Prospects of Enhanced Oil Recovery (EOR) Application in Niger Delta Heavy Oil Field

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***Abstract*— Novel technologies have heralded the emergence of unconventional petroleum exploitation, reserves that were deemed not productive by earlier available technologies have now been exploited. Exploitation and production still goes deeper to more difficult and challenging reservoir systems as the petroleum industry transcend to mature EOR processes and advanced drilling techniques. However this methods are very costly when in comparison with exploitation and production of conventional light oil reserves such as the prevalent operation in the Niger Delta. This paper proposes methods for the exploitation of Nigeria unconventional reserves using enhanced oil recovery methods. Even though Nigeria has a large deposit of conventional reserve but the government has not made efforts to develop it as much of the emphasis has been on the conventional light crude. As oil is the main say of Nigeria economy and the conventional crude rapidly exhausting, there is urgent need for unconventional petroleum exploitation. Analysis shows that more recovery efficiency of 50% is achieved using cyclic steam injection as compared to average recovery of 42 percent realized by using in-situ combustion methods. Cyclic steam as thermal oil recovery process have been proposed here for development of the Niger Delta heavy oilfield. Furthermore, the results from the heavy oil exploitation in Nigeria have been compared with that of Venezuela and it is seen that the Niger Delta heavy oilfield holds more prospects in terms of ultimate recovery efficiencies than Venezuela. Also, it is seen that although the EOR means of exploiting these heavy oils are capital intensive and challenging but the method will be profitable as long as oil price is above $50/bbl.**

***Index Terms*— Enhanced oil Recovery, Heavy oils, Steam injection, Unconventional reserves**

I. INTRODUCTION

Fossil fuels will continue to remain the dominant energy source in the foreseeable future. Due to increasing demand and usage the conventional reserves may not match up with current growth in utilization. For a country like Nigeria whose economy almost entirely depends on petroleum, there is need to venture into productions from her unconventional petroleum reserves. Until now the exploration and production activities in the Nigeria Niger Delta is within the circles of the conventional (light) oil reservoir which comparatively is cheaper and easier to produce than the unconventional reservoirs. But this cheaply available conventional resource is rapidly depleting while the demand for energy is on the rapid rise due to economic growth. The Nigeria government need to consider the development of its unconventional of reservoirs to maintain its oil-dependent economy and to remain relevant in the League of Nations as one of the top producers of oil in the world.

Unconventional petroleum reserves are those whose physical, chemical or geologic conditions hampers their production by normal conventional production means. Most operators and governments have neglected these reserves because of its complexity, difficulty and cost of development which reduces its economic viability [1]. For instance, in the Niger Delta, production have been grossly limited to the conventional reservoirs, this reservoirs are comparatively easier to produce by utilising the primary energy of the reservoir, or supporting it with artificial lift techniques or in some extreme cases injecting water into the reservoir to help mobilize the oil and mobilize to the production interval where it flows to the surface.

Among the various unconventional reserves are the shale reserve, the heavy and extra-heavy oil reserve, tight gas etc. heavy crudes are unconventional reserves whose physical and chemical make-up hampers its production by conventional means. Because of its high viscosity and density these resources are very difficult to recover owing to low mobility [2]. Enhanced oil recovery has never been practiced in the Niger Delta, which is partly because companies shy away from it because of operational cost and high risk associated with it and also because of government non-intervention [3]. Government can intervene by making laws that will favour the development of EOR methods which are the dominant method for development of unconventional reservoirs.

Heavy oil accumulation is seen in the Niger Delta as documented by Tetede [4]. According to him, large deposits of heavy oil is seen at Imeri village in Ijebu-Imushin Ogun state, Nigeria. Tetede claims that Ogun state alone accounts for nearly 40% of the total heavy oil deposits in the Niger Delta. Other areas of high heavy oil accumulations are Ondo, Edo and Lagos states. In their work, Ossai et al [8] stated that about 30-40 billion barrels of heavy oil are contained in the bituminous sand deposits in the south-western Nigeria. This quantity is alarmingly too significant to be left unexploited especially when conventional reserves are declining with production.

