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HARNESSING SCIENCE TECHNOLOGY AND INNOVATION FOR ENHANCING MARGINAL OIL AND GAS FIELD DEVELOPMENT IN NIGERIA: A COMPARATIVE ANALYSIS

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─Abstract ─

Science technology and innovation (STI) is vital to economic growth and industrial development in today's increasingly knowledge-driven world. The importance of STI cannot be undermined in any sector of the economy. The Nigerian government has been encouraging indigenous players in the petroleum industry in order to increase the total crude oil production through oil and gas marginal field development initiatives but this is yet to yield the required result. This comparative analysis study was conducted to investigate the technological innovations deployed across countries to develop marginal oil and gas fields. The survey was carried out among 106 indigenous oil and gas firms engaging in production and servicing at the Nigerian upstream sub-sector. A descriptive analysis was used and the result shows that Nigerian oil firms could enhance their marginal field development through the use of innovative techniques such as infrasonic passive differential spectroscopy, horizontal and directional drilling, acidizing, hydraulic fracturing, miscible gas flooding, thermal recovery and other enhanced oil recovery techniques that have been successfully adopted in other parts of the world but have not been fully harnessed by indigenous firms in Nigeria. This paper provides managerial implication by encouraging the indigenous oil firms to facilitate training of their local employee in these areas as well as collaborating with universities and other international firms which will finally lead to increase in GDP and government revenue as well as improving human capital development of Nigerian firms.

Key Words: *Technology innovation; Marginal oil and gas field development, Local content policy*

JEL Classification: L71, O31, O32, O33

1. INTRODUCTION

Since the discovery of crude oil in commercial quantity and a rise in crude oil price in the 1970s, oil became a major foreign exchange earner and contributor to GDP relegating other sectors of the Nigerian economy especially agriculture and manufacturing to the background. The contribution of oil and gas sub-sector continuously rose from 0.4% of GDP in 1960 to 11%, 21.4%, and 37.5% in 1970, 1980 and 1990 respectively owing to the increase in global oil price and continuous discovery of oil wells in Nigeria (Central Bank of Nigeria, 2016). Its contribution to GDP dropped to 32.5% in 2000 and continues to reduce till date to approximately 12% of GDP. Even the relatively high contribution of oil sector to the industrial sector contribution is driven largely by crude production and not by the associated 'core industrial' components like refining and petrochemicals. Although the oil and gas subsector, despite its general decline in the economy, still account for more than 90% of the country's foreign exchange earnings and above 70% of the revenue collected federally by the Nigerian government (CBN, 2016). This downward trend to GDP contribution may be attributed to socio-economic and technological factors affecting the oil companies to explore oil and gas field. Socio-economic factors in terms of pipeline vandalism, social unrests, fiscal regime and oil price volatility among others which affect oil field development and technological factors in terms of the nature of technology and innovation used, strategies and machinery adopted among others.

In order to improve the downward performance of the oil and gas sector, the federal government of Nigeria in 2003 handed over the operation of some marginal fields, which had been left unattended to for a period of not less than ten years, to 31 Nigerian companies hoping that this will improve the local participation and overall exploration and production of oil and gas activities. Despite this government action, the success of the local players is still insignificant as many of them are yet to make appreciable progress with their concessions which is not moving in tandem with the desired pace for the local content development (Adetoba, 2012). There is no much information on the role that science, technology and innovation (STI) plays towards the development of marginal oil and gas fields among the indigenous firms in Nigeria. Meanwhile, STI is germane to growth and industrial development in today's increasingly knowledge-driven world. This presents what emerged as a "knowledge-based economy" which highlighted the importance of technological innovation and its underlying R&D activities as the engine of growth (Siyanbola, 2014). STI has to do with the implementation of actions enabled by the new knowledge. It is the capacity and practices of an organization to use its acquired and transformed knowledge to refine, build on and leverage on existing learning competencies (Zahra and George, 2012). This implies that for any nation or organisation to compete favourably, such a nation or organisation must be able to continuously innovate which requires building new competencies, new capabilities and new knowledge (Akinwale et al, 2012).

