

ADVANCED DIGITAL TECHNOLOGY SOLUTIONS FOR ENHANCING THE PRODUCTIVITY OF MARGINAL OIL AND GAS FIELDS IN NIGERIA

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Abstract

Since the beginning of the 1990s the government of Nigeria has been struggling to enhance its productivity in oil and gas which is the mainstay of the country's economy. Its long-stated dual objectives have been to increase crude oil reserves and daily production rate to 40 billion barrels and 3 million barrels per day, respectively. An important aspect of its strategy to achieve this objective is the marginal oil field development programme. However, more than two decades later, the programme has not produced tangible results, partly as a result of challenges with developing and setting the country's marginal oil fields on the path of consistent productivity. This article examines the challenges in this regard and is proposing the effective deployment of advanced digital technologie solutions in enhancing the production potentials of the numerous marginal oil and gas fields located in the Niger Delta region of the country.

Keywords: Marginal oilfield, Unconventional technologies, Digital technology solutions, Enhanced oil recovery, Local capacity building

Introduction

Nigeria has harbored plans for increasing its oil and gas performance metrics as far back as the 1990s. This plan received heightened attention in 2007 under the Yar'adua - Jonathan administration which had included it in its four-year, Vision 2010, blueprint. With the country's crude oil reserves then standing at 36.2 billion barrels, the administration resolved to increase it to 40 billion barrels by the year 2010. It also set a target of 4 million barrels of oil per day¹. Failing to be achieved by 2010, the deadline had been shifted to 2020 and now to 2030. Two decades and counting, rather than increasing the reserves figures have remained stagnant while the daily average has been shrinking.² As against its OPEC quota of 1.56 million barrels of daily production, the country's production is around a low of 1.3 million barrels as of January 2024.

The performance metrics has defied efforts on the part of the government which has been formulating policies and programmes aimed at achieving the stated objectives. One of the first things the government did in this direction was to evaluate the entire oil basins in its territory, with particular attention to once-sidelined oil blocks. The latter were then farmed out to small indigenous companies to develop and produce from them. This drive to substantially increase proven reserves and daily production led to an appreciable upswing in exploration activities, with joint ventures, production sharing contracts and indigenous companies stepping up their

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¹ Doidge, F. (2008) "The Price of Nigerian Oil" *Offshore Technology* Available [here](#). (Accessed 5 May 2024).

² Avuru, A. (2022) "Reining in the Collapse of The Nigerian Oil Industry" *Africa Oil and Gas Report* Available [here](#). (accessed 5 May 2024).

exploration and production operations.³ The concession of oil fields to independent Nigerian operations added ounces of barrels to the country's production.

The Legal Framework for the Development of Marginal Fields

The marginal oil field development/farm-out programme was rolled as part of the more generalized indigenization drive in the Nigerian oil and gas industry. The policy behind the programme saw to the amendment of the 1964 Petroleum Decree⁴ whose major thrust is the overall enhancement of oil and gas exploration and production in Nigeria. It sought to bring about the development of the many oil and gas discoveries in Nigeria, a lot of which have been left unattended for too long. In some cases, the fields have remained unproduced or partially appraised. The marginal oilfield development program, according to the revised *Guidelines for the Award and Operations of Marginal Fields in Nigeria* (2020), is to be carried out by the government in collaboration with operating companies, through the “farm-out of un-produced, un-appraised, abandoned or producing fields on existing Oil Mining Lease (OML) to independent and indigenous companies on a periodic basis.”⁵

The Guidelines list the following as the broad objectives of the farm-out and award of marginal oil fields in Nigeria are as follows:⁶

1. To grow production capacity by expanding the scope of participation in Nigeria's Petroleum sector, through diversification of resources and inflow of investments.
2. To increase Nigeria's oil and gas reserves base through aggressive exploration and development effort.
3. To reduce the cost of oil and gas production.
4. To provide opportunity for portfolio rationalization.
5. To promote the participation of indigenous companies in the sector thereby fostering technological transfer.
6. To provide an opportunity to gainfully engage the pool of elevated level technically competent Nigerians in the oil and gas sector.
7. To promote common usage of facilities by different operators to ensure optimum utilization of available capacities.

These initiatives sought to bring about increased indigenous participation in the oil and gas industry, raise Nigerian content level, generate employment for Nigerians, increase crude oil reserves as well as daily production, among others. This article will look at the marginal oil field development programme with the objective of bringing attention to and proffering some advanced digital oil field technologies as a solution to one of the major challenges facing marginal oil field operators in Nigeria.

³ United Nations Conference on Trade and Development (2006) *African Oil and Gas Services Sector Survey Vol 1 - Nigeria: Creating Local Linkages by Empowering Indigenous Entrepreneurs* (United Nations: NY) p.58.

⁴ Petroleum (Amendment) Decree No 23 of 1996, now Petroleum Act Cap. P10, LFN 2004.

⁵ Guidelines for the Award and Operations of Marginal Fields (2020) Art. 2.

⁶ Art. 3.

The Concept of Marginal Oil field

Generally, marginal oil fields in Nigeria are fields which have been proven by major oil companies as having recoverable reserves, but which for one reason or another fail to be developed and put into production. As described in Kalu-Ulu *et al.*, they are those fields with an “uneconomical reserve when produced by major operators but are profitable when operated by local indigenous players because of low overhead and operating costs.”⁷ The 2013 Guidelines describe marginal oilfield as “any field that has (oil and gas) reserves booked and reported annually to the Department of Petroleum Resources (DPR) and has remained un-produced for a period of over 10 years.”⁸ Incorporating some of the provisions of the Petroleum Decree, the 2020 Guidelines defined marginal fields as those that have “been discovered and has been left unattended for a period of not less than ten (10) years, from the date of first discovery or such field as the President may, from time to time, identify as a Marginal field.”⁹

The newly enacted Petroleum Industry Act describes marginal field as “a field or discovery that has been declared a marginal field prior to January 1, 2021 or that has been lying fallow without activity for 7 years after its discovery prior to the Act’s commencement.”¹⁰ This provision has introduced a number of changes to the conception and operation of marginal fields under Nigerian law. First, it has reduced the number of years an undeveloped field should be converted to a marginal field from 10 to 7 years. The first leg of the provision incorporates the over 200 marginal fields so far identified and declared, inclusive of the 24 awarded in 2003, and the 57 fields awarded at the 2020 bid. The second leg places a limit on the timeframe within which new fields can be declared as marginal, effectively putting a cap on the practice of marginal fields designation. In line with the provision, new fields that can now be declared as marginal are only those that must have been lying fallow for 7 years, specifically from 2014 to 2020. This cap is confirmed by Subsection 9 which provides that no new marginal fields can be declared again apart from those falling within the above timeframe.