Enhanced oil recovery (EOR) methods are the methods for development of heavy oil reservoirs. Among the several EOR methods are thermal methods, chemical methods, miscible and immiscible methods, microbial method etc. it has been established that thermal methods are the best for heavy oilfield development. They could produce the heavy oilfields with high recovery factor and increase the development profit. In this work we evaluate the prospects and challenges of effective EOR deployment for production of the Niger Delta heavy oilfield, this will be a strategy to increasing production and managing the high rise and demand of Nigeria crudes.

II. HEAVY AND EXTRA HEAVY OILS

Heavy crude oil is a highly viscous oil that cannot easily flow to production wells under normal reservoir conditions. It is referred to as heavy because its density or specific gravity is higher than that of light oil. Heavy crude has been defined as any liquid petroleum with an API gravity less than 20^o. Heavy crudes have higher viscosities, higher specific gravities and heavier molecular composition than light oil.

Meyer et al. [5] explained that the oil becomes heavy as a result of eradication of light fractions through natural processes after evolution from the natural source materials. A high proportion of asphaltic molecules and with substitution in the carbon network of heteroatoms such as nitrogen, sulfur, and oxygen also play an important role in making the oil heavy. Therefore, heavy oil, regardless of source, always contains the heavy fractions of asphaltenes, heavy metal, sulphur, and nitrogen.

Extra-heavy oil is defined by world energy council in 2010 as crude oil having a gravity of less than 10^o and reservoir viscosity of more than 10000cp. Heavy crude oil is related to natural bitumen from oil sands. Bitumen from oil sands are classified as extra heavy oil. Bitumen is the heaviest, thickest form of petroleum. Natural bitumen also called tar sands or oil sands shares the same attributes as heavy oil but is heavier. Production, transportation and refining of heavy oil presents challenges compared to light oil or conventional oil.

The reservoirs of heavy oil are shallow and have less effective seals (up to 1000 meters below the surface line), which is the reason for the low reservoir temperature (40-60 °C). Low sedimentary overburden tends to ease the biodegradation, and the presence of the bottom aquifers further facilitates the process. As mentioned earlier the less effective seal is due to the low seal pressure, which may cause the dissolved gases to leave the oil, increasing its viscosity [6]. The reservoir lithology is usually sandstones deposited as turbidity with high porosity and permeability; the elevated viscosity is compensated by high permeability.

III. TAR SANDS AND BITUMENS

Tar sands, also known as oil sands or crude bitumen, or more technically bituminous sands, are a type of unconventional petroleum deposit. Tar sand is composed of a mixture of bitumen, which makes up about 10-20% bitumen and about 80-85% mineral matter including sands, clays and 4-6% water. This condition usually applies to oils having a gravity less than 12 °API. The largest world deposits are in Canada, Venezuela, Madagascar, USA, and Russia. Bitumen is about 20% of the actual tar sands found in Nigeria while 76% is for mineral matter that include clay and sand and 4% water [7].

Bitumens are solid or semisolid hydrocarbons which are sticky, black and highly viscous. Bitumens are classified into following groups: Mineral waxes, Asphalts, Asphaltites and Oil-shale bitumen. They are naturally occurring substances that are considered to be complex mixtures of high-molecular-weight hydrocarbons and non-hydrocarbons which can be separated into fractions consisting of oily material, resins, asphaltenes, and carbenes. These fractions merge into one another and their atomic C/H ratio increases with each succeeding member, except for the carbenes which differ mainly in having more oxygen than the asphaltenes. Three types of hydrocarbons are present in bitumens: paraffinic, naphthenic, and aromatic hydrocarbons. Non-hydrocarbons in bitumen have heterocyclic atoms consisting of sulphur, nitrogen, and oxygen. The asphaltenes usually contain more aromatic compounds than the resins and the oily fractions. The resins contain aromatic or naphthenic hydrocarbons and the components of oily fraction may have naphthenic or paraffinic structure. The naphthenic plus paraffinic contents in bitumen increase with decreasing content of aromatic hydrocarbons, the oily fraction having the lowest aromatic content.

The molecular weights of various bitumen fractions vary from about 300 to 1500 for the oily fraction and resins, and from about 600 to 10 000 for the asphaltenes, and to probably higher values for the carbenes.