This study therefore carried out a comparative analysis by assessing the nature of technology use by firms in other part of the country vis-à-vis Nigerian indigenous firms in boosting recoverable reserves in the marginal oil and gas fields so as to increase the country's GDP and revenue as well as human capital development. This paper is divided into 5 sections. Section 1 introduces the paper; section 2 discusses STI in the oil and gas field development; section 3 examines selected countries cases; sections 4 and 5 provide methodology and result discussion respectively and section 6 concludes the paper.

2. STI IN THE OIL AND GAS FIELD DEVELOPMENT

As oil and gas gets harder to find and extract, the costs of extraction escalate, and this drives innovation making the process more efficient and cost-effective (Rajan, 2011). The drive for these technological innovations is associated with the increasing challenges of locating, accessing, and exploiting hydrocarbon reserves especially marginal fields. The emerging new STIs offer the opportunity to reduce costs and improve the economics of marginal field development. The main concern for the marginal field operators is to manage or reduce the new technology deployment risk to an acceptable level, so that the use of such technologies could be justified (Chitwood et al., 2004). It is believed that as more of these technologies become industry practice or field qualified, the significant economic improvements emanating from the field facility should make many of today's marginal fields viable to develop. Specifically to oil and gas field development, innovation relates to anything that extends the ability to access resources that are harder to reach, or to do so more efficiently, effectively, cleanly, and safely (Rajan, 2011). Some of these technologies are discussed in this section.

2.1 Exploration Technologies

Seismic technology has been used by the oil and gas companies to discover the rock where hydrocarbons can be found. Seismic technology uses sound waves to reveal what lies deep in the ground. There have been many geophysical and geochemical technologies such as magnetic geophysical methods, gravitational, passive, magnetic, electric, sonic, and radioactive processes, aerial and satellite remote sensing (LANDSAT), 2-D,3-D and 4-D among others which are used to conduct detailed evaluations of the nature and distribution of rock units as well as frequency, orientation, and geological history of folds or faults that could act as traps for the migrating hydrocarbons(Devold, 2013).

2.2 Drilling and Reservoir Technologies

Once the exploration effort has successfully discovered petroleum within an acceptable range of reserve potential, the next thing to do is to drill for oil and gas in a manner yielding an acceptable economic return on total cash expenditures required over the life of the project (Speight, 2009). The types of drilling usually used for marginal field exploitation include horizontal drilling, directional drilling, slant drilling, rotary drilling, electro and turbo drilling (Economides, Hill and Ehlig-Economides, 1994).

2.3 Well Completion

After a well has been drilled, then such well must be completed before production starts from it. This is a process of equipping a well for development. The process of completion is not the same for all wells. It depends on factors such as the size and shape of the oil reservoir, the surroundings of the reservoir, and the kinds of rocks and oil the reservoir contains (NEED report, 2011). Well completion comprises certain processes such as well casing, tubing, cementing and completion.

2.4 Production Technique

Production starts fully after the whole process of well completion must have been concluded. Ordinarily, oil and gas are extracted using natural drive which means there is enough pressure in the well to move the oil and gas and no pumping is needed. Wells with natural drive have Christmas trees above ground (Hanrahan and Chitwood, 2005). A Christmas tree in the oil and gas industry is a series of valves and gauges used to measure and control the flow and pressure of the well. However, there are wells that do not have enough natural drive to move oil and gas out of the Earth. They must use pumps to lift the oil to the surface. The most common artificial lift system is sucker rod pumps. In a well that has a lot of pressure, a blowout preventer (BOP) is used to avoid explosions and monitors to ensure the well is operating correctly and a set of controls that react to any unexpected pressure change. Electrical submerged pump (ESP) is a modern method which involves inserting the whole pumping mechanism into the well.

Acidizing and fracturing are methods of increasing the output of a well by pumping acid directly into a producing reservoir to open flow channels through the reaction of chemicals and minerals and forces pen the underground channel (Kraus, 2011). Nitrogen may be added to the fluid to stimulate expansion.

2.5 Recovery Technique

These recovery techniques are essentially designed to recover oil commonly described as marginal (Ahmed, 2006). The Figure 1 below shows the techniques/methods for oil and gas recovery.

