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INVESTIGATING THE EFFECT OF WELLBORE WATER ON OIL FLOW RATE USING INFLOW PERFORMANCE RELATIONSHIP ANALYSIS APPROACH (IPRAA)

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Abstract: **The adverse effect of produced water on oil inflow rate and downhole production system cannot be over emphasis. The challenge posed by it is felt both at the upstream and downstream. This is due to the reversed in the function of the reservoir pressure in driving the produced fluids to the surface. Wiggin's model for multiphase was reviewed and used to analyse the inflow performance relationship curves results obtained from the simulation of production data of oil well 1 and 2. The IPR generated in the presence of water in the inflow stream was further investigated by remodeling wiggin's model on Execl program (figure 1). From the simulation, the absolute open flows (AOF) for well 1 were 5576.2 bbl/d and 3771.4 bbl/d for multiphase and single phase respectively (Figure 2). Similarly, well 2 have 9736.1 bbl/d and 7612.4 bbl/d (AOF's) for multiphase and single phase flow respectively (figure 3). The investigation method show more oil production based on the improved IPR curves (figures 6 and 7) obtained as a result of modeling the bottomhole flowing pressure in inverse assumption in the presence of water in the inflow stream using.**

Keywords: **wellbore, productivity index, inflow relationship performance (IPR), Absolute open flow and multiphase.**

1. INTRODUCTION

The rate of movement of reservoir fluids (Oil, Gas & Water) from the reservoir rock matrix to the wellbore at the expense of pressure drop is inflow rate. Basically, two types of flow are pronounce when well performance evaluation is called for, the inflow; which is flow from the reservoir to the wellbore and outflow, which is from the wellbore to the surface wellhead. The two flow terms serves as a tool used in measuring the performance of an oil well by the petroleum engineers. Pressure-rate behavior of oil wells is often analyzed to evaluate various operating conditions, determine the optimum production scheme and to design production equipment and artificial lift methods. Nodal analysis (a widely-used technique in the oil industry) optimizes well production using inflow performance with tubing performance relationships (TPR) that relate the surface pressure to well bottomhole pressure. Inflow performance relationship (IPR) relates the well production rate as a function of the drawdown pressure and gives a comprehensive understanding of what the reservoir can deliver into the well at a specific time.

The accumulations of hydrocarbons are invariably associated with aqueous fluids (formation waters), which may occur as extensive aquifers underlying with hydrocarbon bearing layers as connate water. These fluids are commonly saline, with a wide range of compositions and concentrations. The presence of water in the production stream usually posed some challenges during oil production resulting in interferences with oil inflow rate. Water production kills oil and gas wells, leaving a significant amount of hydrocarbon in the reservoir. Studies conducted on large sample of gas wells revealed that the original reserves figures had to be reduced by 20% for water problems alone (National Energy Board of Canada, 1995). Bendakhlia and Aziz (1989) showed that using an IPR developed for a vertical well gave unsatisfactory results for horizontal well flow which should have its own specifically derived IPR. Furui, Zhu and Hill (2003) also noted that the drainage pattern and flow geometry of horizontal and vertical wells were different. A horizontal well was more likely to have radial flow near the wellbore and linear flow away from the wellbore while a vertical well was most likely to have radial flow only, highlighting the need for separate IPRs.

Gallice and Wiggins (2004) had it that, reservoirs fluids are usually not in single phase, but are often accompanied by bottom water aquifers, and that Phases are commonly segregated because gravity forces lead to water under riding the oil phase. Thus, oil wells drilled in such reservoirs may produce some water depending on the production practice. This water production may be associated with water coning in response to oil production. Various reports indicate the high amount of water associated with the produced hydrocarbons. Schlumberger (2004), reports that 75 percent of the total production from petroleum reservoirs is only water, which is equivalent to 220 million barrels of water per day worldwide. This report also gives an average water handing cost of 0.50 $/bbl. In addition to this cost, uncontrolled water also reduces oil production resulting in the drop in economically proven oil recoverable reserves.

