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WELL STIMULATION METHODS IN PETROLEUM RECOVERY: USING HYDRAULIC FRACTURING AND ACIDIZING IN "WELL X" NIGER DELTA BASIN

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Abstract

Petroleum productivity relies greatly on the characteristic of the reservoir. High temperature and pressure modifies the permeability of the formation. Well stimulation is the well intervention performed on an oil or gas well to increase production by improving the flow of hydrocarbons from the drainage area into the wellbore. In this study, the performance of hydraulic fracturing and matrix acidization of "WELL X", Niger Delta Basin was evaluated. Data obtained was used to evaluate flow efficiency and production performance before and after acidizing. The analysis involves the post net oil and percentage increase in oil achieved after hydraulic fracturing and acidizing, well inflow performance quality indicator and decline rate analysis. Oil Well which showed poor inflow prior to hydraulic fracturing operations, exceeded operator expectations during post fracturing production and matrix acid treatment has proved to be efficient in opening up blocked pores and improving permeability in the near wellbore region, therefore, increases productivity of the well.

Keywords: *Reservoir stimulation, hydraulic fracturing, formation evaluation and management, acidization, Petroleum production, Niger Delta*

1. INTRODUCTION

Oil and natural gas, which are hydrocarbons, reside in the pore spaces between grains of rock (called reservoir rock) in the subsurface. If geologic conditions are favourable, hydrocarbons flow freely from reservoir rocks to oil and gas wells. However, in some rocks, hydrocarbons are trapped within microscopic pore space in the rock. This is especially true in fine-grained rocks, such as shales, that have very small and poorly connected pore spaces not conducive to the free flow of liquid or gas (called low- permeability rocks). Natural gas that occurs in the pore spaces of shale is called shalegas. Hydraulic fracturing can enhance the permeability of these rocks to a point where oil and gas can economically be extracted [1]. Well stimulation therefore is a well intervention performed on an oil or gas well to increase production by improving the flow of hydrocarbons from the reservoir into the well bore. It may be done using a well stimulator structure or drilling vessels known as "Well stimulation vessels [2). When an oil or gas reservoir is penetrated by a well, its content flows naturally to the surface production facilities with the aid of the primary reservoir drive mechanism via production conduit.

The main purpose of well stimulation is to improve the flow hydrocarbons into the wellbore so as to increase the productivity. Well stimulation operation can be carried out in existing as well as newly drilled wells and the assortment of drilling fluid pumped down the well during drilling and completion can often cause damage to the surrounding formation by entering the reservoir rock and blocking the pore throats "the channels in the rock throughout which the reservoir fluids flow". Similarly, the act of perforation can have a similar effect by jetting debris into the perforation channels. Both these situations reduce the permeability in the near wellbore area and so reduce the flow of fluids into the well bore. A simple and safe solution is to pump diluted acid mixtures from surface into the well to dissolve the offending material. Once dissolved, permeability should be restored and the reservoir fluids will flow into the well bore, cleaning up what is left of the damaging material. The study involves how performance evaluation of well completion stimulation methods in petroleum production using hydraulic fracturing and acidizing helps in reservoir performance.

2. MATERIALS AND METHODS

2.1 Location of Well of Study

This study was conducted in "WELL X" Greater Ughelli Depobelt of the Niger Delta Basin.

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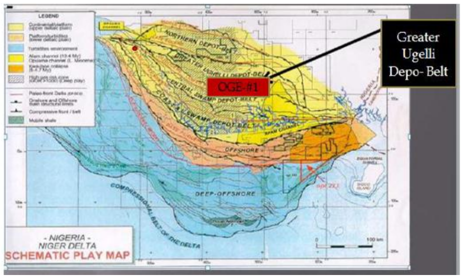

Fig. 1: Map showing location of study – Niger Delta Depo-belt [3]

2.2 Geological Setting of the Niger Delta Basin

The Niger Delta Basin is located in the Gulf of Guinea in the southern part of Nigeria (Fig. 1). It lies between longitudes 40°E and 8.80°E and latitudes 30°N and 60°N. It occupies the coastal ocean ward part of the Benue-Abakaliki Trough; hence its evolution has been linked with that of this larger sedimentary complex [4].

It is a clastic fill of about 12,000 metres with sub-aerial portion covering 75,000 sq. km. and extending more than 300km from apex to mouth [5]. The Niger Delta Basin consists of massive and monotonous marine shale at its base. This grades upward into interbedded shallow marine fluvial sands, silts and clays, which form the typical paralic portion of the delta. The uppermost part of the sequence is a massive, non-marine sand unit. These are referred to as the Akata, Agbada and Benin Formations respectively [6]. These three lithostratigraphic units are strongly diachronous. However, the Cenozoic Niger Delta complex is greatly affected by large scale synsedimentary features in the subsurface, such as growth faults, roll-over anticlines and diapirs [7].

