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Enhanced Recovery of Heavy Crudes in the Niger Delta: Chops Application A Key Option

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ABSTRACT

Cold Heavy Oil Production with Sand (CHOPS) is one of the key techniques employed for primary heavy oil production. It has gained wide application with great success to enhance heavy oil production in countries like Canada, China, Venezuela, California, USA and Kazakhstan. In order to investigate the productivity of CHOPS technology in the Niger Delta Oil field of Nigeriaa, aanalysis was performed on data collected for five reservoirs, in which comparison was made between the natural case and the artificial case of Progressive Cavity Pump (PCP), all without sand proof technology. The fluid flow for each case was modelled with PROSPERS, in order to ascertain the quantity of fluid (heavy oil) that could be producible. An inflow performance curve (IPR) was obtained for each case, IPR versus VLP curves were equally obtained. From the study it was discovered that, heavy oil with 18.07 to 22.14^o API can be produced naturally but higher rates are obtainable with CHOPS. This is because the oil viscosities were between 100cp and 102cp. In addition, the corresponding sand productions were estimated with a mathematical model, and sand management in CHOPS were also discussed. With the favourable attributes of heavy crudes in the Niger Delta Oil Field of Nigeria, it is evident that the application of CHOPS would be a great success.

Keywords: Production, Sand, Recovery, Heavy-Oil.

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INTRODUCTION

Over 6 trillion barrels of heavy oil are present on Earth, compared to 1.75-2.3 trillion barrels of conventional oil, of which about 40% has already been produced (Smalley, 2000). The majority of heavy oil deposits are found in two countries; Canada, in its Albertan oil sands, and Venezuela, in its Orinoco belt. Nigeria however has heavy oil reservoirs with abundant reserves. Heavy oil is primarily defined as petroleum–like liquids and semi-solid petroleum less than 22°API gravity, and viscosity of the range between 100-10000cp that occur in porous formations mainly sands and little carbonates, at reservoir conditions. According to Farouq Ali (1997), most heavy crudes exist in shallow depth (3000ft or less), high permeability (one to several Darcies), high porosity (around 30%), unconsolidated sand formations.

The density (specific gravity) of heavy oil is equal or greater than that of water but less than 22^{o}API. As a result, they cannot be extracted, refined and transported by conventional methods. For instance, Chuks (2010) stated that Oloibiri field started oil production between late 1957 and early 1958, and the first oil production from the field came at the rate of 4928 barrels per day. The field produced at an average rate of 5100 barrels of oil per day for the first year. The production increased thereafter as more wells were completed and put onto production and reached its peak in 1964. The field was drained from eleven production wells. The oil produced from the field is sour and heavy and has an API of 20.6^{o}. Oil production finally stopped in 1978 and the field was abandoned that year because they could not embark on appropriate technology for enhanced recovery of the heavy crudes present.

Owing to its high viscosity, the primary recovery factors for heavy oils are generally low. With careful design and implementation, various thermal recovery schemes can enhance production, but high operational cost restricts their applicability. In recent times, the introduction of cold production technologies gives a promising future to the development of heavy oil reservoirs. Heavy oil cold production technologies nearly have no restrictions, and the production cost is extremely low, these technologies can be intensively applied to the exploitation of heavy oil reservoirs. Kobbe (1917) reported that though it has long been recognized that the maximum recovery of oil from an unconsolidated sand is directly dependent upon the maximum recovery of the sand itself, (CHOPS) was not widely implemented with commercial success until advanced pumping systems (such as the progressive cavity pumps) were perfected in the late 1980s for slurries containing sand. Since then, because of reasonable recovery factors (approximately 15- 20%), production rates (20-300 bbl/day), and effective sand handling and disposal, CHOPS has grown in application. Issues relating to sand in the fluids, pumping, separation, transportation and disposal have been solved by utilizing the produced sand mixed with asphaltenes for road construction.

The aims of this study are:

- To identify some heavy oil reservoirs present in the Niger Delta of Nigeria.
- To predict the incremental oil production for a given amount of produced sand.
- To compare the increment in heavy oil production with CHOPS relative to the conventional oil production techniques.
- To identify an effective method of produced sand disposals from heavy oil reservoirs.