Vogel (1968) used a computer model to generate IPRs for several hypothetical saturated oil reservoirs that are producing under a wide range of conditions, such as unity flow efficiency. Vogel normalized the calculated IPRs and expressed the relationships in a dimensionless form. He normalized the IPRs by introducing some dimensionless parameters: Pd, $(Q_o)_{max}$, where $(Q_o)_{max}$ is the flow rate at zero wellbore pressure.

Wiggins (1993) used four sets of relative permeability and fluid property data as the basic input for a computer model to develop equations to predict inflow performance. The generated relationships are limited by the assumption that the reservoir initially exists at its bubble-point pressure.

Gilbert (1954) examined the effect of water-cut on IPR curves and its relationship to other factors such as interflow rates. For solution drive reservoirs, he showed that the gross inflow rate decreases as the water cut increases whereas the gross (total of flow rates for all phases) inflow rate for active water drive wells will increase as the water cut increases. Brown (1984) and Wiggins (1991) proposed inflow performance models for oil wells producing water. Brown's method (also called the Petrobras method) combines a Vogel (1968) inflow performance relationship (IPR) for oil flow with a constant productivity index (linear IPR) for water inflow. The method requires well test data including oil (q_o) and water production rates (q_w), flowing bottomhole pressure (p_{wf}) and average reservoir pressure (p_r).

2. METHODOLOGY

Integrated method of analysis was developed based on wigging's expression for multiphase flow to determine oil production rate and water production rate in a multiphase flow system. The real time production data were simulated on FASTWELL program and the simulated IPR results analysed for absolute open flow (AOF), production rate at the tested point for both the oil and water rate. The generalized equations used for predicting inflow performance relationship for oil and water phases flow rate are derived as follows;

The oil production rate in the presence of water is given in equation (1)

$$Q_o = (Q_o)_{max}\left[1 - 0.52\left(\frac{P_{wf}}{\bar{P}_R}\right) - 0.48\left(\frac{P_{wf}}{\bar{P}_R}\right)^2\right] \qquad (1)$$

Similarly, equation (2) gives the water production rate in the flow stream as

$$Q_w = (Q_w)_{max}\left[1 - 0.72\left(\frac{P_{wf}}{\bar{P}_R}\right) - 0.28\left(\frac{P_{wf}}{\bar{P}_R}\right)^2\right] \qquad (2)$$

The productivity index (J) of the flow stream was determined using equation (3) as stated below;

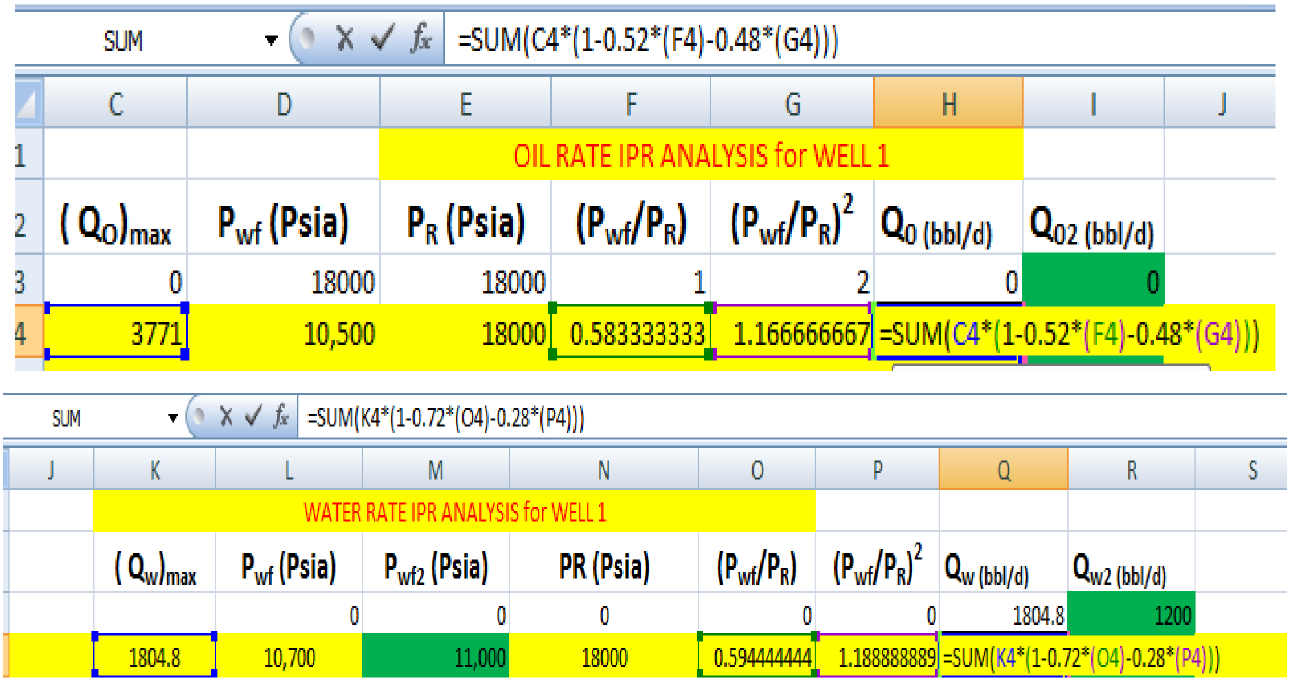
$$PI = \frac{Q}{P_R - P_{wf}} = \frac{Q}{\Delta P} \qquad (3)$$