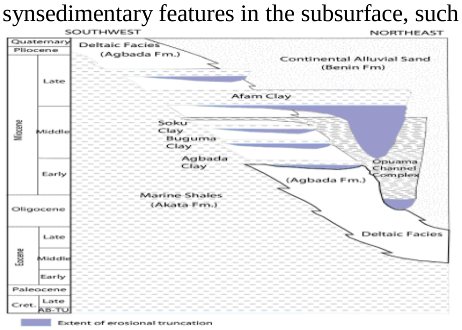

Fig. 2. Stratigraphic Formations of the Niger Delta. (the Marine Akata shale, the paralic Agbada formation and the continental Benin sandstone. (Modified from [7].

2.3 Methodology

Two major processes were employed in this study; they include: hydraulic fracturing (Hf) selection/Subsurface evaluation and Acidization.

2.3.1 Hydraulic Fracturing (Hf) Selection Conditions

Hydraulic fracturing, informally referred to as “fracturing,” is an oil and gas well development process that typically involves injecting water, sand, and chemicals under high pressure into a bedrock formation via the well. This process is intended to create new fractures in the rock as well as increase the size, extent, and connectivity of existing fractures. Hydraulic fracturing is a well stimulation technique used commonly in low-permeability rocks like tight sandstone, shale, and some coal beds to increase oil and/or gas flow to a well from petroleum-bearing rock formations.

The decision to implement hydraulic fracturing depends on the integration of reservoir, petrophysical, production and geomechanics data sets. Entire reservoir compartment (pool) understanding is required to understand why production ceased and to justify the candidacy for HF. In the well, multiple offset well data were analyzed and integrated to build reservoir understanding at an area level. Information from already existing dynamic reservoir model was incorporated for the well under this study. Selection has been conducted in two-steps namely: Step-1 preliminary screening and Step-2 detailed subsurface evaluation.

2.3.1.1 Step-1 Preliminary screening:

This step identifies the most prospective well. A quick review of various well reports, production history & petrophysical evaluation is performed to capture the key parameters that determines the fracture success. Well is screened through a weighted parameter based preliminary ranking and further passed to step-2 detailed subsurface evaluation. These key parameters & their preferences are listed below.

a. ***Oil in place (OIP)*** - high value preferred. Well with high OIP is most suitable for long term post fracture production and its sustainability. This should justify the cost of HF and make it economically viable. Few other indicators of remaining reserves are porosity multiplied with net pay thickness, cumulative production, current hydrocarbon saturations & current reservoir pressure etc., [8].

b. ***Net Pay Thickness*** - high value preferred. As determined by the Darcy's law, well productivity is proportional to effective net pay thickness (H). H can be increased by fracturing in scenarios of thick zones with low vertical permeability. Also, fracturing a laminated reservoir can connect a large interval of multiple thin low permeable pay zones, thus increasing H. Fracturing can also increase H, in case of multi-layered reservoirs within the fracture height interval.
Well with higher total net pay thickness is usually given preference for fracturing.

c. ***Reservoir Pressure*** - high value preferred. Higher reservoir pressure, flowing bottom hole pressures, preferably self-flowing capacity or greater than 50% of initial reservoir pressure are considered as ideal conditions for fracturing. Low reservoir pressures (gradient <0.15 psi/ft), poses challenges to post fracture production, fracture fluid flow back & well activation, even with the lift application.

d. ***Water Cut*** - low value preferred. Water cut > 20% is not recommended for fracturing, as fracturing will increase water cut by invading into the water source zone and eventually leading to watering of well. Therefore, low water cut well is highly preferred for HF.

e. ***Water/Gas Zone Proximity*** - high value preferred. Well with treatment zone closer to undesirable water/ gas bearing zone (contacts within the same reservoir), without any stress barriers (Shale/Siltstone layers) separation was rejected. Fracture placement in these zones can connect to the water/gas zone, due to lack of stress barrier. Well with no water/gas zone in near proximity or water/gas zones with shale/siltstone separations, was given high preference for fracturing. Stress barrier capacity of this shale layers & fracture containment were further evaluated in step-2 geomechanical & fracture modelling.

