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Diagnosing High Water Production in Kalama Field, Niger Delta

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Authors' contributions

This work was carried out in collaboration between both authors. Author AJ designed and supervised the study and also wrote the article while author FJ did the research and analysis. Both authors read and approved the final manuscript.

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Case Study

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ABSTRACT

Produced water is water trapped in underground formations that is brought to the surface along with oil or gas. It is by far the largest volume by-product or waste stream associated with oil and gas production especially in brown fields. Management of produced water present challenges and costs to operations. In this paper, the possible causes, effects and solutions of high water-cut is being investigated in some production oil wells in Niger Delta, using Kalama field as a case study. Diagnostic and performance plots were developed in order to determine the source of water as well as to evaluate the impact of excess water production on oil production and in field economics in general. Results obtained from the diagnostic plots showed the possible sources of water production are channeling behind casing and multi-layered channeling. The recommended remediation is cementation through a workover operation. Also, a concise step to be taken for identifying excess water was also developed in this work to effectively control excess water production in oil producing wells.

Keywords: Water-cut; diagnostics plots; channeling; WOR.

1. INTRODUCTION

Water-cut is the ratio of produced water compared to the volume of the total hydrocarbon production from a well. For crude oil, it can be referred to as the percentage of the mass of water in association with the crude oil. Water-cut is generally expressed in percentage and it is

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usually measured by a device known as water-cut meter.

Produced water is the largest volume by-product or waste stream associated with oil and gas production [1]. Increasing volume of produce water in a field is one of the many challenges in effectively producing oilfields as it poses great threat to continued economic viability and may lead to lower production rates, reduction of recoverable reserves and premature abandonment [2,3]. Managing produced water is costly. Thus, using water control measures and conformance treatment strategies in reducing the volume of produced water has been considered as veritable measures to improving performance from oil reservoirs.

When water underlies an oil column, the phenomenon of *coning* can occur when the oil is produced. Coning is most likely to occur when a wellbore only penetrates a portion of the formation or when the perforations are placed close to the oil water contact [4]. In subsurface formations, naturally occurring rocks are generally permeated with fluids such as water, oil or gas (or some combination of these fluids). The virgin fluid in the formation is water as it occupies the small pore spaces of the reservoir thereby serving as the wetting phase in most hydrocarbon reservoirs prior to the invasion and trapping of petroleum [5]. Every stage of oilfield life is affected by water starting from exploration (the oil-water contact is a crucial factor for determining oil-in-place) through development, production, and finally to abandonment.

Some characteristics of water can help improve production if they are known readily. For example, parameters such as total dissolved solids (TDS), can help define pay zones when coupled with resistivity measurements [6]. From the produced water constituents, producers can determine the proper application of scale inhibitors and well treatment chemicals as well as identify potential wellbore or reservoir problem areas [6].

Activities like data acquisition, diagnostics using downhole sensors, production logging, and reservoir modelling to characterize flow are used to manage the cycle of water production, together with other technologies that eliminate water problems such as downhole separation and injection, chemical and mechanical shutoff, and surface water separation. Majority of water problems issues range from the one that are easily controlled like Casing leaks, tubing leaks, parker leaks, moving oil/water contact, watered out layers, and channel flow behind the casing, to the ones that are more difficult, but control is still feasible like fractures or faults between injector and producers, and fractures or faults from a water layer [7]. There are other ones that do not lend themselves to simple and inexpensive near-wellbore solutions and require completion or production changes as part of the reservoir management strategy (e.g., multilateral wells, sidetracks, coiled tubing isolation, and dual completions).

Oil producers are looking for economic ways to improve production efficiency, and water control services are proving to be one of the fastest and least costly routes to reduce operating costs and improve hydrocarbon production simultaneously. Therefore, it is important to fully understand the different mechanisms that contribute to undesired water production to better evaluate existing information, identify additional tests, and design the optimum solution to the problem.

The use of systems with inbuilt diagnostic tool helps in isolating causes and effects of challenges for complex systems to improve safety, productivity and operator's performance [8]. One notable diagnostics for water entry detection is the water-oil ratio (WOR) and its derivative (WOR') plots against time, also known as Chan plots [9]. These diagnostic plots were used to distinguish mainly water entry due to coning and channeling based on the signature of the trends.

