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Relative Study of Internal Gravel Packing and Chemical Sand Consolidation: Sand Control Techniques of Niger Delta Wells

[1]Offor Francis Maduabuchi, [2]Dulu Appah, [2]Ejike Samuel Okoro

[1]*Centre for Petroleum Geosciences, School of Graduate Studies, University of Port Harcourt, Port Harcourt, Nigeria.*

[2]*Petroleum Technology Development Fund Gas Research Group, University of Port Harcourt, Port Harcourt, Nigeria*

***Abstract**: Sand production is a serious problem in Niger Delta Wells, owing to its environmental impacts. To predict sand production, the production data of the six wells were analysed. This work compared the internal gravel pack (IGP) and chemical sand consolidation (SCON) methods of sand control. Analysis of the production and wellbore data obtained from six wells was done. From this, ideal and actual productivity indices were calculated, thus, enabling the well inflow quality indicator (WIQI) to be used as a criterion in the determination of the well performance of the sand control techniques. In checking for the effectiveness and durability, the efficiency and duration before sand production of the wells,a bar chart of total sand production before and after sand control against the sand control type was plotted. Results from the study showed that IGP treated wells have a better performance with values of WIQI ranging from 0.74 – 0.94, recorded 6 – 10 years in terms of durability before sand production, and produced 8 Ib/Mbbl of sand after treatment, compared to the SCON WIQI values of 0.57 – 0.79, 2 – 4 years durability before sand production, and 33 Ib/Mbbl produced sand. Hence IGP technique is recommended for Niger Delta wells.*

***Keywords**: Internal Gravel Pack, Chemical Sand Consolidation, Well Inflow Quality indicator and Productivity*

Symbols and Notation

IGP	Internal Gravel Pack
SCON	Chemical Sand Consolidation
WIQI	Well Inflow Quality Indicator
ESS	Expandable Sand Screen
SAS	Stand-alone Screen
HRWP	High Rate Water Pack
G-S	Gravel to Sand
PI	Productive Index
PI_{actual}	Actual Productive Index
PI_{ideal}	Ideal Productive Index
r_e (ft)	Drainage radius
r_w (ft)	Wellbore radius
K_o(md	Permeability
H(ft)	Reservoir thickness
μ_o(cp)	Viscosity
B_o(rb/stb)	Oil Formation Volume Factor
P_r(psi)	Reservoir Pressure
P_{wf}(psi)	Flowing Well Pressure
Q(bbl/D)	Oil Production Rate
q	Flow rate post sand control job
ΔP	Pressure difference

I. INTRODUCTION

Most of the world's hydrocarbon is found in sandstone reservoirs. Approximately 70% of oil and gas reservoirs worldwide are unconsolidated [6], [13]An implication that a larger extent of oil and gas fields worldwide, are faced with challenges of sand and fines production. Sand production has been a major challenge in oil and gas production, and has proven to be one of the toughest to solve. It is initiated when the formation stress surpass the strength of the formation. The formation strength is mainly gotten from the natural material that cements the sand grains, but the sand grains are also held together by cohesive forces resulting from immovable formation water. The formation sand grains stress is due to factors such as, actions from tectonism, overburden pressures, pore pressures, stress changes due to drilling, and drag forces on produced fluids. It is usually associated with shallow geological young formations with little or no natural cementation. In some cases, sand production starts late in the life of a field, when pressure drops such that the overburden is being maintained primarily by the vertical component of inter grain stress rather than by the pore pressure [4].

A number of conditions are accountable for the production of sands in hydrocarbon wells. When wells flow, due to unconsolidation of the formation, reservoir sands are produced. The unconsolidated sands are very likely to be migrated into the borehole and to the surface. Secondly, the rate of production from a formation canlead to production of sand in a well[1]. When the threshold pressure of a reservoir is exceeded in a bid to produce from a sandstone reservoir at maximum rate, sand production would set in, and a high amount of fluid influx from the sandstone reservoir into the wellbore would be obtained when thereservoir pressureis high compared to the wellbore pressure. The unconsolidated reservoir sand may be produced with the fluid flowing with high velocity from the producing formation into the wellbore [13].