CHOPS Technology

Cold Heavy Oil Production with Sand (CHOPS) is defined as quasi primary heavy oil production which involves intentionally urging of sand influx into a perforated oil well and substantial production of sand along with the oil for long period of time. It can take several years of production depending on the producing company. Schaefer (2010) in his work, averred that cold simply means non-thermal method, no heat is applied to initiate flow. Thackey (2011) said that CHOPS technique utilizes progressive cavity pump, an auger device, installed in the well to create enough pressure to draw sand out of the formation to create fissures allowing the heavy oil to flow. A progressive cavity pump can also be installed in a horizontal producing well to aid production. CHOPS can be very effective, even in thin beds where other methods are inefficient but the application requires a good understanding of the production mechanisms based on operational experience. This understanding must include the consequences of high levels of sand production and the fact that very high drawdown can lead to water production, which will reduce recovery

According to Thackey (2011) Progressive Cavity Pump (PCP) systems are generally the preferred method for lifting cold viscous, sand laden fluids. It is equally a positive displacement pump with a helical metal rotor which rotates in an elastomeric stator. The elastomeric stator is attached to metal tubing. In its most basic form, the rotor has a single helical shape and the stator has a double helical shape. The eccentric motion of the rotor turning inside the stator provides a series of sealed cavities between the stator and rotor. The close fit of the rotor and the viscosity of the fluid help to provide a seal. The fluid progresses from the intake to the pump discharge, which is connected to production tubing. The pump displacement rate is proportional to the rotational speed of the rotor and the differential pressure across the pump. PCP's are usually driven by "top-drive" systems attached to the top of the wellhead, using hydraulic or electric power to turn the rod string. Bottom-drive systems using modified Electric Submersible Pump (ESP) components have also been developed to drive the PCP system, thus eliminating the rod string and problems associated with top-drive systems in highly deviated wells. In some cases bottom drive systems enable higher production rates than top-drive systems. The figure 1 shows the PCP.

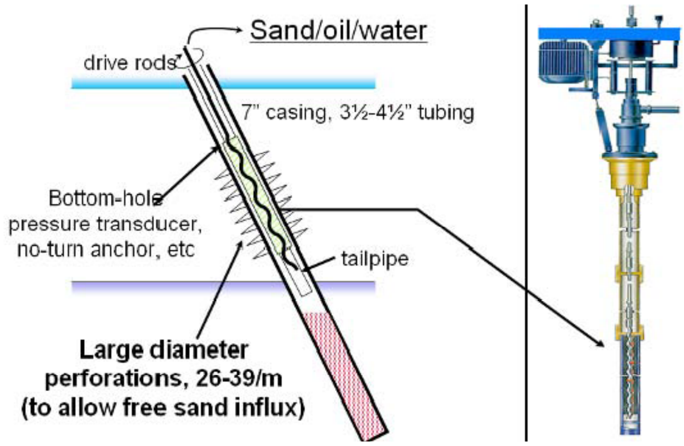

Figure 1: CHOPS WELL SCHEMATICS AND DRAWING OF PCP (SOURCE:DUSEAULT, 2008a)

Effects of Wormholes Creation

Lines (2007) pointed out that, Researchers have shown that pumping out sand opened wormholes in the sand formation, allowing more oil to reach the borehole. Wormholes are permeable sand tubes of very high porosity which extend out from the borehole. The simultaneous extraction of oil and sand generates high porosity channels termed "wormholes". It is believed that the wormholes play an important role in heavy oil production due to their permeability effects in the heavy oil reservoirs. The development of wormholes causes the reservoir pressure to fall below the bubble point, and the dissolved-gas comes out of solution.

Mechanisms of CHOPS

Smith (1986) observed that because of several unique characteristics of unconsolidated heavy oil reservoirs, well productivity may be between 10-20 times higher in CHOPS wells than predicted by conventional Darcy's law flow equations. The mechanisms responsible for the enhanced production rate in CHOPS as reported by Dusseault (1999); Chalaturnyk (1992); Geilikman (1997) are;

- Porosity and permeability are enhanced as sand is removed from the formation, along with any mechanical skin that may have being developed;
- The oil flow velocity relative to fixed coordinates is increased if the matrix is partially mobilized; therefore production rate increases, as predicted from Darcy's law;
- Foamy oil behaviour, where solution gas stays as bubbles and a continuous gas phase does not form, thus contributing to flow enhancement;
- Increased compressibility and porosity dilation occur, leading to easier formation compression and compaction drive; and,

•Sand removal leads to vertical stress concentrations and lateral stress reductions, causing shear dilation, continued sand destabilization, and plastic extrusion of sand to the wellbore. From experimental evidence, Vaziri and Lemoine, (2000) reported that the first two mechanisms could increase the oil flow rate by as much as 5 to 50 times.

Mechanisms of Massive Sand Production in Heavy Oil

Dusseault (1997) averred that, since the initiation and maintenance of continuous sand production involves aggressive perforation strategies, the use of progressive cavity pumps, and novel work over techniques should be employed. Hence maintaining sand production after initiation means dealing with large initial sand/fluid ratios for several weeks, and smaller sand/fluid ratios for many months or years. Therefore the oil rate augmentations arise as a result of sand mobility, growth of high permeability region, skin positive effects.

