Petroleum and Coal

Article Open Access

IMPROVEMENT OF OIL PRODUCTION: CASE STUDY OF THREE WELLS IN NIGER DELTA

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Received July 25, 2017; Accepted October 30, 2017

Abstract

Formation damage is a major problem experienced in the operation and development of petroleum reservoir. Its occurrence, occasioned with the release of particles, water, emulsions or scales, hitherto impairs the hydrocarbon delivery/transport system. Formation or skin damage impedes flow of fluids into the wellbore and cause low permeability, hence reducing the productivity of the wells. The production loss directly reflects the economic loss due to formation damage. In the extreme, damage may cause the Well to be uneconomic and be shut-in. The objectives of this project was to determine Stimulation Candidate for three (3) Wells in the Niger Delta Oilfield, using the R ratios, stimulate the candidate wells and make comparison between the wells with regard to the Pre-Stimulation and Post-Stimulation analysis. An analytical method was used to calculate Productivity Index, PI; Permeability, K; Skin, S; Production Rate, q, R-Ratio and Pressure Drawdown, ΔP using data from Pressure build up test in well testing analysis using Miller-Dyes-Hutchinson(MDH) method before and after acidizing treatment. From obtained results, the flowrate increased from 2000 STB/Day to 2230 STB/Day, productivity index also increased from 3.74 STB/Day/psi to 9.78 STB/Day/psi for well 1, while for well 2, flowrate increased from 1132 STB/Day to 1170 STB/Day, productivity index also increased from 0.82 STB/Day/psi to 8.34 STB/Day/psi and well 3 flowrate increased from 1500 STB/Day to 1800 STB/Day, productivity index also increased from 4.12 STB/Day/psi to 6.91 STB/Day/psi.

Keywords: Stimulation; Formation Damage; Skin; Permeability; Productivity Index; Pressure Drawdown; R-Ratio; Niger Delta.

1. Introduction

Over the past years, a considerable amount of work has been devoted to the stimulation methods that will bring optimum well performance. Most of these techniques and methods have been successful and economical. To attain economic production of an oil reservoir, the formation must be produced at the optimum oil rate with minimum operating costs. The production optimization of oil fields is aimed at accelerating the recovery of oil from reservoirs. Ajienka *et al.* [1] defined production enhancement as involving production surveillance and proper treatment of the production problems to enhance production. Proper diagnosis would aid the selection of wells with highest production potential and least risk, if the wells were worked over. The work over should lead to increased economic returns from the well.

Formation damage includes the existence of a barrier to flow in the near-wellbore region of the reservoir rock, which results in reduced production and/or abnormal decline in productivity [2]. It is the reduction of the natural natural permeability of reservoir rock near the well bore [4]. It is an undesirable operational and economic problem which can occur during the various phases of oil and gas recovery from subsurface reservoirs including drilling, production, hydraulic fracturing and work over operations [12]. Amaefule *et al.* [3] expressed it as a costly issue in the oil and gas industry. Tyler *et al.* [10] reported that a lower flow rate (than expected) and a sharp pressure drop are results of formation damage which can occur at a well during its production life.

Nearly all operations embarked upon to bring wells on stream is a source of potential damage to wells. Some well operations that may lead to formation damage include [9]:

- Damage Due to Drilling Fluid
- Damage Due to Casing and Cementing
- Damage Due to Perforation
- Damage Due to Production
- Damage Due to Stimulation
- Damage Due to Workover
- Damage Due to Producing Phase

Natural damage to formation occur as produced oil flow across the reservoir, while induced damage is caused by external operations like drilling, well completion, workover or stimulation[9]. The natural damage phenomenon like migration of fines, swelling of clay and organic deposition are also caused by the damage that results in poor production rate. According to Mitchell. [9] formation damage is caused by the following:

- Solids Plugging
- Emulsion Blockage
- Aqueous – Filtrate Blockage
- Precipitation
- Deposition of Paraffins or Asphaltenes
- Clay Particle Swelling or Dispersion
- Saturation Changes
- Wettability Reversal
- Fines Migration
- Condensate Banking

Anomalies in production rates, water cut and gas-oil ratio could indicate formation damage. [7] stressed that significant pressure drop may occur during flow in a damaged well. He recommended pressure transient testing should be used in evaluating reservoir pressure drops after which the formation permeability data and skin factor that characterize the extent of the damage well be determined. Once the damage and its origin are known, it is easier to apply appropriate remedial actions to ensure its removal. Gatlin *et al.* [6] recommended pressure build up method analysis as one of the quantitative ways of analyzing formation damage. A rapid increase in gas-oil ratio (GOR) or water cut caused by high production rate indicates formation damage (reduced permeability) near the wellbore. Onyekonwu [8] reported that skin and permeability of the formation could be determined through bottom hole pressure tests. He acknowledged that these parameters are useful in determining formation that are damaged and also stimulation candidates.

