Petroleum and Coal

Article **Open Access**

Oil well sidetracking in mature fields: Its potential for increasing recovery from Nigeria's mature fields

*Augustine Okechukwu Chukwuemeka *, Goodluck Amede, Mustapha Abdulsalam, Oyintinloye Eganoba Shada, Kazeem Alani Odunlami.*

Institute of Oil, Gas and Energy, Kuban State Technological University Krasnodar, Russia

Received December 5, 2016; Accepted February 3, 2017

Abstract

Around the world, sidetracking on mature fields has given new life to a number of oil wells, increasing their production, reducing water production or restoring production in once abandoned oil fields. Through this technology, an additional 67,300 tonnes was produced from Pamyatno-Sasovskoye field in Russia and the PuCheng oil field had increased production by 5.1×10^4 tonnes. In Nigeria, the Oiloibiri oil field is a clear example of an abandoned mature field where no enhanced oil recovery method was applied before abandonment. This oil field, located in present day Bayelsa state has a reported 21.26 million barrels (3,380,000 m^3) of unrecovered oil. In addition to this, about 22 other oil fields are abandoned in Nigeria today. This work includes a brief description of the history of oil production in Nigeria, the technology of sidetracking and a discussion of the problems associated with sidetracking wells of mature fields in addition to an estimation of the potential for increased recovery of oil by sidetracking the abandoned fields of Nigeria. Applying the sidetracking technology on Nigeria's mature fields will help recover a good amount of their un-swept reserves and through this, Nigeria will be able to increase her daily production while taking advantage of the cheap cost of sidetracking in an oil based economy where market conditions favour neither exploration for new fields nor drilling new wells.

Keywords: mature field; sidetracking; Oloibiri; Un-swept Oil; sandstone reservoir.

1. Introduction

The oil and gas industry today, as in a number of other instances in the past, is faced with the problem of falling oil prices which has led to the shutting down of a number of oil rigs around the world and a tremendous loss of jobs especially in the upstream sector. Explorations for oil and drilling of new wells have become in large part, of less economic gain and companies are downscaling in these areas. Hopes are, that oil price bounces back at some point and activities once again peaks in these areas.

However, in the meantime and indeed not just now, enhancing oil recovery from mature fields is and will likely continue to be a scientific challenge to the petroleum engineer.

While exploration for new oil fields and drilling new wells in mature fields are good, the cost of these projects are very high and not of great economic gain in the present situation of the industry. Sidetracking a number of wells of mature fields can help recover an additional percentage of un-swept residual oil. This percentage in large parts will be dependent on a number of factors ranging from the drilling practice to the production practice applied on the field. Considering the amount of mature fields around the world some of which have been plugged and some others on their third stage of production, usually characterized by a falling output of oil and an increasing water production, and the fact that oil recovery is never hundred percent, sidetracking the wells of these fields will greatly increase the world's total output at a low cost while preserving new oil fields for the energy needs of the future.

The oil industry does not give a strict definition to the term mature field but it could be any oil field regardless of its location that falls into any of the categories described by Hull in his 2012 paper '' What is a Mature field?'. He writes that, the term "mature field" has no single definition. Often, engineers consider fields mature when they have declined in production by more than 50% of their plateau rate [1]. Different companies might apply their own specific definitions though. For example, Total considers the surface and the subsurface. For the sub-surface, they consider a field mature when the cumulative production has reached 50% of the initial 2P (proved plus probable) reserves. And for the surface, they consider a field mature after 10 years of production. They use other criteria, but these are the main ones. Halliburton defines a mature field as "one where production has reached its peak and has started to decline.[1]. These kinds of fields abound around the world. About two-thirds of the world's daily oil production comes from mature fields [2].

The industry, having grown in technology and innovation, now stands a better chance of reentering wells of these mature fields which in many cases were drilled using older technologies. Newer technologies have improved the chances of hitting targets that were hitherto unpenetrated and getting their reserves to surface.

The industry has over the years developed a number of enhanced oil recovery methods such as the water alternating gas method, gas injection method, chemical treatment of the reservoir as well as hydraulic fracturing of the reservoir among others. These have, and continue to play great roles in petroleum extraction today. However, in dealing with mature fields, these methods have a certain limitation that is common to them all. Neither of the methods promises to or is able to reposition the bottom of an oil well and as such they are unable to connect untapped reserves. This limitation is comprehensively taken care of by sidetracking the wells of mature fields on which the above methods can still be applied for a yet higher oil recovery ratio.

