International Journal of Engineering and Advanced Research Technology (IJEART)
ISSN: 2454-9290, Volume-5, Issue-8, August 2019

Prospects and Evaluation of Progressive Cavity Pump for Niger Delta Field Application

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***Abstract*— The recent interest in unconventional heavy oils have spurred a lot of interest. Operators seek technical and economically viable means to recover viscous petroleum reserves. Although this has been challenging but recent advancements in drilling and enhanced oil recovery methods have made it possible. The prevalent activity in the Niger delta have been primary and secondary production of the light conventional reserves. Gas lift have generally been applied when the oil that flows to the wellbore lacks sufficient energy to flow to the surface. The choice of gas lift was greatly aided by the availability of large volumes of associated gas coming out from the oil which is notable with Niger Delta 'foamy' crudes. However gas lift may be threatened by the increased utilization of gas for other applications due to the emergence of gas monetisation technologies. Furthermore, gas lift will not be practicable in lifting heavy oils from Niger Delta heavy oilfield. Other artificial lift methods such as progressive cavity pumps have been considered. The ability to handle viscous crudes makes progressive cavity pumps (PCP) important in heavy oilfields. Aside that, its lower cost makes it a better alternative when compared to gas lift or electric submersible pumps especially in marginal fields where flowrate are comparatively low and in crudes with high sand contents. In this work progressive cavity pump is analyzed in terms of its technical and economic performance. Production data have been gotten and analyzed with regard to the Niger Delta operating conditions, the results show that PCP pumps hold great potentials for application in the development of the Niger delta heavy oilfield.**

***Index Terms*— Artificial Lift, Heavy oilfield, Niger Delta, Progressive cavity pump.**

I. INTRODUCTION

Fluids will flow from reservoir to the surface when the well is completed and reservoir pressure is sufficient to receive fluid from matrix, transport it to the wellbore and lift to the surface. During the reservoir production life reservoir pressure will decline and this could cause increase in water cut and decrease in gas fraction. These reasons decrease or even may cause to stop flowing of fluids from the well. Some techniques must be applied to prevent the production decline. Before artificial lift application the wells were being produced only naturally. Therefore, most of the brown fields were abandoned as reservoir pressure depleted. Because wells were produced under the natural flow regime and there was not any additional energy to the well as bottom-hole pressure decreased. Additional energy source must be added to the well in order to lift up the fluid to the surface [1].

In these cases, artificial lift techniques are applied to add energy to the produced fluids. It increases production rate by reduction down-hole pressure referring to increase in drawdown. Major artificial lift techniques are: gas lift (GL), electrical submersible pump (ESP), sucker rod pump (SRP), hydraulic pump (HP) and progressive cavity pump (PCP). Artificial lift techniques are different from pressure maintenance techniques. Because they add energy to the produced fluid in the well rather transfer it to the reservoir. Some types of artificial lift techniques increase the production rate by pumping the fluid from bottom to the surface. It causes the reduction in bottom-hole pressure and increase in drawdown as results with increased production rate. Other types of artificial lift techniques decrease the BHP by lightening the fluid column. Decrease in fluid column causes the reduction in bottomhole pressure (BHP).

Progressing cavity pump (PCP) is a positive displacement pump which has been used for the artificial lift to enhance oil production in the oilfield. For a conventional PCP in operation, a helical rotor rotates eccentrically inside a helical stator with interference between them, in which the stator is generally deformable and made of elastomeric material. It has many benefits in oilfield applications, such as simple installation, easy operation, low flow pulsation, high efficiency, and high tolerance for gas and solid contents. Most importantly, it shows a good adaptability for pumping the fluid with high viscosity, which makes it widely used in viscous oil fields [2].

II. PROGRESSIVE CAITY PUMPS

The development of Progressing Cavity Pump (PCP) was done by Moineau in 1920s. But the use of PCP in oil industry began in 1970s. As it was developed by Moineau, PCP also called Moineau pump. The design of PCP is very simple and recently the requirement for PCP has been widely increased in production of high viscous fluids. PCPs are applicable in horizontal and deviated wells. PCPs can handle large amount of water. Therefore, PCPs are also applicable in water wells, coal bed methane fields. Installation of PCPs is very expensive, but they decrease energy requirement as production increases. PCP could be installed at 4000 ft depth. Down-hole pump has a moving part with no reciprocating part. Therefore, there is no gas lock, paraffin plugging, scaling in PCPs and they could easily handle fluids with high sand content.

