

A Comparative Analysis of the Well Performance of Vertical, Horizontal and Multilateral Wells

Ameena A. Gaji, Petrus Nzerem, Oghenerume Ogolo*, Ikechukwu Okafor, Ternenge Joseph Chior

Department of Petroleum and Gas Engineering, Nile University of Nigeria, Abuja, Nigeria

Received October 24, 2019; Accepted December 29, 2019

Abstract

The demand for energy in the world has been ever increasing. Conventional technologies are being replaced gradually by different new technologies. Horizontal wells and multilateral wells have proved to be highly beneficial by improving production rates significantly. This study focuses on investigating the well performance of vertical well (Well V), horizontal well (Well H), and multilateral well (Well M) in the Hurricane field using PROSPER software. PVT matching, well modelling and well performance analysis was carried out. Sensitivity analysis was performed on key parameters such as tubing diameter, water cut, wellhead pressure and tubing roughness to determine their effects on well productivity. It was observed that increasing the water cut decreased the production rates of Well V, Well H and Well M by 41%, 36.1% and 33.5% respectively. An increase in the tubing diameter improved the production rates, wellhead pressure had high impacts on the well performance while tubing roughness had a minimal effect on oil production. The optimum production rates of 21,622.5 STB/day, 28,653.6 STB/day and 29,800.9 STB/day for Well V, Well H and Well M respectively were achieved at reservoir pressure of 3500 psig, wellhead pressure of 400 psig, water cut of 5% and a 5.5 inches tubing diameter.

Keywords: Sensitivity analysis; Inflow performance relationship; Multilateral wells; Horizontal well; PROSPER software; Well performance.

1. Introduction

As the oil and gas industry is moving away from conventional reservoirs towards unconventional reservoirs, traditional vertical wells may not be the most effective medium of maximizing hydrocarbon recovery in challenging zones such as; tight reservoirs, compartmentalized reservoirs, layered formations, marginal fields, etc [1-4].

However, each reservoir has unique conditions; therefore, horizontal or multilateral wells may not be also necessarily ideal for effective drainage of a reservoir [5].

Thus, the significance of this study is to aid engineers in decision-making on whether to drill and complete a well by conventional methods or more sophisticated configurations such as drilling of horizontal, multilateral wells, etc. while maximizing recovery, and also to understand the effects of productivity indicators such as tubing size, wellhead pressure, water cut etc. in production optimization process.

Fossil fuels such as coal, petroleum, and natural gas account for 81% of global energy consumption [6]. This percentage will change over time as experts believe the annual supply of oil and gas is gradually declining as the global appetite for energy increases due to population growth and industrialization [6].

Historically, oil and gas exploration involved conventional methods such as vertical drilling, which is less expensive and complicated when compared to well types such as horizontal and multilateral wells [7]. However, production rates of prolific oil and gas reserves are drastically declining. This has led the petroleum industry to improve the productivity of wells by discovering new technologies that can increase well deliverability while reducing costs. Development

of new technologies such as horizontal wells, multilateral well completion and hydraulic fracturing has proven to create a sustainable development of fields which is of utmost concern to oil and gas companies today [2-3].

This research work was aimed at investigating and comparing the production rates of a vertical well (Well V), horizontal well (Well H), and multilateral well (Well M) in order to aid engineers in the decision making the process of maximizing production from a reservoir [8]. This was achieved by simulating the well performance of the different well configurations using PROSPER software.

2. Methodology

The methodology presented in this study was designed to assist engineers in the decision making process. PROSPER (Production and System Performance) software was used in this study. The software assists reservoir engineers in predicting the tubing and pipeline hydraulics and temperature with much accuracy, conducting sensitivity analysis to understand the effects of future changes in system parameters for production optimization etc. This study was done using three wells named Well V, Well H and Well M in the Hurricane field located in Tulsa County, Oklahoma. Well V is a vertical well, Well H is a horizontal well and Well M is a multi-lateral well (Dual lateral). The sandstone reservoir produces under-saturated oil with API gravity of 25 and a solution gas oil ratio (GOR) of 400 Scf/Stb. The specific gas gravity is 0.75 and the aquifer salinity is 80,000 ppm. The black oil PVT model was used and the *Glaso* correlation was selected for bubble point pressure (P_b), solution gas oil ratio (R_s) and oil formation volume factor (B_o) while Beal et al. correlation were selected for oil viscosity. The data used in this study was adapted from literature [9-10] and relevant data are given in Table 1. All calculations were done with PROSPER (Version 11.5). The main PROSPER window is divided into the five major sections as seen in Figure 1.