Producing formation sand with well fluids can have adverse effects on the long term productivity of a well. Upon production of sands with the formation fluids, a number of potentially dangerous and costly problems are created. Some of the problems include:

1. Wellbore sanding
2. Erosion
3. Sand fouling
4. Sand accumulation

These problems have direct effects on the reservoir, surface equipment and subsurface equipment. Some of the effects include, productivity loss, reserve loss, reduced access to interval of production, irregular functioning of surface and subsurface equipment, failure of equipment, non-productive time, casing/tubing buckling etc.Produced sand has essentially no economic value. The ability to predict and control sand production is a major part of the effective operation of unconsolidated oil and gas wells [14], [16].

1. 1 Sand Production Control

Sand production may start very early in the life of a well, say from the moment it is firstproduced or at some point during production. There have been a number of researches on the prediction of sand production and best ways to control or eliminate it. Sand production in most cases will continue except some sand control method is adopted. Such techniques include:

1. Gravel packing (internal/external)
2. Expandable sand screens (ESS)
3. Stand-alone screens (SAS)
4. Frac packs
5. SCON

These sand control mechanisms have been used at various times to control sand production in open hole or cased hole completion, during drilling or production operation.These sand control techniques which are mechanical measures, with the exception of SCON which is a chemical measure, are used to hold the formation in place.

The choice of a sustainable sand control technique is influenced by conditions which include; reservoir features, service infrastructure, rates of production, production scheme, the magnitude of the skin etc. The capability of a sand control measure to manage migration of load bearing solids, establish a positive result on productivity and stay effectual for the productive years of the well, are essential objectives to be met before the sand control method is considered effective. Competently predicting sand production before well completion isfundamental to controlling sanding problems [15].

1.2 Gravel Packs

Gravel pack is a common sand control technique deployed in many formations with unconsolidated or poorly consolidated sands. It is a specialized completion method that needsexceptional completion and pumping equipment. Irrespective of completion configuration, any gravel pack job tends to achieve the primary objectives of sand-free production, completion longevity and high productivity while minimizing productivity impairment. In achieving these objectives, operatorsmust carry out gravel packs appropriately under a wide variety of field conditions. Thus, gravel packing must be approached from a total systems standpoint which involves interconnected technologies.

The gravel pack is an effective, extensively used and cost effective technique of holding back reservoir sand from produced fluids. It finds use in vertical, inclined and deviated wells, bellow are types of gravel packs [15].

1.2.1 Open Hole Gravel Packs

The theory of a gravel pack is to pump gravel as a slurry mix into the well, thus packing the annular space around the tubing throughout the reservoir interval. The aim of this is for the gravel to screen out the reservoir sand, and at the same time allow the production of reservoir fluids. It is commonly used in combination with a form of sand screen, with the sand screen the inmost element, making sure that the grit of the gravel pack is kept in place and not produced. The gravel pack will accumulate around the screen and screen out the reservoir sand. Installing a gravel pack successfully with a fully packed annular space, will provide support for the borehole wall, which also helps to minimize sand production.

1.2.2 Cased Hole Gravel Packs

It uses typically the same tools and techniques as the Open hole gravel Pack. The difference being that it is desirable with both squeezing and circulating, in attempt to ensure proper packing of the perforations. It is also possible to pack the perforations at a pressure higher than the fracture pressure, in which it is called a “High Rate Water Pack” (HRWP), which may be characterized as a sort of a hybrid between the conventional gravel pack and the frac-pack. The high pressure will guarantee proper packing of the perforations, but at the same time the pressure is not sufficiently high to cause any more than minimal fracture growth. The HRWP is not a very multifaceted operation; however it does require high pump rates and volumes of gravel pack fluid owing to the high leak-off into the fractures [5].

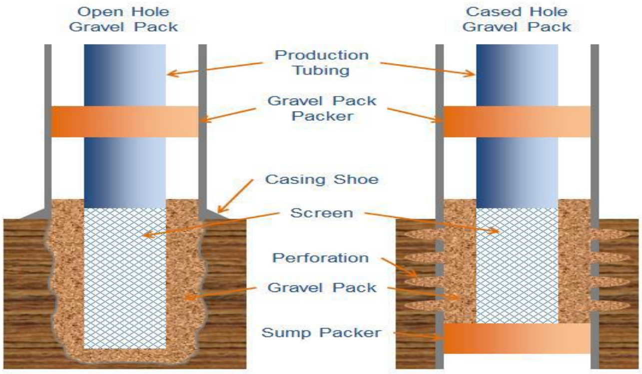

Figure 1: Schematic of internal and external gravel pack installation.