According to Bratil (1998) and Dusseault, (1989) sanding is not automatically a negative factor in oil well management. Negative facets of sanding are measured to be steel goods erosion (safety), casing stability impairment, and separation and disposal requirements. However, the positive aspects include: reduced completion costs, improved production rates, and continued improvements in Productivity Index through the destruction of skin effects. The derivable benefits include; elimination of expensive gravel packs, well cleans up at the same time, and finally the elimination of expensive workovers to get rid of scales. The major driving forces that are responsible for initiation of sand influx include: gravitational force, natural fluid pressure gradient and foamy oil flow phenomena.

The behaviour of CHOPS well is well known (Dusseault, 2007); the distinctive feature of this process being foamy oil drive with the intentional production of sand. Sand production continually increases well productivity for the first few years, in contrast to conventional wells in which productivity is highest at the onset. Initial sand flux is very high, perhaps exceeding 25%/vol, declining to a steady-state value, about 1.5%/vol within weeks or months.

Sand Disposal Methods

Disposal options of sand produced from CHOPS according to Dusseault (2001) include ;

- Road spreading. - Heavy oil industry was given permission at an early stage to spread oily produced sand on roads. The produced sand is taken from company stockpiles and transported to the road to be used for spreading and placed in a layer.
- Sand Incorporation into Road Bases.- some produced sand and other oily solid waste materials that cannot be spread on road surface, can be used as part of road base materials when new roads are built.
- Land Spreading. – This usually involves the dispersal of wastes in a field or non-cultivated land. This land must be approved before usage.
- Permanent Landfill Placement. - Here an approved landfill is meant for disposal. The technology is too straight forward and surface facilities are low technology but the danger of potable aquifer might become contaminated in the future.
- Salt caverns. - This is most preferable method of sand disposals because of its extremely low permeability and the tendency of the salt carven to close.

MATERIALS AND METHODS

Data Were Collected from reservoirs in the Niger Delta Oil Field. Five(5) heavy oil reservoir data were collected from the region. The field is located about 45miles (72km) East of Port Harcourt and has depth that ranges between 4170ft -7872ft, all in a bounded or infinite reservoirs. The gravity of oil ranges from 10.14 – 22.64^{O}API, porosity ranges from 20-30% and permeability is about 900md to 1500md. The gas oil ratios lie between 50-490, and gas gravity is in the range of 0.6-0.65. The apparent bubble point pressure was determined to be within 20% of the original reservoir pressure, suggesting that the reservoir contained enough solution gas to sustain primary cold production. Table 1 contains the full details of the data collected.

Table 1: Details of reservoir data used in the analysis

s/n	OWC ft	GOC ft	Press psia	BP psia	Rsi scf/b	Temp deg/f	S.G oil	Oil cp	GOR Scf/b	API°
1	6518	6408	2794	541	61	128	0.946	86.75	50	18.08
2	7872	7720	3384	1515	189	164	0.923	4.76	150	21.80
3	4239	4170	1816	164	56	113	0.939	31.81	50	19.19
4	4741	4670	2033	362	180.7	122	0.940	25.49	50	19.03
5	6028	5995	2612	1212	247	127	0.921	29.31	235	22.14

Modelling of Heavy Oil Wells

PROSPER was used to model the rate of flow of oil wells. During this process, simulations were done on the selected five reservoir data. The PVT laboratory data were matched using black oil models: the best correlation was chosen. PI entry model of unity was used and the well performance was then evaluated.

Design for Natural Flow of Heavy Crudes using Prosper software

This scenario involves the prediction of flow rates of the five heavy oil reservoirs- that is obtainable when the well is allowed to flow naturally.

Several steps that were taken include; Pressure Volume Temperature (PVT) matching, Inflow performance relation (IPR) matching, IPR and VLP matching using PI entry model of unity, Correlation that best explains PVT and IPR/VLP matching were selected, details of solution including the oil rates, gas rate and mass flow rates were taken, as well as Absolute Open Flow (AOF) for each case was recorded. The schematic representation of completion designs for natural flow is presented in figure (2).

