Performance Evaluation of Different Sand Control Techniques in an Oil Reservoir

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Abstract: *Sand control techniques basically involve technologies designed to curtail or keep within check, the sand production associated with oil and gas production. These technologies, while impeding sand production, also go a long way in ensuring the maintenance of the integrity of the production system components. However, they have been known to create somewhat undesirable and inevitable pressure drops in the well system, influencing the well production and performance. In this research, the impact of the choice of sand control technique on well performance is investigated. Three sand control methods are studied namely, Gravel pack, Wire wrapped screen and Slotted liner. The performance of the well when installed with each of these was scrutinized using the Absolute Open flow potential (AOP), Productivity Index, Drawdown, Completion efficiency, sand control efficiency etc as indices. These parameters were compared to an ideal well condition presumed to be a case of a wholly open hole production with zero skin. To make this comparison, well models were built in the Petroleum Experts Software PROSPER Software. From the results, it was established that the wire wrapped screen offered very little impedance to flow resulting in almost 100% efficiency. The gravel pack completion also proved beneficial as efficiency was at 82%. However, the slotted liner produced below performance with an efficiency of 7%. Further sensitivity analysis was carried out for the slotted liner to discern if the poor efficiency was due to slot dimensions. Results indicated that for the Niger delta well studied, the slotted liner was generally unsuitable irrespective of selected slot dimensions.*
Keywords: Performance, Sand control, oil reservoir, Techniques, Production and Prosper Software.

INTRODUCTION

The production of formation sand into a well is one of the oldest problems plaguing the oil and gas industry because of its adverse effects on well productivity and equipment. It is normally associated with shallow, geological young formations that have little or no natural cementation to hold the individual sand grains together. Therefore, when the wellbore pressure is lower than the reservoir pressure, drag forces are applied to the formation sands because of fluid production [1].

Sand control refers to managing or minimizing sand and fine production during petroleum production. Sand and fine produced with oil and gas can cause erosion and wear of production facilities/equipments, resulting in production downtime, expensive repairs and potential loss of containment. For normal flow of oil, formation should be porous, permeable and well cemented together, so that the large volumes of hydrocarbons can flow easily through the formations and into the production wells. Unconsolidated sandstone reservoirs with permeability of 0.5 to 8 Darcies are most susceptible to sand production. Sand production (or sanding) is the production of the formation sand alongside with the formation fluids (gas, oil and water) due to the unconsolidated nature of the formation. Produce sand has essentially no economic value [2]. On the contrary, formation sand does not only plug wells to reduce recovery rate it also erode equipment and settles in surface vessel. Controlling formation sand is costly and usually involves either slowing the production rate or using gravel packing (mechanical method) or sand-consolidation technique (chemical method). As a result of this, sand production is a major issue during oil and gas production from unconsolidated reservoirs. It effect is a peculiar problem of the Niger Delta Oil province which describes the Niger Delta as complex and its geology.

There have been several studies on sand control methods using laboratory experiments, theoretical modeling and field observations [3] conducted laboratory experiments in which sand failure was observed for near cavity effective stresses above a certain threshold independent of applied drawdown. The result led to the conclusion that cavity failure under compression or tension stress in most cases depends only on cavity size and not on near-wellbore stress or drawdown. Sand prediction tools based on theoretical modeling include the works of [3].

Sand production is a common occurrence in the Niger Delta Oil and Gas reserves because the reserves are located within the tertiary Agbada sandstones and the upper Akata formation [5]. When hydrocarbons are produced from the reservoir solid particles sometimes follow the reservoir fluid into the well. This unintended solid particle produced alongside with well fluid is what is termed sand production.