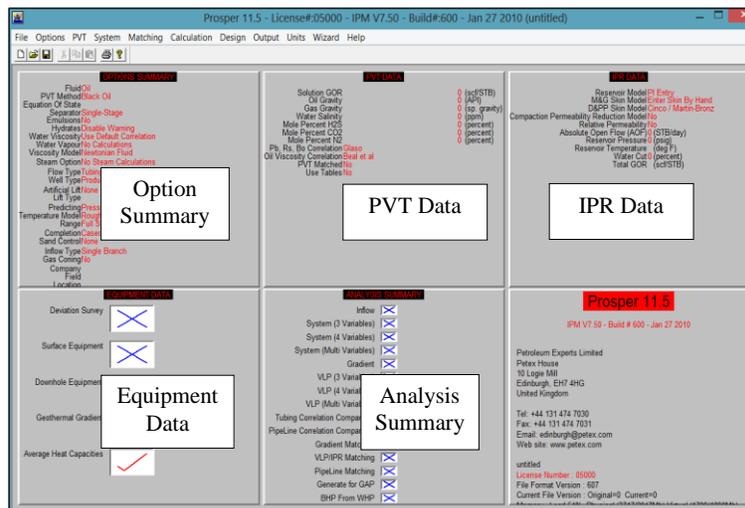


Figure 1. PROSPER Window showing the various sections

Table 1. Fluid and reservoir properties

Parameters	Values	Parameters	Values
Fluid type	Oil and water	Water salinity (ppm)	80,000
Fluid method	Black oil	Impurities (CO ₂ , N ₂ , H ₂ S)	None
Reservoir inflow type	Single branch	Reservoir permeability (md)	100
Reservoir pressure (psig)	3500	Reservoir thickness (ft.)	500
Bubble point pressure (psig)	2500	Oil gravity (^o API)	25
Reservoir temperature (^o F)	200	IPR method	Darcy
Solution gas-oil ratio (scf/STB)	400	Wellbore radius (ft.)	0.354
Oil gravity (API)	25	Drainage area (acres)	574
Gas gravity	0.75		

2.1. Sensitivity analysis

For an effective optimization of a system, there is a need to carry out sensitivity analysis on the key parameters affecting the productivity of the wells [11]. In this study, four parameters were used for sensitivity analysis in PROSPER. These were: water cut, tubing roughness, tubing diameter and wellhead pressure.

A range of tubing roughness (0.0006 in., 0.0015 in. and 0.004 in.) was selected. The wellhead pressure, water cut, reservoir pressure, and fluid properties were kept constant while varying the tubing roughness. For each tubing roughness, the bottom hole pressure and production rate were recorded at the node.

This method was used to construct different sensitivity plots for the three wells considered in this study. The same procedure was carried out for water cut, wellhead pressure and tubing diameter. Table 2 shows the parameter ranges for the sensitivity analysis

Table 2. Sensitivity parameter ranges

Parameter	Ranges	Parameter	Ranges
Tubing diameter (inches)	4.0 – 6.0	Water cut (%)	5 – 30
Wellhead pressure (psig)	400 – 800	Tubing roughness (inches)	0.0006 – 0.004

3. Results and discussion

3.1. Well performance curves

An IPR curve represents the behavior of a reservoir in producing oil through the well [12]. It is a plot of production rate versus bottom hole pressure. From the IPR-VLP curves in Figures 2, 3 and 4, the point of intersection of the inflow and outflow curves indicates the operating point (solution point) of the well. Therefore, the production rates for Well V, Well H and Well M were 15,586 STB/day, 19,120 STB/day and 29,658.6 STB/day respectively. Well M has a greater production rate due to the wide extent covered by the laterals. While other system solution results were given in Table 3.

