EXPLOITATION OF BITUMEN FROM NIGERIAN TAR SAND USING HOT-WATER/STEAM STIMULATION PROCESS

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Exploitation of Bitumen from Nigerian Tar Sand Using Hot-Water/Steam Stimulation Process

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Abstract

With the upward surge in global demand for energy, unconventional energy resources are being considered as options to quell the growing energy demand. These unconventional energy resources like oil sand, shale oil, shale gas, tight gas, are fast becoming alternatives to complement the conventional energy resources. Tar sand exploitation is being commercialized globally. With success stories from Canada, Venezuela and U.S.A., other countries tend to follow. Nigerian tar sands, which is similar to Canada's tar sand in terms of chemical composition, water wet nature, etc., has some characteristics which will yield enormous economic benefit when exploited. The possibility of producing heavy oil from the Nigerian tar sand deposits by steam stimulation was evaluated in this paper with respect to the technology (Cyclic Steam Stimulation), environmental impact and the economic analysis, with Canada's success stories used as reference point. The result of the study showed that heavy oil could be produced with steam stimulation process with little impact on the environment and with huge economic potentials.

Keywords: Bitumen; Tar sand; Cyclic Steam Stimulation; Oil Sand; Nigeria.

1. Introduction

The global demand for energy in rapidly increasing and conventional oil reserves will not be able to meet up the increasing energy demand. The need to exploit unconventional resources is being considered globally. Some of the unconventional resources include tar sand, shale oil, shale gas and tight gas. These resources (with tar sand inclusive) are termed unconventional because they cannot be exploited with the available technologies used in exploiting the "conventional crude oil and gas". Again, exploitation of these resources is quite expensive.

The problem associated with the exploitation of tar sand include:

- The best technology to exploit tar sand.
- Environmental implication of processes of exploiting tar sand
- Economic considerations.

Based on the stated challenges and the understanding of the thermal processes used in the exploitation of tar sand, this study is therefore concerned with the following:

1. Evaluation of the hot water/steam stimulation process applied in tar sand exploitation.
2. Environmental impact evaluation of the processes.
3. Economic evaluation of tar sand exploitation.
4. Tar sand market and prospect in Nigeria.

1.1. Concise description of tar sand and its origin

By definition, tar sands are sedimentary rocks (consolidated or unconsolidated) that contains bitumen (solid or semisolid hydrocarbons) or other heavy petroleum that, in natural state, cannot be recovered by conventional petroleum recovery methods. Technically, tar sand is not a combination of tar and sand as the name implies, since tar is a viscous liquid; black in colour with adhesive properties, obtained by the destructive distillation of coal, wood, shale, *etc.*, and such an origin for tar in tar sands are rarely implied. On the other hand, "bitumen" is the name given to viscous liquids or solid materials black or dark brown in colour having adhesive properties, consisting essentially of hydrocarbons derived from petroleum or occurring in natural asphalt and soluble in carbon disulphide. Bitumen is found mixed with other component such as clay, water, *etc.*, in sand known as "tar sand" by name, which is a misnomer or an inappropriate term and should rightly have been called "bitumen sand" since it is bitumen and not tar from destructive distillation of coal that is intermingled with the sand deposits. Bitumen is simply the name of the oil found in tar sands and until recently, Alberta's bitumen deposits were known as tar sand but are now called "oil sands". A section of tar sand showing its composition is shown in Figure 1.