Many investigators have extended the works of Chan, 1995. For example Al-Otaibi et al. [10] scrutinized the Chan's diagnostic plots with production logs (PLT) and pressure transient analysis (PTA) to gain better insight into water entry through fractures in carbonate reservoirs. Cinar et al. [11] developed an automated workflow to diagnose and evaluate water production signatures for a mix of vertical and lateral wells in carbonate reservoirs under water-flooding for rate optimization, remedial intervention planning and reservoir description. This work investigates the possible causes and solutions to the high water cut production problems in oil wells using Kalama field in Niger Delta as a case study.

1.1 Description of Kalama Wells

Kalama field is a mature oilfield discovered in 1972, and is located in the Northern fringe of the

Niger Delta in OML 40 some 92 KM North-west of Warri. To date, seven wells have been drilled in this field. Kalama well 3S and 3L is owned by the Nigerian Petroleum Development Company (NPDC). The wells used in this study were selected owing to their high percentage of water cut and will be examined to determine reasons for the high water-cut.

Kalama 3S commenced production in August 1975 from two sand units; upper and lower sand units. Initial production rates were relatively stable at 2100 stb/d until water breakthrough in July 1977. Thereafter the oil rate declined relatively rapidly with water cut increasing to 82% by December 1981 when the well was shut in for a workover. After the workover (perforations squeezed off and re-perforated 15ft higher in same upper sand unit), the well was brought back on stream in June 1984. Water breakthrough occurred within 6 months following the workover and then increased to 80% by 1988 at which time the water cut remained relatively stable throughout the well life until 2006. The average oil rate during this period was about 400stb/d. At the time the field was closed in February 2006, the total production from this interval was 4.89MMstb. The well was re-opened for production in 2014 and is currently producing 1,624BLPD with a water cut of 34%

Key observations with respect to the production history for the wells include:

- Significant reduction in well productivity after the workover in 1981; this has been attributed to formation damage associated with workover fluid losses to the reservoir. It was however noted that an unsuccessful sand consolidation treatment was also attempted in the well which may have contributed to lower well productivity post-workover.
- Potential re-pressurisation and reduction in water coning post shut-in second quarter of 2003.
- Gas and water metering issues, particularly during low production rate periods, seem to have occurred throughout well life. This was an issue that was considered for all allocated liquid and gas rates in historical Kalama production histories.

Kalama 3L, E2 reservoir commenced production at the end of 1975 after an initial workover prior to start up due to a blockage in the tubing. The average oil rate for the well was approximately 1000 stb/d; however, it was observed that production was characterised by high GOR and the well was progressively brought back throughout the production life (flowing tubing head pressures increased from 1,400 to over 2000 Psig).

A workover was conducted in 1981 due to high gas production (producing GOR approx. 4 times Rsi) and the E2 reservoir was perforated deeper within the main channels sections. After the workover, production continued at 1000 stb/d with gas breakthrough controlled by progressive bean back of the well. From 1988 the GOR began to increase rapidly indicating breakthrough from the gas cap and the final producing GOR was 5000 scf/stb (approx 5 times Rsi) at the end of 1991. Initial completion of the D1 reservoir occurred during the workover in 1981. At that time, a sand consolidation (SCON) treatment was attempted but was aborted due to low injectivity of the chemical treatment.

The zone remained closed in behind a sliding sleeve up until February 1995 when the E2000 reservoir was isolated. Initial oil production rates were 800 stb/d with an average producing GOR of 300 scf/stb. Following a 3-month shut-in from September 1998, productivity appears to be significantly higher with liquid production rates of 2,000 stb/d. No detailed production records are available for this period so it is unclear whether this was related to a lower flowing tubing head pressure (not noted in allocated production data) or a workover to improve production performance.

Water breakthrough occurred in June 2000 and the water cut increased to 80% in 2006 when the well was shut in. The potential increase in producing GOR up to 3x Rsi at the end of well life is considered suspect and may be associated with metering issues at relatively low oil production rates. Wireline access for pressure gradient surveys on both the long and short strings in 2005 and 2006 respectively indicates, at least at that time, that there is reservoir access and that the tubing strings are not plugged with solids or scale.

Cumulative production from the D1 interval in Kalama-3L was about 3.42 MMstb at the time the field was closed in (2006). Final oil production rate was 560 stb/d with a water-cut of 78%. The well was re-opened for production in 2014 and is currently producing 1,248blpd with water cut of

86%. In this work, measures have been developed to investigate the reasons for the high water cut and the reemergence of high water cut after intervention.