The new petroleum industry legislation also specifies that marginal fields may have some or all of the following determining characteristics:

1. Fields not considered by license holders for development because of assumed marginal economics under prevailing fiscal and market terms;
2. Fields with at least one exploration well drilled and have been reported as oil and/or gas discovery for more than 10 years with no follow up appraisal or development effort;
3. Fields with crude oil characteristics different from current streams (such as crude with exceedingly high viscosity and low API gravity), which cannot be produced through conventional methods or current technology;
4. Fields with high gas and low oil reserves;

⁷ Kalu-Ulu, T.C. *et al.* (2023) “Overcoming the urge for infill drilling in marginal field redevelopment through artificial lift deployment” *Int J Sci Res* 2023;12(6): 2784-800 p.2784. DOI: 10.21275/SR23624065052.

⁸ Guidelines for Farmout and Operation of Marginal Fields (2013) Art. 5.

⁹ Guidelines for the Award and Operations of Marginal Fields (2020) Art. 4.

¹⁰ Petroleum Industry Act (2021) Section 94(8)(a).

5. Fields that have been abandoned by the leaseholders for upwards of three years for economic or operational reasons;
6. Fields that leaseholders may consider for farm-out as part of portfolio rationalization programmes.

For all practical purposes, and notwithstanding the above provisions, it would appear that the marginality of oil and gas fields in Nigeria is largely determined by the conduct of oil field operators in failing to develop and produce from a given field. As provided by the Petroleum (Amendment) Decree, a field becomes marginal upon its identification as such by the President.¹¹ Thus, a field declared as marginal by the President “may or may not have the technical characteristics of a marginal field.”¹²

Regardless of the technical characteristics, economic considerations bordering on profitability are the critical factors in the determination of oilfield marginality. According to Nwaozuzu, “the most important factor is always the degree of profitable production ... regardless of the actual size of the oilfield”.¹³ And as maintained by Akinwale & Akinbami, these “fields have been considered marginal for the IOCs since their overhead expense is huge in exploring such fields.”¹⁴ International oil companies operating in Nigeria may have been discouraged from developing these fields due to local factors such as community strifes associated with operating onshore assets in the Niger Delta, or because they have more important priorities on bigger, often offshore, fields.¹⁵

The Performance Index and Increasing Expectations on Marginal Oil Fields in Nigeria

Nigeria's current marginal fields number upto 251, with proven reserves modestly estimated at 2.3 billion barrels.¹⁶ According to Price Water Cooper, of the marginal oil fields awarded between 2001 and 2003, only 30 percent were able to hit full production. Out of a total of 24 marginal fields awarded in the 2003 bid round, only 9 were reported to have attained first oil and gone into production.¹⁷ These are reported by the Department of Petroleum Resources as consisting of the following active fields:

1. Egbaoma – OML 38; operated by Platform Petroleum Ltd;
2. Ibigwe – OML 16; operated by Walter Smith & Morris Petroleum;
3. Uquo – OML 13; operated by Frontier Oil Ltd;

¹¹ Petroleum (Amendment) Decree No 23 of 1996, Para. 17 (4), First Schedule.

¹² Dentons LLP (2014) “Marginal fields in Nigeria: recent developments” Available [here](#). (Accessed 5 May 2024).

¹³ Nwaozuzu, C. (2018) “Overcoming constraints of developing marginal oilfields” in Local Content Digest Q3 2018, *Modular Refineries: Promoting Inclusion and Local Content Growth*. Available [here](#). p.41. (Accessed 5 May 2024).

¹⁴ Akinwale, Y.O. & Akinbami, J.K. (2016) “Economic evaluation of Nigerian marginal oil and Gas field using financial simulation analysis” *Int. J Energy Econ Policy* 563-74, p.573.

¹⁵ Dentons LLP, *Supra*, note 12.

¹⁶ Ezekiel, M.P. & Okwuchukwu, O.B. (2020) “A Critique of the Legal Framework for the Development of Marginal Oil Fields in Nigeria” *NAUJILJ* Vol 11 (2) p.136.

¹⁷ PriceWaterCooper (2021) “Tax Bites: The Petroleum Industry Act and the Marginal Fields” Available [here](#). (Accessed 5 May 2024).

4. Ajapa – OML 90; operated by Britania-U Nig Ltd;
5. Umusadege – OML 56; operated by Midwestern Oil & Gas/Suntrust Oil Ltd;
6. Umusati – OML 56; operated by Pillar Oil Ltd;
7. Ebendo – OML 56; operated by Energia Limited/Unipetrol Petroleum Limited (bought over by Oando);
8. Ebok – OML 67; operated by Oriental Energy;
9. Ogbelle – OML 54; operated by Niger Delta Petroleum Ltd.