Sidetracking is the drilling of a new lateral from an existing well that has poor or no productivity due to mechanical damage to the well or depleted hydrocarbons at that particular site [3]. It may also be defined as the term used for drilling a directional hole to bypass an obstruction in the well that cannot be removed or damage to the well, such as collapsed casing that cannot be repaired. Other applications of sidetracking are deepening a well or relocating the bottom of the well in a more productive zone [4]

There are many reasons for sidetracking: the casing is damaged or collapsed, junk may be lost in the hole, the production zone may have been damaged in the original well, or to tap into another less-depleted drainage area [5]. The process today is increasingly being employed, for the purpose of enhanced and sometimes accelerated recovery form mature oil fields. The initial primary purpose of sidetracking was however, to bypass around an unrecoverable fish.

2. Literature review and success of sidetracking on mature fields around the world

The practice of sidetracking on mature oil fields for enhanced recovery has been carried out successfully in a number of oil fields around the world. Most countries where oil production started more than fifty years ago have either sidetracked a number of wells on their mature fields or have mature fields with un-swept reserves waiting to be tapped. Mature fields occur throughout the world. Onshore North America and the Gulf of Mexico continental shelf have many fields that are late in their lives. Many oil fields in the North Sea have passed their production peak, and the potential in Russia's older fields is large. Other areas, including China, India, Australia and Argentina, contain significant numbers of mature fields. Many parts of the world that are still developing their resources also have fields that are moving into the late production plateau including Mexico, Thailand, Nigeria and Egypt [6].

Reports of increased recovery and decreased water production after sidetracking a number of wells in some mature fields of a number of the countries listed above, signal a possible positive result should the sidetracking technology be applied to other mature fields of other countries.

A Russian oil Company drilled sidetracks at 224 wells in 2010 and gave average daily flow of 19.7 tonnes. In 2010 this company drilled a total of 12 sidetracks in Urevskoye field and eight sidetracks in Unvinskoye field. In Pamyatno-Sasovskoye field, which is one of the largest in the Volga region, total additional oil production achieved by drilling of sidetracks was 67,300 tonnes [7]. Another Russian oil company has operation rights on 1000 wells on the Sakhalin Island. These wells are un-active with proven Reserves, but the wells have been drilled over a period of half a century. Implementation of new technology such as extended reach sidetracks into these mature oilfields would increase production significantly [8].

A joint venture of three companies managed to drill a 650-m horizontal sidetrack with a complex 3D profile to improve productivity and to maximize reserves recovery in a mature Chinese oil field. The target was a low-quality clastic reservoir with very thin oil pockets of 1.5 m thickness [9].

Due to the apparent thin oil column in Gunung Kembang Field in the South Sumatera Extension area of Medco E&P Indonesia working areas, three horizontal wells,GK-1 HW, GK-3 HW and GK-6 HW, were executed in 2004 by side-tracking existing vertical wells, GK-1, GK-3, GK-6 [10]. This improved both the amount of recoverable oil and had a highly positive effect on field development operations. Through sidetracking the reserve of PuCheng oil field had increased by 5.1×10^4t, water drive reserves had increased by 130×10^4 t, and recoverable reserves had increased by 50×10^4t. Sidetracking well, to a certain extent, slowed the decline of production [11].

3. The technology of sidetracking

To sidetrack a cased well, a window has to be cut through one of the well's casings, depending on the depth of either the fish being bypassed or the location of the targeted oil reserve. In most instances of sidetracking wells of mature fields for increased recovery, the window is cut on the production casing. In other situations, the sidetrack might start from an open section of the parent well.

To kick off the sidetrack, a cement plug or whipstock is commonly used to start bit deviation along the desired trajectory. Cement plugging has a number of disadvantages when compared to the use of whipstock and these include but not limited to the following:

1. The need to wait for proper cement curing and hardening before sidetracking can start. Which is an additional cost in rig time,
2. The cement plug may not gain enough hardness to start a sidetrack in casings of high hardness and such formations as granite which can force the bit to drill through the cement plug itself or any other path of lower resistance,
3. A layer of residual mud or oil may prevent proper bonding between the cement plug and the wellbore.