To investigate the effect of water on the oil production rate, equation (2) was re-modeled to give (4) with the introduction of a constant increase to the bottomhole flowing pressure by 300 psi for water flow rate. The implication of this increment on oil flow rate was further study by the re-arrangement of equation (4) to give equation (5). The assumption here is that bottomhole flowing pressure reduction to oil inflow rate led to increase in oil production while inverse of bottomhole pressure to water led to reduction in water rate.

$$Q_{wR} = (Q_w)_{max}\left[1 - 0.72\left(\frac{P_{wf+300}}{\bar{P}_R}\right) - 0.28\left(\frac{P_{wf+300}}{\bar{P}_R}\right)^2\right] \quad 4$$

$$Q_{oR} = (Q_o)_{max}\left[1 - 0.52\left(\frac{P_{wf}}{\bar{P}_R}\right) - 0.48\left(\frac{P_{wf}}{\bar{P}_R}\right)^2\right] + (Q_w)_{max}\left[1 - 0.72\left(\frac{P_{wf+300}}{\bar{P}_R}\right) - 0.28\left(\frac{P_{wf+300}}{\bar{P}_R}\right)^2\right] \quad 5$$

These equations were modeled on the excel program and used to analyse the simulated results with staging reference to the values of the flow Parameters at the tested point. The snapshot of the Excel model page is as shown in figure 1. The resulting variables from the Excel analysis were plotted to show the IPR curves for oil and water departure response to bottomhole flowing pressures.



SUM =SUM(C4*(1-0.52*(F4)-0.48*(G4)))

OIL RATE IPR ANALYSIS for WELL 1

	C	D	E	F	G	H	I
2	$(Q_O)_{max}$	P_{wf} (Psia)	P_R (Psia)	(P_{wf}/P_R)	$(P_{wf}/P_R)^2$	Q_O (bbl/d)	Q_{O2} (bbl/d)
3	0	18000	18000	1	2	0	0
4	3771	10,500	18000	0.583333333	1.166666667	=SUM(C4*(1-0.52*(F4)-0.48*(G4)))	

SUM =SUM(K4*(1-0.72*(O4)-0.28*(P4)))

WATER RATE IPR ANALYSIS for WELL 1

K	L	M	N	O	P	Q	R
$(Q_w)_{max}$	P_{wf} (Psia)	P_{wf2} (Psia)	PR (Psia)	(P_{wf}/P_R)	$(P_{wf}/P_R)^2$	Q_w (bbl/d)	Q_{w2} (bbl/d)
	0	0	0	0	0	1804.8	1200
1804.8	10,700	11,000	18000	0.594444444	1.188888889	=SUM(K4*(1-0.72*(O4)-0.28*(P4)))	

Fig. 1: Excel Modeled Formulae for investigating effect of water on IPR Curves.

