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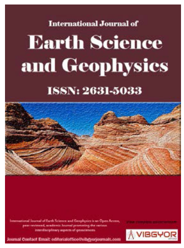
Electric Submersible pump (ESP), A Better solution to Heavy Oil Production in Nigeria: Case Study of Enuma 3T in Niger Delta



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Abstract

The use of electric submersible pumps (ESP) in producing conventional heavy oils from hydrocarbon reservoirs is gaining huge attention following the level of success rates recorded in fields where they have been deployed. Howbeit, due to their high failure rates, even at the inception of installation, had made many companies stay clear of its consideration as a means of improving recovery over other artificial oil recovery methods. This study evaluates the impact of the installation of GN 7000 ESP model pump designed to operate at 172 stages at 50 Hz on oil recovery at Enuma 3T well in Niger Delta. The pump was installed in 2003 and produced for about 10 years before its failure in September 2013. Upon installation, it produced on the average of about 8000 barrels of oil per day (bopd) of oil in the first year at a frequency of 52 Hz uninterrupted. The project payout within the first 6 months of installation, a remarkable achievement centered on adequate design and adherence to regulatory framework in the use of ESPs in Niger Delta, Nigeria.

Keywords

Heavy oil, ESP, Recovery, Viscosity

Introduction

The global energy demand is on steady rise and fossil fuels remain a major component of the energy mix. Although, there is a persistent call for cleaner and environmentally friendly source of energy, there are no current alternate sources of energy capable of completely replacing fossil fuels as a substitute for global energy supply. Globally, oil reserves are fast depleting, and the cost of new finds are increasing at astronomical rate following their locations and the depth of deposition. And even where the hydrocarbon resources are located at accessible and economically viable locations, the recovery of hydrocarbon has been limited by available technologies. Therefore, efficiently producing reserves using improved recovery methods for existing and proven reserves will enhance the sustainability of the oil and gas supply for commercial and industrial usage. Recently, attention has been drawn to the huge global deposits of heavy oils as a driver for the sustainability of the oil and gas supply, as well as an alternative energy source, because they constitute one of the largest reserves of previously unexploited fossil fuels on earth [1].

Heavy oils are formed from the alteration of conventional oils. In most cases, they are

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Table 1: Distribution of Recoverable Heavy Oil Reserves by Region [4].

Region	Discovered OIIP Billion barrels	Prospective Additional Billion barrels	Total OIIP Billion barrels
North America	650	2	651
South America	1099	28	1127
Europe	75	0	75
Africa	83	0	83
Transcaucasia	52	0	52
Middle East	971	0	971
Russia	182	0	182
South Asia	18	0	18
East Asia	168	0	168
South East Asia and Oceana	68	0	68
Total	**3,366**	**30**	**3,396**

fundamentally different in chemical composition from conventional crude oils due to biodegradation. The light hydrocarbons in heavy oils are consumed by bacteria, leaving behind a complex mixture of organic compound with incredibly low gas-oil ratios [2]. Heavy oils have low API gravity in the range of 10-20 degrees, with viscosity greater than 100 cp and density between 920-1000 kg/m^3. In some classifications like that from the World Petroleum Congress, heavy oils are defined as crude oils with API gravity somewhat slightly higher than 20° API but below 22.3° API [3]. Heavy oil can be classified as conventional and unconventional resource. The conventional heavy oils are those whose API gravity is between 10°-20° API inclusive and a viscosity greater than 100 cp [4]; which can be produced using some conventional recovery mechanisms whereas the unconventional heavy oils are the natural bitumen and extra-heavy oils, which are the remnants of very large volumes of conventional oils that have been generated and degraded, principally by bacterial action [5]. The focus of this paper is on the recovery of conventional heavy oil using ESP: A case study of Enuma 3T well in Niger Delta.