The above producing fields have reportedly grown their reserves from 141 million barrels in 2004, to 302.6 million barrels in 2013.¹⁸ On the whole, however, the contribution of the entire marginal fields, consisting of the 24 awarded in 2003 and the 57 awarded at the 2021, has been infinitesimal and fluctuating. For example, in the 2015/2016 financial year, the marginal fields accounted for just 3.09 percent of the country's crude output, having produced the amount of 23.243 million barrels out of a total of 751.882 million barrels produced within the period.¹⁹ The volume appreciated to 6 percent in 2019²⁰, only to fall down to 2.97 percent in 2020, representing 1.52 million barrels of a total of 51.147 million barrels.²¹

With the 2021 award of new fields, analysts speculated a boost in production of about 8.835 million barrels monthly. The volume of output was “expected to grow by 285, 000 barrels per day, going by the estimated 5,000bpd output projected for each field.”²² Despite the optimistic outlook the situation failed to improve with crude output from the fields still trapped below 4 percent as of 2022.

Meanwhile, there is increasing expectation and pressure on local oil and gas producers, inclusive of marginal operators, to ramp up their production. The *Domestic Crude Supply Obligation* guidelines recently released by the Nigerian Upstream Production Regulatory Commission (NUPRC) mandates local producers to “supply around 483,000 (bpd) of crude oil to local refineries for the first 6 months of 2024.”²³ This is pursuant to the provision of the Petroleum Industry Act which requires indigenous oil producers to allocate a chunk of their crude output to domestic refineries to keep them from shortages. The government has announced its plan to produce 1.8 million barrels per day in 2024, over and above the 1.5 million barrels per day quota imposed by OPEC.²⁴ Thus, regardless of the production level hovering around 1.3 million barrels per day, the government with a nod from the NNPC, has set a target of 1.78 million barrels in the 2024 budget. Analysts are, however, highly pessimistic and see the target as unrealistic.²⁵

¹⁸ Ezekiel & Okwuchukwu, *Supra* note 16 at 135.

¹⁹ Eboh, M. (2016) “Marginal fields contribute less than 4% of oil output” *Vanguard Nigeria*. Available [here](#). (accessed 5 May 2024).

²⁰ Oladipo, O. (2019) “Why Marginal fields account for just 6% of Nigeria’s crude production”. Available [here](#). (Accessed 5 May 2024).

²¹ Eboh, *Supra* note 19.

²² Akintayo, O. (2022) “Operators may earn N4.37tn from marginal oil fields”. Available [here](#). (Accessed 5 May 2024).

²³ Anthony-Uko, N. (2023) “Local Oil Producers Must Supply 483,000bpd To Local Refineries By June—NUPRC” Available [here](#). (Accessed 5 May 2024).

²⁴ *Ibid*.

²⁵ Jeremiah, K. (2024) “Nigeria explores options as oil production crisis persists”. Available [here](#). (Accessed 5 May 2024).

Technologies to The Rescue of Marginal Fields Operators

Oil and gas operation is a particularly technology-intensive affair, with progressive technological advancements ensuring the continuous relevance, competitiveness and profitability of the industry. It is therefore natural that technology is the life saver when it comes to marginal field development. Indeed, it is in light of this reality that aspects of the farm-out agreement set out in the *Guidelines for the Award and Operations of Marginal Fields* contain reference to the deployment of appropriate technologies. According to the Guidelines, the awardee of a marginal field is “encouraged to develop new programmes and deploy new technologies to grow reserves and enhance production in the field.”²⁶

Conditionality of Marginality

Running through the various characterizations of marginal oil and gas fields is the element of conditionality. The state of a field being marginal is not a permanent state that is associated with total absence of productivity in the field. It is rather a state that comes to be at a specific point in time due to some factors. The most recurring of these factors is the economic considerations and calculation of the field owners or operators, based in turn on difficult geographic, geological,²⁷ local and technical realities, etc. This means that oil field marginality can be turned around by a change of ownership, methods, techniques, business priorities, fiscal systems, local circumstances, etc.²⁸

One of the major turn-offs for the big oil companies that own these marginal fields is the fact that the fields, while promising small revenue streams, require expensive infrastructure befitting of large profitable fields.²⁹ Portfolio rationalization based on these considerations often leads to abandonment of otherwise profitable fields. However, the position can be changed by transferring the fields to small oil and gas companies with the “requisite financial, technical and local capability.”³⁰ These companies can then apply “special field development planning and reservoir management strategies to yield acceptable return on investment.”³¹ In light of availability of indigenous companies in the industry, the Nigerian marginal field development campaign is timely and full of promise.

Factors reported as being responsible for the lack of success of the Nigerian marginal oilfield development programme include limited organizational competence amongst the operators, unfavorable regulatory framework, socio-political environment, funding, fiscal regime, and institutional barriers.³² Economic and technological constraints, many times more than the others, are severally reported as being the factors challenging the productivity of the fields. In the literature, however, fiscal challenges receive more attention and remedial proposals when compared with technical or technological issues. Meanwhile, an appreciable number of indigenous companies are already in production having developed their marginal fields. This is clearly after

²⁶ Guidelines for the Award and Operations of Marginal Fields in Nigeria (2020) Art. 12.4.

²⁷ Ezekiel & Okwuchukwu, *Supra* note 16 at 137.

²⁸ Offia, U.S. (2011) “Development and Management of Marginal Oil Field in the Niger Delta Basin: Opportunities and Challenges” *NAUJILJ* Vol. 1, 135-148 at 2.

²⁹ Ezekiel & Okwuchukwu, *Supra* note 16 at 137.

³⁰ Dentons LLP, *Supra*, note 12.

³¹ Nwaozuzu, *Supra* note 13 at 41.

³² Humphrey, O.O. & Dosunmu, A. (2017) “The Influence of Technological Factors on Marginal Oil Field Development in Nigeria” *IJSIT* 6(4), 405-419 p.406.

having scaled through the economic (and some the other) constraints. The proposals in this article are, therefore, decidedly on the technological aspect towards helping these companies optimize the productivity of their marginal fields.