3. RESULTS AND DISCUSSION

3.1 Results

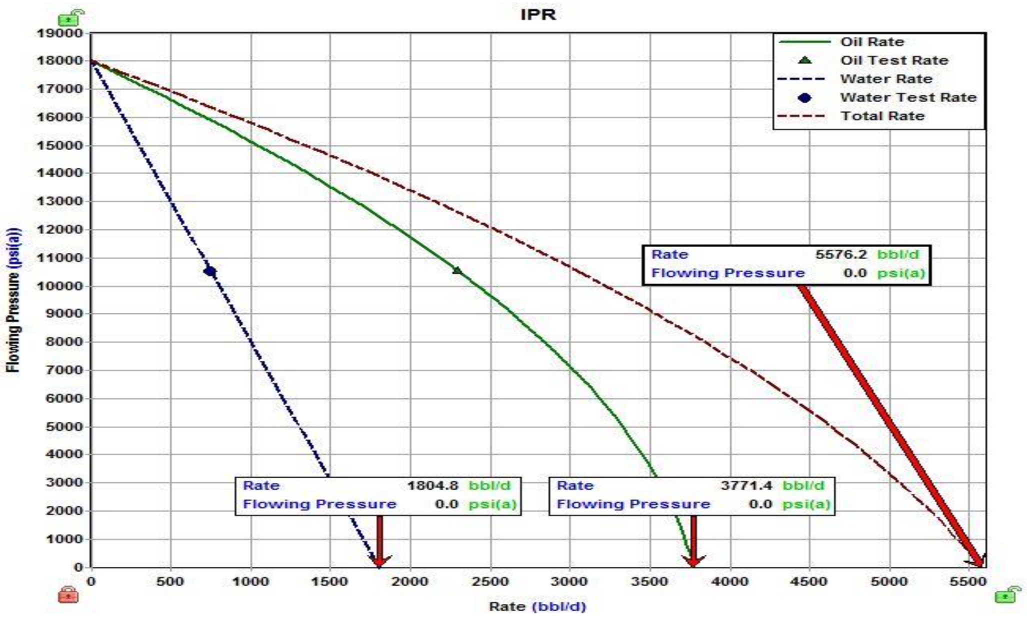


Fig.2: Simulated IPR for wellbore multiphase flow of well 1

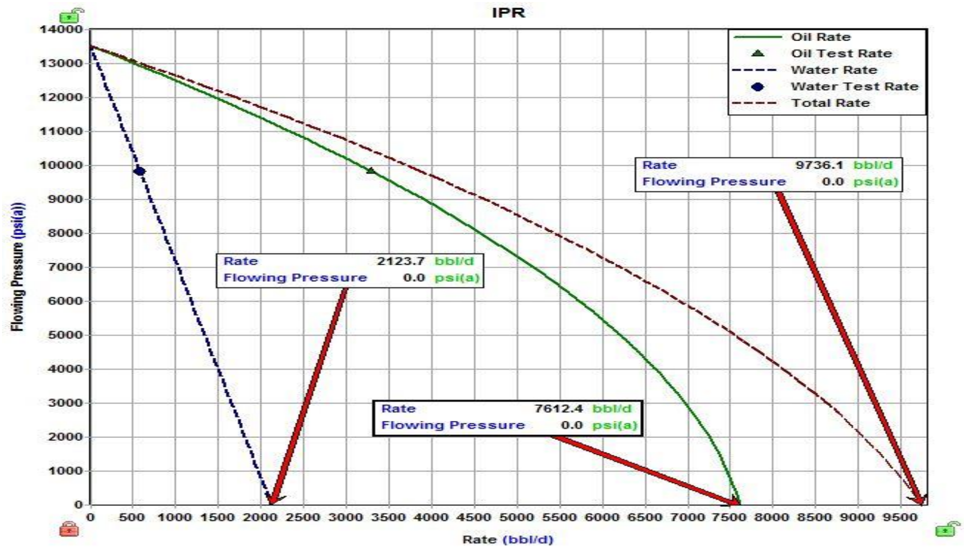


Fig.3: Simulated IPR for wellbore multiphase flow of well 2

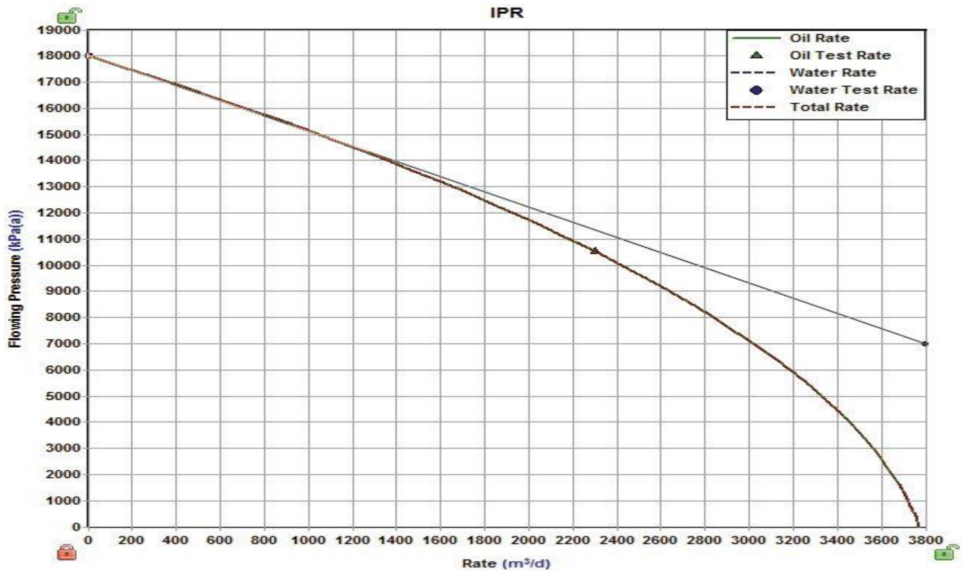


Fig.4: Oil flow rate Productivity index for Well1under negligible water phase

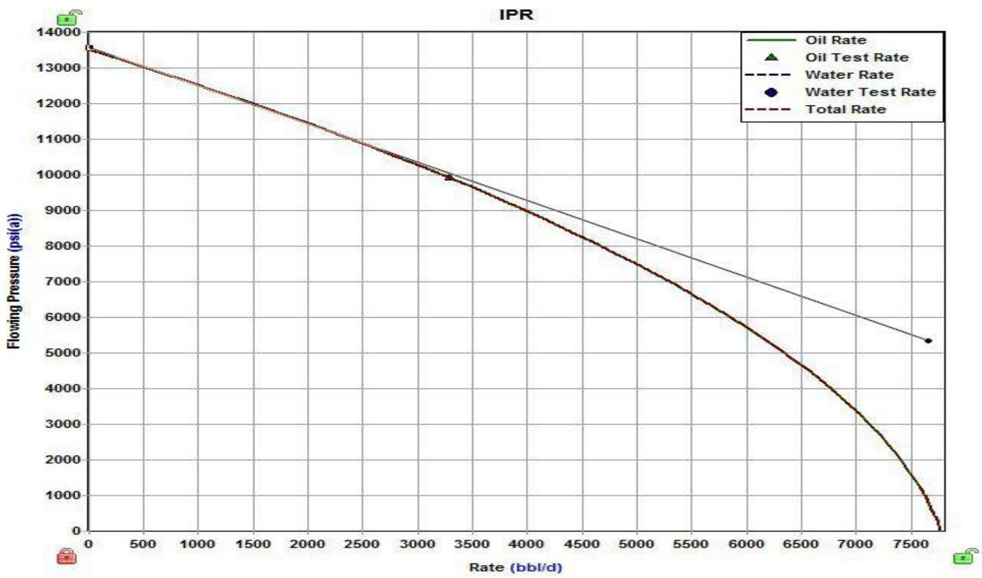