Global deposits of heavy oil

It is estimated that about 3,396 billion barrels originally oil in place (OIIP) heavy oil deposits exist worldwide with 30 billion barrels of prospective additional heavy oil [4]. The largest known deposit of heavy oils occurs in three regions: North America (651 billion barrels); South America (1127 billion barrels); and the Middle East (971 billion barrels) respectively. These regions hold about 81% of the total recoverable heavy oil reserves in the world. In terms of deposits by country, Venezuela holds the largest deposits with 924.19 billion barrels, followed by United States of America with 198 billion barrels while Russian holds about 182 billion barrels, respectively. Table 1 shows the distribution of heavy oil reserves worldwide.

Heavy oil recovery processes

There are different methods used in recovering heavy oils. Some of these methods include dynamic recovery methods, steam-assisted gravity drainage (SAGD) and cyclic steam injection (Thermal) methods, gas injection, chemical method, and pumps. The choice of a given method depends on several factors amongst which are: The viscosity of the crude, the depth of deposition, the composition of the crude, impact on the environment, energy efficiency, economics, and technical difficulties.

Viscosity is a limiting factor for heavy oil recovery and because of high viscosities, recoveries are extremely low, fluid drives are inefficient and production rates are uneconomical [2,6]. Even at shallow depths (below 3000 ft), oil recoveries are less than 11% compared to 30% from conventional reservoirs [6]. In fact, it is estimated that less than two per cent of heavy oil resource is, at present, considered to be producible and of this, less than half remains [7]. The operating cost, energy consumption and the associated environmental impact also play major roles in selecting a given technology for heavy oil recovery. For instance, it has been reported that heavy oil development

Table 2: Emerging and new heavy oil development technology [8].

New Heavy Oil Development Technology		
Hybrid processes that combine different technology ■ CHOPS + PPT and a second SAGD phase ■ SAGD + solvent injection	**Techniques to reduce the environmental impact.** ■ Carbon capture ■ Cogeneration facilities ■ Non-condensable gas injection ■ Use of renewable energy (Solar in Oman) ■ Paraffinic Froth Treatment (PFT) - Applied to Mining by Exxon Mobil	**Technology that does not use steam and reduces environmental impact.** ■ Vapor Extraction) (VAPEX) (Evaluated by Equion in Colombia) ■ Solvent Vapor Extraction (SVX) ■ N-Solvent ■ Electro-Thermal Dynamic Stripping Process (ET-DSP) ■ Enhanced Solvent Extraction (ESEIEH) ■ Incorporating Electromagnetic Heating ■ Walter Alternating Gas (WAG) ■ Radiofrequency warming
Technology to improve the recovery factor. ■ In situ combustion (Using the Colombia`s Star Project) ■ Toe to Heel Air Injection (THAI) + CAPRI ■ Super Sump	**Technology to improve the energy efficiency of thermal processes and reduce water consumption.** ■ LASER ■ Solvent-Assisted SAGD ■ SAGD + surfactants ■ Expanding Solvent SAGD (ES-SAGD) ■ Solvent Cyclic SAGD (SC SAGS) ■ Solvent Co Injection (SCI)	

technology that provide higher recovery factors (e.g *in situ* combustion, steam flooding, cyclic steam stimulation (CSS) and mining) tend to have the greatest environmental impact and consume the most energy [8]. Consequently, to make heavy oil recovery competitive with conventional oil recovery methods, more efficient technologies with less environmental impacts are being developed and used. Some of these new technologies use steam assisted gravity drainage (SAGD) principles but apply solvent and alternative warming techniques to enhance the heavy oil recovery and improve the recovery factor [8]. Examples of these new technologies are shown in Table 2. Therefore, good candidate selection criteria must be adopted to optimally recover heavy crude oils.

Conventional heavy oils are best produced using artificial lift methods. There are several artificial lift methods currently in use. However, the choice of a given method depends on several factors ranging from depth of operation, operating volume, ability to handle solids etc.: including statutory regulatory frameworks in host countries. Table 3 shows the selection guidelines for frequently used artificial lift methods for oil production with ESP having a good capability of handling low API gravity crudes.