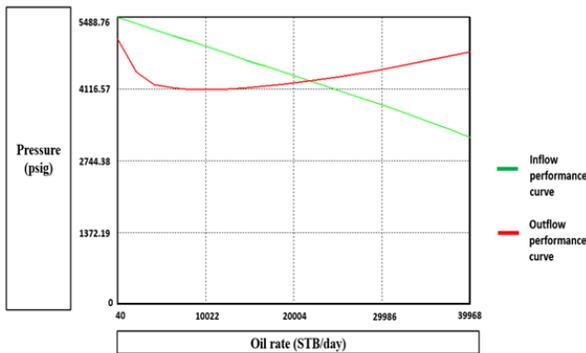


Figure 2. IPR-VLP curve of Well V

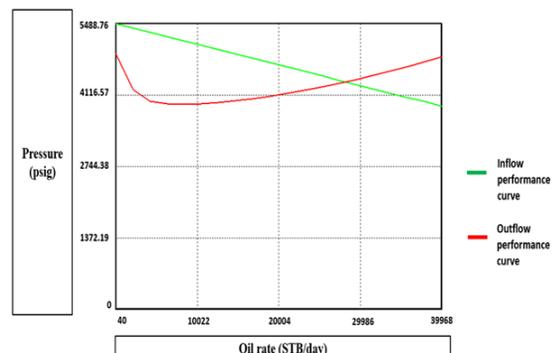


Figure 3. IPR-VLP curve of Well H

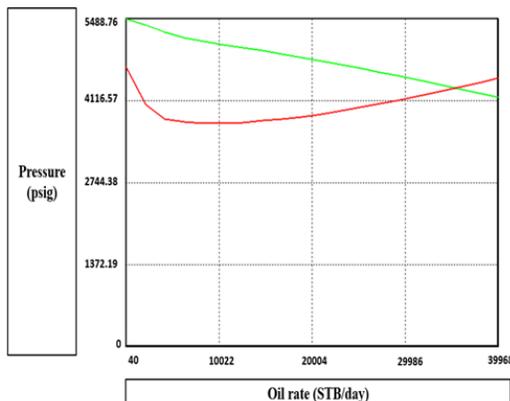


Figure 4. IPR-VLP curve of Well M

Table 3. System capacity for the three wells

Parameters	Well V	Well H	Well M
Liquid/Oil rate (STB/day)	15 586	19 120	29 658.6
Water rate (STB/day)	0	0	0
Gas rate (MM scf/day)	6.234	7.648	11.863
Solution node pressure (psi)	2 943.67	3 121.49	2 831.19

3.2. Sensitivity analysis results

Sensitivity analysis of four parameters was carried out to investigate their effect on the production rate as well as the well performance of Well V, Well H and Well M. The parameters considered include tubing diameter, wellhead pressure, water cut and tubing roughness.

3.2.1. Effect of tubing diameter

In a sensitivity analysis of tubing diameter, two cases were investigated. Case 1 involved varying tubing diameter at constant reservoir pressure of 3500 psig and Case 2 which involved varying tubing diameter at different reservoir pressures.

3.2.1.1. Case 1- Effect of tubing diameter at constant reservoir pressure

To investigate the effect of tubing diameter on the performance of the wells, a sensitivity analysis was run by varying the tubing diameter from 4.0 in. to 6.0 in. keeping all other parameters constant. The results for the three wells were tabulated in Table 4. It is observed from Table 4 that tubing diameters of 4.0 in., 4.5 in., 5.5 in. and 6.0 in. produced high oil rates as a function of tubing diameter. This indicates that increasing the tubing diameter increases the production rate. This is true because increasing tubing diameter decreases the friction losses which lowers the bottom hole pressure and increases production rate.