f. ***Reservoir Permeability*****.** Typically, low permeability zones less than 5 mD for oil & 0.5 mD for gas reservoirs are chosen for fracturing, as it's the only way to establish well production. However, well with moderate to relatively high permeability cannot be ignored. These wells respond with significantly higher accelerated production, with a small improvement in PI, when compared with low permeability wells [9]. Since production gain was the key objective of this project, well with moderate permeability in range of 5 – 30 mD was also given preference to be investigated in step-2 post stimulation production modelling.

g. ***Reservoir Skin*** - high value preferred. Well with high formation damage skin is a potential hydraulic fracturing candidate, as bypassing this high formation damage increases well production. Production history showing up a significant decline in well production over a course of time can indicate formation skin development, on condition if the decline is not due to reservoir pressure depletion [8]. Production modelling through skin sensitivity (matrix acidizing to frac) to evaluate production potential, damage & mineralogy characterization, can determine if the ideal treatment is fracture or matrix acidizing.

h. ***Productivity Index*** - low value preferred. PI is a very easy and quick method for screening underperforming wells, if compared between wells with same characteristic, typically in the same reservoir compartment. Well having low PI in a reservoir compartment where offset wells are at higher PI, can be the right candidate for stimulation.

i. ***Presence of nearby faults, tectonics, discontinuities***. Fracturing treatment near faults, discontinuities can pose risk of fault activation, fracture fluid leak off and high fracture pressures (due to tectonics). Therefore, well closer to faults within the typical fracture half-length vicinity and fracture gradients closer to overburden is eliminated from the study.

j. ***Operational/Completion Challenges***. Well with evident challenges like well site difficulties, very old completions and complicated workover requirements due to casing parting, integrity issues, untreatable poor cements etc is eliminated from the list of fracture candidates.

2.3.1.2 Step-2: detailed subsurface evaluation

The detailed subsurface evaluation involves integrated evaluation of subsurface data across the various disciplines. Evaluation begins with developing reservoir compartment/area level understanding, comparing the candidate well behaviour with offset wells, investigating ceased producers, determining the production methods and identifying potential well fracture candidates.

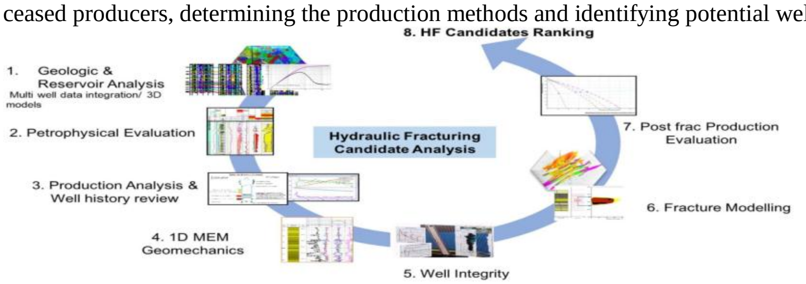

Fig. 3: Outline of Step-2 Detailed Subsurface Evaluation for HF Selection

2.3.2 Acidization

In this study, the performance of matrix acidization for well from the Tertiary sandstone reservoir in the Niger Delta was evaluated. Data obtained was used to evaluate flow efficiency and production performance before and after acidizing. Evaluating well performance after acid treatment is critical in determining the performance of matrix acid treatment and its further future application in the Niger Delta for near wellbore formation damage removal. Some of the useful well performance indicators considered includes:

2.3.2.1 Productivity Index (PI)

The productivity index is a valuable tool for predicting the future performance of wells anddetermining if the well has become damaged due to completion. The productivity of an oil well is quantified by the productivity Index (J).

$$J = \frac{q}{pr - pwf} \qquad (1)$$

In general, the PI will remain constant over a range of production rates, i.e. the IPR will be a straight line as long as the flowing bottom-hole pressure Pwf is greater than the bubble point pressure (Pb). Below Pb, the inflow performance relationship will become a curve and rate dependent [10].