Description of Enuma 3T

Enuma 3T is situated in the swamp area of Bayelsa State, Niger Delta, Nigeria. The well was drilled in the period between February to March 2003 and completed single selective string in level and commingled level with electric submersible pump (ESP) and gravel pack (GP) on each level. The well was then put-on production in April 2003 on ESP with initial net oil rate of 6645 barrels of oil per

Table 3: Artificial Lift selection guidelines for producing hydrocarbons [10,11].

	Rod pump	Progressive cavity	Gas lift	Plunger lift	Hydraulic piston	Hydraulic Jet	Electric Submersible
Operating depth (ft)	To 16,000 TVD	To 6,000 TVD	To 15,000 TVD	To 19,000 TVD	To 17,000 TVD	To 15,000 TVD	To 15,000 TVD
Operating volume (bbl/d)	To 5000	To 4,500	To 30,000	To 50	50 - 4,000	300-15,000	200-30,000
Operating temperature (°F)	100/500	75/250	100/400	120/500	100/500	100/500	100/400
Corrosion handling	Good to excellent	fair	Good to excellent	Excellent	Good	Excellent	Good
Gas handling	Fair to good	Fair	Excellent	Excellent	Fair	Good	Poor to fair
Sand handling	Fair	fair	Excellent	Poor	Fair	Fair	Fair
Paraffin handling	Poor	excellent	Poor	Poor	Good	Good	Good
Fluid gravity	> 8° API	> 35° API	> 35° API	GLR required 300 scf/bbl/1000 ft depth	> 8° API	> 8° API	> 10° API
Crooked hole	Poor	Fair	Good	poor	Good	Good	Fair
Casing size	Fair	Fair	Good	Good	Fair	Fair	Good
Servicing	Workover or pulling rig	Workover or pulling rig	Wireline or workover	Wellhead catcher or wireline	Hydraulic or wireline	Hydraulic or wireline	Workover or pulling rig
Prime mover	Gas engine or electric	Gas engine or electric	compressor	Well's natural energy	Gas engine or electric	Gas engine or electric	Electric motor
Offshore application	Limited	Good	Excellent	N/A	good	excellent	excellent
Overall system efficiency	40-60%	40-70%	10-30%	N/A	45-55%	10-30%	35-60%

day (bopd) and water-cut of 10%. In August 2006, flow test was conducted, and the result showed that the oil production rate (Qo) has increased to 7164 bopd with a flowing tubing head pressure (FTHP) of 626 psi and water-cut of 13% respectively. On 29th May 2013, the ESP pump failed, and the well was finally put-on natural flow until it was shut-in on the 10th of September 2013.

Why ESP in Enuma 3T?

Electrical submersible pumps (ESP's) are well suited for high-rate, high-water-cut light oils from medium to shallow depths. Adaptation to hot heavy oils included larger motors and pumps and modifications to the pump stages to handle higher-viscosity fluids [1]. ESP's improve flowing tubing head pressure (FTHP) by lowering the flowing bottom-hole pressure (FBHP) to nearly zero; improves production rate in many candidate wells and allows economic production of potential candidate wells at high water cuts. They are very helpful in mature assets where improvement in vertical lift performance of wells is critical and have great positive impact on the ultimate recovery