(i) Primary recovery (natural) method

This is the process of producing a reservoir by means of its natural pressure. In other word, it refers to the process in which the petroleum in the reservoir trap is forced to the surface by the natural pressure contained in the trap. Thus, primary recovery techniques usually account for less than 30% of the total volume of petroleum recovered (Tunio *et. al* 2011).

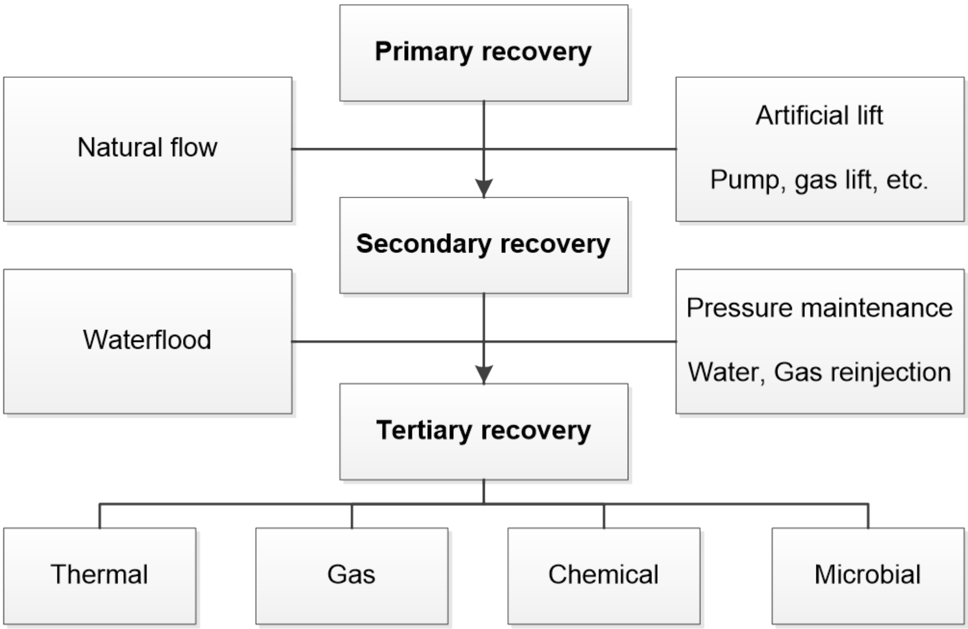
(ii) Secondary recovery

This is a recovery method which is applied when the oil well has reached a point in its lifetime which the natural pressure of the well is insufficient to force the oil to the surface. This secondary technique mainly increases the reservoir’s pressure by water injection (otherwise called *waterflood)* and gas injection *(*otherwise called *gasflood* (Speight, 2000). The application of secondary recovery can make ultimate recovery reach up to 40% (Speight, 2009).

(iii) Tertiary (enhanced) recovery

This technique is also refer to as enhanced oil recovery (EOR) technique which may actually be used at any point in the life of a field (even from the beginning in some reservoirs), relies on the reduction of surface tension or viscosity to encourage the flow of oil trapped in the rock (Shell Global Solution, 2012). Some of these technologies are highly advanced and expensive. It involves injecting steam, detergents, solvents, bacteria or bacterial nutrient solutions into the remaining oil (Speight, 2009; Tunio *et. al;* 2011). These methods focused on recovering the remaining oil from a reservoir that has been depleted of energy during the application of primary and secondary recovery methods.

Figure-1: Techniques and Methods for Oil and Gas Recovery



Source: Speight, 2009

3 SELECTED COUNTRIES CASE STUDY ON MARGINAL FIELD TECHNOLOGIES

3.1 Bantumilli Marginal Fields in India

Bantumilli field is located in the eastern coast of India in the Krishna–Godavari basin (KG basin). The reservoirs, however, are thin, sporadic, and cannot be discerned in the seismic sections (Rode et al., 2010). As a consequence, mapping of the reservoirs is riddled with uncertainties. The seismic and electrolog analysis did not help in deciphering the spread of the hydrocarbon containing reservoirs. At this point the operator of the Bantumilli field adopted the non-conventional method of Infrasonic Passive Differential Spectroscopy (IPDS) to characterize the oil bearing area, estimate the reserves, and identify the locations for drilling (Rode et al., 2010).