Sand control is the method or technique used totally to prevent the production of sand entering into the well bore [6]. This has been a major problem in the oil and gas industries for many years. A lot of work has been done in the past years by researchers to see how sand production can be minimized. To some extent, some of the methods have proved successful while some unsuccessful. The two most common and widely used methods for prevention of sand from entering into the well bore are the gravel pack method (open or closed hole) and chemical method (SCON) of sand control

[7] in his work sand control completion reliability and failure rate comparison with a multi-thousand well database concluded that in broad terms, face packs appears to work better on layered or laminated, lower permeability (< 100 to 00 mD) formations with reasonably vertical well bore sections across the pay zone another large part of the success was that the flow in a fracture may, at least slightly spread out the high flux inflow from a high permeability streak, decreasing the local flux rate on the screen and lessening erosion by fluids and by mobile fines. Also he said that in high formations and especially in highly deviated wells with large reservoir contacts in block sands, the openhole gravel packs appear to reliably deliver high rates with relatively low failure. One key to OHGP performance may be the very large wellbore flow area of the OHGP – theoretical 100% of wellbore compare to theoretical 4 to 8% open entrance hole area in a cased and perforated completion. Horizontal wells are high-angle wells (with an inclination generally greater than 85^o) drilled to enhance reservoir performance by placing a long wellbore section within the reservoir [8]. Horizontal drilling is considered an effective reservoir development tool. The advantages of horizontal wells include [9]:

Reduce water and gas coning because of reduce drawdown in the reservoir for a given production rate, thereby reducing the remedial work required in the future.

Increased production rate because of the greater wellbore length exposed to the pay zone.

Reduce pressure drop around the wellbore.

Lowers fluid velocities around the wellbore.

A general reduction in sand production

Lager and more efficient drainage pattern leading to increased overall reserves recovery [10].

Producing from a horizontal well is a technology that has to be mastered [11]. Horizontal and multilateral wells, as opposed to the conventional vertical wells, have proven to reduce coning problems and improve recovery in thin oil rims.

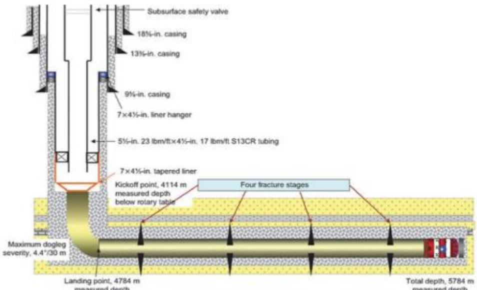

Figure 1: A Horizontal Wellbore Section [12].

Production increases of 2-5 times those of vertical wells have been observed, and horizontal wells are now accepted as the better way to improve recovery [13]. This improved performance is attributed to:

smaller drawdowns, which reduce coning effects,

Enlarged contact and drainage areas, and

Improved sweep, production rates, and recovery efficiencies.

The production strategy for horizontal wells in a thin oil column is normally to place the well near the gas-oil-contact and allow the aquifer to drive the oil upwards to minimize the loss of oil [14].

MATERIALS AND METHODS

Materials

Data Collection and Analysis

For the purpose of this work, production profile and data for three (3) oil wells in the Niger Delta will be procured and used for the analysis.

Data Preparation

The Data Preparation basically involves, as accurate as possible, a Quality Assurance and Quality Check to ensure the data meets expected production trend and behaviors and is devoid of unexplainable gaps.

Data Presentation

Prior to the analysis, production history plots, oil and sand included, will be prepared and presented. The essence of this would be to ascertain the present scenario prior to subsequent analysis and preferment of solutions.

Data Analysis

The data analysis would involve a preliminary analysis prior to the final/conclusive analysis.

Preliminary Analysis

The aim of drilling an oil well is primarily to transfer the oil from the bottomhole to the surface. Achieving this target requires that the well must be able to

First allow the inflow of oil from the reservoir. This function is represented by the Inflow Performance Relationship (IPR) characteristic of the well.

Secondly, transfer the oil from the bottomhole to the surface. This defines the

Vertical Lift Performance (VLP).

This must be achieved at an economic, safe and technically feasible manner. Hence, for this research, prior to the sand production analysis, a preliminary analysis of the IPR and VLP trend of the selected wells will be examined. Different IP and VLP models will be tried on the data to get an adequate fit. Bottlenecks attributable to other well components or condition will be isolated so as to absolutely account for the impact of the sand production on oil well performance. Furthermore, the economic status of the wells will be studied and established.