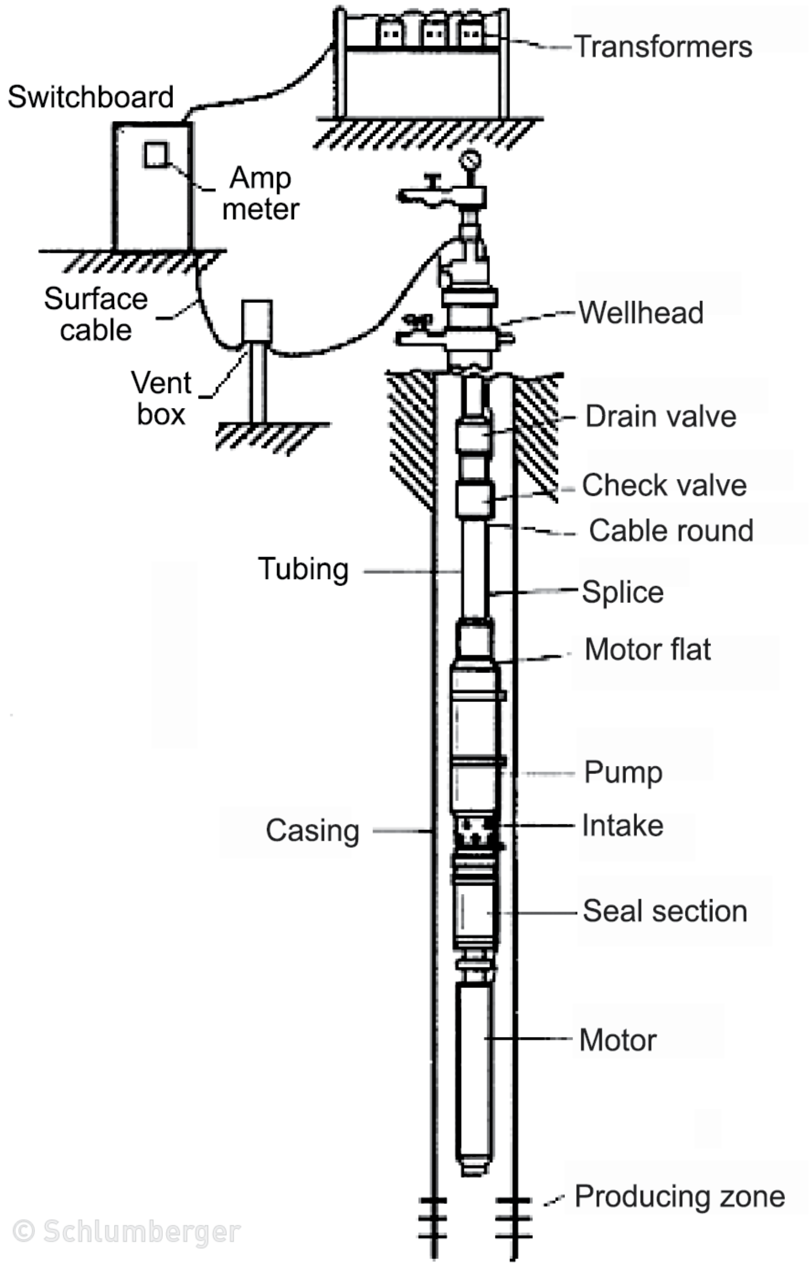

Figure 1: ESP system installed in a well (Courtesy of Schlumberger, (REDA) [9]).

recorded in selected candidate wells. A typical example of installed ESP in a well showing its primary components (a multi-staged centrifugal pump, three-phase induction motor, seal-chamber section, power cable and surface control) are shown Figure 1.

Although, the water-cut and API gravity in Enuma 3T is low, the viscosity is high to risk the installation of other artificial lift methods to ensure sustained production. Moreover, so many factors limit the application and operation of ESP's, among which is increasing depth [12]. As the depth increases, the ambient temperature and the produced fluid temperature also increases; both affects the motor cooling and thus the performance of the pump and the motor [13]. The depth of Enuma 3T is within acceptable operating depth (10,360.89 ft) of an ESP that would not require retrofitting special features on the ESP (above 15,000 ft) to enhance its performance and improve hydrocarbon production. Additionally, like other countries producing oil and gas, installation of ESPs in Nigeria must meet certain regulatory requirements before any company would be permitted to deploy it as shown in Table 4; The oil gravity of Enuma 3T is 19° API with an average fluid viscosity of 4.4 cp and

Table 4: Regulatory Requirements for ESP Installation in Nigeria.