3.2 A Shale-gas Reservoir in British Columbia, Canada

More recently, horizontal drilling with multistage fracturing technologies have been applied to new and mature oil fields. Determining the fracture spacing to use along a horizontal wellbore is critical for economic optimization of these assets. For the shale-gas reservoir in British Columbia, a combination of reservoir and fracturing simulation was applied which made many nonviable fields become viable (Taylor *et al;* 2010).

3.3 Offshore Field Development Plan from Steel Structures to Artificial Island in Abu Dhabi, United Arab Emirates (UAE)

The field is 84 km offshore Abu Dhabi, UAE. It was discovered in the early 1960s and covers approximately 1200 km^2 (Modavi, 2011). The increasing complexity and cost of such an expansion motivated a major change of the development plan through construction of artificial islands and the use of extended-reach and long-horizontal completions. The artificial-island concept was introduced as drilling and production centres for the subject field as an alternative to continued development with well head platform towers (WHPTs).

3.4 Al-Huwaisah and Harweel Reservoirs in Oman

The Al-Huwaisah field was discovered in 1969 with first production in 1971. The field is a northeast/southwest elongated dome and produces mainly from the Cretaceous Upper Shuaibah formation at a depth of approximately 1450 m subsea (1520 m true vertical depth). Although, after 30 years of production, the field has witnessed major declined in production rate but various technologies have been used to improve the oil recovery from the field. Some of the methods used include both vertical and horizontal technologies with various combinations of gas lift or electrical-submersible-pump (ESP) completions in barefoot or lined reservoir sections (Al-Mugheiry, 2003).

Also, miscible gas injection has also been used at the Harweel cluster of fields in Oman which are characterised by approximately 100 m thick carbonate stringers. This has increased the production rate from the oil and gas well. Miscible gas flooding is a particularly effective way of maintaining reservoir pressure and raising oil production rates. The gas essentially acts as a solvent for the oil: the resultant solution has reduced viscosity and hence better flow characteristics.

4 METHODOLOGY OF THE STUDY

The study was carried out in the South-South Zone of Nigeria due to the predominance of oil and gas production in the Zone. This data was obtained in 2015 through a survey using a questionnaire similar to that of Community Innovation Survey (CIS) 4. The CIS questionnaire draws on a long tradition of research on innovation. The CIS is primarily focused on investigation of the innovative phenomenon at the firm-level (Organisation for Economic Cooperation and Development (OECD), 2005).

The survey adopted multistage sampling technique in the selection of the respondents. Random sampling was used to choose 150 indigenous oil and gas firms that engage in the production and servicing at the upstream subsector in the Nigeria petroleum industry. Afterwards, purposive sampling was used to select the head of human resources department and/or head of technical department depending on who has the best information in the firm to fill the questionnaire. The questionnaire was used to elicit information on profile and activities of the firm, the knowledge stock, nature of technology and equipment used among others. At the end of the survey, 106 firms returned valid questionnaires representing a response rate of about 71%. Qualitative analysis was adopted because there are very few publications on this topic in Nigeria, and such technique is adjudged appropriate in such situation (Myers, 2009).

5 DISCUSSION

5.1 Descriptive Analysis

Table 1 shows that 63% of the sampled firms introduced a new or significantly improved product and 72% of them introduced a new or significantly improved process for the production of marginal fields. This implies that oil firms engage more on process innovation than product innovation in the production of marginal fields in Nigeria. The innovation as mentioned here is not necessarily referred to as a radical innovation, but rather technological innovations which are new to the firms. Furthermore, it was enquired from the firms on the extent at which introducing technology innovation has improved their marginal field production. While 51% of the firms ranked the extent at which technology innovation improved their marginal field production at medium level, 33% ranked it at high level while 16% ranked it low. This reveals that majority of the firms accepted that the technology innovation introduced actually improved the marginal field production.