Injectivity or productivity test, pressure build-up test or fall of test may show the extent of the well damage.

Well stimulation is a well intervention process performed in an oil or gas well to increase production by improving the flow of hydrocarbon from the drainage area to the wellbore. It is a treatment given to a well to remove damage and increase the productivity or injecting of a well. Well stimulation is carried out either to remove or bypass the damage depending on the location of the damage in the formation. Sometimes a well initially exhibits low permeability and simulation is employed to commence production, other times, stimulation is used to further encourage permeability and flow from an already existing well that has become under productive. The most common well stimulation techniques are hydraulic fracturing and acidizing.

2. Methodology

An analytical method was used to calculate Productivity Index (PI or J), Permeability (K), Skin (S), Production Rate (q), R-Ratio and Pressure Drawdown (ΔP), making use of data from Pressure build up test in well testing analysis by Miller-Dyes-Hutchinson(MDH) method before and after acidizing treatment.

2.1. Flowrate

Flow rate is the amount of fluid that flows in a given time. It is the quantity of gas or liquid moving through a pipe or channel within a given or standard period (usually a minute, hour or day). Flow rate within a pipe is defined as the volume of fluid each second that is passing through a cross-sectional slice of the pipe. Mathematically it is calculated as

$$Q = AV \quad (1)$$

where units of Q are in volume per hour; A is the cross-sectional area and V is the velocity.

In the oil and gas industry, it is the quantity of oil or gas produced within a given time (usually per day). It is denoted by the symbol Q and measured in STB/day for oil and SCF/day for gas.

2.2. Permeability

Permeability in fluid mechanics is a measure of the ability of a porous material to allow fluids to flow through it. It is a rock's ability to transmit fluids. It is denoted by the letter "K" and measured in darcies (d) or millidarcies (md). Formations that transmit fluids readily, such as sandstones are described as permeable and tend to have many large, well-connected pores. Impermeable formations such as shales and siltstones tend to have fine grain or of a mixed grain size with smaller, fewer or less interconnected pores. There is absolute permeability conducted when a single fluid or phase, is present the rock. Effective permeability is the ability to transmit a particular fluid through a rock when other immiscible fluids are present in the reservoir. Factors that affects permeability include; relative saturations of the fluids, nature of the reservoir, porosity, bedding etc. There are a lot of equations used to calculate the different types of permeability, for the purpose of this work, permeability is calculated mathematically;

$$k = \frac{162.6qB\mu}{mh} \quad (2)$$

where: q = flow rate (STB/d); $B =$ formation volume factor (rb/STB); μ = viscosity (cp); h = thickness (ft); m = slope.

2.3. Skin factor

Skin is a dimensionless factor which is calculated to determine the production efficiency of a well. Skin impedes the productivity of a well. A negative skin value indicates enhanced productivity, typically resulting from formation damage.

$$S = 1.1513\left[\frac{P_{1hr} - P_{ws}}{m} - log\frac{k}{\emptyset\mu C_t r_w^2} + 3.23\right] \quad (3)$$

It is dimensionless pressure drop caused by a flow restriction in the near-wellbore region Where: P_{1hr} = shut in pressure at 1 hour (psi); P_{ws} = shut in pressure (psi); m = slope; k = Permeability (md); φ = porosity; C_t = Rock Compressibility (psi^{-1}); r_w = wellbore radius (ft); μ = viscosity (cP); ΔP_{skin} = additional pressure drop caused by formation damage; B = formation volume factor; S = skin factor; Kh = permeability and formation thickness.