	API Gravity	GOR Scf/bbl	Temperature (°F)	Water-cut	Sand Production
Maximum	39	2,725	178	unlimited	low
Average	25	497	120		
Minimum	17	77	70		

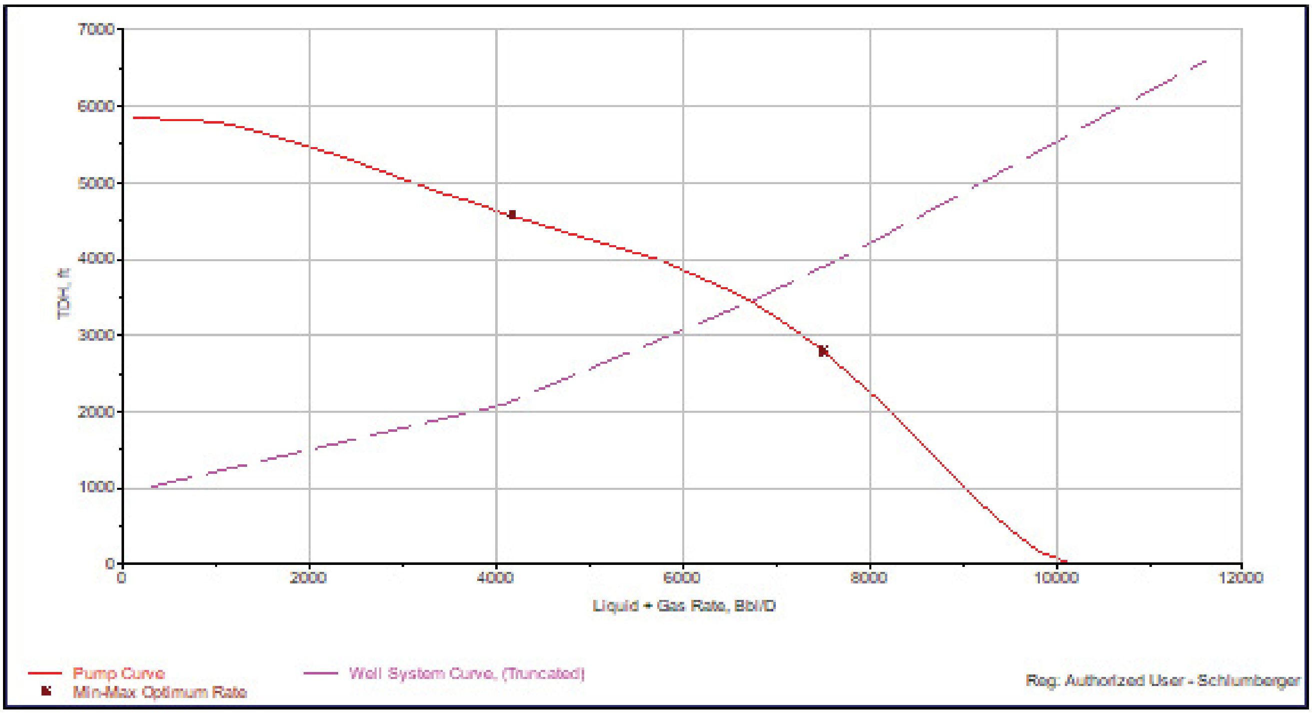

Figure 2: Pump performance plot for Enuma 3T at design stage, showing the minimum and maximum optimum rates (as triangular markers) on the pump curve and the well system curve (magenta dashed line).

Gas-oil-ratio (GOR) of 277 scf/bbl. Since the fluid properties of Enuma 3T are within the permissible range of operating ESPs in Nigeria as shown in Table 4; the installation of ESP to effectively produce Enuma 3T and to substantially reduce the residual oil reservoir becomes imperative.