Centrality of Technological Constraints

In tandem with several other researchers, the position of Kalu-Ulu *et al.* is that marginal fields are technically difficult to develop or impossible to be produced using conventional methods.³³ This presupposes that the use of unconventional methods enabled by current advanced digital technologies can turn things around and show the otherwise economic viability of marginal fields. Thus, for fundamental marginal field problems, such as assumed low reserves and complex geological formation, technology is the ultimate game changer. In fact, a study on marginal fields by Humphrey and Dosunmu found that “technological factors account for 96% of the variance in marginal field development.”³⁴

Accordingly, a number of technologies have been put forward as suitable candidates for use in the development of marginal fields in Nigeria. This solves part of the problem identified by Ayo Shote, the then Vice President and Managing Director of Baker Hughes, that one of the big challenges faced by marginal field operators is the inability to timeously recognize the precise technology to be used to achieve efficiency.³⁵ The proposed technologies include slim hole drilling, horizontal and extended-reach drilling technologies, intelligent well completion, infill drilling, coil tubing, down hole electric submersible pumps (ESP), surface multiphase pump.³⁶ Other highly important ones include waterflooding, chemical/gas injection, and other artificial lift techniques.³⁷ These technologies can be categorized as falling under well and reservoir engineering and as being suitable to develop mature and declining fields to extend field life and increase recovery.

In 2001 Hassan *et al.* reported the turnaround of the Younis marginal field operated by the Gulf of Suez Petroleum Company (GUPCO) in Egypt. This is through the integrated application of what were then the most advanced oilfield technologies which helped to turn the field into an economical production site, resulting in “a doubling of the oil production rate as well as the proven field reserves.” The techniques applied include:³⁸

1. 3D seismic techniques to delineate the field’s reservoirs;
2. Infill drilling of water injectors and new producers to improve oil sweep efficiency;
3. Gravel packs used in injectors and producers to minimize sand migration;
4. Extreme overbalance techniques for the field's high permeability reservoirs for more effective gravel pack placement;
5. Coiled tubing pipelines to feed the field with gas for artificial lift and water for injection;
6. Combined use of reservoir saturation and production logging measurements to monitor water front advancement and thus enable proper management of the water injection project.

³³ Kalu-Ulu, *et al.* (A) *Supra* note 7 at 2784.

³⁴ Humphrey & Dosunmu, *Supra* note 32 at 405.

³⁵ Shote, A. (2013) “Finance, technology big issues for marginal field operations” *Vanguard Nigeria*. Available [here](#). (accessed 5 May 2024).

³⁶ See Offia, *Supra* note 28.

³⁷ Kalu-Ulu, *et al.* (A) *Supra* note 7.

³⁸ Hassan, S. *et al.* (2001) “An Integrated Approach To Marginal Field Development: Case History From The Gulf Of Suez”. Paper presented at the Offshore Mediterranean Conference and Exhibition, Ravenna, Italy. Paper Number: OMC-2001-026.

With specific reference to marginal fields in Nigeria, Toluse *et al.*, Oruwari, Dagogo *et al.*, Oyakhire and Omeke have suggested a number of specified technologies to address specific issues identified in individual marginal fields.³⁹ With respect to the Umusadege field which faced the problem of decline in reservoir pressure, Toluse *et al.* proposed the use of water and chemical flooding at the boundaries of the reservoir to induce efficient sweep of hydrocarbon deposits. The field also suffers from limited process facility capacity which limits its daily production rate. For this problem, they suggested the deployment of surface multi-centrifugal pump stations to conduct hydrocarbon from header to nearest facility with higher processing capacity. This is to ensure that no available hydrocarbon is left unproduced.

For the Sango field, which is being reported as experiencing rapid decline in production despite the use of infill drilling, Dagogo *et al.* suggested the use of electrical submersible pumps (ESP) as an artificial lift technique to reverse the decline and prolong the life of the field. In the X-Field (a pseudonym) associated with poor production data recording, Oyakhire and Omeke suggested the deployment of digital oilfield tools to enable real-time data collection and remote control of field operations. Appreciating the importance of ample and accurate data in field development, especially when it comes to marginal resources, they identified these practical solutions to overcome the data gaps which are hampering the operators' field development campaigns.

Bringing Advanced Digital Technologies into the Mix

The technology solutions proffered above belong to the old order of things where operations are largely mechanical and not underpinned by data-driven intelligence. The conception of some of the technologies is more than three decades old and hampered by operator bias, limited knowledge, lack of workflow integration, team work, flexibility and speed. These are characteristic of the old technological order where electronic and information systems are deployed to merely automate production systems. But we are now in the fourth industrial revolution where digital data, high computing power and topnotch expertise are applied to decipher and extract value from disparate patterns of numbers and letters to create actionable intelligence.⁴⁰

The deployment of advanced digital technologies in the oil and gas industry has unlocked “new levels of operational efficiency and productivity while also helping to reduce safety risk and environmental impact.” Advanced digital techniques such as the internet of things (IoT) cloud computing, machine learning (ML), artificial intelligence (AI), big data analytics, predictive analytics, etc. have “enabled the industry to leverage the massive amounts of data that it generates to completely transform how it operates.”⁴¹ By taking over the repetitive tasks of data analytics, detection of anomalous behavior, classification of wells, and driving control changes, artificial intelligence, for example, gives oil and gas companies an excellent chance at field optimization as well as maintaining that optimization state to positively impact bottom line performance.⁴²

³⁹ Kalu-Ulu, *et al.* (B) (2023) “Marginal Fields Development in Nigeria: A Review of Extant Strategies” *J. of Energy Research and Reviews* Vol. 15, Issue 1, 1-25; Article no. JENRR.103612 p.19.

⁴⁰ Presley, J. (2023) “Data Journey: Digitalization Projects Deliver Returns for Operators” *Journal of Petroleum Technology* 75 (01): 24–29.

⁴¹ Lakshmi pathi, K. *et al.* (2023) “Rethinking Energy with Generative AI” *Amazon Web Services* Available here. (Accessed 10 February 2024).

⁴² Zahn, D. (2020) “What Global Pandemic Responses Teach Us in Upstream O&G” *Ambyint Insights*. Available [here](#). (Accessed 2 January 2024).