2.3.2.2. Well Inflow Quality Indicator (WIQI)

The well inflow quality indicator (WIQI) is another relative index for deciding the efficiency with which a well has been drilled and completed. This is defined as the ratio of the actual productivity index of a well to its productivity index if there were no skin. It is a diagnostic parameter which gives an indication of how good a well was completed (initially, after work over, recompletion or stimulation). This is obtained by carrying out BHP survey immediately after completion or re-entry. The well inflow quality indicator is determined by comparing PI actual to PI Ideal. WIQI measures how good a well is producing.

$$WIQI = \frac{PI^{actual}}{I^{ideal}} \qquad (2)$$

Where the PI actual and PI ideal for a steady-state radial flow system are defined as shown below.

$$PI^{actual} = \frac{7.08*10KH}{\mu\beta ln\frac{re}{rw}} \qquad (3)$$

$$PI_{ideal} = \frac{7.08*10KH}{\mu\beta ln\frac{re}{rw} + Sc} \qquad (4)$$

Q = Production rate (stb/d)
Pr = Reservoir Pressure (psi)
Pwf = Well flowing Pressure (psi)
K = Permeability (mD)
Dp = Draw down (psi)
µ = Viscosity (cP)
B = Formation volume Factor (rb/Stb)
Re = Reservoir radius (ft)
Rw = Well Radius (ft)
Sc = Completion Skin.

The productivity of an oil well is quantified by the productivity index. In general, the PI will remain constant over a range of production rates, i.e. the IPR will be a straight line as long as the flowing bottom-hole pressure Pwf is greater than the bubble point pressure (Pb). Below Pb, the inflow performance relationship will become a curve and rate dependent.

3. RESULTS AND DISCUSSION

The results generated for the study entails the summarization of the results of production of different stimulation methods and data analysis for the Hydraulic Fracturing and Acidizing stimulation methods.

3.1 Hydraulic Fracturing Execution

Table 1: Well X Fracturing details

Parameter	**Unit**	**Well X**
TVD	**M**	3762
Slurry rate	**Bpm**	**18**
Maximum surface pressure	Psi	8960
Job Proppant	1lbs	147226
Fracture Height	Ft	245
Fracture Width	Ft	0.3

Fracturing execution was at the pumping rate of 18bpm. The executed well was vertical/deviated with TVD of 3724. Challenges due to low matrix injectivity and no improvement after acid soaking, led to higher fracturing pressures at low pumping rates. Fracture fluid viscosity reduction with low gaur loading & friction reducer's utilization helped in reducing frictional loss, which helped in limiting treatment pressures (8960 psi surface pressure limit). Hybrid PAD (combination of Linear & crosslink gel fluid stages) was implemented in the treatments, to reduce the net pressures & thus maintaining fracturing treatment pressures within the well completion pressure limitation.

3.1.1 Well X Analysis and Execution

Well-X was the analogue of production revival by fracturing in a moderate permeable sandstone reservoir (10 mD), due to bypassing formation damage (skin 12), connecting thin untested additional pay zones and further reducing drawdown in reservoir. This was a mature oil well with 10 years of significant cumulative oil production. Well started at an oil rate of 40m3/d, ceased to flow in 4 years, which led to installation of sucker rod pump lift (SRP) from year 4 to revive well production. Pre-fracture oil rate was 11 m3/d on SRP with reservoir pressure declined to 3420 psi (0.28 psi/ft) at the 10th year of production.

Table 2: Well X Analysis

Parameter	**Value**	**Parameter**	**Value**
Producing interval pay thickness (Target HF zone)	4m	Water zone vicinity	40m (separated by intermittent shales)
Additional nearby untested pay thickness	7m	Reservoir fluid	30 API oil
Total pay thickness	11m	Pre-fracture water cut	10%
Effective Porosity	10-13%	Cement bond	Good
Permeability, skin	10mD, 12	Pre frac production, PI	$11 m^3/d$, $0.2 m^3/d/psi$
Current reservoir pressure	3500psi, 0.28psi/ft	Post frac rate predicted, PI	$70 m^3/d$ (at prefrac operating THP 100 psi), $1.3 m^3/d/psi$

3.1.2 Well X Selection Criteria:

a) Additional untested oil bearing sands (7m) near to the producing interval were identified, separated by thin shale streaks, which were estimated to be connected by hydraulic fracturing.
b) Compartment level understanding confirmed these sand packs as continuous and oil bearing as per offset wells cased hole saturation logs & few layers are producing in the offset wells and thus increased confidence to connect these untested zones by fracturing.
c) Well had high remaining oil in place, as it is the single well producing in the sand interval in the entire area.
d) Low PI of 0.2 m3/d/psi and a positive skin of 12 was identified during production history match.
e) Water zone was identified 40m below the treatment zone and doesn't pose any risk due to several intermittent shales.
f) Stress & fracture modelling showed fracture height connecting the producing interval with the untested pay zones & confirms fracture bottom away from the water zone.
g) Production modelling with modeled fracture geometry & added nearby net pay due to stimulation, estimated post frac production of 70 m3/d oil rates (at last operating THP 100 psi) and PI increase from 0.2 to 1.3 m3/d/psi. This incremental gain was higher when compared to matrix stimulation and hence well was chosen for HF.