Final Analysis

In this phase, different sand control mechanisms will be investigated. Their applicability to each of the wells will be discussed. Subsequent analysis would involve deducing their impact technically (in terms of incremental production) and economically (relating to cost associated to achieving the incremental production).

The steps of what is to be done here is as follows:

i. Establish the incremental oil achievable using the sand control technology ii. Estimate the duration or extension in the well's lifespan and the production profile over time. Here, the aim is not just to ascertain the incremental oil but also the duration and cumulative production achievable from the use of this technology iii. Perform an economic analysis of the use of the selected technology. Its capital and operating cost requirement will be compared to the increase in net cash inflow attributable to the incremental oil achieved from the use of the technology.

Performance Measurement and Appraisal

The performance of the sand control technique will be ascertained via the use of certain well performance indicators, compassed towards the impact of the sand control method.

Some of the well performance indicators to be used are presented in the ensuing sections.

Technical Indicators

Well Inflow Quality Indicator (WIQI)

This is a diagnostic parameter which gives an indication of how good a well was completed initially, after work over, stimulation. This is obtaining by carrying out Bottom Hole Pressure (BHP) survey immediately after completion work or re-entry. The well inflow quality indicator is determining by comparing the actual productivity index (PI_{actual}) from BHP survey to the ideal productivity index (PI_{ideal}) and it is expressed as

$$PI^{actual} - WIQI = PI^{ideal} \qquad (1)$$

The WIQI is an important factor in measuring how good a well is producing, the greater the WIQI the better.

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Productivity Index

This is the relation between the flow rate and pressure drawn down, and it is expressed as:

$$PI = \frac{q}{PRxP_{wf}} \qquad (2)$$

From Darcy's Flow Equation

$$Q = \frac{7.08\,x10^{-3}Kh(P_r - P_{wf})}{\mu_o B_o In\left(\frac{r_e}{r_w}\right)} \qquad (3)$$

Where:

Q = Flowrate, bbl/d

K_o = Oil permeability, md

h = Net oil sand thickness, ft

P_r = Reservoir pressure, psi

Pwf = Flowing wellbore pressure, psi

μo = Oil viscosity, CP

B_o = Oil formation volume factor, bbl/stb

r_e = Drainage radius, ft

rw = Wellbore radius, ft

Substitute 3.2 into 3.1 we have:

$$PI = \frac{7.08\,x10^{-3}Kh(P_r - P_{wf})}{\mu_o B_o In\left(\frac{r_e}{r_w}\right)} \qquad (4)$$

Equation 3.4 is the ideal PI for an oil well.

The PI may be used to predict the inflow performance of well; the higher the PI, the better the flow performance.

Sand Cut

Whatever sand exclusion method that is adapted, it cannot be guaranteed that they will work indefinitely. Consequently, it is essential that the sand content of the produced fluids be monitored so that if a well starts producing sand it can be shut-in before subsurface or surface equipment becomes blocked or damaged. Sand production monitoring can be achieved using a batch system of measurement, a sand probe or downhole sand detection system. The sand cut (Ib of sand produced/1000bbl) will be graphed against time (in years), prior to and following the application of each treatment. Projections will be made based on sand production models fit to the production history accordingly.

Methods

Steps for Building Prosper Model

The Well model for the sand control analysis and comparison was built using the IPM Prosper ® 11.5 well performance software.

Three sand control methods were compared:

i. Gravel Pack ii. Wire – wrapped sand screens iii. Slotted liner

Data Source

A well was selected from a field in the Niger Delta for this analysis and production data for this system analysis were obtained from a company's well report profile. In reviewing the data, identification of existing problems is crucial in making the best decision with regards to selecting and choosing well candidate.

Well Description

The well selected for this study is located onshore of the Niger Delta area of Nigeria. For research purpose the well is designated as "Y – 04", but due to company rules and regulations, other information about the well were not released. Using the available reservoir data, fluid, PVT data, knowledge of the well geometry and data from well test, it is requiring to model an optimum completion design to be imposed on the well to
incremental oil production.