1.4 Chemical Sand Consolidation

The chemical sand consolidation method utilizes the injection of chemicals normally resin into the formation through perforations to cement the sand grains. The chemicals solidify and help bind the sand grains together.

Three criteria necessary for a successful sand control treatment are:

1. The sand control treatment has to be done through all the perforations
2. Permeability of the well after treatment must be retained
3. The consolidation over time, should not weaken

The most commercially available systems use resins which are phenolic, furan and epoxy resins. Clay concentration can hamper the effectiveness of the consolidation process, so a clay stabilizer is sometimes used as a pre-flush [3], [4]. The process of sand consolidation depends on a procedure that involves four different steps:

1. Resin application in the formation by means of a carrier fluid
2. Resin separation from the carrier fluid
3. Resin accumulation around the grain contact points
4. Curing of the resin

The epoxy and furan techniques involve resin-coated gravel mixed at the surface and pumped into the well. The gravel plastic slurry is allowed to settle and cure. Upon curing, the residue is drilled out of the well before production starts. The phenolic resin-coated gravel processes involve phenolic-coated gravel that is partially polymerized. When being subjected to temperatures higher than 57^{o}C, the resin cure is completed so that the gravel is consolidated. Unlike the epoxy and furan processes, the phenolic resin-coated gravel is dry and can be handled much like ordinary gravel [1].

The gravel pack functions as a down-hole filter, allowing reservoir fluid movement but preventing production of formation sands. Bridging of the borehole wall against the gravel pack is the key to the control of sand movement.

When effective bridging is achieved, sand and other solid particles carried by the formation fluids are deposited at the pack's periphery, allowing clean fluids to be produced. The bridging action is controlled by the size of the openings in the gravel pack.These openings are controlled by the size and uniformity of the gravel.The foundation for designing effective gravel pack completion is toobtain and properly install correctly sized gravel. The basic requirements involved for designing the gravel flow pack are:

1. Analysis of the producing formation
2. Determination of the gravel-to-sand ratio
3. Determination of the formation sand uniformity
4. Estimation of the velocity through the slots.

The final well development, correct choice of completion fluids, gravel, and pack thickness are other significant factors contributing to successful gravel packs [8], [9].

II. SELECTION CRITERIA FOR PROPER SAND CONTROL METHOD

The conditions upon which sand control techniques can be measured and compared are:

1. Reliability: Failure in sand control would result in a side track or well abandonment. Hence, careful measures must be taken a historical data is used on reliability to ascertain a similarity in environment, technological update and validity of statistical approach.
2. Productivity: To be of use for economics, the reservoir completion productivity needs to be converted to comparable production profiles, which should include the upper completion effect, reservoir depletion and water/gas influx.
3. Costs: For full comparison, the costs must be all-inclusive [5].

2.1Performance of Sand Control Techniques

Considering a one phase flow system, where production from the wells are directly proportional to the pressure difference between the wellbore and the reservoir; the constant of proportionality is PI.

$$PI_{actual} = \frac{q}{\Delta P} \qquad (1)$$

PI_{ideal} can be calculated from the equation:

$$PI_{ideal} = \frac{7.08\times10^{\wedge}3\times ko\times h}{\mu o\times\beta o\times In(\frac{re}{rw})} \qquad (2)$$

For this study, the WIQI would serve as a basis for the determination of performance of the control techniques. It is a measure of the proportion of the $PI_{actual}$to the PI_{ideal} with an assumption that there was no formation damage for a given drawdown.

$$WIQI = \frac{PIactual}{PIideal} \qquad (3)$$

Hence, WIQI ≤ 1

A well is said to be of higher performance when the WIQI value is closer or equal to 1.