Method/ESP Design for Enuma 3T

Enuma 3T has been shut-down for a considerable period of time because of its inability to flow even though it has a reservoir pressure of 3500 psi and temperature of 152 °F which are considered high enough to guarantee flow for typical conventional oil wells. The inability of the wellbore fluid to overcome the pressure losses in the production string gave rise to the deployment of GN 7000 ESP model pump designed to operate at 172 stages at 50 Hz to assist in the removal of accumulated wellbore fluids. The design Pump Intake Pressure was 3446 psi with a fluid velocity of 1.634 ft/sec while the expected fluid flow rate was 6000 bbls/d to lift a 53.808 lb/cuft liquid from the wellbore. The pump was designed to be placed at a depth of 3158 m (10,360.89 ft), 75m (246.06 ft) away from the top perforations. The design system plot for Enuma 3T is shown in Figure 2. From the design plot shown in Figure 2, the minimum and maximum operating rates for this pump is 4200 bbl/d and 7700 bbls/d while the optimum operating rate is 6800 bbls/d at a frequency of 50 Hz respectively.

Results and Discussions

Figure 3 is the pump performance curve showing the optimum operating windows of the pump at different frequencies. The design operating point (shown as the green square marker; the intersection between the pump curve (red line) at 50 Hz and the system curve (green line)) is the reference. The other frequencies where chosen below and above this point to understand the operating window for this pump. As can be seen in Figure 3, as the frequency increases, the pump capacity