While sidetracking to bypass a fish is a much similar process to sidetracking on wells of mature fields, the later requires a number of considerations and stages for quality result. These stages cover the processes of milling out a window on an old well, the actual drilling of a sidetrack well and the well's completion. The stages can be summarized as follows:

1. Choosing the candidate wells for sidetracking: In this process the operator identifies the wells to be sidetracked considering the production history of the field and the field's geology.
2. Geophysical testing of the chosen wells: After a well or some wells have been chosen as candidates for possible sidetracking, geophysical test and logging should be carried out on the well(s) to ascertain their exact state of strength and to enable the driller make the proper choice of the kick off point as well as well trajectory.
3. Drilling the sidetrack: This includes the process of cement plugging the well or setting the whipstock in place, milling a window and the proper drilling of the directional sidetrack well. The standard drill stem of drill pipes or coil tubing technology may be used; both having their own special applications and advantages.
4. The final stage is well completion: The sidetracked well as any other oil well may have open completion or be cased at the production zone depending on a number of factors which includes formation strength.

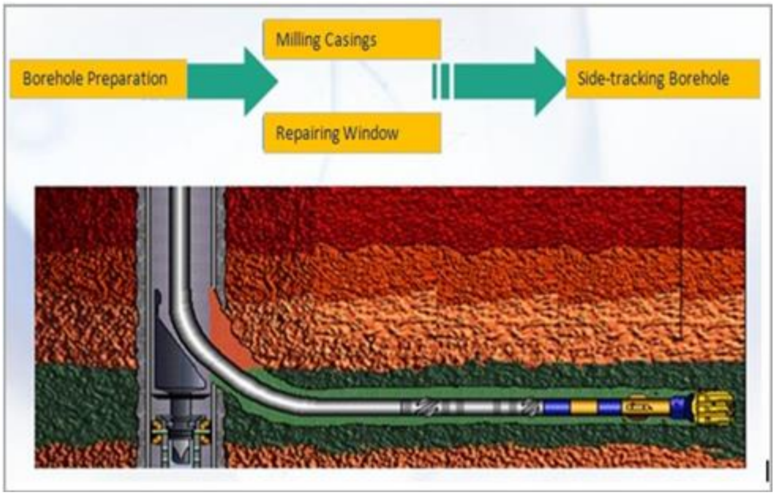

Figure 1. Profile of a sidetracked well showing the various stages of the sidetracking process [12].

4. The challenges of sidetracking wells of mature fields

While the prospect of increased recovery which means more petro dollar, from sidetracking mature fields is high, it is very important to note the following challenges which are associated with sidetracking on mature fields. They include the:

1. Geological and stratigraphic uncertainties: While we can always have geophysical and drilling log data of the field from previous wells to consult, the geology of the environment as well as it's stratigraphy after many years of drilling and production does in large part differ from the data obtained while drilling the earlier wells on the field. This brings certain degree of uncertainty into the drilling process and special attention must therefore be paid to this. Depleted reservoirs will have a varied pressure condition and a varied stress pattern from previous wells.
2. Abrasive metallic particles from the window milling process: When the kick of point of a side-track well is not in an open hole, a window has to be created through a metallic casing. This process produces metallic particles which the drilling fluid picks up to the surface. If not immediately taken care of, these can cause abrasive damage to the mud cleaning equipment.
3. Limited choice of well diameter: The diameter of a sidetrack well on wells of mature fields is dictated by the diameter of the open hole or casing located at the kick off point, restricting its diameter to less than that of the casing through which the window is milled. This way, the drilling string will be in much closer contact with the wellbore which can lead to well bore instability issues. This calls for increased attention to the type and properties of the drilling fluid to be used; especially, it's lubricating property among others as well as its water loss property. Formation of a thick mud cake will usually have an increased negative consequence in this case. In situations of lost circulation, the level of the drilling fluid could decrease tremendously, which means, an enormous instantaneous decrease in hydrostatic pressure with a possibility of catastrophic blow out. This calls for adequate preparation with measures put in place to possibly avoid lost circulation in such wells or at least bring them under immediate control should they occur. It is important also, to note that mature fields have depleted reservoirs, where formation pressure are much lower than they used to be; such are possible lost circulation zones.
4. Wellbore stability issues: Sidetrack wells usually show a tendency for high instability around the kick of point where instability is a consequence of both instability in the main well and the sidetrack well. The type of the stress regime and the orientation of the principal stresses have no or negligible effect on the stability of the sidetrack compared to sidetrack inclination and therefore it cannot be generally considered as a factor affecting the bend stability. On the other hand, the sidetrack deviation angle from the vertical main well plays the major

