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Analyses of Electric Submersible Progressive Cavity Pumps for Production of Heavy Oil Reservoir in the Niger Delta

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Abstract
A new artificial lift pump technology has emerged to increase the production of heavy oil in order to meet up high global demand for energy. The technology is a hybrid of two principal artificial lift pumps for lifting crudes. The hybrid called electric submersible progressive cavity pumps integrates the applicability and usefulness of electric submersible pump and progressive cavity pump. This gives it enhanced performance and more adaptability to varied reservoir conditions. This technology has the advantages of sample technology and management convenience. Electric submersible progressive cavity pump (ESPCP) is suitable for the viscous crude containing sand and high gas oil ratio oil extraction. In this paper, developing history of ESPCP is introduced and the structure and principle are analyzed. The advantages of ESPCP are compared with other oil extraction technology. In addition, the technical applicability of this new technology in the Niger Delta heavy oil fields and economic evaluation of the ESPCP were evaluated. The result of this research work showed that ESPCP showed better performance when compared with ESP and PCP making it a choice pumping system to replace the traditional gas lift predominant in the Niger Delta artificial lift operations.

Key words: SPCP; Heavy oilfield; Production enhancement; Artificial lift

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1. INTRODUCTION

Production of heavy oil mainly involves the handling of fluid having high viscosity and high gas void fraction. This is the reason why producing these fluids are more capital intensive than producing light or medium crude oils. Furthermore, production with steam injection EOR processes creates additional high temperature challenges which must be considered in the design of supportive production configurations. The challenge in producing heavy oil is to achieve a profitable improvement in the process of extraction. This entails using high efficiency extraction systems that allows reduction in energy consumption, production increase, and diminished operating cost resulting from equipment failures and extended operating life of equipment used for the extraction (Gamboa, et al, 2003).

In many applications, artificial lift mechanisms are used in conjunction with EOR processes in improving oil recovery from the reservoir to the surface. While the choiced EOR processes aid fluid flow from the formation to the wellbore, artificial lift system provide additional energy to the fluid column in the wellbore by pushing them to the surface. It has been observed that greater recovery efficiencies have been realized by using EOR means alongside suitable artificial lift methods. In this regards for heavy oil production Pumps have been in major application.

Artificial lift systems constitute a fundamental part of the production process mainly in maturing oilfields where the reservoir does not have sufficient energy to bring the crude oil to the surface. Many oil wells require artificial lift or some form of assisted lifting methods to produce its fluids. The artificial lift methods in use for lifting crude oils includes, beam/sucker rod pumps, plunger lift, gas lift, progressive cavity pumps (PCP) or electric submersible pumps. A new hybrid artificial lift pump system has emerged known as electric submersible progressive cavity pump. It incorporates the desirable qualities of Electrical submersible pump (ESP) and progressive cavity pump (PCP) and it is intended to replace gas lift for lifting crudes especially heavy crudes in the Niger Delta. Before now, the predominant artificial lift method in the Niger Delta is gas lift. Gas lift involves the injection of gas of high pressure from the surface into the wellbore to the producing oil column. This is achieved through one or more subsurface valves set at pre-calculated depths. The reason for gas lift predominance in the Niger Delta is due to the fact that Niger Delta crudes contain large portion of dissolved gas and has the capacity to produce high volume of gas required for gas lift operations. But gas lift is subject to the following restrictions.

• Gas lift is associated with relatively lower efficiency when compared with other artificial lift techniques.

• Gas lift application is restricted to fields with large number of wells. it is more expensive to apply gas lift in fields with fewer wells than when artificial lift pumps are used

• High volume of gas is required to lighten the fluid column in gas lift which mostly comes from associated gas. But this amount of gas may not be always available because of emergence and development of gas utilization and monetization projects.

• Gas lift is not applicable in heavy oilfields that are associated with high oil viscosities and is not applicable to Niger delta heavy oilfields.