System Information

Within the system summary, the well completion (i.e.., sand control) approach to be followed is selected.

Table 1: System Information

Fluid	Oil and Water
Method	Black Oil
Seperator	Single stage seperator
Emulsions	No
Viscosity Model	Newtonian fluid
Flow type	Tubing flow
Well type	Producer
Completion	Cased hole
Gas coning	No
Inflow type	Single branch
Artificial lift	None

PVT Modeling

For the PVT modelling, the Glaso correlation was selected for the Bubble point pressure (P_b), Solution GOR (R_s) and Oil Formation Volume Factor (Bo). The choice was based on the correlations' performance for Niger Delta fields. However, absence of PVT Laboratory data to affirm this applicability remains a restraint on the acceptability of this proposition.

Table 2: PVT Input Data

Parameter	Value
Solution GOR	510 SCF/STB
Oil Gravity	0.91
Gas Gravity	0.62
Water salinity	0.0

Inflow Performance Relationship (IPR) Modeling

The Productivity Index (PI) entry option was selected for the reservoir model.

Table 3: Reservoir Data

Parameter	Value
Reservoir Pressure	3105 Psia
Reservoir Temperature	154^0F
Water Cut	0.0
Total GOR	510 SCF/STB
Relative Permeability	No

The Productivity Index was given as 2.27 STB/day/psi.

Downhole Equipment

The subsurface configuration of the well is set up as follows.

Table 4: Downhole Equipment Data

Type	Measured Depth (ft)	Tubing Inside Diameter (Inches)	Tubing Inside Roughness (Inches)	Casing Inside Rough-ness (Inches)	Casing Inside Diamter (Inches)	Rate Multipler
Xmas tree	0					1
Tubing	120	1.991	0.0006			1
Restriction		1.75				1
Tubing	8288	1.991	0.0006			1
Casing	8289			0.0006	6	1

Temperature Gradient

The well temperature profile was setup with the associated heat transfer coefficients as follows

Table 5: Formation Temperature Information

Formation TVD (ft)	Formation Measured (ft)	Formation Temperature ^{0}F	Heat Transfer Coeffiicent (BTU/h)
0	0	82	3
8285.38	8289	154	8

The Specification for the Different Sand Control Techniques used are shown in the Tables below:

Table 6: Specifications for Gravel Pack Installation

Method	Darcy
Gravel Pack Permeability	5000 mD
Perforation Diameter	0.5 inches
Shots per foot	12
Gravel Pack Length	2 inches
Perforation Interval	83 feet
Perforation Efficiency	0.8

Table 7: Details of the Wire Wrapped Screen

Method	Darcy
Reservoir Thickness	83 feet
Reservoir Permeability	500 Md
Production Interval	83 feet
Wellbore Radius	0.333 feet
Screen Outer Radius	0.1 feet
Outside Permeability	-
Outside (Turbulence)	4.217e.13 1/ft

Table 8: Slotted Liner Specifications for Prosper ® Simulation

Method	Darcy
Reservoir thickness	83 feet
Reservoir permeability	500 md
Production interval	83 feet

Wellbore Radius	0.333 feet
Linear inner Radius	0.2 feet
Liner Outer Radius	0.3 feet
Slot Height	2 inches
Slot width	0.025 inches
Slot Density	4 1/ft
Screen Outer Radius	0.1 feet
Outsides Permeability	-
Outside (Turbulence)	4.217e.13 1/ft

RESULTS AND DISCUSSIONS

Within this section the performance for the three (3) sand control mechanisms selected are compared. The methods used are the Gravel Pack, wire wrapped screen and slotted liner. For each case, a well model was built within Prosper with adequate PVT, IPR and VLP models' match.

Performance Analysis

Case 1: Naturally Flowing Well

The case 1 assumes the well to be completed without any sand control technology installed. This implies a cased and perforated hole with no mechanism to hold back the fines from migrating. Although damage will be inevitable, skin due to the sand control mechanism would actually be eliminated, yielding higher flow rates particularly at the start of the well.