IV. METHODS OF PRODUCING HEAVY OILS

Under this description we recognize two broad methods

1. Non-thermal means
2. Thermal EOR means

Non Thermal Means: Cold Production by CHOPS Method

In this method sand is produced aggressively along with the heavy oil without applying heat. The oil production is improved substantially through the regions of increased permeability wormholes. The basis of this process is the oil production and recovery when sand production occurs naturally. The production of the unconsolidated un-cemented reservoir sand results in significantly higher oil production.

Oil production and sand production are bound together intimately in the process. This can be described in a three step process

1. **First Step:** The mobile heavy oil flows toward the production well, sharp pressure gradients are generated in the reservoir.
2. **Second Step:** This results in failure of the unconsolidated sand matrix.
3. **Third Step:** The failed sand is dragged to the well by the high viscosity oil.

Cold heavy oil production with sand (CHOPS) is now widely used as a production approach in unconsolidated sandstones. The production of sand from an unconsolidated heavy oil reservoir generates a network of high permeability channels known as wormholes that grow into the reservoir (as discussed earlier).

As a result of sharp pressure gradients, sandcuts are generated which according to Chugh et.al. [8] can be as high as 40% in the first days of production dropping to 1-2% in the long term. Sand production is thought to be a function of the following according.

a. **The absence of clays and cementation materials:** as the presence of clay stabilizes the sand grains which reduce sand movement.
b. **The viscosity of the oil:** because higher oil viscosity increases the frictional drag between the oil and the sand grains, which promotes sand movement.
c. **The producing water cut and gas/oil ratio:** because water and the sand grains inhibit sand movement.
d. **The rate of pressure drawdown:** increasing the drawdown rate also promotes sand movement because the increase in the velocity of the fluid in the well bore will increase the frictional drag on the sand grains.

This process increases the productivity due to the following reasons:

- **Sand grain flow**: the flow of sand with the oil has the potential to reduce the frictional drag (as earlier discussed), which could increase the productivity in the sand flowing region.
- **Sand removal**: as the sand is removed it makes the way for the overburden weight to act as a shear and destabilize the sand, helping to drive the sand and oil towards the wellbore.
- **Enlarge the drainage radius**: the produced sand creates a modified wellbore geometry that could have several configurations including wormholes (as discussed earlier) and a significant increase in permeability due to an increase of porosity in the dilated zones.
- **Foamy flow**: gas coming out of the solution in the heavy oil in the form of bubbles which do not coalesce, but expand down gradient, this is called as a foamy flow. This helps to locally destabilize the sand and sustaining the process.
- **Liberation of the pore blocking minerals:** pore throats can be blocked by fines migration that occurs during the oil production. This blockade reduces the number of flow paths available for the oil flow, dilation of sand creates the larger pore throats which eliminates the blockade because it is very difficult to block those pore throats.
- **Clean up drilling damage**: there is one more blockage, which is between the wellbore and the sand face caused by the drilling mud and the drilling fines. Producing sand adjacent to the well is an effective means of cleaning up the damage. The continuous sand production means the asphaltenes or fines plugging of the near well-bore environment does not occur, so there is no possibility of an effect to impair productivity.

V. THERMAL EOR METHODS FOR RECOVERING HEAVY OILS

Generally there are two thermal methods of recovering heavy oil:
1. The process in which heat is injected into the reservoir.
2. The process in which heat is generated within the reservoir itself.

Steam based process were used before the advancements in the field that introduced new processes such as in situ combustion or fire flooding. Thermal recovery process reduces the viscosity by means of heat and also provides the force to increase the flow rates of the oil to the production well that's why thermal processes are also classified as thermal drives. In the thermal stimulation techniques, only the reservoir near the production well is heated. Stimulation techniques can also be combined with thermal drives, and in this case the driving forces are both natural and imposed.
The fluid is injected continuously through injection wells to displace oil and obtain production from other wells. The same pressure which maintains the injection of the fluid in the well also increases the driving forces in the reservoir, which increases the flow of crude oil. Driving forces present in the reservoir, such as gravity, solution gas, and natural water drive, affects the improved recovery rates once the flow resistance is reduced and overcome by the driving force. Thermal processes use heat in well bores to increase the production rates for heavy crude oils. The drive process can also be applied to recover the residual oil in energy depleted reservoirs that hold conventional oil.