1.1 Electric Submersible Pumps (ESP) and Progressive Cavity Pumps (PCP)

in areas where heavy crudes limits the applicability of gas injection, or high water cut and low bottom-hole pressures hinder the use of gas lift method then ESPC can be used. ESPs generate centrifugal force that adds pressure to the wellbore fluids and are capable of lifting fluids from depths of 20,000-ft (6,100-m) or more. However, installations to 10,000-ft and less are more common (Breit and Ferrier, 2011). ESPs are especially effective in wells with low bottom-hole pressure, low gas/oil ratio, low bubble point, high water cut or low API gravity fluids. ESPs use multiple stages in raising the liquid pressure very high such that it overcomes the static head of the discharge column

Some of the advantages in application of ESP are

• applied to wells with high productivity index
• Installation and operation of ESPs are easy.
• ESPs are applicable in offshore fields.
• They could be easily applied in deviated wells or crooked holes.
• ESPs also could be applied in high water cut wells.

Some of the disadvantages that limits ESP application are

• ESPs require high electricity.
• ESPs are not applicable in deep wells.
• ESPs are not suitable in low- volume wells
• High temperature damages electric cables and motor
• ESPs are not applicable in commingled wells unlike sucker rod pumps.
• Has high maintenance and Workover costs.
• Efficiency is reduced by the presence of solids and gas contents in the produced fluids

Progressive cavity pump is a positive displacement pump that consists of a single external helical shaped rotor turning eccentrically inside a double internal helical shaped stator of the same minor diameter and twice the pitch length of the rotor.PCP has been widely used in production of high viscous fluids and applicable in horizontal and deviated wells. PCPs can easily handle fluids with high sand content.PCP has some shortcomings in temperature resistance (<160∘C) and abrasion resistance (Wang et al, 2016), which limits its application in oilfield, especially in thermal production wells. Installation of PCPs is very expensive, but they decrease energy requirement as production increases.

1.2 Electrical Submersible Progressive Cavity Pump, ESPCP

In the petroleum industry, there are varieties of wellbore conditions that limit the use of typical centrifugal or rod pumps. For example in wells with high gas content, fluids with high sand content the performance of ESPC is greatly reduced. In deviated wells mechanical wears occurs between the sucker rod pups and the production tubing. And these pose a great problem during production. To solve this problem there is need to design hybrid technologies equipped with the useful features of the parent technologies. For example, Engineers designed Electric submersible progressive cavity pumps to solve the inherent problems of individual uses of electric submersible pump and progressive cavity pumps. This technology was developed to incorporate ESP motors with PCPs to create the electrical a new hybrid system. With this combination, PCPs are now able to match ESPs in depth and deviation capabilities.

The ESPCP system is made up of seven components: the submersible motor, gear-reduction unit, seal section, flex-shaft assembly, pump, variable speed drive and submersible cable.

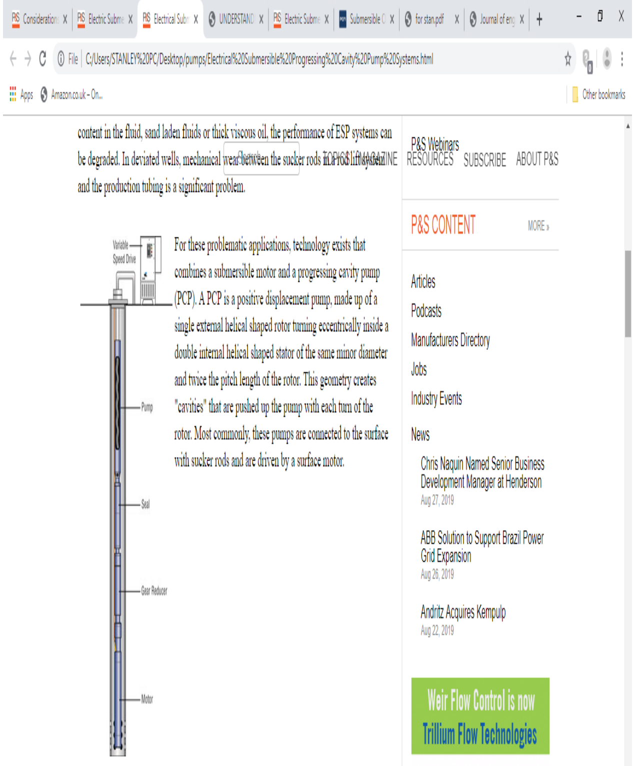

Figure 1
ESPCP system assembly (Shirley, 2011)

1.3 ESPCP Technology Developments

The main productions of ESPCP in U.S.A. are Reda and Baker Hughes Centrilift company. Reda company has mature technology and software of selection of pumps (Yurong, 2009). The technology has been successfully applied to the directional and horizontal wells, they replace sucker rod pump and has significant advantage in heavy oil recovery fields. Centrilift company is an American famous electric submersible pump complete products manufacturer, which can manufacture all the key parts of ESPCP system.