role in the stability of the bend area. It is predictable that by the increase of the deviation angle the bend area become more unstable. This factor has a more significant impact when the sidetrack is near the vertical position, 0°-15°. Then by the increase of the deviation angle the needed mud pressure increases with a lower rate and even in some cases no changes can be seen in the required mud pressure, especially when the deviation angle differs from 45°to 60 [13].

5. Brief history of oil exploration and production in Nigeria and the existence of mature fields today

Exploration for oil is believed to have started in Nigeria several years with little to no discovery of oil before the discovery of oil in commercial quantity at Oloibiri in 1956. Before this discovery, Germany owned Nigeria Bitumen Company had drilled an exploration well in 1908.

Other oilfields would later be discovered in Nigeria both onshore and offshore; the first offshore field being the Bonga field discovered by Shell in 1996. This field is 120 kilometers southwest of the Niger Delta and started production in the year 2005 from the Middle to Late Miocene unconsolidated turbidite sandstones formation in an average water depth of about 1000 meters.

A number of other oil companies have joined in the exploration and production of oil in Nigeria including: Mobil, Elf, Chevron, Addax. Continuous progress was made in oil production in Nigeria till 1967 when the Biafra war interrupted activities in the oil sector. However, after the war ended in 1970 companies resumed normal operations and Nigeria was able to benefit economically from the then rising oil price.

Most oil exploration and production activities in Nigeria has been within the area popularly referred to as the Niger Delta comprising of Rivers, Ondo, Edo, Bayelsa, Akwa-Ibom, Cross River, Abia and Imo states until recently when drilling and production started in Anambra state; where crude oil production started in the year 2012 and in Lagos state where Aje oil field discovered in 1997 finally started production on May 3rd 2016.

Aje is an offshore field located in OML 113 in the western part of Nigeria in the Dahomey Basin. The field is situated in water depths ranging from 100 to 1,000 meters about 24 km from the coast. The Aje Field contains hydrocarbon resources in sandstone reservoirs in three main levels – a Turonian gas condensate reservoir, a Cenomanian oil reservoir and an Albian gas condensate reservoir [14]. The federal government of Nigeria has lately intensified oil exploration activities in the lake Chad basin.

Petroleum in the Niger Delta is produced from sandstone and unconsolidated sands predominantly in the Agbada Formation. Characteristics of the reservoirs in the Agbada Formation are controlled by depositional environment and by depth of burial. Known reservoir rocks are Eocene to Pliocene in age, and are often stacked, ranging in thickness from less than 15 meters to 10% having greater than 45 meters thickness [15]. Previous studies on the stratigraphy of the Niger delta include the following: Short and Staubles [16] classified the subsurface Niger delta into three stratigraphic units; Benin Formation being the youngest, Agbada Formation and the oldest is Akata Formation. The Agbada Formation is the hydrocarbon - prospective sequence, a paralic clastic sequence which lies below the Benin Formation (continental sand) in the Niger Delta [16]. The Agbada Formation consists of predominantly sandy units with minor shale intercalations and thick shale units at the base (which is an alternation of paralic sandstone, shale and clay). This sequence is over 4,000 m thick, but thicker at the central part showing that the depocentre is located in the central Niger delta [15].

After much studies and discussions on the possible source rock of the Niger delta's oil for example (Evamy and others, 1978; Ekweozor and others, 1979; Ekweozor and Okoye, 1980; Lambert-Aikhionbare and Ibe, 1984), the identified possible source rocks include variable contributions from the marine interbedded shale in the Agbada Formation and the marine Akata shale, and a Cretaceous shale (Weber and Daukoru, 1975; Evamy and others, 1978; Ejedawe and others, 1984; Ekweozor and Okoye, 1980; Ekweozor and Daukoru, 1984) [15,17-23].