However, as the tubing size is further increased, the well begins loading with liquid, and the flow becomes unstable. The liquid level builds up and the well eventually depletes. Furthermore, when tubing diameters are small, excessive friction losses are experienced as a result of resistance to flow which increases the pressure drawdown and decreases the production rate.

Table 4. Production rates at different tubing diameters

Tubing diameter (inches)	Production rate (STB/day)		
	Well V	Well H	Well M
4.0	12 853.3	14 930.5	11 565.3
4.5	15 586.0	19 120.0	19 428.3
5.5	20 154.5	27 711.8	29 658.6
6.0	21 858.4	31 766.9	32 981.7

3.2.1.2. CASE 2- Effect of tubing diameter at varying reservoir pressure

Sensitivity analysis was run by varying the tubing diameter from 4.0 in. to 6.0 in. and reservoir pressure from 2500 psig to 3700 psig keeping all other parameters constant. The results for the three wells are seen in Figures 5 to 7.

It is observed that at reservoir pressures below 3000 psig, the wells would not produce even when the tubing diameter is increased from 4.0 in. to 6.0 in. Therefore, an increase in the tubing diameter results in an increase in production rate only if the reservoir pressure is high enough. Considering reservoir pressure depletion from 3500 psig to 3000 psig, tubing diameter of 5.5 in. was suggested as the optimum tubing diameter because it has a lower rate drop with depletion in reservoir pressure. The optimum oil rates were 20,154.5 STB/day, 27,711.8 STB/day and 29,658.6STB/day for Well V, Well H and Well M respectively. Even though, tubing diameter of 6.0 in. seems to produce at a slightly higher rate than 5.5 in. tubing, this slight increase of 7.8% in oil rates was considered minimal as the cost of production is almost the same as using a 5.5 in. tubing.

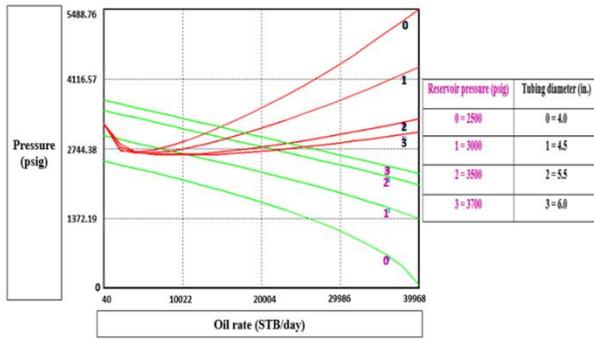


Figure 5. Well performance at varying tubing diameter and reservoir pressure-Well V

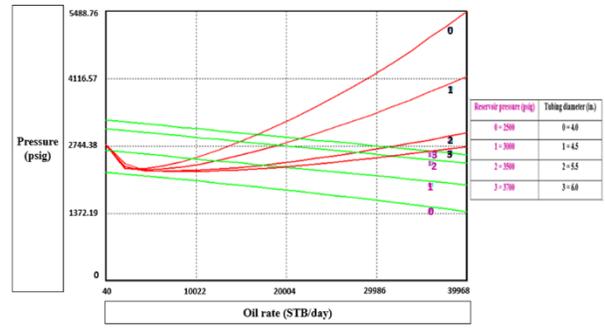


Figure 6. Well performance at varying tubing diameter and reservoir pressure-Well H

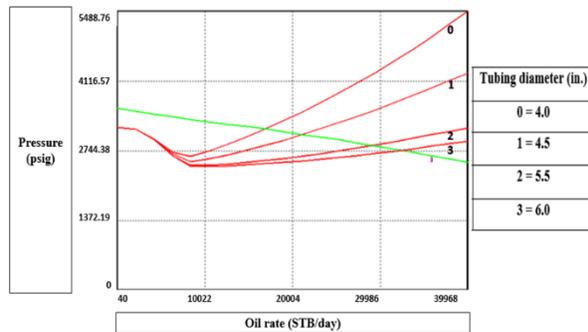


Figure 7. Well performance at varying tubing diameter and reservoir pressure-Well M

3.2.2. Effect of wellhead pressure (WHP)

Similarly, in the sensitivity analysis of wellhead pressure, two cases were also investigated. Case 1, which involved varying wellhead pressure at constant reservoir pressure of 3500 psig and Case 2, which involved varying wellhead pressure at different reservoir pressures.