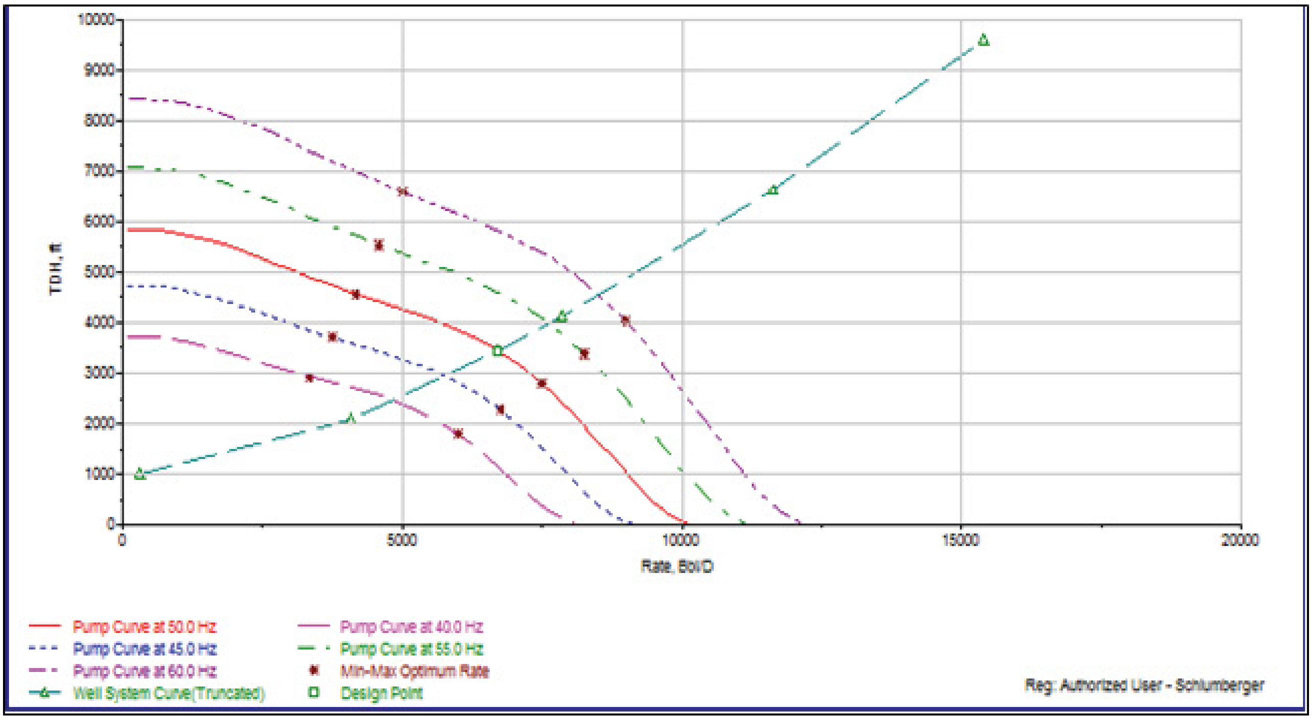

Figure 3: Pump performance curve at different frequencies, showing the design point (as green square marker) and minimum-maximum oerating rates.

also increases. However, care must be taken to ensure that very high frequencies are avoided to prevent sudden pump failure. Therefore, at a given frequency, the pump should be made to operate at the optimum condition that will not result to any detrimental effects.

From Figure 3, the minimum and maximum frequencies considered in this investigation are 40 and 60 Hz and their minimum and maximum operating rates at these frequencies are 3700 and 6000 bbl/d, and 5000 and 8800 bbl/d respectively. The operating points for each frequency (the point of intersection of the performance plots) are 4900 bbl/d for 40 Hz and 8000 bbl/d. Hence, the higher the frequency, the more fluid is produced from the wellbore across the production string and the lower the frequency, the lower the production rate. Typical production and operating conditions after the installation of ESP in Enuma 3T between 22 June 2003 and 06 December 2003 at a frequency of approximately 52 Hz is shown in Table 5. Table 5 shows that on the average, about 8000 bbl/d of net oil was produced along with about 0.800 MMscfd of gas with trace amounts of water production per day (BS&W is below 35%); a remarkable improvement from zero production due to overdue shutdown. Subsequent annual net production history for ten years after installation is shown in Table 6.

Economic Evaluation of Enuma 3T Well ESP Installation

Enuma 3T was completed in May 2003. The installation of ESP at Enuma 3T took about 165 Rig days to complete. The rig cost per day circa $70,000 while the cost of the full assembly of the ESP was $1,000,000. Other miscellaneous cost was about $350,000 while the approximate cost of operation for 5 years is $5,000,000. Hence, the total cost for the period of 5 yrs of operation is about $17,900,000.

Enuma 3T produced 8,000 bopd for the first one year without interruptions. The average cost of crude oil as at installation was assumed to be $28/bbl. The field produced traces of water while the average rate of gas production was 0.8 MMMscfd for the first year. Hence, income for the first 6 months of production was about $40,992,000. This result is consistent with similar investigations where the use of gas lift and electric submersible pump was compared in the production of heavy oil in Niger Delta; and the economic advantage of ESP surpassed that of gas lift significantly [14].

Conclusions

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Table 5: Production and Operating conditions of Enuma 3T.