PCPs have three major components:

(a) Surface components- this part drives rods to activate pump. Mainly electric or hydraulic motors are used to drive rods.

(b) Rods- this part is used to connect surface components with subsurface components.

(c) Subsurface unit- down-hole pump is the main component of this unit, which consists of rotor and stator.
The main part of subsurface unit is down-hole pump. This pump is a positive-displacement pump and consists of rotor and stator. Rotor is located inside a stator and made of steel rod. The stator is inside a casing and molded in the shape of helix. Rotor and stator acts as a pump. The rotation of stator creates a cavity and it goes up as rotor rotates inside a stator. Increase in the pressure could be gained by number of stages. Estimation of pressure increase per stage is 200-300 kPa. But pressure could decrease if there is a friction between rotor and stator. Therefore, lubrications are used to avoid these problems. Like in other artificial lift methods, presence of free gas in produced fluid decreases the efficiency of pump. Therefore, gas anchor also is installed in completions.

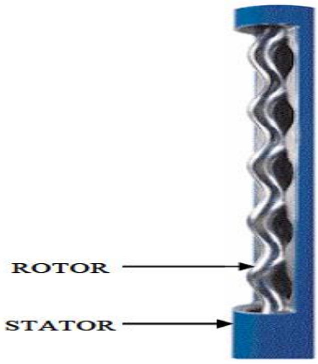

Figure 1: Progressive cavity pump [3]

The success of the PCP like Artificial Lifting Method of oil heavy and wells of high GOR, it depends on the capacity of the system in maximizing the acting of the pump achieving a good interference between the rotor and the stator to control the slip. The interference creates seal lines among the stator and the rotor that limit the cavities, maintain them separate through the pump with each rotation, if the interference diminishes it produces an increase of the slip. When the interference is negative (clearance), that is to say, when the diameter of the stator is bigger than the diameter of the rotor, slip takes place because contact doesn't exist among the elements, which changes along the pump, in function of the relative position of the rotor. When the interference is positive, a state of efforts that deform to the stator takes place (elastomer), due to the existent contact among the elements.
If the material of the stator is elastomer the factors that modify the interference mainly are: the swelling that suffers the elastomer due to the light aromatic fractions that present the oil ones transported that which reduces the slip, the thermal dilation of the material, the permanent deformation for the mechanical goods of the pump, the component viscoelastic of the material, deformation in the time, the waste and the abrasion.
The slip, factor that defines the behavior of the pump, is the quantity of fluid that escapes through the internal clearance of the pump and it is function of the viscosity of the managed fluid, the distribution of pressure (that changes according to the movement of the rotor) and the gap width line (that depends of the geometry of the components of the pump) that is considered constant if it is metallic stator, but that it is variable if the stator is elastomeric. The slip is a parameter that affects so much to the net flow as to the effective work of the pump. To be able to improve the design and operation of the Progressive Cavities Pumps, many investigations that are based on the study of the flaws caused by the operation variables like: abrasive fluids, discharges differences of pressures and speeds, chemical attack, high temperatures, content of H_2S (Sulfide of Hydrogen) and CO_2 (Dioxide of Carbon) that modify the characteristic curves of the pump. A way to carry out this analysis is by means of computational models that allow to simulate the operation of PCP, the experience obtained in field show that the characteristic curve of a PCP can be affected by changes in the mechanical states of the rubber, originated with the increment of the temperature or due to recurrent loads that degrade this states due to the generated heat (hysteresis losses) that accelerates the flaw of the stator.
Due to their unique design and principle of operation, PCPs provide many benefits in oilfield applications, such as high solid content tolerance, best efficiency with high viscosity fluids, simple installation and operation. Oil production with PCPs is generally designed over the knowledge of characteristic pump curves provided by manufacturer, but several variables can affect and change the volumetric efficiency of both metallic and elastomeric stator pumps. It is common knowledge that the characteristic curves change significantly with liquid viscosity and gas content, therefore pump curves provided by manufacturers usually do not represent the real pump performance at down hole conditions. Moreover, in order to design PCPs that can be operated at extreme conditions, it is important to understand the effect of each geometric design parameter on the pump performance. These are the main reasons behind research efforts dedicated to study the flow inside PCPs.
PCP has some shortcomings in temperature resistance (<160∘C) and abrasion resistance [4], which limits its application in oilfield, especially in thermal production wells. Fundamental understanding of the PCP performance can provide scientific basis for the pump application in the artificial lift system, which is significant for oilfield engineers