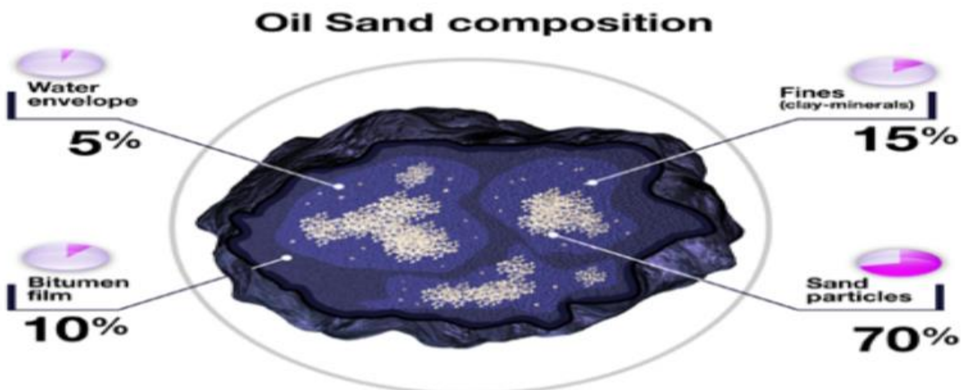

Figure.1. A Section of tar sand showing its oil composition

Tar sands is not only made up of bitumen but also consist of feldspar, Mica clay minerals in minor amount and quartz as the dominant mineral constituting over 90% of the entire assemblage of mineral grains. Tar sands are water wet by nature. In Nigerian, the tar sand belts fall within the Eastern Dahomey basin which is a coastal sedimentary basin filled with over 2500 metres of cretaceous and younger sediments unconformity overlying the block faulted basement complex rocks. The basin sedimentary fill was subdivided into three intervals by Durham Pickect [1] namely:

- Sand and sandstone at the base.
- Alternating sand and shale.
- Upper shales which correspond to the three formations of Ise, Afowo and Ararom respecttively [2].

The grain size of the tar bearing sands vary from fine to coarse grained. The quartz sand forms a bulk of the material with either the bitumen i.e. Oil wet (as in the case of some US deposits - Utah), or water wet (as for the Athabasca in Canada and Okitipupa in Ondo State of Nigeria), forming the continuous phase, generally depending on the grade of the oil sand.

The microscopic examination of the Athabasca tar sand shows that the thin film of water is about 10mm thick. The similarity of the grain/water relationship of both the Nigerian and Canadian tar sand makes it characteristically easy to derive comparative studies on processing Nigerian tar sand from the Canadian experience. Although, the Nigerian tar sand has been discovered since the dawn of the past 2 decades, they have largely remained unexploited due to the availability of the conventional oil in the neighbouring oil rich Niger Delta of the country.

According to Adegoke *et al.* [3], the lithology, hydrocarbon contents area and spatial distribution of the bituminous sands have been well documented. Adegoke *et al.* [3] recommended that bitumen be exploited by open cast mining in areas where the bituminous sands outcrop or where they are overlain by less than 50 – 75 metres of over burden while heavy oil be exploited by the use of in-situ techniques in all areas south of the tar sand mine zone, especially where the over burden thickness is in excess of 100 meters.

The work presented by this paper is aimed primarily at giving the technical, environmental and economic evaluations (benefits and implications) of exploiting Nigerian Tar sand using hot water/steam stimulation.

2. Properties of Nigerian tar sand

Oil sand (tar sand) consists of an initiate mixture of bitumen, water, quart sand and clays and other minerals which is either oil or water wet. The case of oil sands in Utah in U.S.A is oil-wet but the oil sands in Canada and Okitipupa in Ondo State of Nigeria are water-wet. This makes the Nigerian and Canada tar sand similar. The Nigerian and Canadian tar sand are also similar in the area of mean value of chemical composition as shown on Table 1 [4].

Table 1. Chemical composition of Nigerian and Canadian oil sands

Element	Nigeria's composition (%)	Canada's composition (%)
Carbon	85	83.4
Hydrogen	10.7	10.4
Nitrogen	0.5	0.4
Oxygen	1.7	1.0

Other similarities between Nigeria and Canada tar sand properties on the bases of characteristics is in the area of having similar texture parameter, oil saturation, chemistry and water-wet nature of grains. However, the Nigerian tar sand are more asphalthenic and lesser in trace metals. Table 2 shows the comparison of the metal compositions of Nigeria and Athabasca tar sands.

Table 2. Metal composition of Nigeria's and Athabasca's tar sands

Element	Nigeria's Composition (ppm)	Athabasca's Composition (ppm)
Vanadium	35	75
Nickel	33	198

The close similarity of the characteristics of the tar sands of Nigeria and Athabasca suggest that the Canadian experience can be used as a model for the development of Nigerian tar sand. The similarities make it characteristically easy to derive comparative studies on processing of the Nigerian deposits, easy determination of similar techniques for exploitation and draws the difference from those oil wet deposits of California, New Mexico and Utah.