III. METHODOLOGY

Prediction of Niger Delta reservoir failure and sand production is necessary in determining whether downhole sand control is required and what sand control technique to use, therefore the production data of the six wells were used to predict sand production as shown in figure 2 - 7. To determine the best sand control method for optimum oil production, a comparative analysis of SCON and IGP was carried out using key well performance indicators which include: WIQI, effectiveness and durability of sand control techniques.

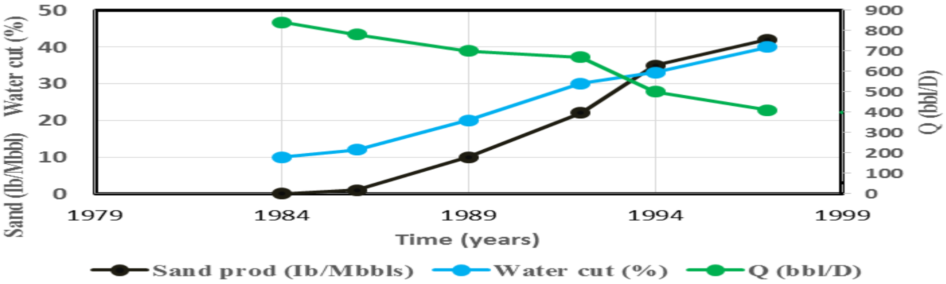

Figure 2: Graph of Production data against time (years) for Well 1

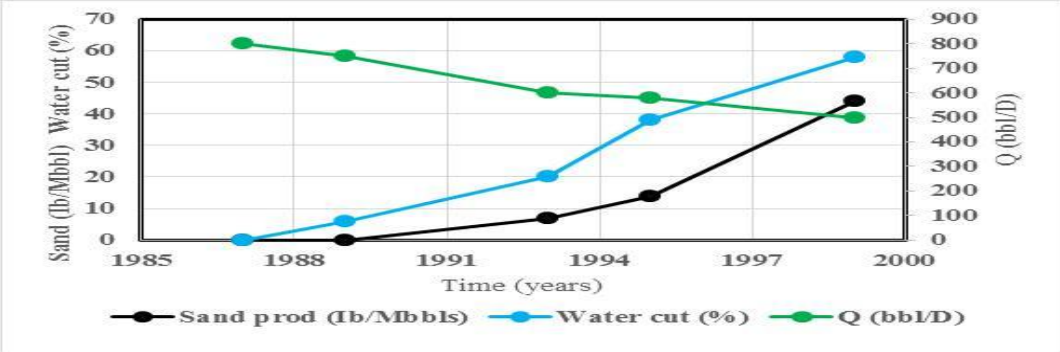

Figure 3: Graph of Production data against time (years) for Well 2