Advanced digital technologies are now being applied throughout the oil and gas value chain, from upstream through to downstream. In field development, digital technologies help in figuring out precisely where best to drill oil wells, how many of them, and the optimum spacing between them. In hydraulic fracturing, they help in intelligent process design, choice of fracturing fluids as well as tracking and monitoring of large fleets of specialized vehicles used in fluid injection. In artificial oil lifting, big data analytics help optimize polymer dosage, equipment performance surveillance, failure prediction, etc.⁴³

One good illustration of efficiencies brought by digital technology solutions is the *Field Development Planning* tool from Halliburton. The product automates the field development process by integrating data from multiple sources to offer exact proposals for the ideal development plan based on, among other things, economics, technical capabilities and environmental footprints. It helps simplify field development and well construction by enabling operators to make more informed subsurface and production decisions to perfect investment and maximize return on assets. More remarkably, Halliburton's *Digital Well Program*[®] brings speed to well completion by enabling engineers to minimize well design time from 30 days to just to 1 day!⁴⁴

Select Digital Technology Solutions For Enhancing Productivity at Two Marginal Oil and Gas Fields

Advanced digital technology solutions hold immense potential for improving the Nigerian marginal field development campaign by leading to operational and production optimization.⁴⁵ As stated above, studies by Toluse *et al.*, Dagogo *et al.*, Oyakhire & Omeke and Oruwari made technological proposals for addressing the challenges identified at some marginal fields in Nigeria. However, the conception of the suggested technologies is outdated and not affected by the efficiencies introduced by the massive technological advancement that took place in the last couple of years. This section will look at some of the said technologies in light of the digital transformation taking place in the oil and gas industry, and the enhancements that digital tools can bring to Nigeria's marginal oilfields.

Addressing Reservoir Pressure Decline at the Umusadege Field

Hydrocarbons are ordinarily forced up to the surface by the natural pressure in the reservoir formation. This natural lift process yields only up to 30 percent of the oil in place, and the percentage goes considerably down over time with decline in reservoir pressure.⁴⁶ Thus, with or without pressure decline, it is advisable to use secondary recovery techniques if best production levels are to be achieved. Hence the proposal to apply waterflooding at the Umusadege marginal field. The Umusadege field (OML 56) is jointly operated by Midwestern Oil and Gas (70% ownership) and Suntrust (30%). It has proven reserves of 49.86 mmbbl and a daily rate of 30.0 mbopd. However, depletion of reservoir pressure is negatively affecting oil recovery from the field.

⁴³ Al-Rbeawi, S. (2023) "A Review of Modern Approaches of Digitalization in Oil and Gas Industry" *Upstream Oil and Gas Technology* 11;100098 p.3.

⁴⁴ "Halliburton and Aker BP Collaborate to Automate Field Development Plan" Available [here](#). (Accessed 1 March 2024).

⁴⁵ Kalu-Ulu, *et al.* (A) *Supra* note 7.

⁴⁶ Akinwale, Y.O. (2016) "Harnessing Science Technology and Innovation for Enhancing Marginal Oil and Gas Field Development in Nigeria: A Comparative Analysis" *Int. Journal of eBusiness and eGovernment Studies* Vol. 8, No 2 p.53.

The Waterflooding Technique

Waterflooding is the process of pumping water into the field's reservoir via an injection well so as to sweep or flush oil into the production well.⁴⁷ It is a reservoir management issue that requires careful planning for successful execution and achievement of optimum economic returns.⁴⁸ It requires making high-stakes decisions about where to inject flood-water and at what direction, volume and velocity.⁴⁹ A successful waterflooding campaign depends on finding the optimal trajectory for injection and production that will optimize the oil recovery performance index.⁵⁰ The latter will in turn help prevent problems associated with the campaign such as early water breakthrough, poor oil sweep efficiency and low contact factor, which can all affect ultimate recovery. Early water breakthrough occurs when the injected water gets beyond the breakthrough point of the injection system resulting in high water cut and low volume of ultimate oil recovery. At high water-cut levels, (e.g over 75%) about two-thirds of the oil is unswept and stays trapped in the reservoir. This makes the waterflooding campaign highly suboptimal.⁵¹

Digital Technology Workows and Models for Optimized Waterflooding

In waterflooding, the problem of low contact factor is caused by faulty water injection plan which results in water being improperly displaced at right angles to reservoir strata. Poor oil-sweep efficiency is caused by heterogeneity in flow-determining rock properties, e.g porosity.⁵² Early water breakthrough is caused by high permeability zones in the reservoir. These problems have hitherto been checked by using smart wells equipped with sensors, valves and inflow control devices (ICDs) to monitor and remotely adjust flow rates, pressure and other parameters. This technology allows inflow control valves (ICVs) to be set up to automatically open and close in order to meet the desired production targets. The foregoing traditional techniques used to plan, execute and address waterflooding problems are now being replaced by advanced digital solutions. In the prevention of early water breakthrough, for example, machine learning algorithms are currently being deployed to monitor, control and change well profiles to move water injection flow paths away from high permeability zones.⁵³

The replaced traditional waterflooding plan is based on numerical simulation. The method goes ahead as follows. After building a model of the field geology, numerical reservoir simulation is done to build a reservoir model. Based on field experience, the reservoir engineer manually changes reservoir model parameters for historical matching, constructs a number of flooding

⁴⁷ Inkpen, A. & Moffett, M.H. (2011) "The Global Oil & Gas Industry: Management, Strategy & Finance (PennWell Corporation: USA) pp. 191-192.

⁴⁸ Shang Wui Ng, C. *et al.* (2021) "Application of nature-inspired algorithms and artificial neural network in waterflooding well control optimization" *J of Petroleum Exploration and Production Technology* 11:3103–3127 p. 3103.

⁴⁹ Ghedan, S.G. *et al.* (2021) "Rapid and Efficient Waterflood Optimization Using Augmented AI Approach in a Complex Offshore Field". Abu Dhabi International Petroleum Exhibition & Conference, SPE-207458-MS p.2.