VI. CHALLENGES OF PRODUCING HEAVY OILFIELDS

The challenges of EOR techniques include
1. High capital cost
2. Crude oil price
3. Specialized expertise
4. High Risks
5. Environmental concerns
6. Reservoir dependent factors

High Capital Cost
There is extra investments being spent to develop new EOR facilities and to rejuvenate the production infrastructure. These activities are requiring huge capital expenditure (CAPEX) and operational expenditure (OPEX). From laboratory work to field implementation of an EOR project requires long time, and money. Thus, after implementation, production response does not occur immediately. During that time, the oil company had spent a lot of much money and effort. Thus the payout time for EOR methods of producing fluids are generally higher than that for conventional production because of the huge capital outlay from each stage of the EOR process.

Crude Oil Price
The decisions on the future EOR will not only be based on depth and oil gravity criteria, but oil price as well, which is important. Obviously, the economy is playing a role in whether EOR projects move on or not. In general, EOR activities increases when the oil prices increases and vice versa. For example, in the early 1980s when oil prices were up to $50/bbl, EOR activities increased drastically. But in 1994, when oil price crashed, the impact was a reduction on EOR projects. At that time, the oil price was below $20 /bbl. Oil price influences the petroleum industry activities. The lower the oil price the more the reduction in several activities such as research, developing budgets, capital spending, employment pattern, and exploration.

Specialized Expertise
EOR methods requires specialized skills and expertise. This is both at the laboratory and in the field scales. Then, to solve the complicated problems it requires expert skills. Currently, lack of expert skills in EOR design and implementation will greatly impact output. To address this, special trainings must be conducted routinely to staffs and contractors to acquaint them with the latest ideas, techniques and technologies aimed at optimizing cost and performance.

High Risk
Conventional oil production is not as risky as EOR methods, the high risk and complexities of EOR methods have limited their usage especially by operators in Nigeria whose production border still falls within the conventional light crudes. This risk can be obviated by improved research and development of better technologies toppled with better understanding of the prevailing conditions.

Environmental Concerns
EOR processes contribute to environmental degradations. This is one of the limitation of EOR processes. In most cases, thermal recovery means as well as other EOR methods generate greenhouse gases that leads to greenhouse effects. In planning EOR methods and application great care must be taken to ensure minimal environmental upset is done to the environment.

Reservoir Dependent Factors
Reservoir factors such as depth and gravity of the fluid also affects the implementation and success of EOR methods. For areas where the pay zone are shallow, thermal EOR technique may not be successful. If the heavy oils are not within zones that will enable a successful thermal EOR application then it may be a great challenge exploiting such reserve by EOR techniques.

VII. POTENTIALS FOR NIGERIA HEAVY OILFIELDS

Unconventional petroleum when exploited has the capability of contributing 15% of the total oil productions in Nigeria. The estimated recoverable volume of Nigeria oil sands alone is 31 billion barrels, shale oil amounts to 1.7 billion barrels of recoverable hydrocarbon reserve. The Nigeria heavy oilfields holds great potential for the Nigeria government some of the potentials are

1. Provision of more revenue for the government
2. Provision of employment opportunities
3. Rapid development of host communities
4. Expansion of local industries
5. Increase in foreign investor partnerships
6. Open windows for research and developments.

VIII. METHODS

Selected method for production of heavy oils
For this work steam injection has been selected as the choiced artificial lift technique for the production of the Niger Delta heavy crude reserves. We discuss some features characteristic of steam injection project.