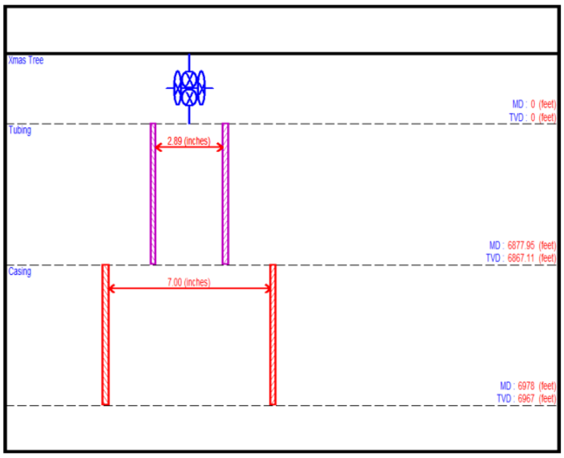

Figure 2: Schematic Representation of Completion Designs for Natural Flow

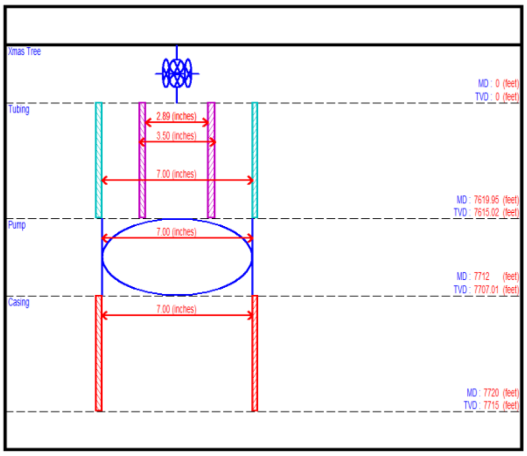

Figure 3: Schematic Representation for Completion Design of Articial Lift (PCP)

Table 2: Input Parameters for Different Cases

Parameters	Case1	Case2	Case3	Case4	Case 5
Oil Viscosity(cp)	86.75	4.76	31.81	25.49	29.31
Pay ZoneThickness(Ft)	110	152	69	71	33
Fluid Density(lbs/cuft)	59.03	57.59	58.59	58.57	57.47
Sand Radius(microns)	1000	1000	1000	1000	1000
Sand Density(lbs/cuft)	165.34	165.34	165.34	165.34	165.34
Arch Cavity(Ft)	10-30	10-30	10-30	10-30	10-30

Progressive Cavity Pump (PCP) Design Flow for Heavy Crudes using Prosper

Design of a progressive cavity pump for the oil wells were carried out so as to improve the oil production from the natural flowing scenarios. Table 2 shows the pump data used in the analysis and the schematic representation for completion design of artificial lift (PCP) is shown in figure 3.

Sand Production Estimation

This is necessary since the amount of sand recovery at the surface accounts for quantity of fluid to be obtained. Isehunwa and Olanrewaju (2010) in their work proposed an equation most suitable for sand prediction in the Niger Delta. Expected cumulative oil to be produced obtained from the PROSPER is substituted in the sand mass equation stated below, this solves the radius of cavity as;

$$Ra = \frac{Q_f U_f}{\frac{4}{9} Rs^2 \pi H \rho_f g} \qquad 1$$

Thus, the sand produced can be expressed in volume as:

$$V_{sp} = \pi R^2 H \qquad 2$$

Or, in weight as:

$$S = \rho_s V_{sp} \qquad 3$$

Equation (1) is a simple analytical model which can be combined with equation (2) and (3) to predict sand production in a well. It is similar to the Bratil-Risnes model given in equation (4), and it shows that flow rate, fluid viscosity, grain size, grain density and cavity height are key factors of sand production.

$$R_a = \frac{Q_f U_f}{T + \frac{1}{T} 16 S_{co} \pi K_c \tan\alpha} \qquad 4$$

Ra, radius of cavity.
f, distributed volume factor.
U_f, Fluid velocity
ρ_s, Sand density
ρ_f, Fluid densityVsp, Volume of sand produced The parameters applied to the model are given in table 3.

Table 3: Pump data used in the analysis

Manufacturer	PCM	
Pump series	4’’	
Pump model	400TP 1350	
Pump size	4.72	(inches)
Maximum Head	4430	(feet)
Reference Speed	500	(rpm)
Reference Rate	2534	(STB/day)
Pump volume	34	(in3)
Pump length	28.5433	(feet)
Stator pitch	15.2756	(inches)
Specific Rotor OD	1.49606	(inches)
Rotor Elements	1	

Evaluation Procedure

Production of heavy crudes tends to increase faster when an artificial lift system is being introduced into the well. Owing to the fact that it reduces BHFP and creates a high potential differential between the wellbore and the formation, several designs were performed in order to prove these scenarios, the analysis was performed with PROSPER on the data from the heavy oil reservoirs.

A natural case design was performed in order to estimate the amount of crude that could be recovered at the surface without sand control measures. From the data collected there are solution gas, unconsolidated sand formation and the pressure of the reservoir is above or at bubble point, which are the major criteria upon which CHOPS can be applied. Amount of sand to be recovered are then calculated using a sand prediction model, and graph of oil rates were plotted against sand rates produced for each case. Inflow Performance Relations Curve (IPR) was drawn indicating the flow of reservoir fluid into the wellbore to be viable owing to high viscosity. Vertical Lift Performance (VLP) curve was matched with IPR assuming productivity index to be one (1) and Absolute Open Flow (AOF) was determined.

RESULTS

CHOPS technology employs the use of Progressive Cavity Pump (PCP) and an artificial lift system, to enhance production, it becomes necessary to design for fluid flow into the wellbore for the five reservoirs that were investigated for CHOPS application. PROSPER was then used for this purpose. Increase in flow rates were observed together with the sand rates.