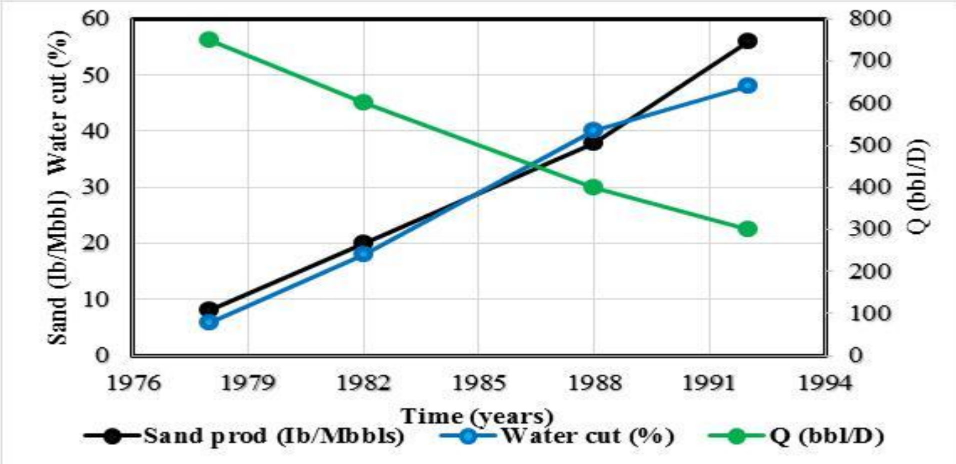

Figure 4: Graph of Production data against time (years) for Well 3

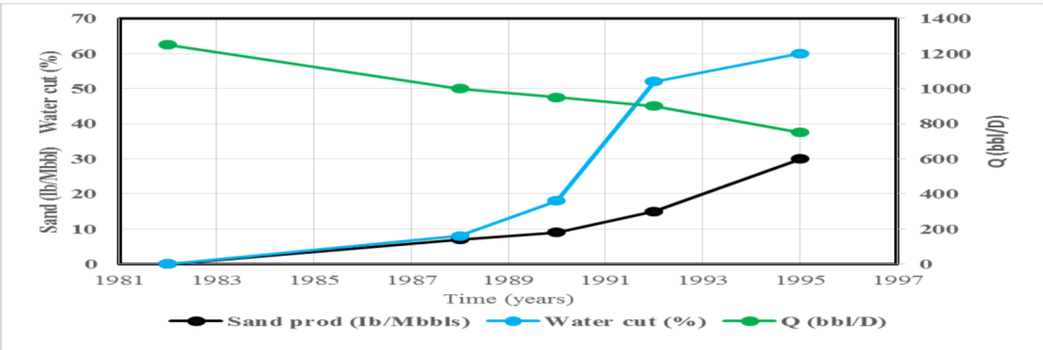

Figure 5: Graph of Production data against time (years) for Well 4

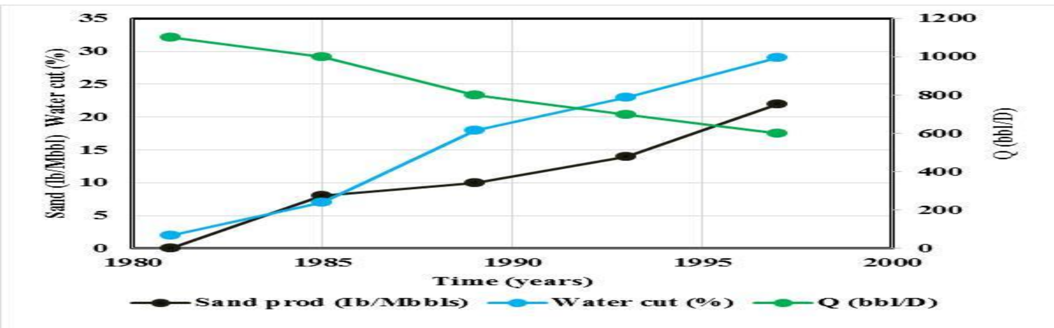

Figure 6: Graph of Production data against time (years) for Well 5

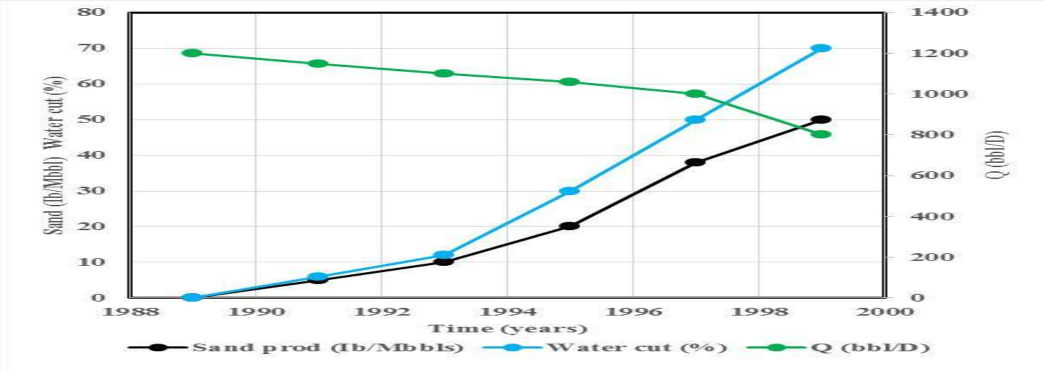

Figure 7: Graph of Production data against time (years) for Well 6

Table 1: Reservoir Data for the Wells

	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6
re (ft)	1500	1500	1500	1500	1500	1500
rw(ft)	0.8	0.35	0.5	0.45	0.4	0.5
Ko(md)	1000	900	1000	1000	1380	1200
h(ft)	13	9	10	16	8	12
o(cp)	2	1.7	2.65	2.2	1.8	2.8
Bo(rb/stb)	1.5	1.5	1.7	1.5	1.6	1.5
Pr(psi)	3300	2890	3000	3060	3100	2950
Pwf(psi)	3150	2550	2840	2910	2815	2665