3.2.2.1. Case 1- Effect of wellhead pressure at constant reservoir pressure

Sensitivity analysis was carried out on the flowing wellhead pressure (WHP) to investigate the effect of wellhead pressure on the production rate. Figure 8 shows the three well types varied at three different wellhead pressures of 400 psig, 600 psig, and 800 psig with a 5.5 in. tubing diameter and reservoir pressure of 3500 psi.

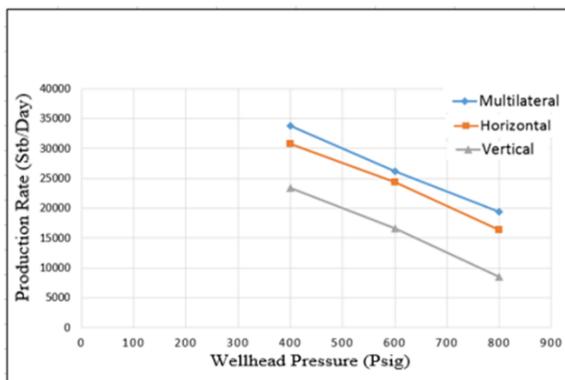


Figure 8. Well performance at varying wellhead pressures for the three wells

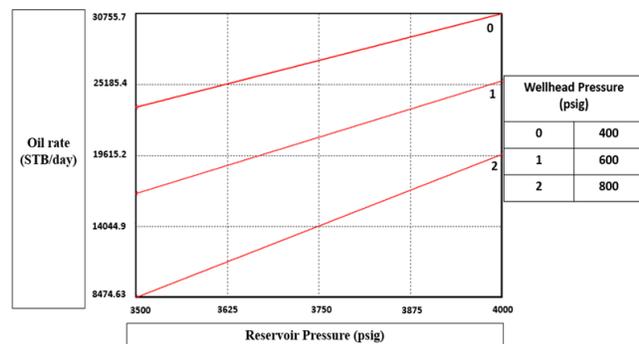


Figure 9. Sensitivity plot at varying wellhead pressure and reservoir pressure-Well V

It is observed that when the wellhead pressure was decreased from 800 psig to 400 psig, the liquid production rate increases. This is because reducing the wellhead pressure results in an increase in pressure drawdown which consequently increases the production rate.

Wellhead pressure can be adjusted in different ways, such as changing the choke size, surface pressure, and flow line. Therefore, the optimum oil rates obtained were 23,423.9 STB/day, 30,780.4 STB/day and 31,845.6 STB/day for Well V, Well H and Well M respectively.

3.2.2.2. CASE 2- Effect of wellhead pressure at varying reservoir pressure

Figures 9, 10, and 11 are sensitivity plots of Well V, Well H and Well M respectively. At a reservoir pressure of 3500 psig and WHP of 400 psig, the production rate of Well V was 23,423.9 STB/day, Well H was 30,780.4 STB/day and Well M was 31,845.6 STB/day.

When the reservoir pressure and WHP were increased to 400 psig and 800 psig, respectively, the production rates for the three wells declined. It is observed that decreasing the WHP increases the production rate resulting in a better well performance irrespective of increasing the reservoir pressure.

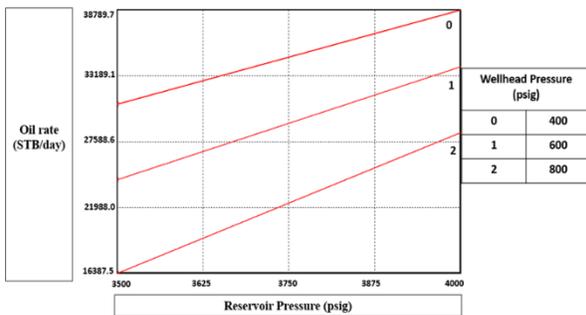


Figure 10. Sensitivity plot at varying wellhead pressure and reservoir pressure-Well H