Table 1: Technology Innovation among the Nigeria's Indigenous Oil Firms

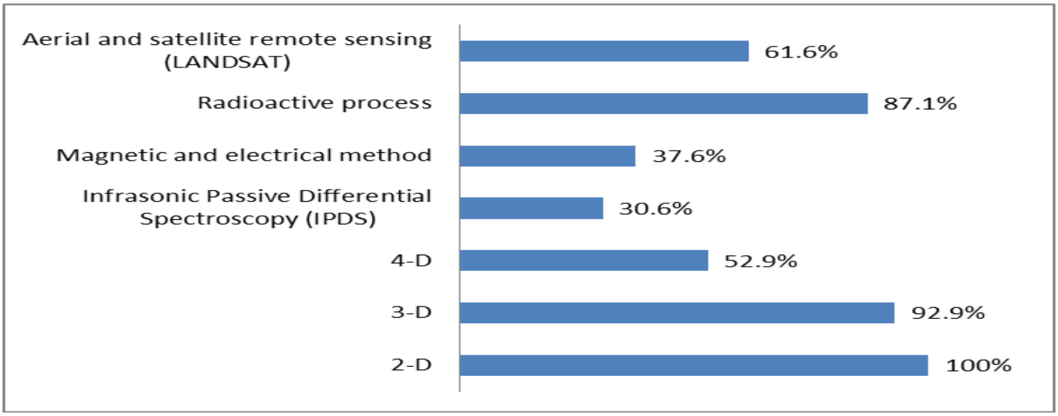
Firms characteristics	% of firms
The firm introduced a new or significantly improved product (either a good or a service) during the referenced period.	63
The firm introduced a new or significantly improved processes for the production or supply of its products	72
Extent at which introduction of technological innovation improve field production	
Not at all	-
Low	16
Medium	51
High	33

5.2 Technology Innovation Engagements of Oil Firms in Marginal Field Production

This sub-section shows various technologies and equipment used by the Nigerian indigenous oil and gas firms at different phases of oil and gas field development namely: exploration and seismic phase, drilling phase, production phase and recovery phase. This is captured through the multiple responses from the Engineers and Scientists in these firms.

Figure 2 reveals the engagements of the Nigerian oil firms at the exploration and seismic phase. The figure shows that all (100%) the respondents in this category claimed to be using 2-D technology in their firms followed by 92.9%, 87.1%, 61.6% and 52.9% of the respondents who claimed to be using 3-D technology, radioactive process, aerial and satellite remote sensing (LANDSAT), and 4-D technology respectively. While the use of magnetic and electrical method was perceived to be low (37.6%), the application of infrasonic passive differential spectroscopy (IPDS) was the least (30.6%) method used by the Nigerian indigenous oil firms in marginal field production.

Figure 2: STI engagements at the exploration and seismic phase



However, some studies (Rode et al., 2010; Mukherjee, 2009) have shown how IPDS has successfully been used to develop some marginal fields such as Bantumilli oil fields in India. Figure 3 reveals the STI engagements of the indigenous oil firms at the drilling phase. Drill bits (96.5%), drilling rig (95.3%), vertical drilling (93%), fixed platform (85.9%), submersible (85.9%), drill ship (83.5%), mud (81.4%), drilling barges and jackup rigs (81.2%), floating production storage and offloading (FPSO) (67.1%) characterised the major technologies and equipment that the indigenous oil firms' respondents claimed to be using at the drilling phase. While 44.2% and 43% of the respondents claimed to be using electro and turbo drilling and horizontal drilling respectively, the least (34.1%) of the respondents claimed to engage in directional drilling.

According to Al-mugheiry (2003), many marginal oil fields, such as Al-Huwaisah field in Oman, which were ordinarily not viable have been exploited and made viable through horizontal and directional drilling technologies. Devold (2013) also opined that electro and turbo drilling are newer methods which provide more direct power to the drill bit. However, it can be deduced from the respondents' perception that the level of using horizontal, directional, electro and turbo drilling technologies is still relatively low among the Nigerian indigenous firms.