2. MATERIALS AND METHODS

2.1 Evaluation of Water Production Mechanisms

Evaluation of water production mechanism is a very important component of identifying the source of water. The step outlined in this study may not necessarily apply to all reservoirs since reservoirs have their unique features and peculiarities, however may serve as a useful guide. The steps are as follows:

i. This work flow starts with the evaluation of the historical geological and reservoir properties and geologic data history (petrophysical properties).
ii. The next step is the gathering of production data of the reservoir.
iii. Thereafter, performance evaluation of the reservoir production data is done in other to ascertain whether there is excess water production or not.
iv. For cases where there is excess water production, diagnostic plots are generated to determine the source of water and then, help proffer possible solution. But, if there is no excess water production, constant monitoring of the produced effluents from all the wells connected to the reservoir continues.
v. Going further with the diagnostic plots (if excess water production exists), inferences will be drawn based on the signatures from the diagnostic plots. From the diagnosis with the help of production logs, one can infer if the problem is mechanically induced or not. For mechanically induced problems, a sonic tool can be deployed to detect any possible leakage on the casing or poor cementing job. Sonic tools are wire line tools used mainly for evaluation. It is used to evaluate the state of the set cement. A leaky casing close to a water zone can be detected and an effective treatment administered. Most mechanical problem are casing related. That is, either a casing with compromised integrity or a poor cementing job. These usually require remedial cement job like squeeze cementing to shut off the zone or a change of the casing in question. This can serve as treatment of the mechanical problem in question.
vi. However, where the problem is not mechanically induced, further diagnostic plots are developed focusing on the reservoir itself to determine if there is channeling or coning.

These outlined steps above are repeated on regular basis and they are not streamlined to any particular reservoir. Style and approach depend on the petrophysical properties of the reservoir. Prior to the necessary treatment and even after the treatment, it is a good management practice to continue monitoring the reservoir performance. This will help to determine if the reservoir is producing as required or if a necessary treatment has improved the reservoir performance.

2.2 Field Production Performance Evaluation

This entails historical plots to ascertain the health status of wells using production data. From these plots, historical trends of pressure, oil, gas and water production rates against time can be visualized. More so, the water-cut, water-oil ratio and cumulative production rates can also be made to know if actually there is persistent increase in water production and if the excess water production is contributing to a shortfall in the production of hydrocarbon. The water-oil ratio and water-cut are estimated using:

Water-oil-ratio (WOR)

$$\mathrm{WOR} = \frac{\text{Water rate}}{\text{Oil rate}} = \frac{\mathrm{qw}}{\mathrm{qo}} \quad (1)$$

Water cut

$$\mathrm{f}_w = \frac{\text{Water rate, qw}}{\text{Total liquid rate}} = \frac{\mathrm{qw}}{\mathrm{qw+qo}} \quad (2)$$

$$f_w = \frac{\mathrm{WOR}}{\mathrm{WOR+1}} \quad (3)$$

2.3 Field Production Data Diagnostic Plots

To ascertain the water entry points, and mechanism of water production from the reservoir to the well, diagnostic plots are inevitable. Diagnostic plots are used to gain understanding of the physics behind the water entry process. Diagnostic plots used for the analysis are:

1. The log - log plot of water oil ratio with time.
2. The log - log plot of water oil ratio derivative with time.

The WOR and the WOR derivative (WOR′) plots are used in combination to diagnose the reservoir related water production mechanism prevailing in the reservoir. An upward sloping of the WOR plot with time indicates increased water production, an upward sloping of the WOR derivative indicates multi-layer channeling while a downward sloping indicates water coning [9,12,13]. Central difference first order derivative was used to obtain WOR' because it yields a more accurate approximation. A diagnostic log-log plot of WOR versus time can be used to help determine the specific problem type by making comparisons with known reservoir behaviors. Three basic signatures distinguish between different water breakthrough mechanisms; open flow through faults, fractures, or channel flow behind casing; edge water flow or a moving OWC; and coning problems.

3. RESULTS AND DISCUSSION

3.1 Evaluation of Well 3S in Kalama Field

Oil and water rates from well 3S in Kalama field are shown in Figs. 1 and 2. Fig. 1 is a plot of cumulative production against oil and water rates while Fig. 2 is a performance plot of oil and water rates against time. From Figs. 1 and 2, it is obvious that well 3s experienced high water-cut at different times during its productive periods which has led to a reduction in oil production.