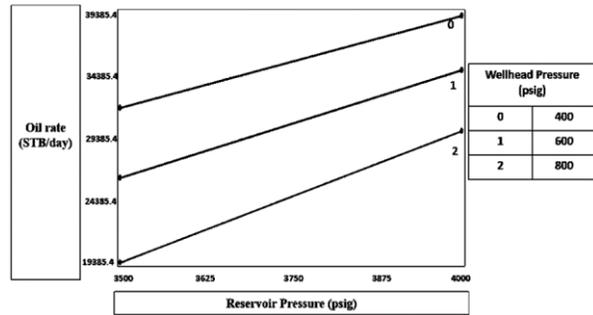


Figure 11. Sensitivity plot at varying wellhead pressure and reservoir pressure-Well M

3.2.3. Effect of water cut

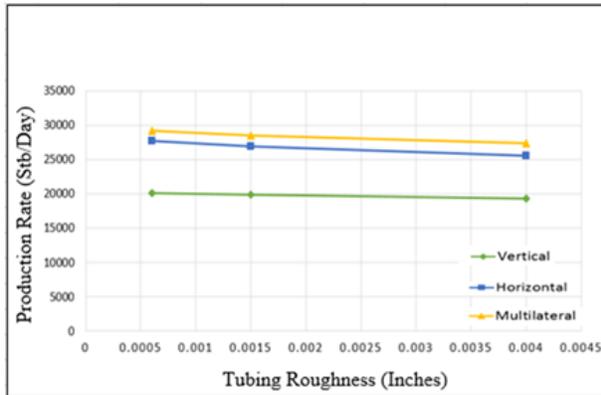
At a wellhead pressure of 400 psig, 5.5 in. tubing diameter and reservoir pressure of 3500 psi, while keeping all other parameters constant, sensitivity analysis was run on four different values of water cut 5%, 20%, 25%, and 30% to investigate their effect on the IPR and VLP curves of Well V, Well H and Well M. The effect of water cut on production rates is given in Table 6. It is observed that when water cut increases from 5% to 30%, the production declines by 41%, 36.1% and 33.5% for the three wells respectively. Therefore, high water production will increase the hydrostatic pressure loss (between the reservoir and the surface); consequently, greater reservoir energy is needed to lift the reservoir fluids to the surface. Furthermore, the production of water at any stage of the well irrespective of the percentage also contributes adversely to the decline in the oil production rate [13].

Table 6. Production rates at varying water cut

Water cut (%)	Production rates (STB/day)		
	Well V	Well H	Well M
5	21 622.5	28 653.6	29 800.9
20	16 191.0	22 327.6	23 630.3
25	14 477.1	20 309.2	21 544.6
30	12 747.1	18 316.7	19 814.2
Production decline	41%	36.1%	33.5%

3.2.4. Effect of tubing roughness

Three different tubing roughness values were considered for the sensitivity analysis to study their effect on well performance. The sensitivity results for the tubing roughness values (0.0006 in., 0.0015 in. and 0.0040 in.) are shown in Figure 12. From Figure 12, it was observed that when tubing roughness was increased from 0.0006 in. to 0.004 in. the production rate for the three wells decreased by 4.4%, 7.7%, and 2.3% respectively. Generally, an



increment in tubing roughness reduces the production rate which increases the frictional loss in the tubing string.

Figure 12. Well performance at varying tubing roughness for the three wells

4. Conclusion

The performance of three different wells configurations was analyzed and investigated using PROSPER software. From the results of this study, the following conclusions were made.

The initial production capacity for Well V, Well H, and Well M were 15,586 STB/day, 19,120 STB/day and 29,658.6 STB/day respectively. Well M has a higher production rate due to its high reservoir contact.