3. Cyclic steam stimulation process

The Cyclic Steam Stimulation (CSS) is the simplest and the most direct of the steam stimulation processes. Steam is injected into the formation of bitumen or tar sand deposits and allowed to soak. The pressure of the steam dilates or fractures the formations while the heat reduces the viscosity of the bitumen. The bitumen is then pumped to the surface through the same injection well. This process is repeated in a cyclic fashion. The CSS could be divided into three (3) different stages.

Stage 1: This is the called the steam injection stage or phase. In this stage, steam is being injected at high pressure into the formation. The high pressure is to fracture the formation while the heat from the steam is to reduce the viscosity of the bitumen.

Stage 2: This is known as the soak period. This is the time interval that is allowed for the bitumen's viscosity to reduce. This is as a result of the heat from the steam. Most often, a period of one to three months is given for the soak period.

Stage 3: Finally, the bitumen with reduced viscosity is then pumped, alongside the condensed water from the steam, to the surface and processed as heavy crude. This stage is known as the Bitumen Production phase.

Figure 2 is a diagrammatic representation of the stages for the CSS process in a vertical well. All the three stages are carried out in a single vertical well and the process recovers 15 to 25% of original oil in place. Finally, the bitumen with reduced viscosity is then pumped, alongside the condensed water from the steam, to the surface and processed as heavy crude. This stage is known as the bitumen production phase.

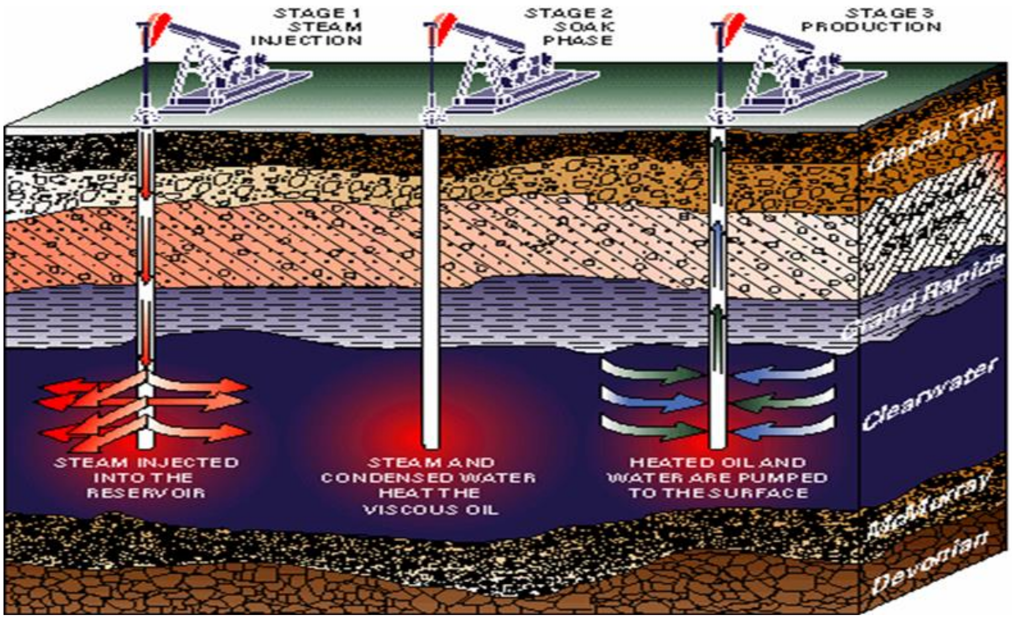

Figure 2. Cyclic steam stimulation showing the three different stages (*Source: IMPERIAL OIL*)

3.1. Production operations and control

The CSS operation requires close monitoring geared at controlling the downhole process, to avoid operational issues and maximize efficiency and recovery. The temperature and pressure of the well should be constantly monitored to balance the steam/liquid interface of the well. Optimum CSS requires that liquid does not accumulate over the well-reducing production rates—but avoiding steam production because it jeopardizes the integrity of the well [5].