Fig.5: Oil flow rate Productivity index for Well 2 under negligible water phase

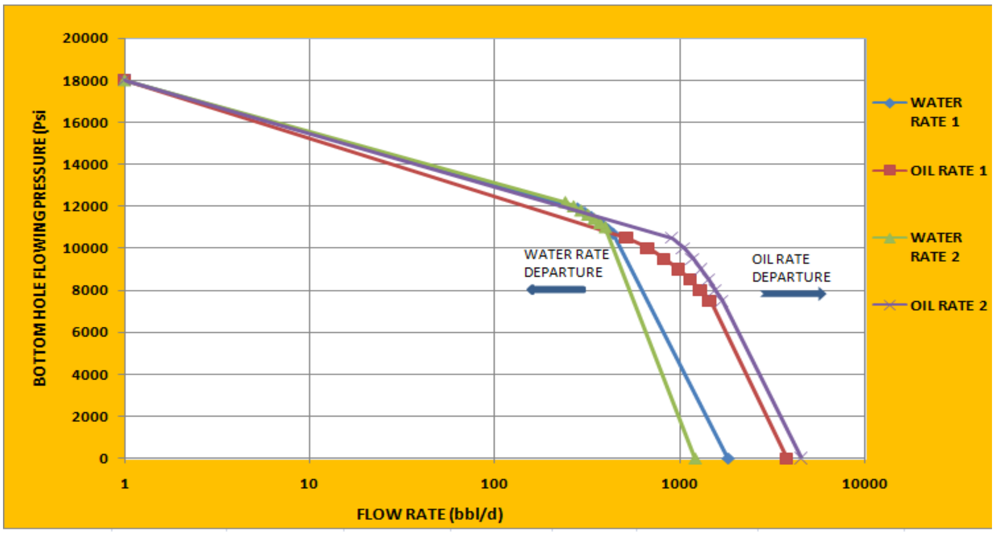


Fig.6: Investigative IPR for well 1 in a Multiphase flow for inverse pressure

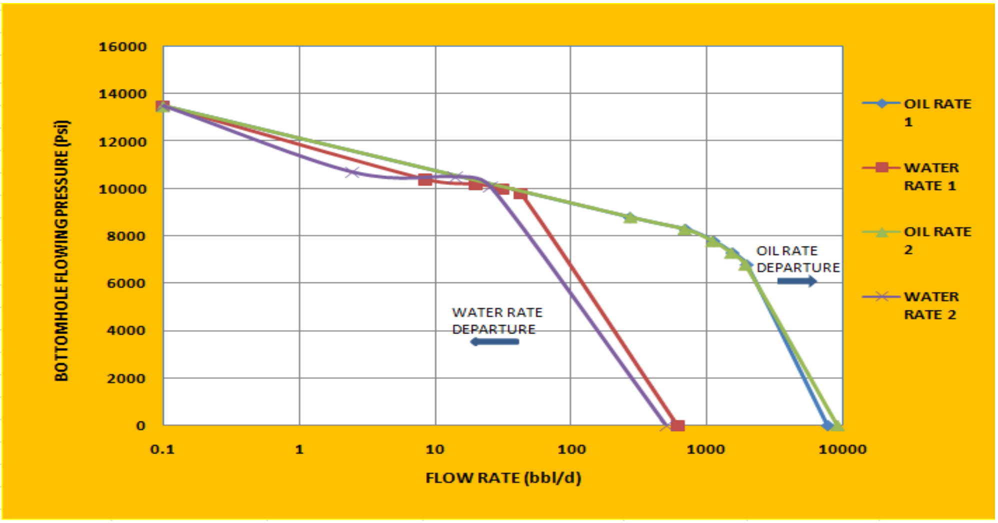


Fig.7: Investigative IPR for well 2 in a Multiphase flow for inverse pressure

3.2 Discussion

The results of the simulated IPR for the multiphase flow of well 1 and well 2 are as shown in figures 2 and 3. Figures 4 and 5 present the productivity index (PI) for the oil production rate under a negligible water phase flow. Finally, the results of the investigated IPR's obtained from the Excel modeled formulae are as shown in figures 6 and 7. These results present the extent water (fluid) has on oil inflow rate for the two oil wells.

