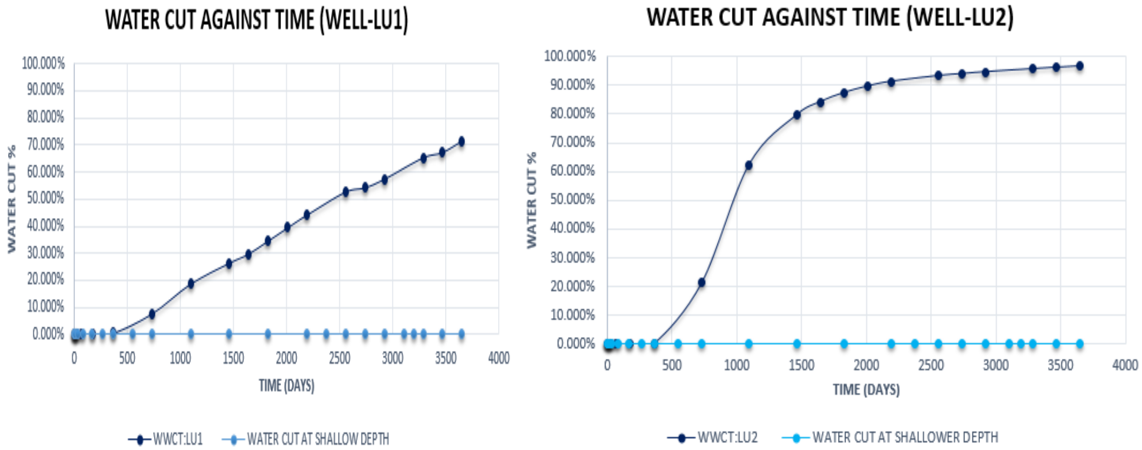


Figure 10. Water production histories of the re-completed wells

6. Conclusion

The review of Nok reservoir performance helped to identify basic problems plaguing the reservoir. The identified problems gave a better understanding of the reservoir and the steps to be taken for its development.

Based on the results and analysis of this work, the following conclusions were arrived at:

i. Well LU1and well LU2 had water cut of 71.5% and 96.6% respectively signifying excessive water production considering an economic limit of 50% water-cut.

ii. For water production problems, diagnostic plots are effective in the indication of the actual cause of excessive water production from the reservoir. This agreed with the work of Changalvaie *et al*. [7].

iii. From the diagnostic plots, the excessive water production in well LU1 and well LU2 is as a result of water conning and channelling.

iv. Based on the result of this, perforating at a shallower depth would solve the problem of excess water production in the reservoir having the same problem.

7. Recommendation

The following recommendations are presented for future research work to help improve the proposed methodology and results obtained from this study:

1. A performance evaluation and diagnosis be carried out for the case study of gas production and guidelines should be established for the mitigation of high Gas-Oil ratios.
2. There is a need to quantify the uncertainty and risk associated with the use of diagnostic plots, and this topic is proposed for further research.
3. The economic analysis of the proffered solutions should be done to evaluate its relevance to the present market and fiscal conditions.
4. There is need to use special gels in treating the perforation to reduce excessive water production.

Acknowledgment

Sincere gratitude to the Petroleum Engineering Department, Federal University of Technology, Owerri, for creating the breeding ground for this work.

References

[1] Bailey B, Crabtree M, Tyrie J, Elphick J, Kuchuk F, Romano C, Roodhart L. (2000). Water Control, Oilfield Review 12 (Spring) 30-51.

[2] Hill F, Monroe S and Mohanan R. Water Management – An Increasing Trend In The Oil and Gas Industry. presented at the SPE/EAGE European Unconventional Resources Conference and Exhibition , 20 – 22 March, 2012 Vienna Austria.

[3] Kim Amos and Crepso Freddy (2013), Excessive water production: Causes and Diagnostics, Halliburtonblog.com/excessive-water-production-causes-diagnosis soured 8th April 2017

[4] Seright RS. (1997). Improved Methods for Water Shutoff. Annual Technical Progress Report (U.S. DOE Report DOE/PC/91008-4), U.S. DOE Contract DE-AC22-94PC91008, BDM-Oklahoma Subcontract G4S60330.

[5] Kikani J, Smith TD. Recovery Optimization by Modeling Depletion and Fault Block Differential Pressures at Green Canyon 110. SPE Annual Technical Conference and Exhibition, 6-9 October 1996, Denver, Colorado, SPE-36693-MS.

[6] Chan KS. Water Control Diagnostic Plots. paper SPE 30775, SPE Annual Technical Conference and Exhibition, Dallas, October 22-25.

[7] Changalvaie AA, Lovimi K and Khaksar A. (2012). Mechanism Of Excessive Water Production In An Iraian Offshore Oilfield. presented at the 2012 International Conference on Bioscience, Biochemistry and Bioinformatics IPCBEE vol. 31 © (2012) LACIST press, Singapoore.

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