Fig. 3 shows diagnostic plots of water-oil ratio (WOR) and WOR derivatives (WOR') against time. The upward sloping is an indication and confirmation that channeling behind casing is the cause of high water-cut in Well 3S. The major cause of channeling behind casing is compromised cementing/casing bond [14]. This can be remedied with a workover operation that could seal off the leak behind casing to provide more formation-casing integrity.

3.2 Evaluation of Well 3L in Kalama Field

The performance plots for Well 3L in Kalama field are shown in Figs. 4 and 5. Unlike Well 3S, water breakthrough in Well 3L is delayed and much less compared to well 3S. From Fig. 5, it can be seen that it took more than 7 months before the emergence of water breakthrough. Moreover, well 3L was producing at a good condition with more oil production than water production. This water production represents 34% of gross production. From the company standard, any well that has gross production of more than 30% water production is considered a high water producer. So, there is great concern on this well because the current water production will keep increasing and will eventually get to a point where water rate will be higher than oil rate.

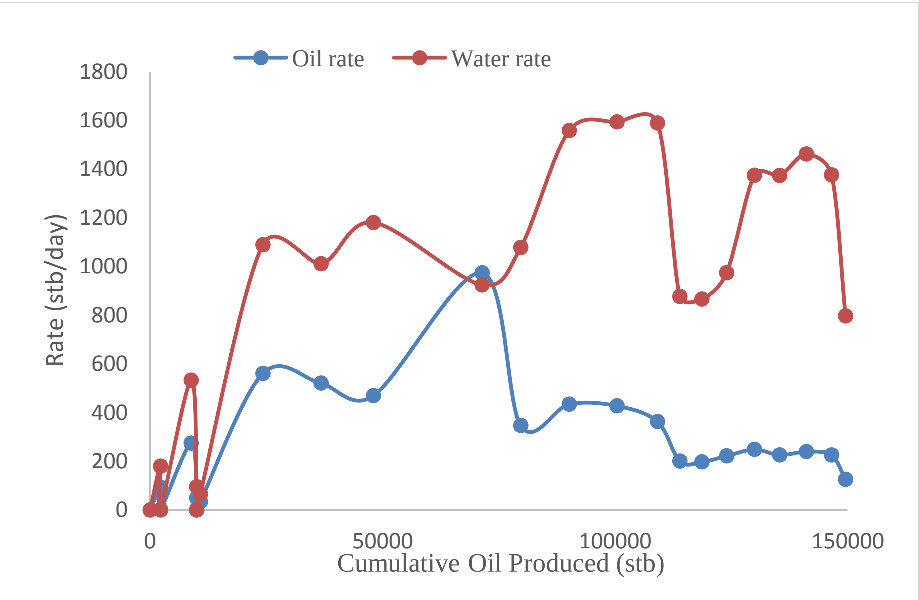

Fig. 1. Oil and water Rates Production against Cumulative Oil Production (Well 3S)

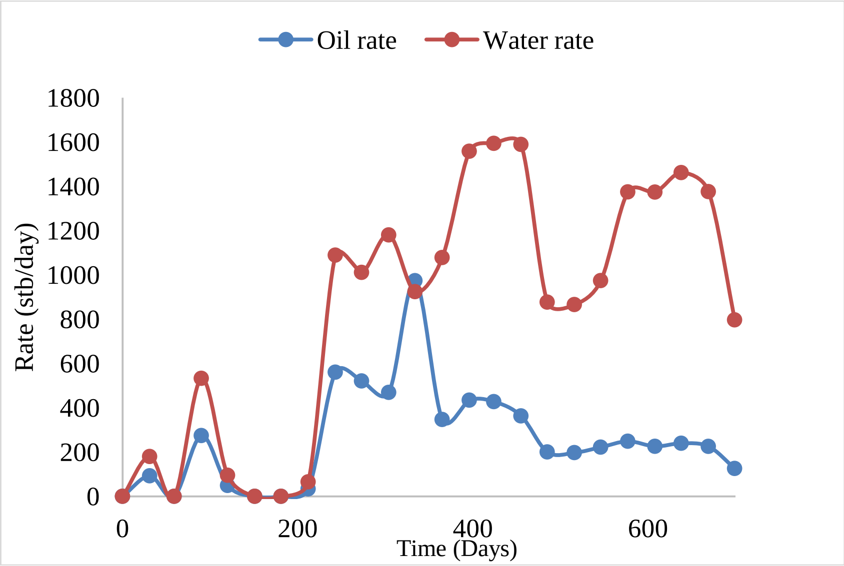

Fig. 1. Oil and water rates production against time (Well 3S)