2.4. Pressure drawdown

It is the differential pressure which helps in moving hydrocarbons from a reservoir into the wellbore. When drawdown tests are performed, the well needs to be closed for sufficient period of time to allow the stabilization of pressure throughout the formation. The purpose of performing drawdown tests is to determine skin factor, permeability and reservoir boundary. Pressure drawdown test aids uninterrupted flow once oil or gas well is online, and also to locate the reservoir boundaries. During the test period, the surface chokes need to be changed periodically in order to maintain a constant flow rate. The pressure difference ($P_R - P_{ws}$), is called the reservoir pressure drawdown, where;

$$\Delta P = \frac{q\mu B\left[\ln\frac{r_e}{r_w} + S\right]}{7.08\times10^{-3}kh} \quad (4)$$

where: P_R = Reservoir pressure (psia); P_{ws} = wellbore shut in pressure (psia) ; q = flowrate (STB/day); r_w = wellbore radius (ft); S = skin; k = permeability (md); h = reservoir fitness (ft); μ = viscosity (cP); B = formation volume factor; r_e = reservoir radius.

2.5. Pressure drawdown due to skin

Pressure drop due to skin represents the total pressure drop caused by apparent or total skin. It is an important value to know in order to determine if corrective action (stimulation) may be warranted. The additional pressure drop due to skin is denoted by ΔP_{skin} and is usually a function of total skin(s) rate (q), permeability (k) and net pay (h)

It is defined as follows (in field units):

$$S = \left(\frac{k_h}{141.2q\mu B}\right) \Delta P_{skin} \quad (5)$$

Therefore,

$$\Delta P_{skin} = \frac{141.2q\mu B}{k_h} S \quad (6)$$

where: S = Skin factor; K = Permeability of formation, md; h = Thickness of formation, ft; q = Flowrate, STB/d; B = Formation volume factor; ΔP_{skin} = Pressure drop due to skin, psi; μ = Viscosity, cP.

2.6. R-Ratio

Onyekonwu [8] stated that Skin may not be the only good yardstick for determining stimulation candidates. Onyekonwu [8] went further to state that R – ratio is also a very good yardstick for selecting stimulation candidate and it is the ratio of the pressure drop caused by skin to the pressure drawdown of the well. It is denoted by the letter R. It is calculated mathematically;

$$R = \frac{\Delta P_{skin}}{\Delta P} \quad (7)$$

where: R = R-ratio; ΔP_{skin} = Pressure drop due to skin, psi; ΔP = Pressure drawdown, psi.

2.7. Productivity Index

The productivity index of an oil well is the ratio of the stabilized flow rate q to the pressure drawdown. It is a measure of the well potential or ability to produce and is a commonly measured well properly. The symbol J is commonly used to express the productivity index. The units typically are in field units, STB/D/Psi. It is generally measured during a production test on the well. The well is shut-in until the static reservoir pressure is reached. The well is then allowed to produce at a constant flowrate (Q) and a stabilized pressure (P_{wf}). Since a stabilized pressure at the surface does not necessarily indicate a stabilized $P_{wf,}$ the bottom-hole flowing pressure should be recorded continuously from the time the well is to flow. The productivity index is than calculated mathematically using the equation;

$$J = \frac{Q_o}{P_r - P_{wf}} = \frac{Q_o}{\Delta P} \quad (8)$$

where: J = Productivity Index (STB/day/psi); Q_o = Oil Flow rate (STB/DAY); P_r = volumetric average reservoir pressure (psia); P_{wf} = Bottomhole flowing pressure (psia); ΔP = drawdown (Psi).

Productivity Index is a valid measure of the well productivity potential only if the well is flowing at pseudo steady state conditions. Therefore, in order to accurately measure the productivity index of a well, it is essential that the well is allowed to flow at a constant flow rate for a sufficient amount of time to reach the pseudosteady state. Since most of the well life is spent in a flow regime that is approximately the pseudosteady predicting the future performance of wells. Further, by monitoring the productivity index during the life of a well, it is possible to determine if the well has become damaged due to completion problems. If a measured J has an unexpected decline one of the indicated problems should be investigated.

3. Result and discussion

The results from the semilog plots and calculated parameters before and after stimulation are as follows:

3.1. Results of pre- and post-stimulation for Well 1

From Table 1, the drawdown reduced from 534.72Psi to 227.94Psi and the flow rate increased from 2000STB/day to 2230STB/day. The skin factor also reduced from 9.70 to 7.43. The pressure drop due to skin also reduced while the productivity index increased. Before stimulation, the R-ratio was 0.63 which showed that well 1 was a stimulation candidate because the ratio was greater than 0.6 and after stimulation, the ratio dropped to 0.57.