Also, Corod company of Canada produces a variety of specifications of the ESPCP system. In China, most of the ESPCPs were tried and applied in China National Offshore Oil Company (CNOOC), where about 140 ESPCPs are now used in the past years (Feng, 2010). In China, ESPCP was applied on Kulin Horizontal wells in 2003 and it resulted into higher pump efficiency compared to tubing pump efficiency at Duli Horizontal wells which has a less efficiency. ESPCP offered longer pump run life, proven at Kulin Horizontal wells never had pump problems or pulling out job (Taufan *et al*., 2005).

In 2014, ESPCP technology was implemented to decrease well intervention index on three wells in Casebe field and the technology exceeded expectations in the three wells. Well 1 showed an outstanding performance (i.e 12 times the historical run life). Well 2 and well 3 also increased run life by 704% and 635% respectively (Cristhian *et al*., 2017).

2. METHODS

The reservoir and well parameters studied for this work is given Table 1.

Table 1
Input data (Aliyev, 2013; Ezekiel et al., 2015)

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
Gas gravity	0.874
Water salinity	160000ppm
Oil FVf	1.4782rb/stb
Oil viscosity	0.428cp
Water gravity	1.03
Produced GOR	400 scf/bbl
Bubble Point	3256 psig
Static reservoir pressure	2000 psig
Productivity index	1 STB/psi
Common cost	
Running cost	$18000000 per year
Fluid disposal	0.35 $/bbl water
Electricity	0.05 $/kW-hr
Oil revenue	60 $/bbl
Tax rate	30%
Discount rate	20%

2.1 Evaluation of Conditions of Applicability of ESPCP

The tables below analysis the screening criteria for comparisons of ESPCP with other notable artificial lift methods in terms of

- Reservoir conditions
- Well conditions
- Operating conditions

Table 2
Reservoir conditions evaluation (Feng *et al*., 2010; Osakwe, 2015; Kefford*et al*., 2016).

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

Table 3
Well conditions evaluation (Feng *et al*., 2010; Osakwe, 2015; Kefford *et al*., 2016).

Well configurations	ESP	PCP	Gas Lift	ESPCP
Offshore well	Excellent	Fair	Fair	Excellent
Deviated/Horizontal well	Good	Fair	Excellent	Excellent
High volume well	Excellent	Poor	Excellent	Excellent
Low volume well	Fair	Excellent	Fair	Excellent
Maximum depth	10000ft	5000ft	10000ft	4000ft

Table 4
Operating conditions evaluation (Feng *et al*., 2010; Osakwe, 2015; Kefford *et al*., 2016).

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

From tables 2-4 it is seen that ESPCP has better applicability and performance than other artificial lift systems for the reservoir conditions, well condition and operating conditions. This makes ESPCP more suitable for deployment in the Niger Delta.

2.2 Economic Evaluation

It is necessary to evaluate the economic returns when ESPCP is used. This is of course in comparison with other pumping methods which are competing technologies to it. We evaluate and compare the economic performance indices of ESPCP in conjunction with that of ESP and PCP.

Table 5
Cost of artificial lift systems (Aliyev, 2013; Ezekiel et al., 2015)

ITEM	Gas Lift	ESP	PCP	ESPCP
Target rate (bbl/day)	1000	1000	1000	1000
Initial installation ($)	239000	105000	100000	110000
Energy efficiency (%)	15	48	52	70
Intake pressure (psia)	900	900	900	900
Lift energy (kw/bbl/day)	0.1	0.031	0.025	0.02
Workover cost ($/day)	1000	1000	1000	1000
Wireline cost ($/day)	1000	-	-	-
Injection gas ($/Mscf)	0.24	-	-	-