3.2. Performance and challenges

The CSS process has some advantages that could help limit environmental impact. Some of these are as follows:

1. The application of this process (CSS) reduces access road construction compared to mining processes.
2. Up to a maximum of 32 wells can be drilled in a single cluster on 2-acre spacing.
3. Utilities (pipelines, flow lines, power lines), including mud cycling plants are economically positioned on a lease to reduce well cost and site clean-up problems.
4. Decreases rig time required per hole since wells are shallow.
5. Minimum tear-down of rig component after each well.

3.3. Limitations

The limitations of the CSS include the following:
1. Low initial formation injectivity.
2. Poor heat conductivity due to low reservoir thermal conductivity.
3. Inadequate control of the movement of the injected steam.
4. Tendency of the injected steam to override (wash off) the section of the bitumen deposit that is to be heated.

4. Environmental consideration

The selection of boiler technology is related to the choice of fuel for steam generation. Natural gas-fueled boilers are the simplest and most economical option. Unfortunately, with the quantities of steam needed for a large-scale development project, the cost of natural gas, whose price may fluctuate considerably in the future, could have a very serious impact on project economics. For other technologies, such as Circulating Fluidized Bed (CFB) boilers designed to burn liquid or solid heavy fuels, feedwater must be free of dissolved minerals, requiring advanced water treatment that adds to operating costs.

Despite the high concentrations of carbon, nitrogen and sulfur compounds, residuum is being considered by some companies as an alternative to natural gas. Use of these heavy fuels would considerably aggravate the problem of carbon dioxide (CO_2) emissions and generate substantial quantities of sulfur dioxide (SO_2) and nitrogen oxide (NO_2), creating a major and negative environmental impact. To counter these problems, specific surface equipment would have to be installed for sweetening (removing the sulfur) and denitrification of the combustion gases, and even for capturing, transporting and storing the CO_2. The cost of such installations, coupled with the cost of feedwater treatment, would diminish or perhaps cancel out any cost gains on the fuel.

However, the latter options can only be envisaged if there is a sufficient quantity of residual from the deep conversion process. To assemble the pieces of this huge and complex puzzle, research and development must therefore make the right trade-offs between economic and environmental criteria. The key to that effort is developing sufficiently reliable tools so that the latest advances can be taken into consideration in industrial decisions.

5. Economic analysis of tar sand

The CSS process cycle could take from four months to 2 years, this long gestation period means that the extraction requires long term investment and the cost implications has to be carefully studied. A thorough and in-depth cost-benefit analysis is required before a project can be fully sanctioned.

5.1. Economic drivers for tar sands exploitation

The nature and composition of tar sands pose a specific challenge to its economic viability. As a developing fuel source, its production and processing costs are still significantly high. Thus, the break-even costs are relatively higher than for conventional fuels especially for new steam driven in-situ projects due to the nature of projects as well as specialist technology required. A full-scale development project would require heavy investment with the potential of leaving operators vulnerable to demand and price fluctuations.

The major economic drivers for tar sands exploitation include:
- Conventional Oil prices
- Extraction Methods and Costs
- Heavy oil Refining infrastructure
- Available market for bitumen product
- Available supply of energy feedstock
- Government subsidies and incentives

With today's oil prices just above US$50/bbl, most projects will either not be economical or investors will have to accept a lower rate of return until prices pick up. However, higher oil prices will drive investment and thus as oil prices expectedly recover, so will the profitability of oil sands projects.

Cost effective and energy efficient extraction technologies can encourage exploitation as seen recently in the case of shale gas in the United States. Better methods have helped drive down operating cost and thus lower the breakeven cost for most investments thereby increasing the profit margin even in the midst of low oil prices.

Government can help promote investment by subsidizing the industry, proving incentives, providing subsidies to importers of heavy machinery used in the extraction process including reduced taxation of oil sands project.

5.2. Tar sands supply costs

Available estimates for the cost of extracting bitumen from the oil sands are based on a 'supply cost' approach. According to the Canadian Energy Research Institute's (CERI) "*The bitumen supply cost is the constant dollar price needed to recover all capital expenditures, operating costs, royalties, taxes, and earn a specified return on investment*" [6].