IV. RESULTS

4.1 Sand Prediction

The result of the investigation reveals that from Figure 2 Well 1 was producing oil at 840 bbl/day and 0 lb/mbbls sand production rate in 1985 but in 1997 Oil production rate dropped to 410 bbl/day while sand production rate increased to 42 lb/mbbls. Well 2 in 1982 was producing oil at 800 bbl/day while sand rate was 0 lb/mbbls but in 1999 oil rate decreased to 500bbl/day, while sand rate soared to 44lb/mbbls as shown in Figure 3. For Well 3, Figure 4, the oil production rate was 750bbl/day, in 1978 while sand production rate was 8 lb/mbbls but in 1992 oil production rate dropped to 300 bbl/day, while sand production rate increased to 56 lb/mbbls. Oil production rate for well 4 in 1982 was 1250 bbl/day while sand production rate was 0 lb/mbbls but in 1995 Oil production rate reduced to 750bbl/day while sand production rate increased to 30 lb/mbbls as shown in Figure 5. From Figure 6 Well 5 was producing oil at 1100 bls/day in 1981 while sand production rate was at 0 lb/mbbls but in 1997 oil production rate reduced to 600bbl/day while sand production rate increased to 26 lb/mbbls. In 1986 Well 6 oil production rate was 1200bbl/day and sand production rate of 0 lb/mbbls but in 1999 oil production rate reduced to 800 while sand production rate increased to 50 lb/mbbls. Generally as sand production rate increases, oil production rate decreases, consequently it can be deduced that sand production is one of the major constraints to optimum oil production in the field, hence a techniques for sand control is required.

4.2 Comparison of IGP and SCON Sand Control Techniques

4.2.1 WIQI

The WIQI which determines the performance of the sand control types for each well are obtained from the productivity indices which were calculated using the reservoir data in Table 1. The values of the actual PI, ideal PI and WIQI are shown in Table 2. The SCON treated wells have values of WIQI ranging from 0.57 - 0.79 and IGP treated wells have ranges of 0.74 - 0.94. The highest WIQI values were obtained in wells 6 and 3 respectively, which are both IGP treated. For SCON treated wells 2 and 5, the decrease in well performance may be due to low reduction in water saturation resulting from a poor pre-flushing job. It can also be attributed to poor displacement (by the viscous oil) of the resin from the pore spaces, thus resulting in low permeability of the treated well. Therefore the IGP treated wells with values closer or equal to one corroborating equation 3 are of higher performance than the SCON treated wells.

Table 2: WIQI Values of the Sand Control Techniques

Well	Method Applied	PI Ideal (bbl/d/psi)	PI Actual (bbl/d/psi)	WIQI
1	IGP	4.07	3	0.74
2	SCON	2.69	1.54	0.57
3	IGP	1.96	1.69	0.86
4	SCON	5.56	4.39	0.76
5	SCON	3.29	2.21	0.67
6	IGP	3.03	2.85	0.94

4.2.2 Effectiveness of Sand Control Techniques

The sand control methods vary in terms of efficiency, which would be measured by the effectiveness of the method.To determine the effectiveness of the sand control types, a graph of total sand production before and after sand control against the sand control type is shown in figure 8. For IGP treated wells, 0, 6 and 2 post sand production were recorded which is below the tolerable limit of sand production in the Niger Delta while SCON wells recorded 13, 15, and 5, Two SCON wells values are above the limit of sand production in the area. From the analysis the SCON treated wells tend to produce more sands when compared to the IGP treated wells.