Figure-3: STI engagements at the drilling phase

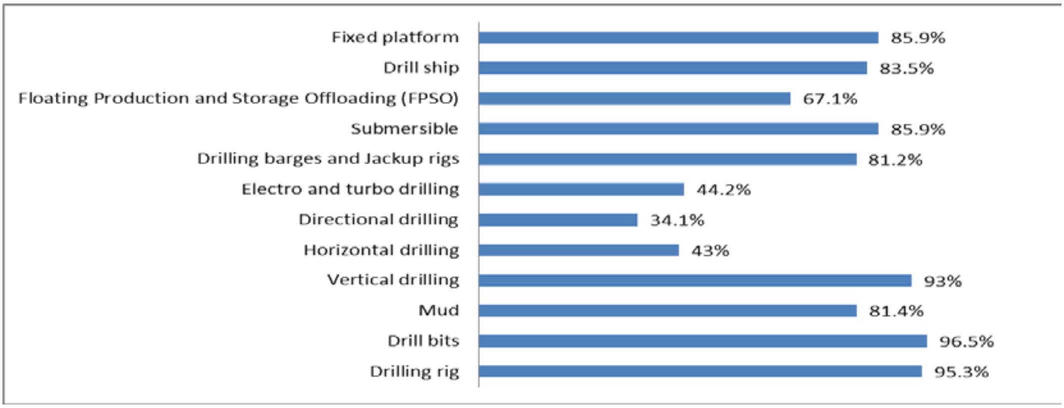
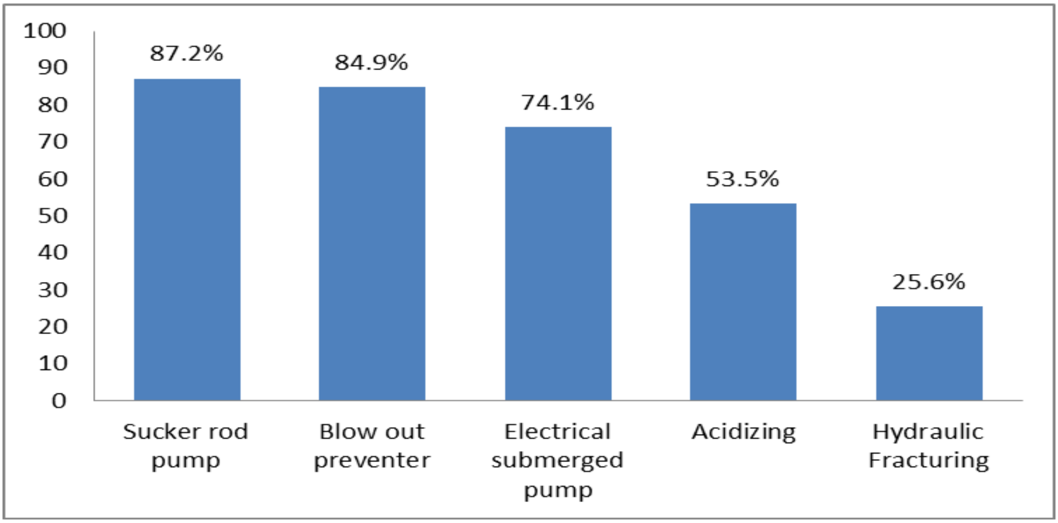


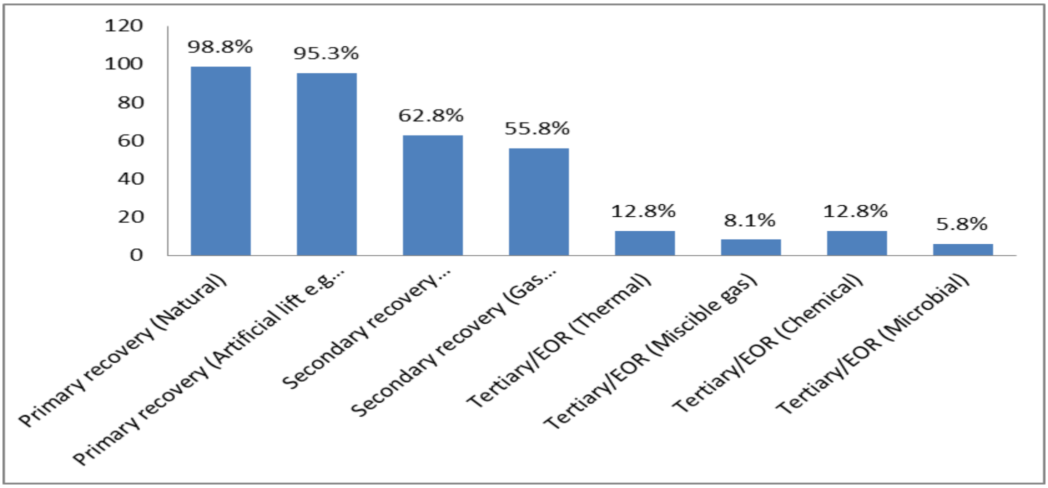
Figure 4 shows the STI engagements at the production phase of marginal oil and gas field development. The respondents perceived sucker rod pump (87.2%), blow out preventer (84.9%) and electrical submerged pump (74.1%) as the main technology equipment used by their firms. Also, 53.5% of the respondents adopted acidizing technique in the production of marginal oil field while the least (25.6%) of the respondents claimed to use hydraulic fracturing technology. It could be deduced that hydraulic fracturing technology is rare among the indigenous oil and gas firms in Nigeria and this was supported by the information gotten from interview with few engineers in these firms.