CASE 1

Analysis pertaining natural and artificial cases were performed. The reservoir has an initial pressure of 2794 psia and bubble point pressure of 541 psia, in which the initial pressure is greater than the bubble point pressure. The crude has an API° of 18.08 and fluid viscosity of 86.75cp. An IPR plot was obtained with an absolute open flow of 2545.3stb/day. When VLP plot was made, the initial oil rate of 79.1stb/day was gotten without PCP. But when PCP was introduced, the rates increased to 989, 2001.9 and 2446.5stb/day having different design rates of 1000, 2000, and 2500 respectively. Mathematical model was used to predict sand production, sanding rates of 0.0014, 0.2275, 0.9323, and 1.3921bbls were obtained and plots as well were made. Figures 4 and 5 depict the IPR/VLP and oil/sanding rates of case 1.

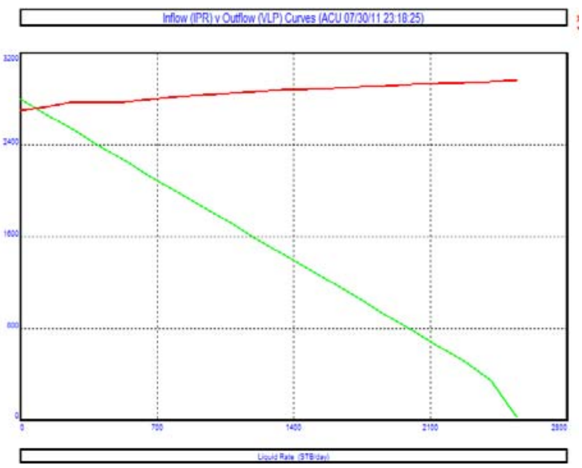

Figure 4: Inflow (IPR) and Outflow(VLP) Curves For Case 1

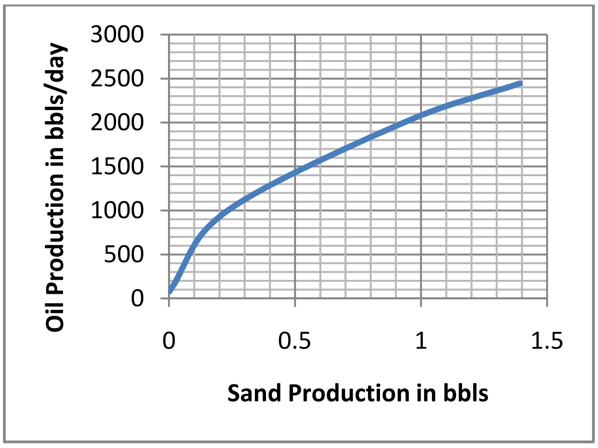

Figure 5: Plot of Oil Production against Sand Production for Case 1

CASE 2

The reservoir has an initial prssure of 3384psia which is greater than the bubble point pressure of 1515psia and depth of oil water contact is at 7872ft. The viscosity of this reservoir is 4.76cp with API° of 21.80. An IPR curve having an absolute open flow of 2840.4stb/day was obtained. Matching the IPR with VLP, the initial oil flow rate without artificial aid was 694.8stb/day with sanding rates of 0.000257bbls. With the introduction of PCP oil rates stood at, 1013.1, 1500.1, 1999.2, 2446.3 all expressed in stb/day with design rates of 1000, 2000, 2500 and 3000 respectively. There corresponding sanding rates are 0.000546, 0.001198, 0.00213 and 0.00318 respectively. Figures 6, 7 depicts IPR/VLP and oil/sanding rates of case 2.