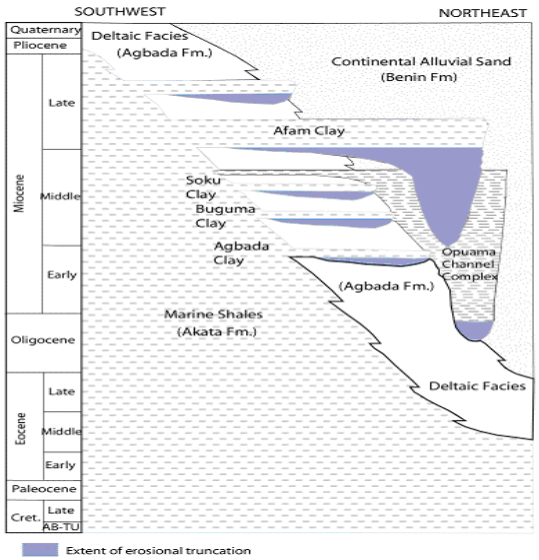

Figure 2. Stratigraphic column showing the three formations of the Niger Delta. Modified from Shannon and Naylor (1989) and Doust and Omatsola (1990) [23]

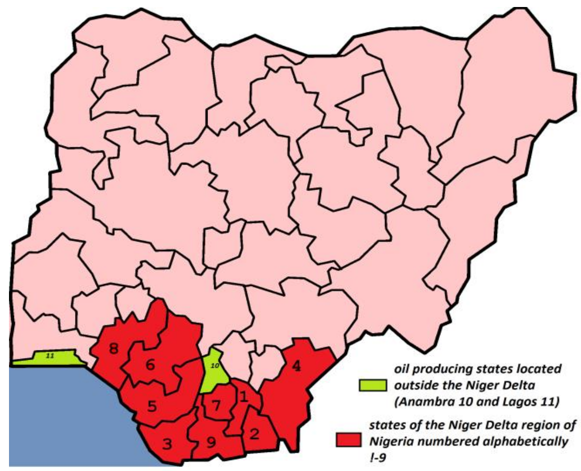

Figure 3. Map of Nigeria showing crude oil producing states [24] with modifications to include Lagos and Anambra

In addition to Oloibiri oilfield which is currently plugged and abandoned, several commercial oilfields have been discovered and put into production in Nigeria between 1956 and today. There are presently 606 oil fields in Nigeria. Of the 606 oil fields in the Niger Delta area, 355 are on-shore while the remaining 251 are offshore. Of these, 193 are currently operational while 23 have been shut in or abandoned as a result of poor prospectivity or total drying up of the wells. Outside the Niger Delta, a total of 28 exploratory oil wells have been drilled all showing various levels of prospectivity. These wells include two (2) discovery wells in Anambra State, one (1) discovery well each in Edo State and Benue State and Twenty-four (24) wells in the Chad Basin [25].

6. Sidetracking wells of Nigeria's mature oil fields for increased recovery- the prospect of Oloibiri field

Around the world as mentioned above, companies have been sidetracking wells in their mature filed to enhance production by either repositioning the bottom of the well, penetrating bypassed reserves and or drilling deeper to reach deeper reservoirs.

Nigeria which has a number of mature fields; some still in production and a number of others already plugged and abandoned, can produce more oil from a number of these fields through sidetracking. Some of the plugged wells in Nigeria have shown evidence that they still contain a reasonable amount of oil reserve. For instance Bodo-West Oilfield and Yula oil field, have both had spillage issues after their abandonment; a sign that a reasonable amount of oil under a pressure high enough to get it to the surface still remained in these fields which for some reasons had been plugged and abandoned.

Nigeria instead of rushing to new oil fields can reenter and sidetrack wells in her abandoned oil and other mature fields to increase her daily production to feed her refineries, maintain her export and secure her foreign exchange earnings. This has become more imperative with the building of Dangote refinery which is currently under construction and expected to start operations in Lagos by 2018.

6.1. The Oloibiri field and its prospect for increased recovery

Olobiri is of great importance to the Nigeria's oil and gas industry and occupies a central position in the history of oil and gas exploration and production in Nigeria; being her first comercial oil field and first source of petro dollar.