Table 6
Cost on daily basis of artificial lift systems

DESCRIPTION	ESP		PCP		ESPCP	
	Daily cost	Annual cost	Daily cost	Annual cost	Daily cost	Annual cost
Equipment (US$)	250000	250000	280000	280000	300000	300000
Installation (US$)	105000	105000	100000	100000	110000	110000
Horsepower (US$/D)	2303	840505	2533	924648	2399	875526
Running cost US$/D	8219	3000000	8219	3000000	8219	3000000
Maintenance Cost (US$/D)	1461	533333	1461	533333	1461	533333
Water treatment cost (US$/D)	959	350000	959	350000	959	350000
OPEX (US$/D)	12942	4723839	13173	4807982	13038	4758860
CAPEX (US$)	355000	355000	380000	380000	410000	410000

3. RESULTS OF ECONOMIC EVALUATION

3.1 Oil Rate

After the water has been separated from the total fluid rate, the resulting volume rate is the oil rate. The oil rate signifies that the ESPCP gave the maximum recovery for the methods considered

Table 7
Oil rate (bbl/day)

Year	GOR	Water-Cut	Pressure (PSI)	NaturaL flow	ESP	PCP	ESPCP
1995	820	50	4246	3794.64	7724.7	8497.17	9655.875
1996	820	55	4045	3285.54	6455.115	7100.627	8068.894
1997	820	57	3906	3031.19	5470.073	6017.08	6837.591
1998	820	59	3878	2791.665	4654.156	5119.572	5817.695
1999	820	61	3678	2507.739	4092.543	4501.797	5115.679
2000	820	62	3608	2259.427	3687.079	4055.787	4608.849
2001	820	63	3451	2126.403	3404.274	3744.701	4255.342
2002	820	65	3316	1900.755	3081.946	3390.141	3852.433
2003	820	66	3181	1738.904	2835.294	3102.418	3535.915
2004	820	67	3046	1583.378	2603.852	2864.237	3254.815
2005	820	69	2911	1389.361	2306.964	2537.661	2883.705
2006	820	70	2776	1249.651	2097.954	2307.749	2622.443
2007	820	72	2641	1077.775	1832.471	2015.718	2290.589
2008	820	72	2506	989.2086	1706.852	1877.537	2133.565
2009	820	73	2371	868.4769	1524.76	1677.236	1905.95
2010	820	73	2236	783.0741	1403.627	1543.99	1754.534
2011	820	74	2101	671.8315	1234.995	1358.494	1543.744
2012	820	74	1966	589.5917	1118.348	1230.183	1397.936
2013	820	74	1831	507.352	1001.702	1101.872	1252.128
2014	820	75	1696	408.7617	851.015	936.1165	1063.769

Table 8
Summary of economic parameters for the artificial lift systems

Economic Paramtre	ESP	PCP	ESPCP
NPV	331677217	366696978	420185996
POT	1.3 years	1.25 years	1.15 years
DCF-ROR	91%	93%	96%

3.2 Sensitivity Analyses

In this section several plots are presented to better visualize the performance of ESPCP when compared to ESP and PCP. The result reveals the better economic advantage of ESPCP.