Flow Test Result of Enuma-3T			**Choke**	**CSG P**	**FTHP**	**FLP**	**Sep. Press.**	**Gross**	**Net**	**Gas**	**GOR**	**Cal. GOR**	**API**	**BS&W**	**Remarks**
Field	Strg	Date	/64"	Psig	Psig	Psig	Psig	Bopd	Bopd	MMscfd	Scf/bbl	Scf/bbl		%	
Enuma	03T	22-jun-03	56	202	605	390	365	7,778	7,778	0.722	92	93	19	Trace	Freq = 52 hz
Enuma	03T	23-jun-03	60	202	580	400	380	8,207	8,207	0.740	90	90	19	Trace	Freq = 52 hz
Enuma	03T	24-jun-03	58	202	590	400	380	8,199	8,199	0.734	90	90	19	Trace	Freq = 52 hz
Enuma	03T	8-jul-03	58	203	600	420	378	8,254	8,254	0.817	99	99	19	0.00	Freq = 52 hz
Enuma	03T	9-jul-03	58	203	600	415	380	8,238	8,238	0.832	101	101	19	0.00	Freq = 52 hz
Enuma	03T	10-jul-03	58	203	600	415	384	8,244	8,244	0.816	99	99	19	0.00	Freq = 52 hz
Enuma	03T	11-jul-03	58	203	600	420	380	8,251	8,251	0.825	100	100	19	0.00	Freq = 52 hz
Enuma	03T	12-jul-03	58	203	600	420	386	8,279	8,279	0.820	99	99	19	0.00	Freq = 52 hz
Enuma	03T	13-jul-03	58	203	600	420	386	8,285	8,285	0.820	99	99	19	0.00	Freq = 52 hz
Enuma	03T	14-jul-03	58	203	600	420	386	8,303	8,303	0.822	99	99	19	0.00	Freq = 52 hz
Enuma	03T	15-jul-03	58	203	600	420	390	8,310	8,310	0.814	98	98	19	0.00	Freq = 52 hz
Enuma	03T	20-jul-03	58	218	600	420	388	8,278	8,278	0.811	98	98	19	0.00	Freq = 52 hz
Enuma	03T	21-jul-03	58	218	600	420	392	8,227	8,227	0.809	98	98	19	0.00	Freq = 52 hz
Enuma	03T	22-jul-03	58	218	600	420	395	8,269	8,269	0.810	98	98	19	0.00	Freq = 52 hz
Enuma	03T	23-jul-03	58	218	600	420	396	8,261	8,261	0.826	100	100	19	0.00	Freq = 52 hz
Enuma	03T	30-jul-03	58	228	600	420	400	8,297	8,297	0.830	100	100	19	0.00	Freq = 52 hz
Enuma	03T	01-aug-03	58	224	595	429	403	8,367	8,367	0.806	96	96	19	Trace	Freq = 52 hz
Enuma	03T	31-aug-03	58	247	584	420	390	8,252	8,252	0.851	103	103	19	Trace	Freq = 52 hz
Enuma	03T	9-sep-03	58	220	596	419	407	8,305	8,305	0.861	104	104	19	Trace	Freq = 52 hz
Enuma	03T	19-sep-03	58	261	729	420	410	8,314	8,314	0.799	96	96	19	Trace	Freq = 52 hz
Enuma	03T	01-oct-03	52	256	740	430	414	8,318	8,318	0.788	95	95	19	Trace	Freq = 54 hz
Enuma	03T	15-oct-03	44	285	940	424	410	7,954	7,954	0.744	94	94	19	Trace	Freq = 54 hz
Enuma	03T	31-oct-03	44	270	940	425	406	7,921	7,921	0.751	95	95	19	Trace	Freq = 54 hz
Enuma	03T	06-nov-03	44	276	930	420	411	7,830	7,830	0.747	96	95	19	Trace	Freq = 53 hz
Enuma	03T	29-nov-03	44	146	900	426	411	7,759	7,759	0.724	93	93	19	Trace	Freq = 53 hz
Enuma	03T	06-dec-03	44	142	900	430	418	7,707	7,707	0.715	93	93	19	Trace	Freq = 52 hz

Table 6: Average annual net production history of Enuma 3T after installation of GN 7000 ESP model pump.

Year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Net Average Production (bopd)	8000	7800	6500	6200	5900	5200	4600	4300	4000	3500

Production of heavy oil generally poses a greater challenge compared to conventional oil. However, using a reliable candidate selection criteria, conventional heavy oils can be effectively and efficiently produced with minimal risks. The installation of the right ESP in Enuma 3T as demonstrated in this paper that ESPs has the potential of reducing the residual oil saturations in heavy oil reservoirs. More importantly, compared to other heavy oil recovery methods, ESP is less energy intensive in application to produce heavy oil and environmentally friendly to be considered as one of the best alternatives in producing conventional heavy oil reservoirs globally.

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