Setting the top node pressure (wellhead pressure) to 100psig and resolving the total well system produced the system plot and solution shown in Figure 2.

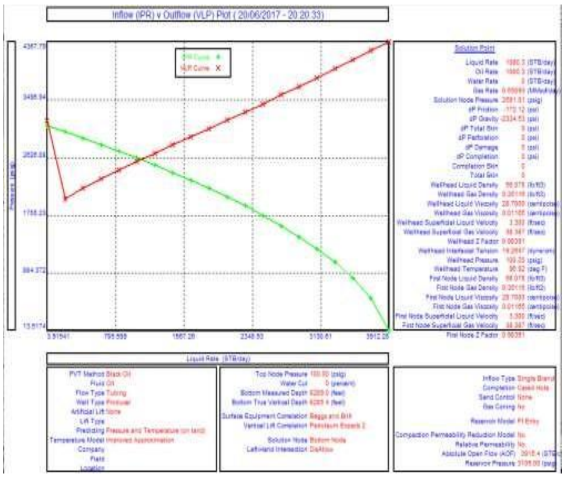

Figure 2: IPR versus VLP System Plot for a naturally flowing well

Figure 2 shows that in the absence of any sand control method, the well can deliver 1080.3 STB/day.

Case 2: Gravel Pack

With a gravel pack installed, fines migration is impeded. But the area open to flow is also simultaneously reduced resulting in the skin due to completion. The details used to run the simulation for the gravel pack setup is given in Table 1.

Figure 3 depicts the system plot obtained from the well model with a gravel pack installed.

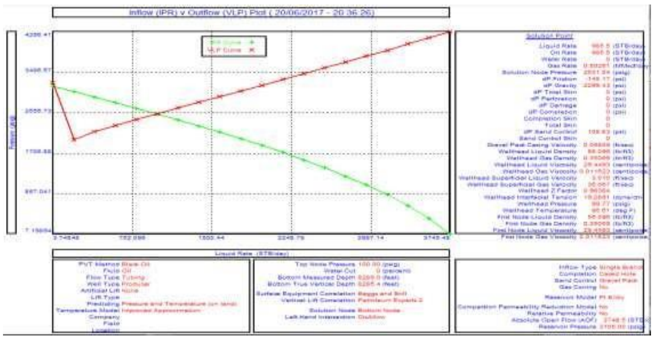

Figure 3: IPR Versus VLP System Plot for Well 1 with Gravel Pack

From Figure 3, the well's Absolute Open Flow Potential (AOF) will be 3748.5 STB/day. The intersection of the IPR and VLP yielded a flow rate of 985.5 STB/day. This value is below the naturally flowing well rate of 1080.3 STB/day implying that the impedance to flow caused by the gravel pack overwhelms the advantage created by the impedance of fines migration. However, it is important to understand that the reason for the installation of the gravel pack is not to increase or maintain the flow rate, but primarily to prolong the lifespan of the well by reducing the loss of well components due to sand issues.

Primary factors that might influence the flow rate obtained include the gravel pack and perforation characteristics. To ascertain the impact of these on the results, a sensitivity study is performed. Figures 3 and 4 depicts the sensitivity of the system to changes in gravel pack permeability and perforation density respectively.