⁵⁰ Grema, A.S. *et al.* (2020) "Evaluation of Intelligent Wells Performance in a Five-Spot Arrangement" *FUOYE Journal of Engineering and Technology*, Volume 5, Issue 1, ISSN: 2579-0625 (Online), 2579-0617 (Paper) p.79.

⁵¹ Osatemple, M.I. *et al.* (2021) "Assessment and Optimization of Waterflooding Performance in a Hydrocarbon Reservoir" Presentation at the Nigeria Annual International Conference and Exhibition Lagos, 2 - 4 Society of Petroleum Engineers SPE-207114-MS. p. 3.

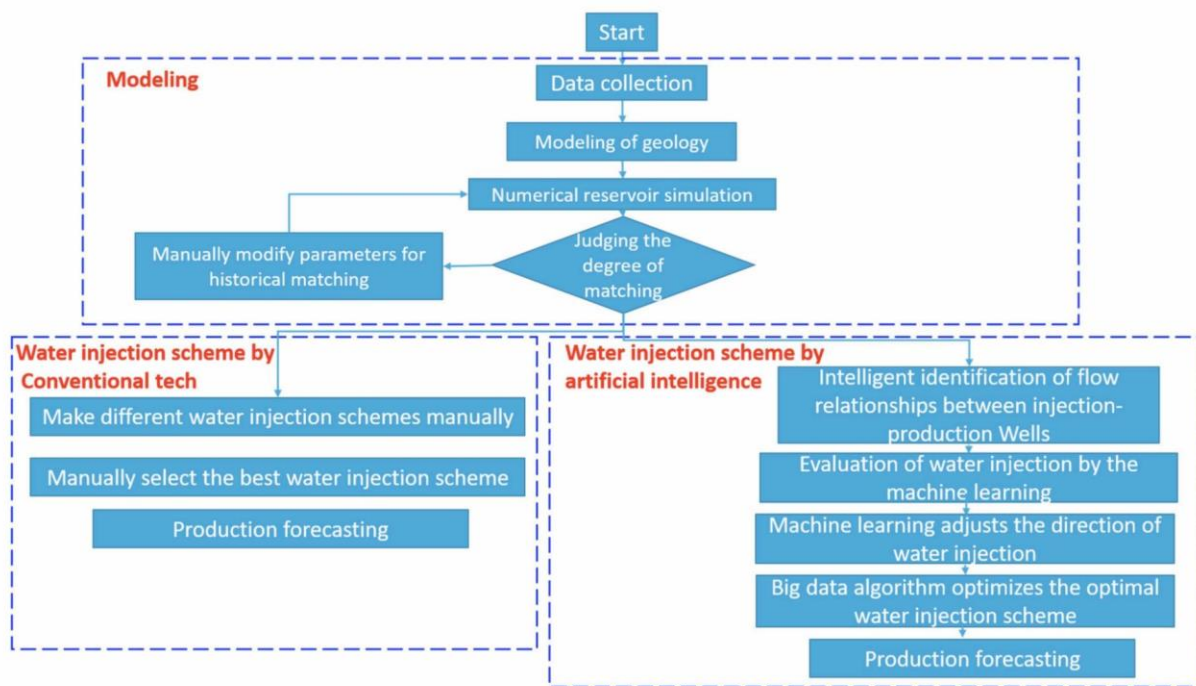
⁵² Grema, A.S. & Cao, Y. "Application of Data-Driven Self-Optimizing Control to Reservoir Production Optimization" *Petroleum Technology Development Journal*, 106 - 116 at 106.

⁵³ Osatemple, *et al.* *Supra* note 51 at 4.

schemes and selects the best one out of them. This method is time-consuming, relies not on the data but on subjective engineer experience and offers limited optimisation options.

Advanced digital technology based on artificial intelligence enhances the conventional water injection scheme by providing a workflow that is integrated with big data analytics. Instead of numerical simulation, data assimilation algorithms are applied to the reservoir model to automatically correct the model's parameters under continuous data drive. In other words, history-matching is done automatically under the dictates of field performance data. Artificial intelligence is then applied to show the flow relation between injection and producing wells. Machine learning is again applied to quantify and assess the effectiveness of the injection plan for further adjustment. Finally, big data analytics is applied to complete and perfect the plan.⁵⁴ See Figure 1 below.

Figure 1



Source: Jia, *et al.*

Jia *et al.* demonstrated the efficiency to be gained in using data-driven algorithms to design water injection plans. Their automated, data-driven, and machine learning based workflow recorded 85% accuracy in data matching, and a 12-month execution in the sample block showed an 8.2% increase in cumulative oil production. Ghedan *et al.* also put forward a workflow for building a waterflooding model which is linked with an optimization engine that provides the best set of operational changes for individual wells. The model can be built and run in relatively short time, and can be updated quickly whenever important well-performance changes are observed.⁵⁵ Using digital technology solutions, history matching and optimization of injection plans which used to

⁵⁴ Jia, D. *et al.* (2023) "Recent Development of Smart Field Deployment for Mature Waterflood Reservoirs" *Sustainability* 15; 784. <https://doi.org/10.3390/su15010784> at 16.

⁵⁵ Ghedan, *et al.* *Supra* note 49 at 18.

be laborious and time-consuming are swiftly and efficiently carried out.⁵⁶ Thus, through the deployment of these new techniques, the waterflooding campaign at the Umusadege marginal field can be intelligently planned and optimized for greater productivity.