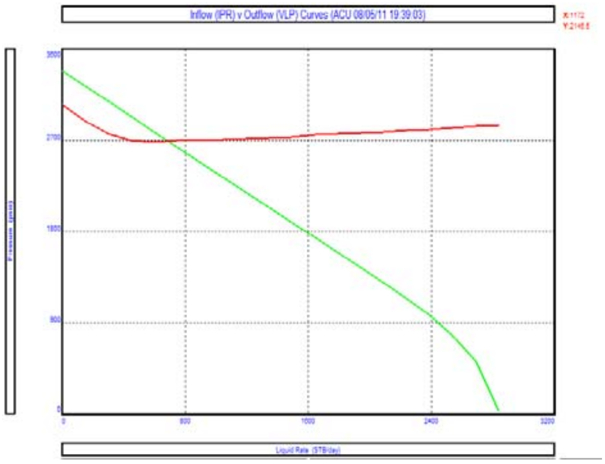

Figure 6: Inflow (IPR) and Outflow (VLP) Curves for Case 2

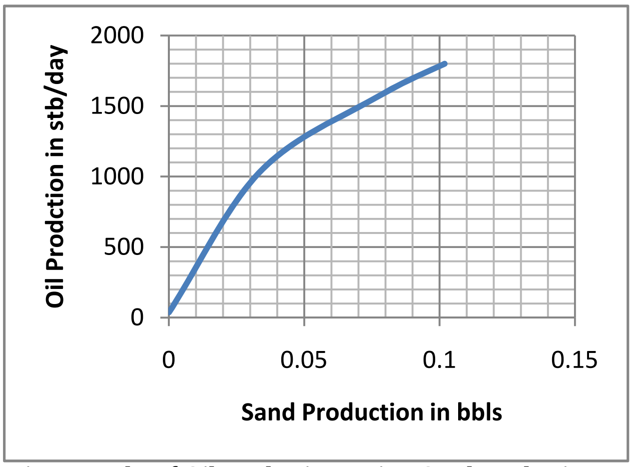

Figure 7: Plot of Oil Production against Sand Production for Case 2

CASE 3

The reservoir has an oil viscosity of 31.81cp, with the corresponding API^{o} of 19.03 and gas-oil ratio of 50scf/bbl. The depth of the reservoir being 4239ft (WOC) and 4170ft (GOC), with a reservoir temperature of 122^{O}F .The reservoir pressure is far greater than the bubble point pressure with a difference of 1652 psia.

Having carried out a simulation run coupled with the matching of PVT data, an IPR curve was obtained. Absolute Open Flow (AOF) value of 1736.2stb/day was achieved. For natural flow scenarios, the rate of oil was 27.3stb/day and the corresponding sand produced is 0.00004bbls.

When PCP was introduced into the well, oil flow rates increased with increase in sand rates. Figures 8 and 9 show the IPR/VLP and oil/sanding rates of case 3.

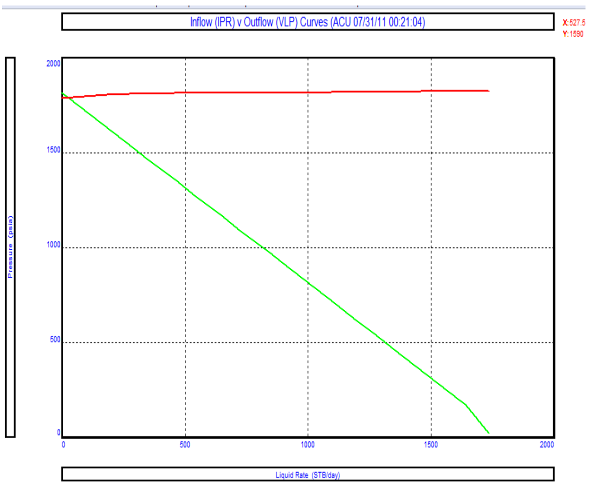

Figure 8: Inflow (IPR) and Outflow (VLP) Curves for Case 3

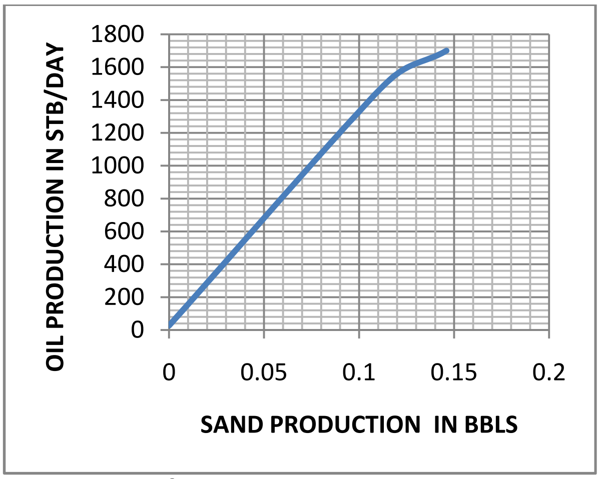

Figure 9: Plot of Oil Production against Sand Production for Case 3

CASE 4

This reservoir has an API of 19.03 and viscosity of 25.49cp, with the initial reservoir pressure and bubble point pressure of 2033psi and 362psi respectively. The depth of the reservoir being 4741ft (WOC), and 4670ft (GOC). The AOF obtained was 2009.3stb/day using PI entry model of unity.

For the natural case, oil rates obtained is 38.1stb/day and amount of sand produced along side is 0.00005bbls. However when PCP was used in the system, oil rates became 1034.8, 1556.3 and 1800stb/day with flow alongside with sand at design rates of 1000, 2000 and 2500. The sand produced are 0.03366, 0.0714and 0.10184bbls respectively. Figures 10 and 11 show the IPR/VLP and oil/sanding rates of case 4.