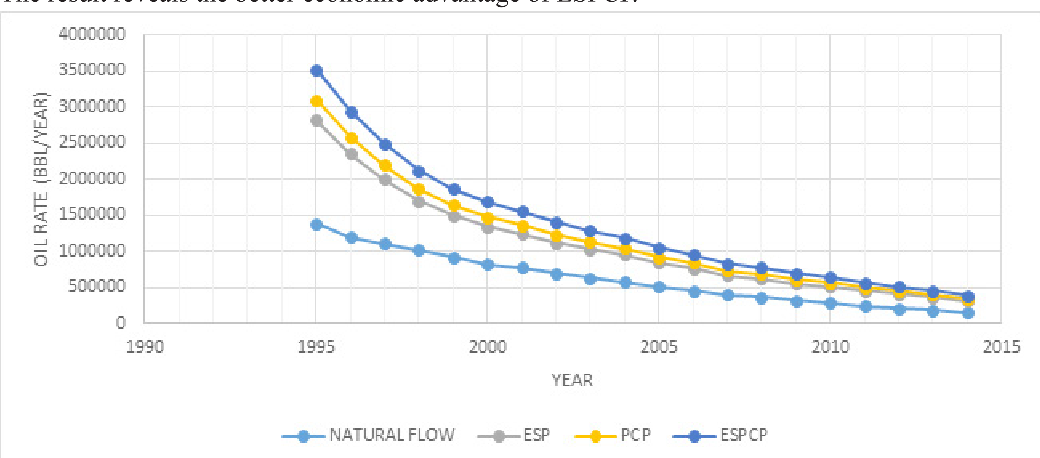

Figure 2
production showing the various flowrate per year

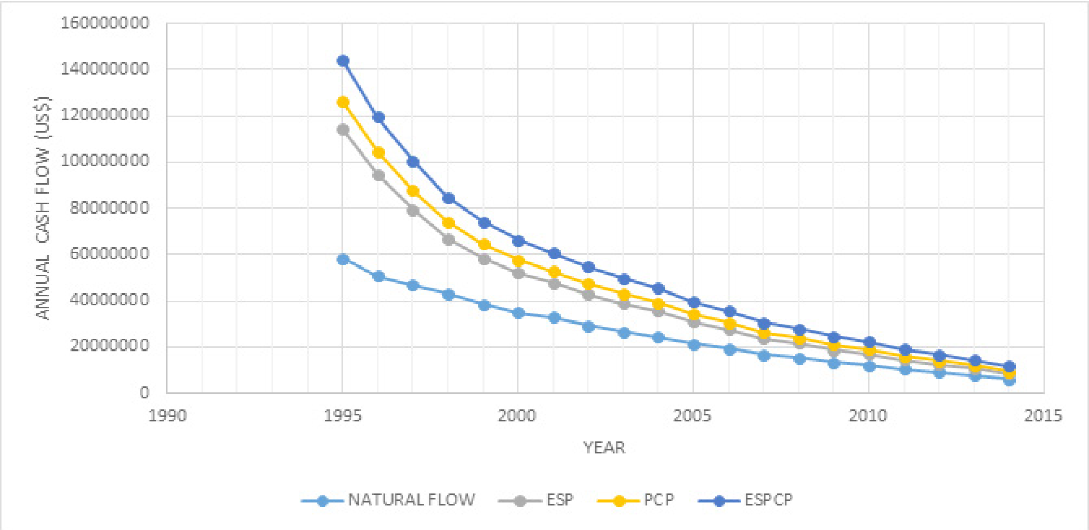

Figure 3
Graph showing annual cash flow for each year

3.3 Discussions of result

From figure 2 and 3, it is seen that for all years there is better production rate and cash flow for the ESCPC than other lift methods. This justifies the use of ESPCP as alternative to gas lift in the Niger Delta for production optimizations. Thus the ESPCP can is more suitable for use in the Niger Delta heavy oilfields as supplement to the choice of EOR method deployed in lifting fluids from the wellbore to the surface and to increase recovery. For the ESPCP to be deployed the revenue from the incremental recovery from the use of ESPCP as compared to the natural case (where there is no use of ESPCP) should be able to cater for the capital and operational expenses in using the system. Thus the NPV for ESPCP should be high enough to justify the operator's investment objectives.

CONCLUSIONS

Prospects of deploying Electrical submersible progressive cavity pump in the Niger Delta Heavy oilfield have been evaluated. The ESPCP shows good adaptability and applicability for the Niger Delta reservoir. Because of the declining rate of conventional oil reserve, unconventional heavy oil reserves holds great potentials. The Nigeria government must begin exploitation of the vast heavy oil resources in the Niger Delta region if the country must maintain its position as one of the highest oil producers in the world.

From the analysis it is seen that for both technical (in terms of conditions off applicability) and economic (NPV, POT etc.) evaluation, ESPCP shows better prospects for deployment than the other artificial lift pumps such as Electrical submersible and progressive cavity pumps considered. This is because ESPCP integrates the positive qualities of both the ESP and the PCP and emerges as a hybrid with more enhance operational features. Also since the emergence of gas utilization projects, operators have sought replacement to the traditional gas lift predominant in the Niger Delta artificial lift operations. ESPCP will not only replace gas lift in application and performance but will be more adaptable to areas where gas lift is seen as inapplicable such as heavy oilfields.

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