CERI's supply cost estimates take into account a 10% real rate of return, taxes, royalties, operating costs and other variables. In its Energy Report for 2015, it stated that the supply cost for SAGD and, surface mining and extraction were calculated hypothetically. Excluding transportation and blending costs, crude bitumen produced by SAGD and mining projects are US$45.08/bbl and US$53.94/bbl respectively. Figure 3 shows the breakdown of Bitumen/SCO supply cost in Canada. On the other hand, Wood Mackenzie, a financial institution, in its February 2015 analysis stated that the breakeven for crude bitumen supply cost for in-situ projects is US$41/bbl and that of mining is US$47/bbl for WTI crude oil. Considering the price of crude oil in the international market as at April 08, 2016, where WTI sells at US$37.26/bbl and Brent sells at US$39.43/bbl, investors would have to consider ways to cut cost so as to produce at profitable margins. For intending investors in the Nigeria Bitumen, the Federal Government of Nigeria would have to provide incentives to make bitumen production profi-table so as to attract capitals and investors. These might be in the form of infrastructural facilities to access the bitumen deposits, tax exemptions and/or probably create free trade zones for bitumen production.

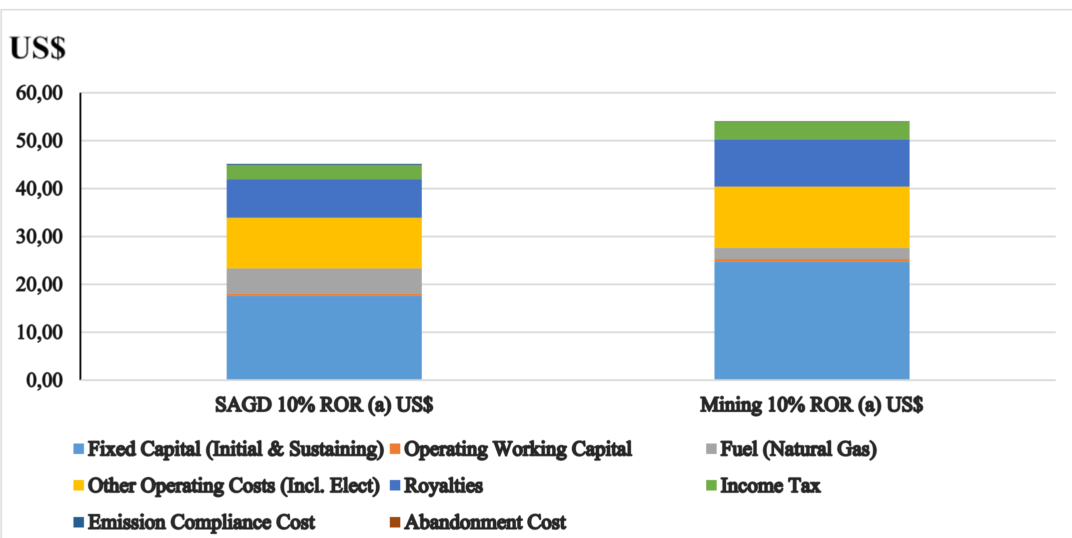

Figure 3. Breakdown of Bitumen/SCO Supply Cost (Source: CERI)

5.3. Economic impact and sensitivity analysis

The analysis of Canadian tar sands undertaken and published by CERI in February 2017 [7], suggests that the supply cost is most sensitive to changes in initial capital expenditure and the assumed discount rate. An increase in any of these two will result in a significant increase in the supply cost and vice versa. This is very critical as capital costs are one of the very few parameters that have an impact on project economics directly under the control of operators. The impact is felt more for a stand-alone mining project than for in-situ steam projects. The non-energy operation costs also significantly affect the profitability of mining projects. However, these costs have shown steady decline on year-on-year basis.

Another important cost element is the energy related costs, given that oil sands projects are very energy- intensive, consuming large quantities of natural gas, electricity and chemicals as feedstock. These are very dependent on the market prices of these commodities.