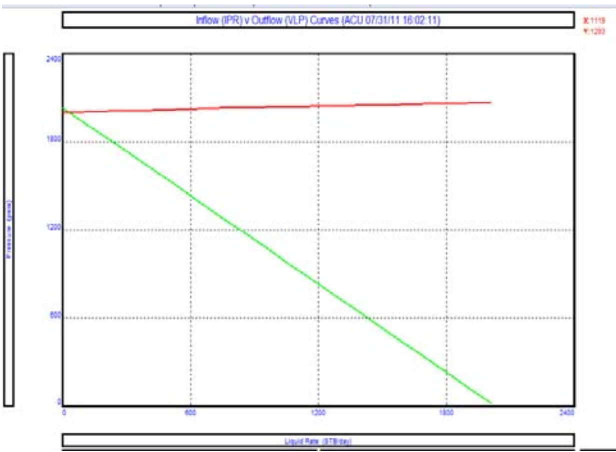

Figure 10: Inflow (IPR) V Outflow (VLP) Curves for Case 4

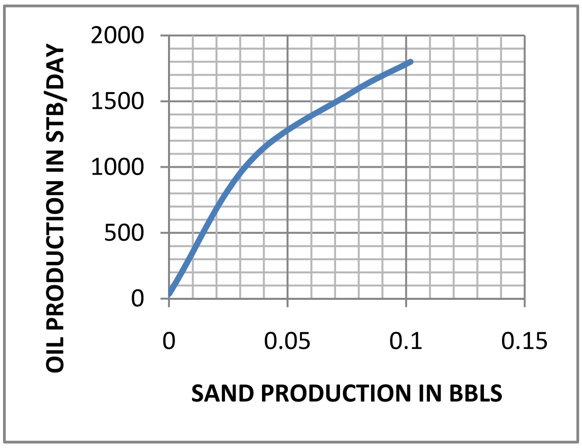

Figure 11: Plot of Oil Production against Sand Production for Case 4

CASE 5

Here the fifth analysis was carried out in order to ascertain the quantity of heavy oil that could be produced with sand. The reservoir has an intial pressure of 2612psia and bubble point pressure of 1212 psia, with an oil viscosity of 29.31cp. The corresponding API^{o} is 22.14 and gas-oil ratio of 235scf/bbl with the depth of the reservoir being 6028ft (WOC) and 5995ft (GOC). An IPR curve having an absolute open flow of 1489stb/day was obtained. With exception of artificial aid, flow rates of oil stood at 646.7stb/day and that of sand at 0.03896bbls.

With the inclusion of PCP, oil flow rates increased to 1021.6, 1213.4 and 1400stb/day and Sand rates also increased to 0.0973, 0.1372 and 0.18266bbls at the design rates of 1000, 2000 and 2500 respectively. Figures 12 and 13 show the IPR/VLP and oil/sanding rates of case 5.

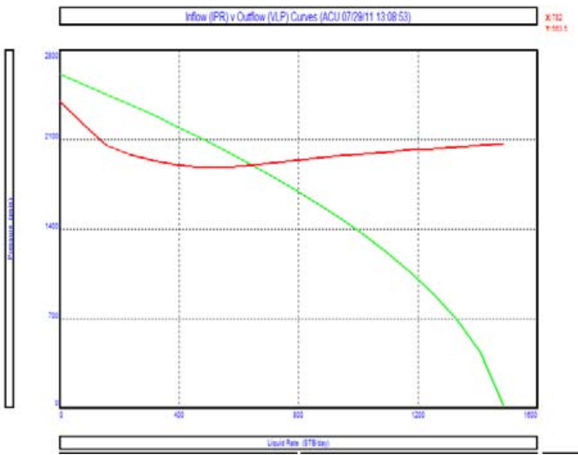

Figure 12: Inflow (IPR) V Outflow (VLP) Curves for Case 5

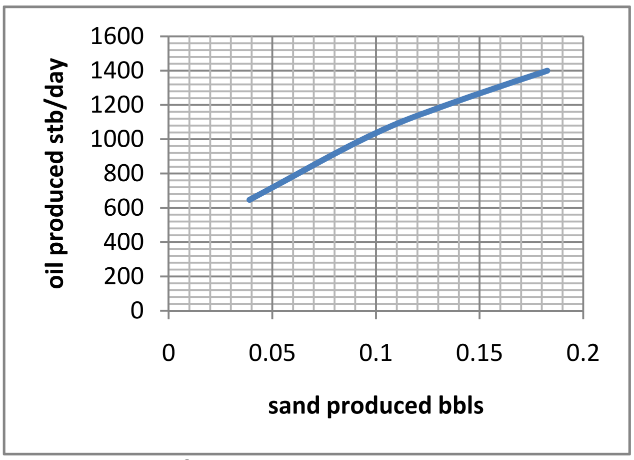

Figure 13: Plot of Oil Production against Sand Production for Case 5

RESULTS AND DISCUSSIONS

The analysis showed that oil production increased with sand production since no sand control measures are incurred. It is clear that in natural case the oil produced in stb/day is lower when compared with the PCP scenarios. For case1, the absolute open flow (AOF) of the well was determined to be 2545.3stb/day. With no installation of any kind of assistance to the flow, the oil rate was observed to be 79.1stb/day with a sanding rate of 0.0014bbls due to the heavy and viscous nature of the fluid. With the intrduction of a pumping device(PCP), at the depth opposite the perforation and pressure induced, with different design rates of 1000, 2000, and 2500, the corresponding oil rates and sanding rates became 989, 2001.9 and 2446.5stb/day, and 0.2275, 0.9323 and 1.3921bbls respectively far greater than what was produced naturally.