III. PERFORMANCE OF PCP

The performance of PCPs is a function of the volumetric pump displacement and the slip flow, i.e. the backward flow between consecutive cavities due to the adverse pressure gradient along the pump. The limitation of simple models on predicting pump performance is related to the difficulties in calculating the internal back flow. For any type of stator, rigid or deformable, slippage is a function of the fluid characteristics, the differential pressure, the dimensions of the different components and the rotor’s kinematics. In the case of elastomeric stators the problem become even more complex, because the geometry of the flow channel becomes a function of the pressure field.
In order to estimate the back flow, Sopilka et al. [5] performed an experimental study and obtained characteristic curves and instantaneous pressure profiles along a metal PCP for single and two-phase flow conditions.
The first and simplest numerical model to describe the flow inside a PCP was presented by
Moineau, 1930 Moineau and it is based on calculating the back flow across the pump, considering a Hagen-Poiseuille flow through the seal lines, which is subtracted from the

volume displaced by the rotating rotor, giving the volumetric flow rate. As the differential pressure across the pump rises, so does the slippage, and the relation between differential pressure and net volumetric flow pumped, can be calculated. Since the slippage gap area is not clearly defined, the model is able to describe the qualitative behavior, but it is not accurate. The volumetric displacement associated with the rotor movement can be easily calculated from pump component's geometry, but calculating the back flow is not a trivial problem. In order to improve Moineau's model, Blanco and Olivet [6] modeled the slip as the superposition of two different mechanism: one due to the rotor's movement and the other due to the differential pressure between two cavities. However, limitations were recognized and the model was not able to fit experimental data.

Only recently, a complete three-dimensional, transient model of the flow inside the cavities of a PCP has been presented by Paladino et al. [7]. The numerical solution obtained with a commercial CFD software is extremely complex and computationally expensive, mainly because of the transient and 3-D character of the flow, the complexity of the geometry and the necessary mesh motion to follow the rotor movement. The results agree well with experimental data, however the use of the model for testing different operating conditions and pump designs is limited, since the time to compute the flow at a single operating condition was extremely high.

Therefore, the time required to produce an entire pump performance curve would be enormous.

Realizing that the back flow, that ultimately defines the flow rate - pressure drop relationship, is governed by what happens in the small clearance between the moving rotor and the stator and that the ratio of length scale in the flow direction to the channel height in this region is very large, we propose an asymptotic model to describe the flow inside PCPs. The proposed model reduces the three-dimensional transient Navier-Stokes equations with moving boundaries to a quasi-steady state two-dimensional Poisson's equation for the pressure field inside the pump.

This is the same idea behind simplified models of the flow in screw extruder, Li [8] and Suresh [9]. The simplified models for extruder can predict the qualitative behavior, but they are still not accurate enough to use as a design tool, mainly because of the geometric and kinematic simplifications used. One of the common hypothesis is to neglect the curvature effect of the cross section, and to describe the geometry of the flow region using cartesian coordinates. Carvalho and de Pina [10] presented a lubrication approximation model in cylindrical coordinates to describe the flow in annular space with varying eccentricity and showed that neglecting the curvature effect can greatly compromise the accuracy of the model.

IV. BASIC SELECTION CRITERIA

The basic selection criteria for choosing any artificial lift method is based on

1. Technical performance and applicability

2. Economic performance of the lift method and NPV

Comparisons of PCP with Gas Lift system in the Niger Delta

PCP can only serve in the Niger Delta when applied to heavy crudes. The dominant artificial lift system in the Niger delta is the gas lift. To make selection of PCP for use in the Niger delta it is pertinent to compare it with gas lift system in terms of its performance and economics.