The Oloibiri Oilfield is an onshore oilfield located in Oloibiri in Ogbia LGA of Bayelsa State, Nigeria, about 45 miles (72 km) east of Port Harcourt in the Niger Delta. Oloibiri field is about 13.75 square kilometers (5.31 sq mi) and lies in a swamp within OML 29. Oloibiri Oilfield is named after Oloibiri, a small, remote creek community, where it is located. It was discovered by Shell Darcy and operated by same company which later changed its name to Shell-BP Petroleum Development Company of Nigeria Limited. The discovery well Oloibiri −1 was spudded on 3 August 1955 and drilled vertical to a total depth of 12008 feet (3660m). The well was tested and it flowed at the rate of about 5,000 barrels (790 m^3) of oil per day and it was deemed to be a commercial discovery [26].

Figure 4. The well head of Oloibiri well №1. Source – Google.

The field started oil production between late 1957 and early 1958 and the first oil production from the field came at the rate of 4,928 barrels per day (783.5m^3/d). The field produced at an average rate of 5,100 barrels (810 m^3) of oil per day for the first year. The production increased thereafter as more wells were completed and put onto production and reached its peak in 1964. The field was drained from eleven production wells [25].

The Agbada Formation which dates back to Eocene in age, is a marine facies defined by both freshwater and deep sea characteristics. This formation is the major oil and natural gas bearing facies of the Niger Delta basin. It has an estimated thickness of 3700 meters.

The estimated oil reserve of the Oloibiri field is 41.26 million barrels however; the Oloibiri oilfield produced over 20 million barrels (3,200,000 m^3) of oil during its 20 years life cycle. Oil production finally stopped in 1978 and the field was abandoned the same year. The Oloibiri oilfield was abandoned without any improved recovery to drain some of the 21.26 million barrels (3,380,000 m^3) of hydrocarbon still left in the field [26].

With 21.26 million barrels of oil left in the Oloibiri oil field, and Nigeria struggling to meet her OPEC production quota in a period when exploration for oil and drilling new wells has been rendered less impressive by low oil prices, there is a need to reenter the wells of Oloibiri field, sidetrack them to recover as many barrels of oil as possible. There is a high prospect for increased recovery through sidetracking given that no enhanced oil recovery method was applied before field abandonment and assuming no external disturbance hampers oil production from the field, at a recovery factor of 30 percent, Nigeria will be adding a total of 6.378 million barrels of oil to her total production by sidetracking on this field.

If crude oil price remains at about fifty dollars per barrel, this will mean a total of 318.9 million dollars. While it is true that this amount will come with some costs which have not been deducted here, such as cost of drilling the sidetrack and other operational costs, proper analysis and re-examination of the Oloibiri Oil field will give a clearer picture of the expected volume of oil that could be produced by sidetracking the field's wells. Sufficient data, which are unfortunately not available to us will enable an accurate estimation of the amount of oil remaining in the field and facilitate the design of a recovery programme that will produce best results. However, the possibility of using a number of the surface facilities used in earlier production and transportation of crude oil from this field will reduce production cost drastically.

Oloibiri is just one of such oil fields in Nigeria which today is either plugged and abandoned or has entered a stage of declining production. If they can all be revitalized through sidetracking, Nigeria will be adding a significantly large amount of barrels to her daily production at a very low cost.

In addition to the above, the Niger Delta of Nigeria could be drilled deeper to explore the possible existence of deeper reservoir of oil and or gas. Drilling deeper wells from the surface will mean an enormous amount of expenditure. Through the application of the sidetracking technology, current wells can be deviated and drilled to reach deeper formations at a much reduced cost to enable proper determination of their nature and characterize them and any fluids that maybe in them accurately.

7. Recommendations

1. To facilitate the production of this residual oil, we recommend that the government of the Federal Republic of Nigeria through either direct investment or amendment of the country's oil and gas laws, puts measures in place for sidetracking operations on the country's mature fields and makes sidetracking a necessary requirement before field abandonment in all cases where it is considered appropriate. One of such adjustments in her laws could be to ensure that the multinationals who own licenses to these fields transfer ownership to local companies or to the government at a fee in situations where they are unwilling to sidetrack.
2. For a more accurate estimation of un-swept oil and appropriate choice of wells to be sidetracked, by independent researchers, reservoir log data, drilling report of these fields as well as the production history and production practices applied in these fields should be made more easily accessible. With these, economic analysis of the sidetracking project can be made.
3. If laws are put in place that make these data more easily accessible, chances of companies leaving economically recoverable oil will be reduced significantly.