Well X responded with stabilized oil rate of 58 m3/d post fracturing rate on self at 10 % water cut during entire first year of post fracture production and the rates are still stable. THP also improved to 780 psi from 100 psi. PI improved from 0.2 m3/d/psi pre fracture to 1.2 m3/d/psi post fracturing (against predicted 1.3 post fracture PI).

3.2 Post fracture production result

Figure 4 below shows a plot of the post fracture stabilized oil rates during the 1st year of production. The well is still maintained at close to the rates below, which proves the hydraulic fracturing's tremendous success in maintaining the production sustainability in the ceased well.

Table 3: Pre and Post Fracture and change in Oil produced rate

Well	Pre Frac (m^3/d)	Post Frac (m^3/d)	Change in Oil Produced rate
Well X	11	58	47

OIL HF Campaign-Post Fracture Stabilized Oil Rates (m^3/d)

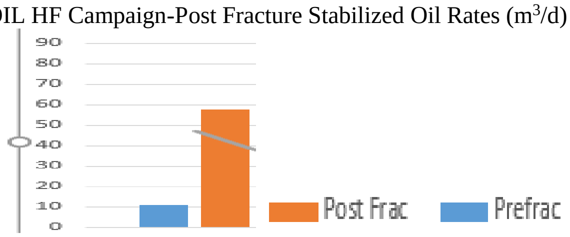

Fig 4: Well X Post fracture year-1 Stabilized oil production rate

3.3 Acidizing

Matrix acidizing has proven to be the best stimulation technique employed in recent years to remove near wellbore damages and invariably increase productivity. This is evidenced in the performance result discussed below. The analysis involves the post net oil and percentage increase in oil achieved after acidizing, well inflow performance quality indicator and decline rate analysis. The chart showed an improvement in well performance after acid treatment, the production efficiency was determined using WIQI. The well showed a very high net oil production after treatment. Production data following the acid treatment also showed a gradual increase in Net oil produced. The result shows increase in well head pressure from 1015psi – 1290psi. This finding shows an average of 61.6% increase in produced oil for the well after matrix acidizing. This increase in oil demonstrates that the acid treatment effectively worked for removing near wellbore damage around the well. The acid treatment increase quartz solubility by improving the adsorption capability of hydrofluoric acid on sand grain surfaces and by strongly chelating silica salts thus holding more silica in solution. The built in anionic charge on the acid makes the formation sandstone water wets, this property makes it easier for oil and gas to flow through the formation to the wellbore.

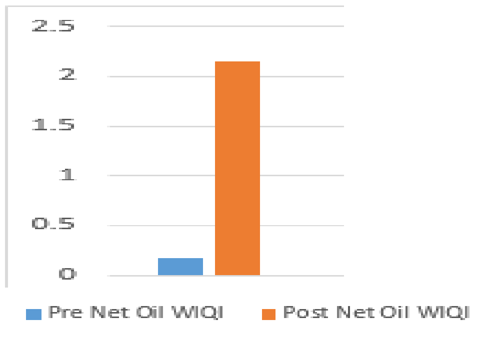

Fig. 5: Well inflow quality indicator pre and post acid treatment

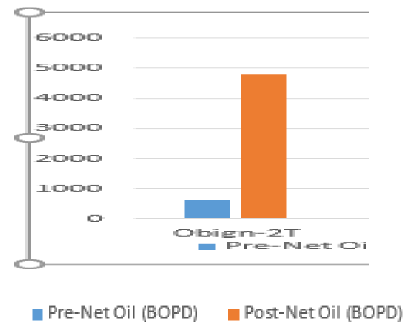

Fig. 6: Net Oil produced pre and post acid treatment.

4. CONCLUSION

This study established hydraulic fracturing, as a very effective method to rejuvenate the ageing fields, but it is imperative to apply the technology only after careful study and selection of well. Fracturing a medium permeability reservoir with good productivity, can accelerate production and generate higher returns, due to the good capacity of reservoir to deliver hydrocarbon till the conductive fracture. Fracturing in a depleted reservoir helps in bypassing formation damage, reduces drawdown across reservoir and can revive well.

Matrix acid treatment has proven to be efficient in opening up blocked pores and improving permeability in the near wellbore region, thereby increasing the productivity of the well. This is evident in the post treatment performance of Well X. The efficiency of the high penetration and dissolving capacity of both HCL and Mud acid was shown in the percentage increase in Net oil produced after acid treatment.

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