Important parametres in steam injection project
1. Down-hole steam quality
2. Formation thickness
3. Steam injection rate
4. Down-hole pressure
5. Soaking interval
6. Production interval

Algorithm for Calculation Scheme
These seven step algorithms is suited for modelling stem injection in heavy oil reservoirs.
1. Initialize the model by inputting reservoir, fluid, and operational properties.
2. Calculate steam zone geometry (volume, height, and thickness), temperature, and saturations during injection and at the start of the production cycle.
3. Calculate oil and water production flow rates at small time steps within the production interval. Also, calculate the cumulative volume of fluids produced and check against original fluids in place.
4. Calculate the average temperature of the heated zone during production and at the end of the production cycle.
5. If additional steps are needed for cycle completion, go to Stage 3 and repeat, otherwise proceed.
6. Calculate the amount of fluids and heat remaining in the reservoir at the termination of the cycle, and thereby calculate recovery and oil-steam ratio (OSR).
7. If a new cycle is required, repeat steps, otherwise terminate calculations

Screening Parametres for Steam Injection and In-Situ Combustion for Heavy Oils
In-situ combustion comes very close in performance as a thermal recovery EOR means to steam injection. To this it is pertinent to compare the parametres used for screening and selection of the choiced method from the two. In some cases the data after screening the results may be almost identical, this means that either of the two methods can successfully and viably be applied to that reservoir and well conditions.

Table 1: Screening parametres for selection of steam injection or in-situ combustion [9]

Screening Parametres	Steam Injection	In-Situ
Oil Gravity (o API)	10-34	9-25
oil viscosity (cP)	≤5000	≤15000
Depth	≤11500	≤3000
thichness of payzone (Ft)	≥20	≥20
Reservoir Temp (oF)	na	na
Porosity (%)	≥20	≥20
Average Permeability (mD)	≥35	≥50
Reservoir Pressure (psi)	≥2000	≥1500
Rock Type	Sandstone or Carbonate	Sandstone or Carbonate

Recovery efficiency of steam injection and in-situ combustion From literatures, the following have been established to be the average efficiencies when using either steam injection or in-situ combustion for recovery of heavy oils

Table 2: Comparisons of efficiency of steam injections with other EOR methods for Heavy oils [9]

EOR Methods	Process Displacement efficiency (%)	Areal Sweep Efficiency (%)	Vertical Sweep Efficiency (%)	Total Recovery Efficiency (%)
Cyclic Steam Injection	90	70	80	0.504
Steam Flooding	85	70	75	0.44625
In Situ Combustion	80	70	75	0.42
Micro-Emulsion	80	50	80	0.32
CO2 Waterflood	35	70	80	0.196

It is evident from table 2 above, that steam injection has the highest recovery efficiency amongst the various EOR methods considered.

Fig. 1 below clearly explains the situation. Steam injection whether cyclic steam or steam flood have the highest recovery efficiency as seen in the figure above. The next in order of magnitude is the in-situ combustion whose average recovery efficiency is around 42% of the recoverable volume in the reservoir at the commencement of the EOR operation.

Comparison of Heavy Oil in Venezuela with that of Niger Delta.

To investigate the potential of heavy oil reservoir, its exploitation and production capability we consider four cases, the first is that of a Venezuela reservoir and the remaining three are reservoirs in the Niger Delta [8]

Table 3: The reservoir Input data for the four reservoirs considered [4]

Parametres	Venezuela	Niger Delta Reservoir A	Niger Delta Reservoir B	Niger Delta Reservoir C
Pay Thickness (ft)	25	110	152	71
Pressure (psi)	2900	2794	3384	2033
Temperature (°f)	146	128	164	122
Oil Gravity (°API)	13	18.08	19.19	19.03
Permeability (mD)	1000	600-1500		
Oil Saturation (%)	55	83.4	82.1	81.4
Water Saturation (%)	40	16.4	17.6	18.3
Oil Viscosity (cp)	280	86.75	31.81	25.49
Porosity (%)	22	20		

Production Results for Heavy Oil Reservoirs

The results for Oil Recovery from the reservoirs are summarized below; the first case is the recovery statistics when in-situ combustion was used while the second is the projected recovery statistics if steam injection (cyclic steam) is used

Table 4: Oil recovery from reservoirs using In-situ combustion method [7]

Parametres	Venezuela	Niger delta Reservoir A	Niger delta Reservoir B	Niger delta Reservoir C
Total Oil Recovery (bbl/day)	485	676.4	664.8	658.4
Total Recovery Efficiency (%)	38	42	41	42

From table 4, it is seen that the Niger Delta reservoir cases gave higher recovery efficiency than that of Venezuela when insitu combustion was applied.