Figure-4: STI engagements at the production phase of the Nigerian oil and gas firms



At the recovery phase, primary recovery through natural means (98.8%) and primary recovery through artificial lift (95.3%) dominated the recovery technologies adopted by the indigenous oil and gas firms in Nigeria as shown in Figure 5. The application of secondary recovery technologies using water flooding (62.8%) and gas reinjection (55.8%) were moderately utilized. Only 12.8%, 8.1%, 12.8% and 5.8% of respondents perceived that tertiary recovery (Enhanced Oil Recovery) technologies using thermal, miscible gas, chemical and microbial organism respectively were adopted.

Figure-5: STI engagements at the recovery phase



Thus, while the secondary recovery technologies were perceived to be moderately used by this category of respondents, tertiary recovery technologies were rarely used among the Nigerian indigenous marginal field operators. However, both the secondary and tertiary recovery technologies had been adopted to develop marginal oil and gas field in various countries across the world (Speight, 2009; Tunio *et.al*, 2011). The follow up interview with some oil experts revealed that some of the fields in Nigeria can still be explored without using tertiary recovery technologies.

6. CONCLUSION

Many marginal oil and gas fields which had been considered unproductive are being exploited by the oil firms through the deployment of appropriate STI strategies across the globe. The efforts of Nigerian government to enhance the contribution of marginal fields to the nation's crude oil production, encourage indigenous players in the production of crude oil, increase government revenue and GDP necessitated this study. This paper shows several technological innovations which have been used by oil firms in different countries at various phases of marginal oil field development. While infrasonic passive differential spectroscopy (IPDS) method has been used to detect hydrocarbons of the Bantumilli field in India at the exploration phase, horizontal drilling with multistage fracturing technology has been used to drill shale gas reservoir in

British Columbia and many oil and gas fields in the Gulf of Mexico in USA and many other countries at the drilling phase. Also EOR techniques have been used on some marginal fields like Numbi field in Angola, Alhuwaisah and Marmul fields in Oman at the recovery phase. Though the survey shows that Nigerian indigenous firms have also engaged in some STI strategies to develop marginal fields but they are still behind as regards the deployment of some advanced technologies and equipment. Magnetic and electrical method and IPDS method at the exploration phase as well as directional/horizontal drilling and electro/turbo drilling at the drilling phase are still not common in usage among the Nigerian indigenous oil firms. In addition to this, acidizing and hydraulic fracturing at the production phase as well as all the methods at the tertiary/ enhanced recovery phase are rarely used to exploit marginal fields by the Nigerian indigenous oil firms.

The results of this study have managerial implications for the executives of the indigenous oil and gas firms operating marginal fields in Nigeria. The results show that different STI strategies that have been used to develop marginal fields in other part of the world are still not fully harnessed by the oil firms in Nigeria. The indigenous firms can facilitate training of their scientists and engineers on some of these technologies such as directional drilling, miscible gas recovery and IPDS at various phases of marginal field development in order to enhance production from these fields. These indigenous firms could also collaborate with local and international universities to broaden their knowledge base as they jointly conduct some researches together. This will also enable them to get access to new form of science, technology and innovation that could assist their innovative performance. Technological collaborations with other international firms as well as investment in research and development should be fostered by the indigenous oil firms.

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