Sensitivity analysis for different parameters such as tubing size, wellhead pressure, water cut, and tubing roughness was conducted to investigate their effects on production rates and well performance. From the sensitivity analysis, the following was observed for Well V, Well H and Well M:

- The effect of changing the tubing diameter was significant in the well performance and increasing the tubing diameter from 4.0 in. to 6.0 in. increased the production rate by 41.2%, 52.9% and 64.9% respectively.
- Increasing the water cut from 5% to 30% decreased the production rate by 41%, 36.1% and 33.5% respectively.
- Increasing the tubing roughness from 0.006 in. to 0.004 in. decreased the oil rate by 4.4%, 7.7%, and 2.3% respectively.
- Decreasing the wellhead pressure from 800 psig to 400 psig, increased the production rate from 8,474.6 STB/day to 23,423.9 STB/day for Well V, 16,387.5 STB/day to 30,780.4 STB/day for Well H and 19,385.4 STB/day to 33,845.6 STB/day for Well M.

The major objective of investigating the effect of these parameters on well production was to detect their contribution to changing a well's production. Parameters with a significant effect on production such as tubing size, water cut and wellhead pressure were optimized while tubing roughness was neglected because of its minimal effect on oil production. This saves more time and effort into the optimization process.

Based on well performance conducted using PROSPER on the different well types, there was a production advantage for the multilateral well in relation to the horizontal and vertical wells. The production rate of Well M is 1.6 times more than Well H and 1.9 times more than Well V.

References

- [1] Keim SA, Luxbacher KD, Karmis M. A numerical study on optimization of multilateral horizontal wellbore patterns for coalbed methane production in Southern Shanxi Province, China. *International Journal of Coal Geology*, 2011; 86(4): 306–317.
- [2] Lyu Z, Song X, Geng L, Li G. Optimization of multilateral well configuration in fractured reservoirs. *Journal of Petroleum Science and Engineering*, 2019; 172: 1153–1164.
- [3] Pan Z, Connell L, Shangzhi M, Sander R, Camilleri M, Downa DI, Carrasa J, Lua M, Xiaokang F, Wenzhong Z, Benguang G, Jianping Y, Briggs C, Lupton N. CO₂ Injectivity in a Multi-lateral Horizontal Well in a Low Permeability Coal Seam: Results from a Field Trial. *Energy Procedia*, 2013; 37: 5834–5841.

- [4] Shadizadeh SR, Kargarpour MA, Zoveidavianpoor M. Modelling of Inflow Well Performance of Multilateral Wells: Employing the Concept of Well Interference and the Joshi's Expression. Iran. J. Chem. Chem. Eng. 2011; 30(1):119-133.
- [5] Dulce MA. Technical, Economic and Risk Analysis of Multilateral Wells. Master's Thesis, Petroleum Engineering, Texas A&M University, 2008.
- [6] Alley RB, Blumsack S, Bice D. Global Energy Sources. In Earth 104: Energy and Environment. Penn's State College of Earth and Mineral Sciences, 2010.
- [7] Elyasi S. Assessment and evaluation of degree of multilateral well's performance for determination of their role in oil recovery at a fractured reservoir in Iran. Egyptian Journal of Petroleum, 2016; 25(1): 1-14.
- [8] Yanping Z, Rongquan R, Hui W, Jun W. Multilateral drilling & completion technology based on Solid Expandable Tubular fixing system. Petroleum Exploration and Development, 2009; 36(6): 768-775.
- [9] Fidan S. Reservoir and Production Management of Hurricane Field. Tulsa: University of Tulsa, 2012.
- [10] Petroleum Experts. PROSPER User Manual. Edinburgh, Scotland, 2009
- [11] Okotie S, Ikporo S, Oveuma A. Gas Lift Technique a Tool to Production Optimization. International Journal of Oil, Gas and Coal Engineering, 2015; 41-46.
- [12] Lyons WC, Plisga GJ. Standard Handbook of Petroleum and Natural Gas Engineering. Elsevier, 2011.
- [13] Parker ES. Effect of Gas-Oil ratio on Oil Production. Abuja: African University of Science and Technology, 2010.

To whom correspondence should be addressed: Dr. Oghenerume Ogolo, Department of Petroleum and Gas Engineering, Nile University of Nigeria, Abuja, Nigeria, E-mail oghenerume.ogolo@nileuniversity.edu.ng