The oil production data obtained at the payzone vicinity were simulated to study the nature of the IPR curve under multiphase flow of oil and water. The simulated results show the IPR curve for water, oil and the total IPR Curves for the two oil wells Figures 2 and 3. These curves show the significant effect that water has on oil flow rate. The absolute open flow (AOF) of the multiphase IPR is 5576.2 bbl/d at zero psia, the absolute open flow for oil and water phases are 3771.4 bbl/d, and 1804.8 bbl/d for well 1 (figure 2). Similarly, for well 2, the IPR gives the absolute open flow of 9736.1 bbl/d for the multiphase fluid flow rate, 7612.4 bbl/d and 2123.7 bbl/d for the oil and water AOF respectively (figure 3). From these results, the significant departure between the multiphase curves and the oil curves shows the extent water effect has limited the amount of oil that could have been produced at the commencement of production. Although the production at this point happens to be theoretically since there must be pressure drop for production to take place. Technically, if the reservoir pressures aiding production were to aid only oil production, the flow rate of oil at the absolute open flow will have increased for the two wells. The governing equations were modeled on excel and used to further investigate the effect of water on oil rate using deduced data from the simulated IPR curves. The productivity index (PI) was also determined for the two oil wells through the simulated IPR under negligible water phase. The productivity index (PI) for well 1 and well 2 are 0.35 bbl/d/psia and 0.86 bbl/d/psia respectively. These PI results indicate the true PI of the wells in their flowing state. The results of the investigation show a negative inflow at a very high bottomhole flowing pressure for well 2. Pressure stabilizes for oil flow at the bottomhole flowing pressures below 10,300 psia against the reservoir pressure of 13,500 psia due to the effect of water. From figure 6 and 7, inverse in bottomhole pressure played a significant role in increasing oil flow rate in low bottomhole flowing pressures, while it reduces water flow rate in high bottom-hole flow pressures. These are shown in the departure of the oil IPR curves denoted as oil rate 1 and oil rate 2, water rate 1 and water rate 2 (figures 6 and 7). These departures show the production of more oil with the available reservoir pressure if water breakthrough is minimize in the oil flow stream.

4. CONCLUSION

In this paper, IPR was used to investigate the effect of water in the wellbore on oil flow rate. The actual IPR curves for oil flow rate, water flow rate and multiphase flow rate were simulated. The outcome from the excel wiggin's modeled equations used for the investigation are;

1. The absolute open flow for multiphase flow, oil and water flow for well 1 are 5576.2 bbl/d, 3771.4 bbl/d and 1804.8 bbl/d (figure 2)

2. Similarly, the absolute open flow for multiphase flow, oil and water flow for well 2 are 9736.1 bbl/d, 7612.4 bbl/d and 2123.7 bbl/d (Figure 3).

3. In figures 2 and 3, the extent of the departure between the oil flow IPR curve and multiphase flow IPR curve indicate the extent water has affected the oil flow rate.

4. The real productivity index for oil flow rate from the IPR curves are 0.35 bbl/d/psia and 0.86 bbl/d/psia respectively.

5. Figures 6 and 7 show that more oil could be produce if water breakthrough is given a great concerned at the early production stage through efficient monitoring of the fluid phases and evaluation of the oil/water contact during completion.

NOMENCLATURE

AOF	-	Absolute open flow
stb/d	-	Stock tank barrel/day
Psi	-	Pound square inch
IPR	-	Inflow Performance Relationship
VPR	-	Vertical Performance Relationship
q_{omax}	-	Maximum oil flow rate
q_o	-	Oil flow rate
P_b	-	Bubble pressure
TPC	-	Tubing performance curve
P_r	-	Reservoir pressure
P_{wf}	-	Flowing bottomhole pressure
bbl/day	-	Barrel per day
J	-	Oil productivity index

5. RECOMMENDATIONS

The idea of the pressure-rate behavior enables engineers to evaluate various operating scenarios to ascertain the optimum production scheme and equally to design subsurface production equipment when necessary. The investigation of wellbore water effect on oil flow rate method used in this paper proves proficient in the separation of oil flow rate, water flow rate and the total flow rate. This research is recommended for used in the study of oil well performance with emphasis on oil inflow rate challenges. The information provided here could also be used for further research of problems of this kind, and for monitoring wellbore condition for effective production planning purpose.

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