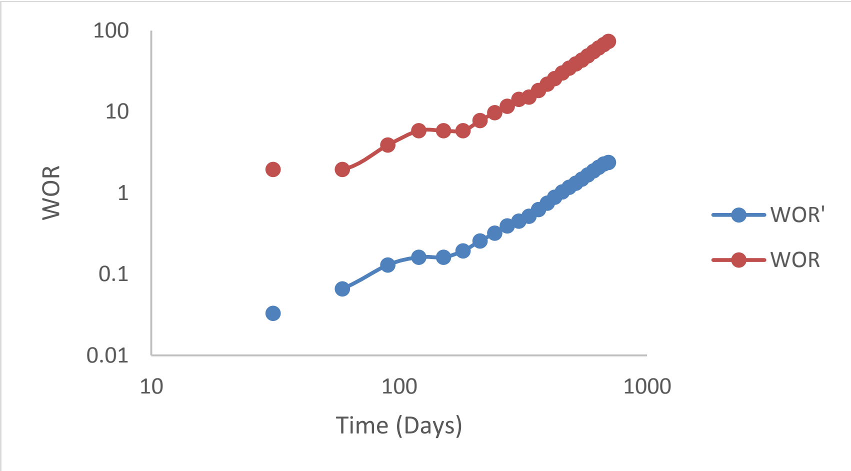

Fig. 3. Log-log plot of WOR and WOR Derivative against Time. (Well 3S)

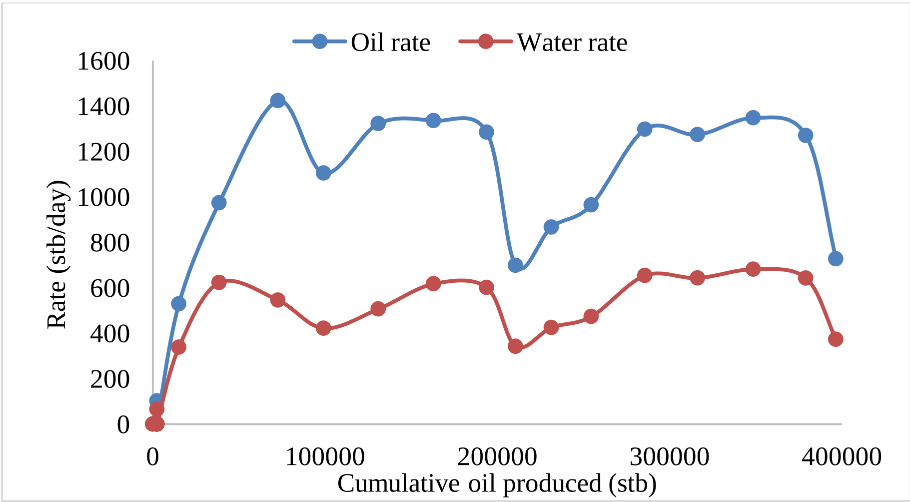

Fig. 4. Oil and water rates production against cumulative oil production. (Well 3L)

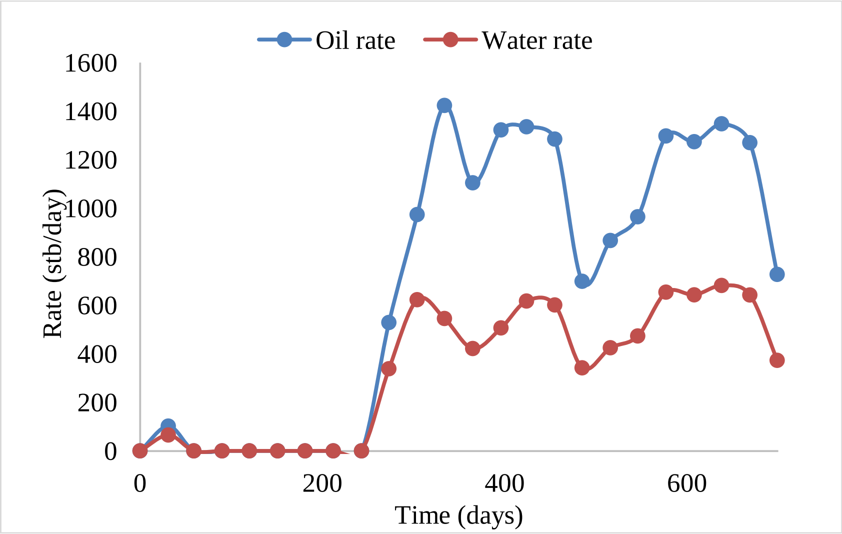

Fig. 5. Oil and water rates production against time. (Well 3L)