Addressing Rapid Decline in Production at the Sango Field

Dagogo *et al.* suggested the use of electronic submersible pumps (ESP) as the most fitting artificial lift technique to address the challenge of declining production at the Sango marginal field.⁵⁷ Declining production usually results from sub-normal pressure levels at the reservoirs. Where the pressure in the formation rock is too low, and waterflooding or gas injection cannot enhance productivity, or where the latter are not suitable, the well must be lifted artificially.⁵⁸ The efficacy of ESPs in the redevelopment marginal fields in the Niger Delta has been confirmed. ESPs have been shown to increase not only production from an otherwise abandoned field, but to increase the productive life of such fields. Kalu-Ulu *et al.*'s study of selected marginal fields found that the ESP lifting technique "increased the production capacity of each well in the field at an average rate of 120% of the natural flow capacity." They also found that "the production life of the marginal oilfield was extended by ten years using ESPs to enhance the production of the field."⁵⁹

The Electric Submersible Pumps system

The ESP system consists of multiple centrifugal pump stages hoisted in series within a casing mated to an electric motor submerged into a well. The pumps are connected to electric power drives and control boards at the surface. Sensors affixed to the pumps and other well structures collect and send configuration and operations data to operators at the control board.⁶⁰ ESPs grapple with subsurface issues such as corrosive fluids and elevated temperatures, and operating issues such as intense pressures⁶¹, high oil-gas ratio at the pump intake, etc. All these affect functions and diminish the run-life of ESP systems.⁶² There is also the rigor of day-to-day operation which all combine to affect ESP function, sometimes resulting in system breakdown. Optimizing the use of ESPs at the Sango marginal field consists in taking care of these performance and risk factors.

The task of operators at the field is that of ensuring the safe operation of ESPs thousands of feet underground. This requires the implementation of systems that can enable efficient monitoring and control of the operation of the pumps.⁶³ This was hitherto done through various distributed control systems (DCS), most notably the Supervisory Control and Data Acquisition (SCADA) system. Serving as the central repository for data from downhole sensors, SCADA enables engineers to set

⁵⁶ Jia D. *et al.* (2020) "Data-driven optimization for fine water injection in a mature oil field" *PETROL. EXPLOR. DEVELOP.*, 47(3): 674–682.p. 681.

⁵⁷ Kalu-Ulu, *et al* (B) *Supra* note 39 at 19.

⁵⁸ Devold, H. (2013) *Oil and Gas Production Handbook: An Introduction to Oil and Gas Production, Transport, Refining and Petrochemical Industry* (ABB Oil and Gas: Oslo) p.35.

⁵⁹ Kalu-Ulu, *et al* (A) *Supra* note 7 at 2797.

⁶⁰ Flatern, R. (2015) "Electrical Submersible Pumps" *Oilfield Review* Spring 2013: 25, no. 1. Available [here](#). (Accessed 6 June 2024).

⁶¹ van Rensburg, N.J. (2019) "Artificial Intelligence Can Reduce ESP Failures?" *Journal of Petroleum Technology*, Available [here](#). (Accessed 6 June 2024).

⁶² Antonic, M. *et al.* (2021) "Implementing the autonomous adaptive algorithm to manage ESP operation in harsh reservoir conditions" *IOP Conf. Ser.: Mater. Sci. Eng.* 1201 012083, p.1.

⁶³ van Rensburg, *Supra* note 61.

predefined rules to keep the production parameters within designed envelopes.⁶⁴ When the system detects a pump reading that is outside preset levels, or when a fault has developed, the operator is alerted of the development via alarms. Necessary remedial actions or adjustments may then be taken.⁶⁵

Digital Technology Solutions for the ESP System

A major issue with the SCADA maintenance system is that it lacks diagnostic and fault prediction capabilities. This essentially means that it enables only reactive remedial action after an unwanted event has already occurred.⁶⁶ Meanwhile, to ensure reliably continuous production, there is need to know of ESP failure before they occur so as to be able to make necessary interventions.⁶⁷ Reactive maintenance strategies are costly, inefficient, and lead to unexpected downtime and other operational problems.⁶⁸ ESP failures lead to disruption in production with associated output losses and significant replacement costs.⁶⁹ Digital technologies are providing solutions to these failures, in addition to generally optimizing production operations. Artificial intelligence, machine learning, cloud computing, the internet of things, etc., now enable intelligent operation and monitoring of ESP systems, autonomous surveillance and early-warning techniques.⁷⁰ In a project report from an onshore oilfield, artificial intelligence was used to build a predictive maintenance model which successfully watches the running 30 ESPs. In one instance, the model discovered significant anomalies 12 days ahead of actual failure.⁷¹

What these modern technologies do differently is leverage data to optimize ESP performance.⁷² Data from downhole sensors are used to train machine learning models which are deployed to improve the efficiency of the ESPs. Model training involves enabling machine learning algorithms to learn the dynamic interactions between well and ESP parameters. Once knowledgeable of the normal ESP behavioral relations, the model becomes capable of comparing incoming operations data with its baseline data set. Through pattern recognition it then watches for any anomalous relationships that may occur. These models identify production optimization opportunities,⁷³ autonomously perform diagnostics and identify and report impending failures.⁷⁴ For example, the Wintershall Dea's model built with data from the Mittelplate field autonomously checks the ESPs

⁶⁴ Antonic, et al. *Supra* note 62.

⁶⁵ Flatern, *Supra* note 60.

⁶⁶ Antonic, et al. *Supra* note 62.

⁶⁷ Abdullah, R. et al. (2022) "Machine Learning Approach for Predictive Maintenance of the Electrical Submersible Pumps (ESPs)" *ACS Omega* 7(21): 17641–17651. doi: [10.1021/acsomega.1c05881](https://doi.org/10.1021/acsomega.1c05881)

⁶⁸ Ohalet, N.C. et al. (2023) "Advancements in predictive maintenance in the oil and gas industry: A review of AI and data science applications" *World J. of Advanced Research and Reviews*, 2023, 20(03), 167–181
DOI: <https://doi.org/10.30574/wjarr.2023.20.3.2432> p.168.

⁶⁹ Pham, S.T. et al. (2021) "Effective Electrical Submersible Pump Management Using Machine Learning. *Open J. of Civil Engineering*, 11, 70-80. <https://doi.org/10.4> p.70.

⁷⁰ van Rensburg, *Supra* note 61.