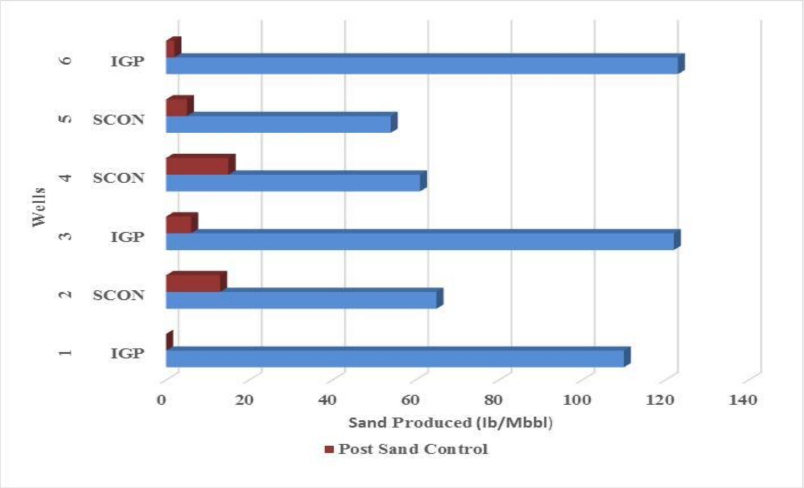

Figure 8: Graph of total sand production before and after sand control against the sand control type

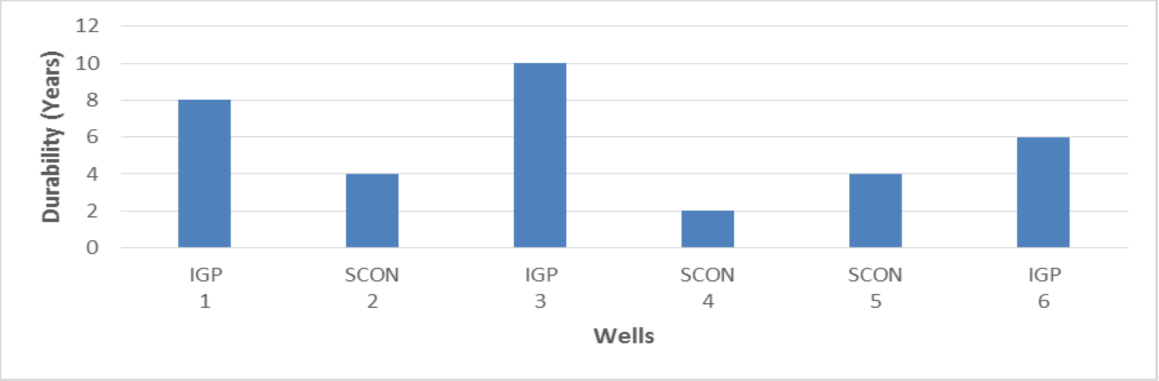

Figure 9: Bar chart of duration before sand production after well treatment

4.2.3 Durability

The time it takes a serviced well to reach the tolerable limit of sand production is a vital key indicator of a sand exclusion technique. After sand control treatment is carried out on a well, oil production improves and sand production is reduced.

The durability of the sand control technique is established on the time interval before the sand production occurs in the well. From Figure 9, IGP wells lasted about 6-10 years after the treatment, while SCON wells lasted about 2-4 years. Therefore IGP treated wells last longer than the SCON wells. This may be as a result of high downhole` temperature which with time weakens the sand consolidation and thus causes a reduction in durability of the SCON treated wells.

V. CONCLUSIONS

The analysis shows that as sand production rate increases, oil production rate decreases and all the wells produced sand above the tolerable limit in Niger Delta. Consequently, it can be deduced that sand production is one of the major constraints to optimum oil production in the field, hence a techniques for sand control is required.

Results from the investigation carried out on the production data of the six wells showed that the WIQI values for the IGP and SCON treated wells ranges from 0.74 - 0.94 and 0.57 - 0.79 respectively. Thus, IGP treated wells have higher WIQI values and perform better than SCON treated wells.

In terms of durability, the sand controlled wells using IGP lasted a period of 6 - 10 years before sand production occurred, while the SCON wells lasted a period of 2 – 4 years only, thus IGP technique is more durable than SCON technique.

From the analysis of sand production after treatment of the wells, it was found that the SCON wells produced 33Ib/Mbbl of sand as against the 8Ib/Mbbl produced by IGP wells. Hence the IGP technique is more effective than the SCON techniques.

Based on the results from well performance indicators used for this work, IGP sand control techniqueis the best for the described wells and reservoir.

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