The increase in production rate from the natural case to that obtained when a pumping device was installed is an indication that heavy crudes could be produced via CHOPS application in the Niger Delta.

For case 2, the oil rate without artificial aid stood at 694.8stb/day with sanding rates of 0.000257bbls. With the introduction of PCP oil rates rose to 1013.1, 1500.1, 1999.2, 2446.3 all expressed in stb/day with design rates of 1000, 2000, 2500 and 3000 respectively. The sanding rates also increased as production rates increased.

From the result of case 2, It is again evident that the application of CHOPS technology will enhance the production of heavy crudes in the Niger Delta.

It is also evident from the results of cases 3,4 and 5 that the application of CHOPS technology will as well enhance the production of heavy crudes in the Niger Delta. In these cases, with the introductionof a pumping device, the production rates increased meaningfully when compared to the natural scenarios.

CONCLUSIONS AND RECOMMENDATIONS

From the study it is evident that heavy crude exists in the Niger Delta, Nigeria. Existence of heavy oil calls for an appropriate technology that could aid it’s recovery. Cold Heavy Oil Production with Sand (CHOPS) is a non thermal method that provides solution to the challenges that confronts the recovery of heavy crudes.

Based on the conditions needed for the application of CHOPS, Niger Delta heavy crude passes almost all the test for the technology to be embarked on. Starting from the solution gas oil ratio, API^{O}, bubble point pressure being less than the reservoir pressure. Viscosity on the other hand was not up to 100cp, which is a key advantage over Canadian case since low viscosity enhances the flow of fluid.

An effective method for managing sand has being deduced. Aborting the importation of Venezuela’s heavy crude and utilization of produced sand mixed with asphaltenes for construction purposes. Produced sand can be can be treated and stored directly into salt caverns because of its extremely low permeability of the salt strata and the tendency of a salt carven to slowly close. Slurry injection of solid sand and other oilfield waste an alternative to surface disposal methods for produced sand. For temporal storage of sand, sand waste stockpile serves the purpose provided a membrane of fibre HC resistant, flexible polymeric fabric is placed on the bottom of ecopit to prevent leaching from the sand.

The gas rate increases since the crude have a sufficient gas in solution. As well produced oil in the form of continuous foam resembling chocolate mousse suggests a foamy solution gas drive occurs insitu. This leads to anomalously high oil productivity and recovery because free gas stays entrained in the foam, thereby sustaining reservoir pressure.

In natural case phenomena, wells 1 to 5 have an oil rate at ranges of 79.1stb/day, 694.8stb/day, 27.3stb/day, 38.1stb/day, and 646.7stb/day respectively. Whereas for an artificial case with PCP having required design rates, the oil rates are equally at ranges of

2446.3stb/day, 1999.2stb/day, 1700.1stb/day, 1800stb/day, and 1400stb/day correspondingly. With the sand rate increasing accordingly.

Moreover these are well-defined situations, since with CHOPS technology fluid (oil) rate increases and oil rate is much higher with CHOPS than conventional case. I hereby recommend that CHOPS should be applied in the recovery of heavy crudes in Nigeria and further research should be embarked on for more clarification and advancement.

Nomenclature and Abbreviation

Ra, radius of cavity (ft)
f, distributed volume factor.
U, fluid velocity (ft/sec)
ρ_s, sand density (lb/cuft)
$\rho_{f,}$ fluid density (lb/cuft)
Vsp, volume of sand produced(bbls)
H, height of cavity (ft)
S, sand produced
g, acceleration due to gravity (ft/sec^2)
U_f, fluid viscosity (cp)
T, 2(tan $^2\alpha$–1)
$Q_{f\,,,}$ flowrate (stb/bbl)
CHOPS, Cold Heavy Oil Production with Sand.
IPR, Inflow Performance Relation Curve.
VLP, Vertical Lift Performance Curve.
SAGD, Steam Assisted Gravity Drainage.
API, America Petroleum Institute.
PROSPER, Production System Performance Toolkit.
PI, Productivity Index
BHFP, Bottom hole flowing pressure.
GOR, Gas-Oil Ratio
OWC, Oil-Water Contact.
GOC, Gas-Oil Contact

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