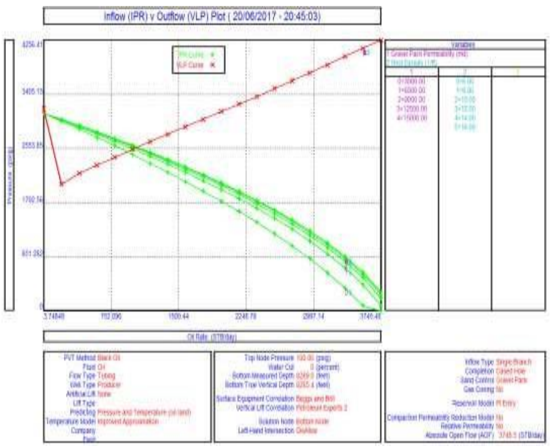

Figure 4:Sensitivity of System to changes in Gravel Pack Permeability

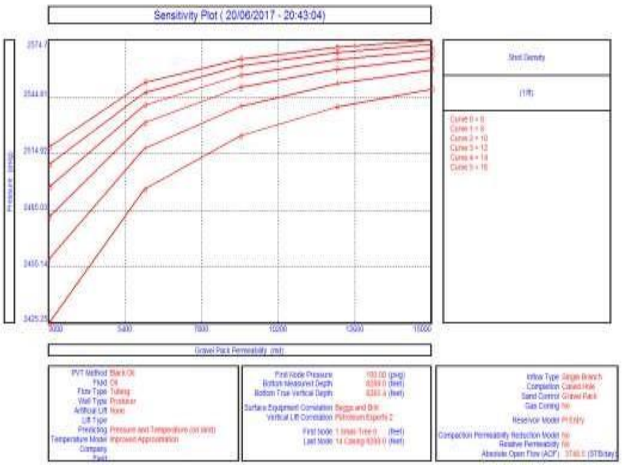

Figure 5: Sensitivity of System to Changes in Perforation Shot Density

It is important to note that changes to these elements affect the flow rate by altering the IPR. This is because they are components of the inflow equation and not the outflow equation.

Case 3: Wire Wrapped Screen

For the case of sand control with the wire wrapped screen, the details of the sand screen are given in Table 5.

Using the wire wrapped sand screen leads to the creation of the system plot depicted in Figure 6.

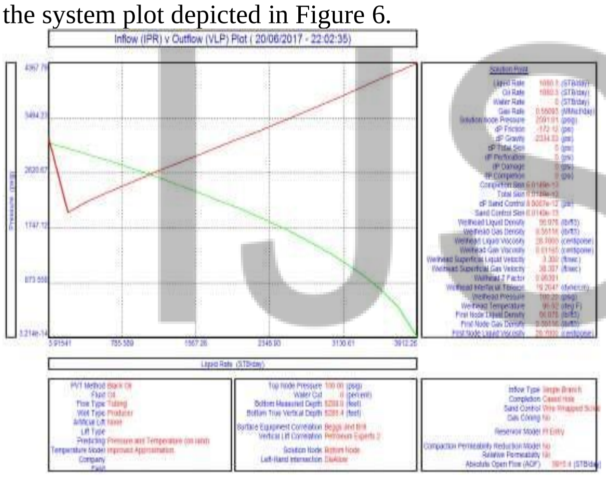

Figure 6: IPR Versus VLP System Plot for Well 1 with Wire Wrapped Screen

Figure 6 shows that the flow rate of 1080.3 STB/day can be maintained with a wire wrapped screen installed. This implies that the wire wrapped screen would not reduce the well potential. Its lifespan as a sand control technique has often been called into question. However, the advantage it offers in terms of the ease of intervention and work over operations has been a major motivation for its continued use.

Case 4: Slotted Liner

Table 9 shows standard slotted liner dimensions.

Table 9: Standard Slot Width and Length Guide

1.5" Long	2.0" to 2.5" Long	2.5" Long
0.0'2" wide	0.024" wide	0078" wide
0.0'5" wide	0.025" wide	0.078" wide
0.0'6" wide	0.038" wide	0.125" wide
0.0'8" wide	0.048" wide	0.250" wide
	0.058 wide	

For this study, the more common 2" long and 0.025" wide slot is selected. The details from prosper that displays the setup parameters used for the slotted liner simulation run are shown in Table 8.

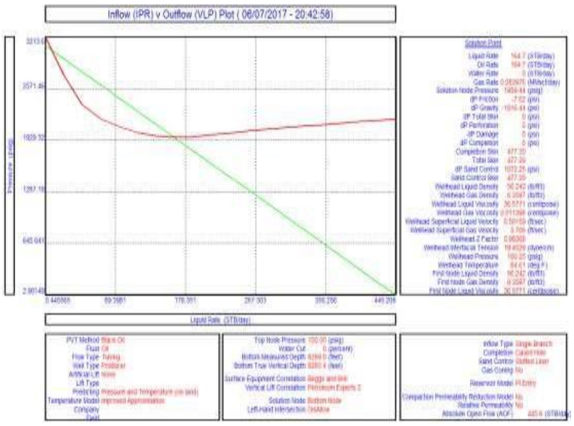

Figure 7: IPR versus VLP System Plot for well 1 with Slotted Liner

This shows that the slotted liner impedes flow the most with the flow rate reduced to a meager 164.7 STB/day. However, the result is highly sensitive to the slot dimensions as can be seen from the sensitivity plot shown in Figure 4.9.