Research based on the capital and operating of pilot projects as at 2016 show that the in-situ extraction method offers a more economical way of extracting bitumen from tar sands compared to a stand-alone mining project. This is also evident from the illustration in Figure 3.

6. The Nigerian tar sand prospect

From the experience of exploiting tar sand in Canada, Nigerian tar sand can as well be exploited with great economic benefit. Though, there might be little differences as regards factors like policies, socio-cultural values and prices of materials, Nigerian tar sand can successfully be exploited using the cyclic steam stimulation process.

6.1. Tar sand market prospect and application in Nigeria

The only source of bitumen at present in Nigeria is the Kaduna Refinery which processes heavy crude. This is insufficient for domestic needs, thus, Nigeria imports bitumen to supplement her internal production. Extracted bitumen from the tar sand belt can be used as feedstock for the Kaduna Refinery and for setting up other bitumen processing units to meet both domestic and West African sub-regional needs. The bitumen is uniquely aromatic and naphthenic in composition, thus can be used for the manufacture of naphthenic base stocks for industries specializing in critical application products. Heavy and extra-heavy crude can be extracted from the Nigerian tar sands. This can be upgraded to Synthetic Crude Oil (SCO) or Syncrude specification tailored as feed stock to refineries.

Sulphur and phenol can be derived from the Nigerian tar sand. Laboratory tests have shown that specification grade grease within National Lubricating Grease Institute (NLGI) are suitable as lubricants for plain and roller bearings and as sealant can be made from the Nigerian tar sand's oil.

Certain basic facilities favourable for conducting business exist in the country and these include:

- A fairly developed infrastructure such as road network, deep ocean ports and jetties.
- A network of gas and oil pipelines
- Improved communication system
- Dynamic banking community
- Relaxed foreign exchange for capital raising
- Large local and sub-regional market for bitumen sales
- Existing joint venture opportunities
- A large community of geoscientists and engineers
- A commitment to privatization

Above all, the government of Nigeria must recognize the fact that an enabling political environment must be put in place to attract foreign investment into the country. To this effect, Nigeria should continuously strive to improve on its political and economic stability, accounttability in government spending and divesting of government concerns under a democratic setting.

6.2. Tar sand project possibilities in Nigeria

Three Potential Project Types (PPT) are envisaged for the tars and resources in Nigeria.

1. Small scale project: asphalt concrete (strip mining)

- Suitable for small-size scale prospect, using specification bitumen as a major component for road asphalt.
- Short-term execution period of three (3) years using strip-mining techniques.
- Production level: 150,000 metric tons/year.
- Bidders will obtain Exploration Prospecting Lease (EPL) and later Mining Lease (ML) or Quarrying Lease (QL).

2. Medium-sized project: synthetic crude production (In-situ mining)
   - Mining at depths below 150m using enhanced oil recovery technique (EOR)
   - Time frame 5years for development
   - Suitable for companies having foreign partners with technological know-how.
   - Successful bidders will be granted EPL
   - Projected production 10,000bbls/day
3. Large-size project: mega mining project (open mining)
   - Focus on tar sands activity within 30-50m of overburden
   - Open cast mining method
   - Major experienced companies to invest in exploitation and full feasibility evaluation prior to commencement
   - Requires periods of about 15years to develop
   - Expected to produce modules of 50,000bpd of synthetic crude for export
   - Processing by water/solvent extraction method.

7. Conclusions

The conclusion drawn from this work are as follows:

1. The close similarity of the characteristics of the tar sands of Nigeria and Athabasca suggest that the Canadian experience can be used as a model for the development of Nigerian tar sand
2. With success stories of the application of CSS with minimal environmental impact on the immediate surroundings, Nigeria can therefore, make good application of this method (CSS) to exploit her huge tar sand deposits.
3. The exploitation of Nigerian tar sand is of huge economic benefit to the Nigerian economy, especially with the upward trend of crude oil demand in the international market.
4. CSS have minimal impact on the environment. The major issues to deal with as regards CSS is mainly recycling the produced condensed water and treating the residual gases can be handled
5. That CSS recovery method for oil sand is economical and environmentally friendly and is therefore recommended as one of the recovery methods to exploit Nigerian Tar Sand.

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