Table 1: Reservoir conditions evaluation [3], [11]

Reservoir conditions	PCP	Gas Lift	ESP
High viscosity fluid	Excellent	Fair	Fair
Solids/sands	Excellent	Excellent	Poor
High temperature	Fair	Excellent	Good
Free gas	Poor	Excellent	Poor
Paraffin	Fair	Good	Good
Corrosion scale	Good	Good	Fair

Table 2: Well conditions evaluation [3], [11]

Well configurations	PCP	Gas Lift	ESP
Offshore well	Fair	Fair	Excellent
Deviated/Horizontal well	Fair	Excellent	Good
High volume well	Poor	Excellent	Excellent
Low volume well	Excellent	Fair	Fair
Maximum depth	5000ft	10000ft	10000ft

Table 3: Operating conditions evaluation [3], [11]

Operating conditions	PCP	Gas Lift	ESP
Testing	Good	Fair	Good
Flexibility	Fair	Excellent	Poor
Intake capacity	Good	Poor	Fair
Reliability	Good	Excellent	Fair
Efficiency	Excellent	Fair	Good

V. ECONOMIC ANALYSIS

Economic factors that influence on selection an artificial lift type are:

(1) Capital Expenses (CAPEX)
(2) Operating Expenses (OPEX) per month
(3) Life of installed equipment
(4) Supplement of equipment
(5) Well production life
(6) Work over costs
(7) Number of wells that require artificial lift installation
(8) Number of employers needed for equipment control

Initial capital expenses play important role in installation of required artificial lift types. But operating expenses are more important than initial capital expenses through life cycle of the well.

Before making a final decision on which method of artificial lift to be used, a thorough economic analysis needs to be carried out. It is the profitability of a project that has to be the final decision criteria. This study is still in the evaluation phase, and a full economic analysis giving the NPV of the projects is not available yet. The NPV will give the value of a project through its entire lifetime taking capital costs, operating costs, depreciation and revenues into account. However, the initial costs of the scenarios are analyzed and can give a good indication of the project magnitude.

Table 4: Economics evaluation [11]

Economics	PCP	Gas Lift	ESP
Capital cost	Low	Moderate	Moderate
Operational cost	Low	High	Moderate

VI. METHODS

PCP pump is selected for use in lifting viscous crude in the Niger Delta. The primary atifical lift system predominant in the area is Gas lift. The method below shows the prospect of using PCP pump for lifting heavy crude in the Niger delta.
First the reservoir is produced by natural depletion utilising the natural energy in the form of dissolved gas in the oil. The well produced for a time until the well could not produce significant volume of oil to justify operational cost. The water-cut rises and PCP is suggested. PCP is suggested for this case since the dissolve gas that makes the oil light has been expended during the natural depletion processes. The production of the much of the solution gas at the surface increases the viscosity of the oil and hence its resistance to flow. Most of the oil only flows from the reservoir to the wellbore and significant energy is lost at wellbore region. The fluid lacks sufficient inherent energy to travel up to the surface. Hence it loads at the well bore region and stops further fluid migration from the sandface region.
The cost of artificial lift equipment and plants are given in the table below.

Table 5: Equipment and operating cost description

	GAS LIFT		PCP	
DESCRIPTION	Daily cost	Annual cost	Daily cost	Annual cost
Equipment (US$)	350000	350000	280000	280000
Installation (US$)	239000	239000	100000	100000
Horsepower (US$/D)	675	246419	2533	924648
Running cost US$/D	8219	3000000	8219	3000000
Maintenance Cost (US$/D)	1096	400000	1461	533333
Water treatment cost (US$/D)	959	350000	959	350000
OPEX (US$/D)	10949	3996419	13173	4807982
CAPEX (US$)	589000	589000	380000	380000

Table 6: Cost of artificial lift systems

ITEM	Gas Lift	PCP
Target Rate (bbl/day)	1000	1000
Initial Installation ($)	239000	100000
Energy Efficiency (%)	15	52
Intake Pressure (psia)	900	900
Lift Energy (kw/bbl/day)	0.1	0.025
Workover Cost ($/day)	1000	1000
Wireline Cost ($/day)	1000	-
Injection Gas ($/Mscf)	0.24	-

VII. RESULTS

The result reveals the production of the PCP pump for a 20 year period. The information is given both for the natural flow before PCP was initiate and the production during the use of PCP.