Table 1. Pre-stimulation and Post-stimulation results for Well 1

Parameter	Pre-stimulation	Post-stimulation
Flow rate (STB/day)	2000	2230
Drawdown (psi)	534.72	22.794
Skin factor	9.70	7.43
Pressure drop due to skin	336.92	129.06
R-ratio =ΔP damaged skin/drawdown	0.63	0.57
Productivity Index STB/day/psi	3.74	9.78
Permeability md	88.54	340.84

Permeability also increased which showed that the damage that was impeding the flow of reservoir fluids to the wellbore reduced appreciably. The stimulation job yielded a positive result and hence was successful for this well and will yield more returns on investments.

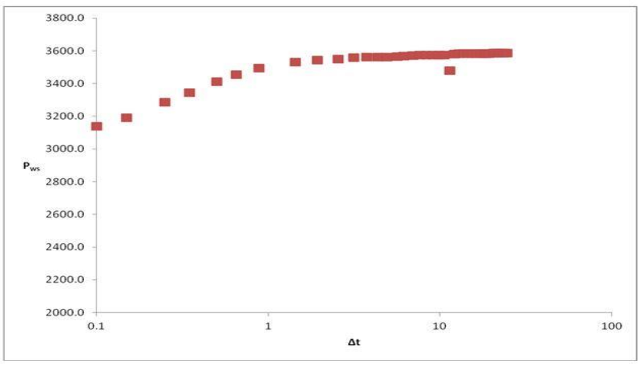

Figure 1. Plot of P_{ws} Vs ΔT for Well 1 (Pre-Stimulation)

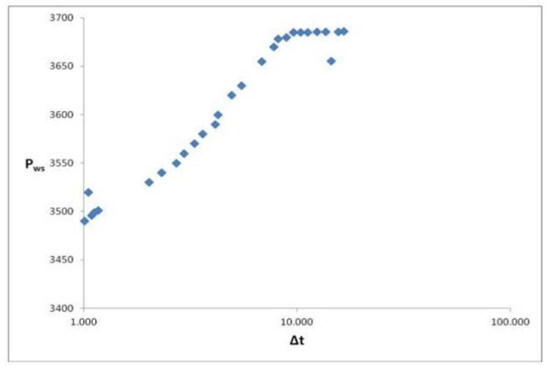

Figure 2. Plot of P_{ws} Vs ΔT for Well 1 (Post-Stimulation)

3.2. Results of pre- and post-stimulation for Well 2

From the results in Table 2 for well 2, the flow rate increased from 1132 STD/day to 1170STD/day, drawdown reduced from 1374.88Psi to 140.29Psi. There was, also, a reduction in the skin level even though not significantly. Pressure drop due to skin also reduced from 1229.30Psi to 125.30Psi. Permeability increased from 72.24mD to 667.54mD. There was a slight reduction in the R-ratio, from 0.89 to 0.86 which shows the well 2 may not have been the best candidate for stimulation although there was a significant increase in the productivity index of the well.

Table 2. Pre-stimulation and Post-stimulation results for Well 2

Parameter	Pre-stimulation	Post-stimulation
Flow rate (STB/day)	1132	1170
Drawdown (psi)	1374.88	144.99
Skin factor	47.50	36.11
Pressure drop due to skin	1229.30	125.30
R-ratio =ΔP damaged skin/drawdown	0.89	0.86
Productivity Index STB/day/psi	0.82	8.34
Permeability md	72.24	667.54

Economically, the well may not have been the best candidate for stimulation but the fact that the production increase means the company/investor may run into losses for performing the acid job, if economic models and analysis proves profitable.

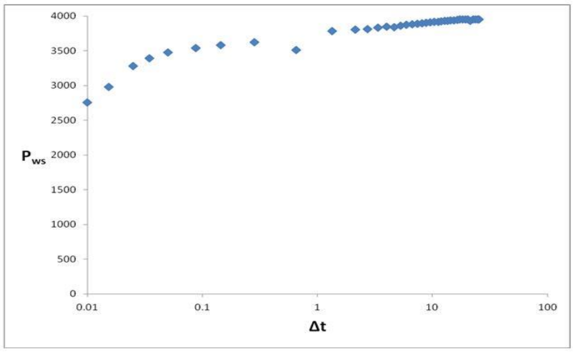

Figure 3. Plot of Pws Vs ΔT for Well 2 (Pre-Stimulation)