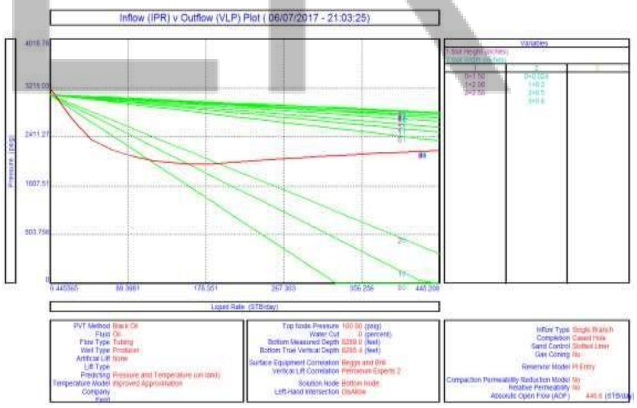

Figure 8: Sensitivity of IPR and VLP to Changes in Slot Height and Width

The major limiting factor to this technology is the tubing potential defined by the vertical lift performance (VLP). Figure 9 shows that the higher slot dimensions produce IPR curves which may never intersect the VLP. This implies that the slotted liner is not a good option for this well.

Performance Comparison

To compare the performance of the three sand control methods, the flow rate, Absolute Open Flow Potential and Sand control efficiency will be used. Taking the flow rate obtained from case 1 (natural flowing well) as the ideal rate, we can estimate the sand control production efficiency with either of the three (3) cases.

Table 9: Performance Parameters for the Select Sand Control Mechanisms

Solution Node Pressure	2591.01	2531.04	2591.01	1959.44
Reservoir Pressure	3105	3105	3105	3105
Absolute Open Flow	3915.4	3748.5	3915.4	445.6
Liquid Rate	1080.3	985.5	1080.3	164.7
dP Sand Control	0	108.83	8.87E-12	1072.25
Sand Control Skin	0	0	6.01E-13	477.2
Drawdown	513.99	573.96	513.99	1145.56
Productivity Index	2.10	1.72	2.10	0.14
Sand Control Production Efficiency	1.00	0.82	1.00	0.07

Figures 8, 9 and 10 depict the plot of these performance parameters for each case considered.

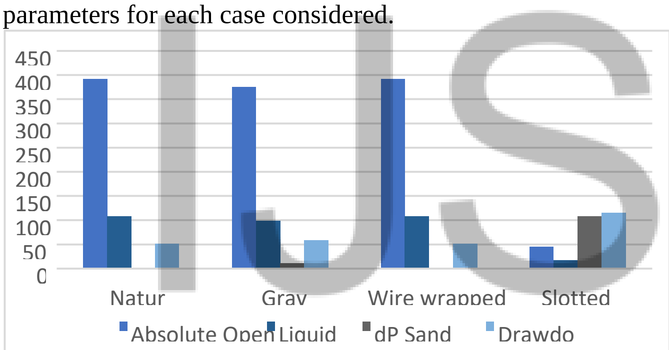

Figure 9: Comparison of Select Production Parameters for the different Sand Control Mechanisms

As can be seen, the wire wrapped screen showed the best performance whereas the slotted liner had the least performance, generating a lot of drawdown, which would eventually lead to sand breakthrough or plugging of the slots, with a massive decline in both the absolute open flow potential and flow rate. This same trend is observed in Figure 11 in which the Productivity Index of the slotted liner is the least amongst all options considered.