Table 7: Daily oil flowrate in bbls/day

Year	Natural flow	Flow with PCP	Additional flowrate due to PCP
1	300	850	550
2	286	821	535
3	272	789	517
4	258	759	501
5	244	729	485
6	230	698	468
7	216	668	452
8	202	637	435
9	188	607	419
10	174	576	402
11	160	546	386
12	146	515	369
13	132	485	353
14	118	454	336
15	104	424	320
16	90	393	303
17	76	363	287
18	62	332	270
19	48	302	254
20	34	271	237

From the table above, it is seen that when PCP was introduce there was appreciable rise in oil rate. The annual flowrate is given in the table 2 below.

Table 8: Annual oil flowrate in bbls/yr

Year	Natural Flow	Flow With PCP	Additional Flowrate
1	109500	310250	200750
2	104390	299665	195275
3	99280	287985	188705
4	94170	277035	182865
5	89060	265902.5	176842.5
6	83950	254770	170820
7	78840	243637.5	164797.5
8	73730	232505	158775
9	68620	221372.5	152752.5
10	63510	210240	146730
11	58400	199107.5	140707.5
12	53290	187975	134685
13	48180	176842.5	128662.5
14	43070	165710	122640
15	37960	154577.5	116617.5
16	32850	143445	110595
17	27740	132312.5	104572.5
18	22630	121180	98550
19	17520	110047.5	92527.5
20	12410	98915	86505

Economic evaluations

In the economic evaluation, we consider the economic indicators of the project. Thus the economic indicators we are to consider are the NPV, the IRR, and the POT.

The table below summarizes the economic information of the project.

Table 9: summary of Economic parametres for the artificial lift systems

ECONOMIC PARAMTRE	NATURAL FLOW	PCP
NPV	65146000	150051300
POT	5years	1yr
DCF-ROR	40%	92%

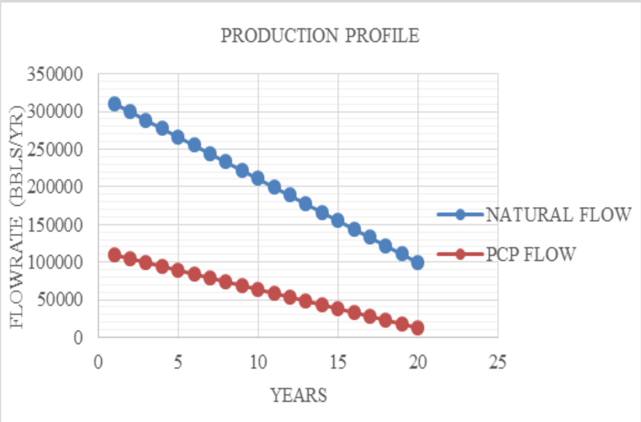

Figure 2: Graph of flowrate for both PCP and natural flow in years.

The figure reveals the flowrate and revenue increase as a result of introduction of artificial lift techniques using PCP for lifting of the viscous crude in the wellbore up to the surface. Despite the capital and operating cost incurred, it is balanced by the marginal increase in flowrate due to the use of PCP.

VIII. CONCLUSION

Performance and economic evaluations have been made for the prospects of using PCP pump for lifting viscous crude in the Niger delta. The technique reveals the techno-economic feasibility of applying non-gas lift techniques in artificial lifting of Niger delta crude when natural depletion processes are not applicable or economically not viable. From the Work PCP shows good potential and can be recommended for use in Niger delta viscous crude.

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APPENDIX

Table 10: Reservoir and well parametres

Vertical Depth to Perforations	6000 ft
Separator Pressure	100 psig
Surface Temperature	100 F
Reservoir temperature	220 F
Casing Size	7 inch
Tubing Size	3.500 inch, Gas Lift, 2.875 inch, Other
Water Cut	50% at first year
Oil Gravity	37 API
Water salinity	160000ppm
Oil FVf	1.123rb/stb
Oil viscosity	2cpcp
Water Gravity	1.03
Bubble Point	3256 psig
Static Reservoir Pressure	2000 psig
Productivity Index	1 STB/psi
Common cost	
Running cost	$15000000 per year
Fluid Disposal	0.35 $/bbl water
Electricity	0.05 $/kW-hr
Oil Revenue	60 $/bbl
Tax rate	30%
Discount rate	20%

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