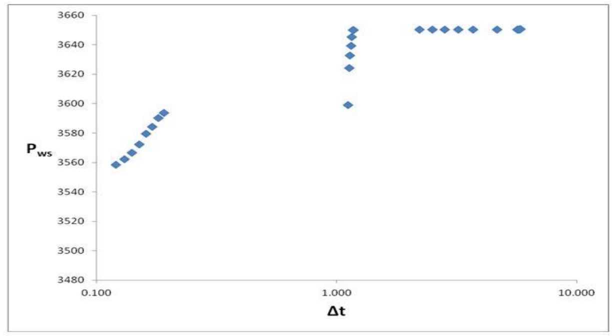

Figure 4. Plot of Pws Vs ΔT for Well 2 (Post-Stimulation)

3.3. Results of pre- and post-stimulation for Well 3

As recorded in Table 3, the flowrate increased from 1500STB/day to 1800 STB/day. Drawdown decreased from 363.79Psi to 260.50psi, pre-stimulation there was no skin but after stimulation, the skin value increased to 1.88 which shows that the well may have been damaged during stimulation. The R-ratio was negative which shows that the well was not a candidate for stimulation at all because the value was less than 0.6. The productivity index increased from 412STB/day/Psi to 6.91STB/day/Psi, which was a minimal increase compared to the cost of stimulation.

Table 3. Pre-stimulation and Post-stimulation results for Well 3

Parameter	Pre-stimulation	Post-stimulation
Flow rate (STB/day)	1500	1800
Drawdown (psi)	363.79	260.50
Skin factor	-3.84	1.88
Pressure drop due to skin	666.85	65.30
R-ratio =ΔP damaged skin/drawdown	-1.83	0.25
Productivity Index STB/day/psi	4.12	6.91
Permeability md	19.40	246.63

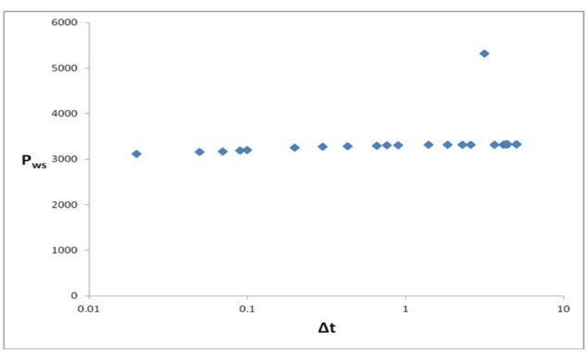

Figure 5. Plot of Pws Vs ΔT for Well 3 (Pre-Stimulation)

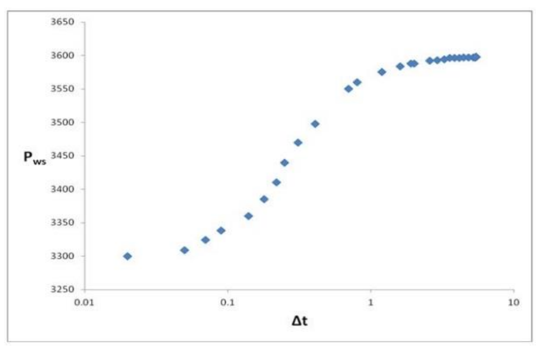

Figure 6. Plot of Pws Vs ΔT for Well 3 (Post-Stimulation)

4. Conclusion

An analytical method has been used to evaluate the effect or impact of formation damage on three (3) wells in a Niger Delta field. The Miller-Dyes-Hutchinson (MDH) method was used to analyze the wells in order to determine the permeability and skin of the wells.

The following conclusions are made:

- The R-ratio was used to determine that well 1 and well 2 are stimulation candidates while well 3 is not a stimulation candidate.

- From the results, using the analytical method, Productivity Index (PI) increases as the drawdown (ΔP), Skin (S), and R-ratio decreases. Also, as flow rate (q) and permeability (k) increases and vice-versa.
- Using the magnitude of damage skin or ratio, for ranking the priority for stimulation, the wells will be ranked as well 1, well 2 and well 3.
- Productivity Index (PI) is the economic indices is used for measuring the economic loss or gain. Table 1 to 2, it showed that wells 1 and 2 will be profitable while well 3 will be at economic loss because the difference between the PI before and after stimulation is very minute, when compared to what it will takes to carry out a stimulation job.

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