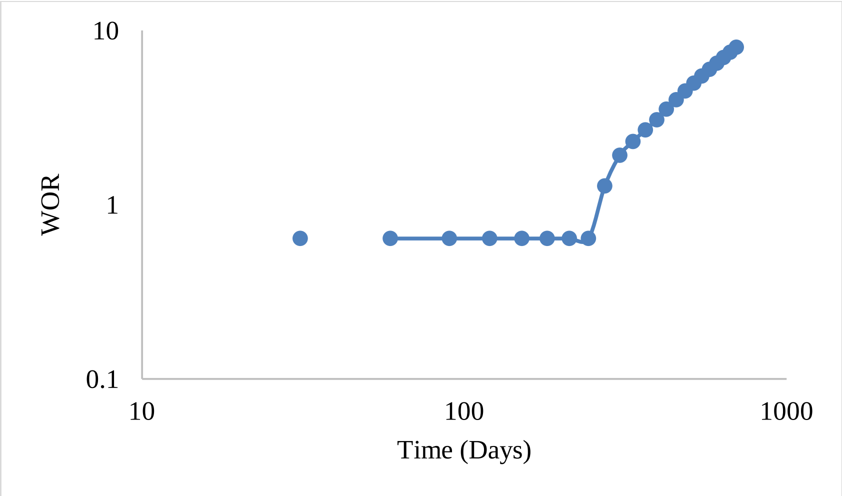

Fig. 6. Log-Log Plot of WOR against time showing multilayer channeling (Well 3L)

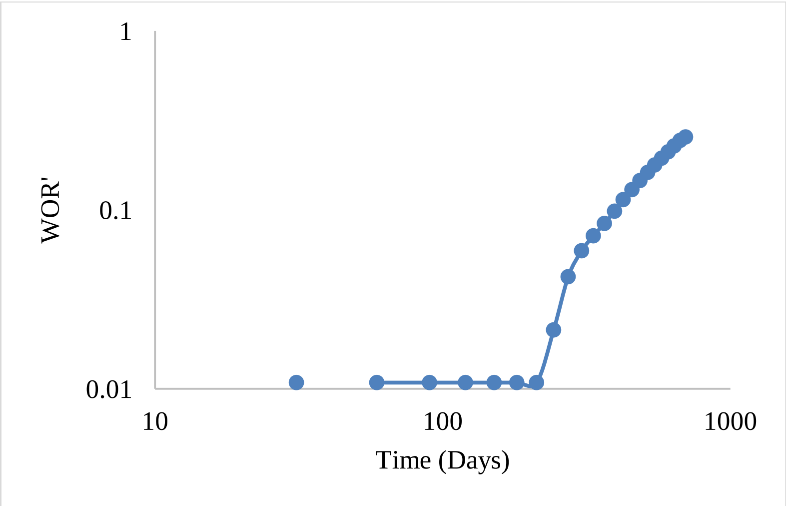

Fig. 7. Log-Log Plot of WOR Derivative against Time Showing Multilayer Channeling (Well 3L)

The diagnostics plots of WOR and WOR' against time are shown in Figs. 6 and 7. Obviously, the cause of the increasing water production is multilayer channeling.

4. CONCLUSION

This work investigates the main sources of high water-cut in two wells, Wells 3S and 3L in Kalama field of Niger Delta. Performance plots were made to investigate the historical trend of water production while diagnostic plots were used to determine the mechanism of water incursion in the wellbore. From the performance plots it was clear that indeed both wells are producing high at high water cut, and thus have a tendency of threatening oil production. Whereas, from the diagnostic plot, it was ascertained that channeling behind casing and multi-layer channeling is the root cause of the high water-cut problems in wells 3S and 3L. A remedial workover operation for cementation is strongly recommended to solve this high water-cut problems in Wells 3S and 3L wells.

DISCLAIMER

The data used for this investigation have been processed and very sensitive information expunged from the manuscript for confidentiality purposes to prevent conflict of interest. There is absolutely no conflict of interest between the authors and NPDC because we do not intend to use these data as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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