⁷¹ Kandziora, C. (2019) "Applying Artificial Intelligence to Optimize Oil and Gas Production" Paper presented at the Offshore Technology Conference, Houston, Texas. Paper Number: OTC-29384-MS
<https://doi.org/10.4043/29384-MS>

⁷² Antonic, et al. *Supra* note 62 at 2.

⁷³ *Ibid.*

⁷⁴ Al-Rbeawi, *Supra* note 43 at 9.

and notify operators of abnormal trends, enabling them to mitigate detected performance problems ahead of time.⁷⁵

Some ESP Digital Solutions in the Market

i) SpyGlass

This is a digital performance analysis tool developed by Halliburton's Summit ESP. It is a cloud-based, cross-platform web application tool that enables operators to create, assess, and analyze the performance of ESPs. With this software, the marginal oilfield operators can access real-time analytic data and report on the current performance and health of ESPs from their mobile devices.⁷⁶ The solution is equipped with 100 custom-built alerts to guide operators through the equipment selection process and troubleshooting pumping systems. Leveraging years of actual field data, the solution enables users to define selected production goals and utilize its multi-variant input analysis to quickly model desired scenarios for optimal production performance.

ii) OptumESPTM

OptumESP is an ESP optimization and failure prediction solution built by Ambyint. The digital product combines advanced physics and subject matter ability with AI to automate ESP surveillance, analysis, optimization and prediction of imminent failure. It is designed to increase production, reduce costs and GHG emissions, and improve equipment runtimes and workforce efficiency.⁷⁷ In one use-case, a major oil producer with conventional onshore and offshore ESP wells reported a 5% increase in production and up to 30% increase in ESP runtime as a result of deploying the application. Additionally, operators were able to foresee imminent 'non-trending' failures, averting substantial well downtime, seeing a 20 percent appreciation in equipment lifespan.⁷⁸

iii) AiRP

AiRP – Ai Response Prioritization for ESPs – is designed by Sensia to close the gap between ESP failure detection and correction. The digital solution captures ESP-related events in real-time, and uses advanced analytics to analyze, classify and intelligently prioritize them based on their relative importance. By removing the need for field engineers to show, qualify, prioritize and respond to well events, the solution reduces the time between failure detection and failure correction from hours to just minutes. AiRP provides real-time insights and an early detection mechanism that ensures the action of field engineers are fast, focused and efficient for reduced operational expenditure and increased production optimization.⁷⁹

Undoubtedly, the use of these and many other digital technology solutions will enable operators at the Sango marginal field to ensure an acceptable oil-flow rate, identify ESP system anomalies

⁷⁵ Diker, G. *et al.* (2021) "Development of a Digital ESP Performance Monitoring System Based on Artificial Intelligence" Paper presented at the Abu Dhabi International Petroleum Exhibition & Conference, Abu Dhabi, UAE. Paper N0: SPE-207929-MS <https://doi.org/10.2118/207929-MS>

⁷⁶ "New Cloud-Based ESP Performance Analysis Tool from Haliburton" *Oil Review Africa*, 28 April 2023 Available [here](#). (Accessed 1 March 2024).

⁷⁷ Ambyint Case Study (2022) "Increase production and runtimes on ESP wells". Available [here](#). (Accessed 10 May 2024).

⁷⁸ "Ambyint Partners with nybl to Deliver ESP Optimization Technology" Available [here](#). (Accessed 10 May 2024).

⁷⁹ "Ai Response Prioritization for ESPs: A big step towards autonomous lift starts with Sensia AiRP for ESPs". Available [here](#). (Accessed 1 June 2024).

and failure probabilities with actionable intelligence about their root causes.⁸⁰ Estimates of the ESP lifespan can be made enabling the operator to make early replacement plans in order to avoid production loss from pump timeout.⁸¹ They can also be leveraged to improve maintenance scheduling and resource allocation.⁸²

Conclusion and Recommendations

This paper is a contribution towards promoting the decades-long efforts of the Nigerian government to increase the country's oil and gas output. The paper has proved the potential of marginal oil and gas fields to contribute to total production as well as the efficiencies to be gained from deploying digital technology solutions in operating those fields. While the use of unconventional technologies as means of turning marginal fields to producing fields have been proposed, their lukewarm deployment has not benefited from efficiencies introduced by advanced digital technologies in the last couple of years.

Earlier research has shown that available field development technologies are not being effectively harnessed by Nigerian marginal field operators as is the case in other parts of the world. As a way of addressing this, Akinwale and Humphrey & Dosunmu proposed that marginal field operators should build capacity in the area by training their engineers and scientists, and by going into technical collaborations with universities and research institutions.⁸³ In this direction, this article recommends that productivity-boosting digital technology solutions, examples of which have given hereunder, should be incorporated into the various unconventional techniques put forward for enhanced marginal field operation in Nigeria.

Since most of the indigenous companies operating the marginal fields are small-to-medium and, therefore, do not have the requisite resources to build capacity in-house, digital technology services should be outsourced from specialized providers. Indeed, this is the standard, and cost-effective, practice even among the large multinational oil companies. Secondly, in light of the absence of indigenous digital technology oilfield service companies, it is recommended that an invigorated campaign be made to build local capacity in the area as part of the country's local content development program. This will help put an end to the reliance on foreign providers such as Halliburton, Schlumberger, ABB, Baker Hughes and Microsoft.

⁸⁰ Antonic, et al. *Supra* note 62.

⁸¹ Pham, et al. *Supra* note 69; Abdullah, et al. *Supra* note 67.

⁸² Ohalet, N.C. et al. (2023) "Advancements in predictive maintenance in the oil and gas industry: A review of AI and data science applications" *World J. of Advanced Research and Reviews*, 2023, 20(03), 167–181
DOI: <https://doi.org/10.30574/wjarr.2023.20.3.2432>

⁸³ Akinwale, *Supra* note 46 at 60; Humphrey & Dosunmu *Supra* note 32 at 417.