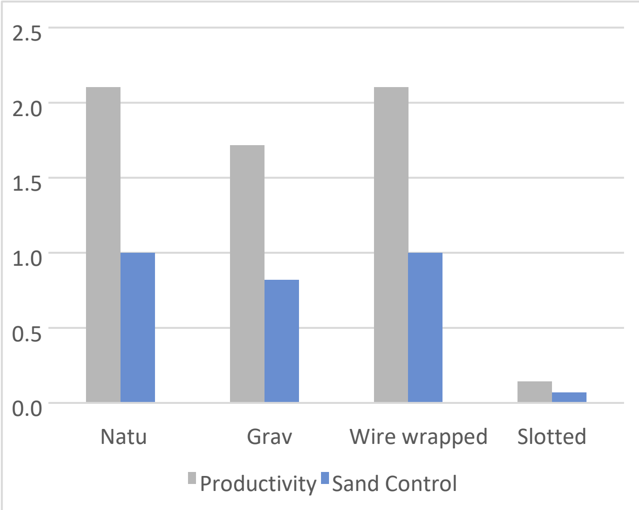

Figure 10: Comparison of Another Set Select Production Parameters for the different sand Control Mechanisms

This also led to correspondingly low sand control production efficiency.

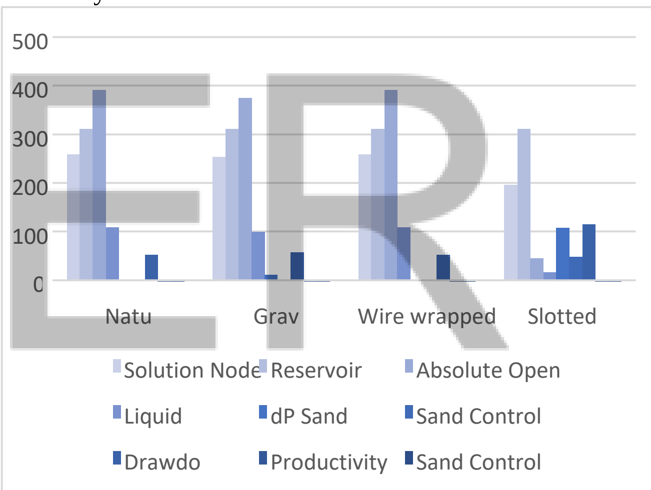

Figure 11: Comparison of All Production Performance Parameters for the different Sand Control Mechanisms

CONCLUSION

The importance sand control Technologies on the integrity and life span of oil and gas production systems has long been recognized. They form a part of the broader Integrated Production System Modeling and Analysis. Neglect of this aspect of the production system analysis could be disastrous as sand production could directly impede production, render a project economically unviable or shorten the life span of the well through erosive actions or sand-out impacts.

In the Niger Delta, reservoir is mainly of the unconsolidated sandstone class. This renders the use of sand control technologies in well completion design and operations somewhat inevitable. Consequently, adequate preliminary studies are often conducted to ascertain the impact of the selected sand control method on the well performance. This study has presented a comparison of different sand control technologies as applied to a Niger Delta Oil Well.

The technologies considered were the Gravel Pack, Wire wrapped sand screen and slotted liner. Performance indices adopted to scrutinize the performance of the well under each of these technologies include Absolute Open flow potential, Productivity Index, Drawdown, Completion efficiency, sand control efficiency etc. these parameters were compared to a case of a wholly open hole production with zero skin, an ideal well condition. To make this comparison, well models were built in the Petroleum Experts Software PROSPER.

From the result, it was established that the wire wrapped screen offered very little impedance to flow resulting in almost 100% efficiency. The gravel pack completion also proved beneficial as efficiency was at 82%. Whereas the slotted liner produced the worst performance with an efficiency of 7%. Further sensitivity analysis was carried out for the slotted liner to discern if the poor efficiency was due to slot dimensions. However, the analysis showed little improvement in production parameters even after increase in the slot dimensions. The exact cause of the poor performance from the slotted liner remains unclear.

Summarily, it was ascertained that the Wire wrapped screen offered the best performance, though the lifespan of the screen could be called into question.

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