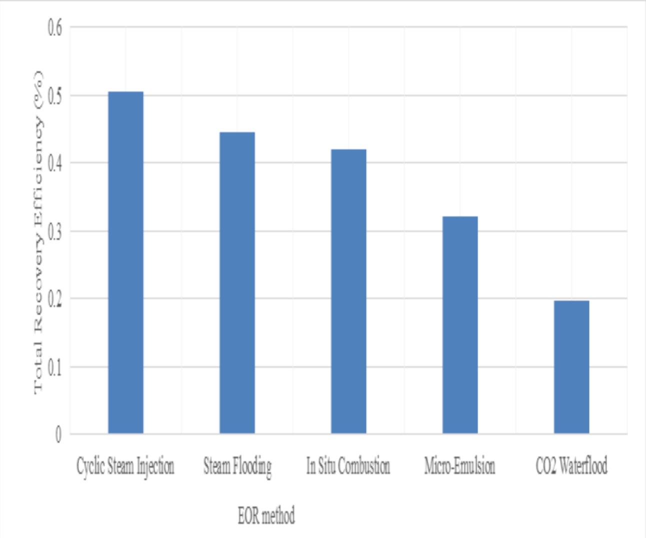

Fig. 1: Comparisons of efficiency of EOR methods

Also, considering table 5 and fig. 2 below, we analyze the production results if steam injection was applied to the four reservoirs instead of in-situ combustion. The result is given below

Table 5: Oil recovery from reservoirs using cyclic steam injection method

Parametres	Venezuela	Niger delta Reservoir A	Niger delta Reservoir B	Niger delta Reservoir C
Total Oil Recovery (bbl/day.)	638.2	805.2	810.7	783.8
Total Recovery Efficiency (%)	50	50	50	50

The cyclic steam injection used has an average recovery efficiency of 50% which is higher than that of the in-situ combustion earlier considered.

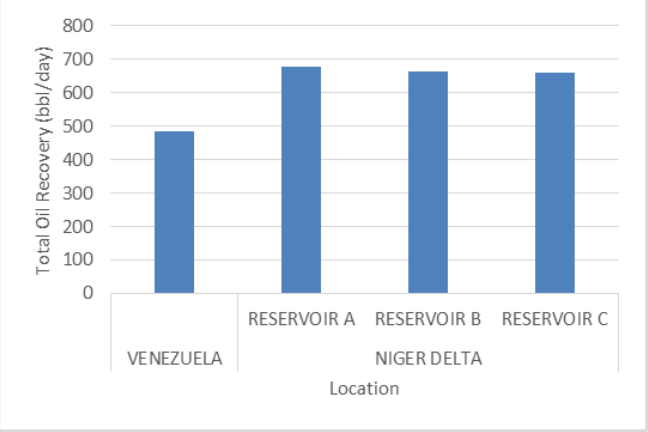

Fig. 2: Oil recovery when cyclic steam injection method is applied to reservoirs

Generally, it is seen that heavy oil reserves holds great potential in the Niger delta. If Venezuela whose recovery efficiency is less than that of the Niger Delta as we have considered is surviving as an oil producing nation from its heavy oil reserve, then the Niger Delta can develop its heavy oil reserve which has been proven to be technically feasible and economically viable. It is evident that EOR methods are capital intensive but as long as crude oil price remains above $50/bbl EOR techniques remains economically profitable.

IX. CONCLUSION

The Nigeria heavy oilfields holds great potential for Nigeria. Development of these resource has great prospects for the Nigeria economy. Although the cost of EOR applications which is used to develop them is enormous, but as oil price increases above $50/bbl thermal EOR processes becomes profitable. It has been established as we have analyzed in this work, that cyclic steam injection method gives higher recovery efficiency than other thermal and non-thermal EOR methods for the recovery and production of heavy oils especially in the Niger Delta. The Nigeria heavy oilfields when put to production can supply more than 15% of the total daily oil recovery at the inception of the development and statistics is sure to increase as more application is made. The Nigeria government must make a strategic move in development of its vast oilfields just as the Venezuela government has done and not wait until the conventional light oils have been used up before they commence.

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