8. Conclusions

1. Sidetracking in mature oil fields around the world has in a large number of cases increased the amount of oil recoverable from such fields.
2. The process of sidetracking in wells of mature oil fields comes with a number of challenges to which special attention must be paid for success.
3. The Oloibiri oil field of Nigeria holds a known 21.26 million barrels (3,380,000 m^3) of unrecovered hydrocarbon. This and the occurrence of oil spillage from such oil fields as Bodo-West and Yula, are an indication that Nigeria has significant oil reserves in her mature fields. It is also on record that no enhanced oil recovery method was applied on the Oloibiri field before its abandonment.
4. Sidetracking wells of the mature fields of Nigeria promises an increased recovery which may be all the country needs to meet her current OPEC production quota in addition to ensuring that newly discovered and unproduced fields are preserved to meet the energy needs of tomorrow while keeping the country in a position to take advantage of any future increases in crude oil price.
5. Sidetracking in these mature fields is a more cost effective method of increasing recovery than drilling new production wells in a time of falling crude oil price.

References

[1] Hull R. 2012. What is a Mature field? Halliburton Solutions Blog. http://halliburtonblog.com/what-is-a-mature-field.

[2] Parshall J. Mature Fields Hold Big Expansion Opportunity. J Pet Technol. 2012; 64(10): 52 – 58. SPE-1012-0052-JPT.

[3] http://www.eurasiadrilling.com/operations/onshore/sidetrack-drilling.

[4] Drilling and Servicing eTool, www.osha.gov.

[5] http://petrowiki.org/Mature_fields#cite_note-parshall-1

[6] Usman Ahmed, 2004. Making the Most of Mature Fields. Schlumberger Oilfield Review.

[7] LUKOIL, 2010. Oil Field development and production. Annual Report.

[8] Drnec ML and Przhegalinsky I. Horizontal extended reach re-entry drilling of sidetracks at sakhalin island increases oil production from mature oil fields. IADC/SPE Drilling Conference, 2008, Orlando, Florida, USA.

[9] Schlumberger, 2011. Sidetrack Horizontal Well in Low-Quality Reservoir Produces Triple the Oil Expected.

[10] Hudya FD, Natali S and Castillo D. The effect of pressure depletion on geomechanical stress and fracture behavior in Gunung Kembang Field. Thirty-First Annual Convention and Exhibition, 2007, Proceedings, Indonesian Petroleum Association.

[11] Huang Lingyan and Tang Hai, 2015. The Optimization of Sidetracking Horizontal Well. EJGE Vol. 20 [2015], Bund. 14.

[12] http://www.petro-king.cn/en/service/tab.aspx?nodecode=119003002003001010.

[13] Elyasia A, Goshtasbi K. The impact of sidetracking on the wellbore stability. Advances in Energy Research, 2015; 3 (1): 1-10.

[14] http://www.offshoreenergytoday.com/first-oil-flows-from-aje-field-offshore-nigeria/.

[15] Evamy BD, Haremboure J, Kamerling P, Knaap WA, Molloy FA and Rowlands PH. Hydrocarbon habitat of Tertiary Niger Delta. American Association of Petroleum Geologists Bulletin, 1978; 62: 1-39.

[16] Short KC, Stauble AJ. Outline geology of the Niger Delta. American Association of Petroleum Geologists Bulletin, 1967; 51: 761–779.

[17] Ekweozor CM, Okogun JI, Ekong DEU and Maxwell JR. Preliminary organic geochemical studies of samples from the Niger Delta, Nigeria: Part 1, analysis of crude oils for triterpanes: Chemical Geology, 1979; 27: 11-28.

[18] Ekweozor CM and Okoye NV. Petroleum source-bed evaluation of Tertiary Niger Delta: American Association of Petroleum Geologists Bulletin, 1980; 64: 1251-1259.

[19] Lambert-Aikhionbare DO, and Ibe AC. Petroleum source-bed evaluation of the Tertiary Niger Delta: discussion: American Association of Petroleum Geologists Bulletin, 1984; 68: 387-394.

[20] Weber KJ and Daukoru EM. Petroleum geology of the Niger Delta: Proceedings of the Ninth World Petroleum Congress, 1975; Volume 2, Geology: London, Applied Science Publishers, Ltd., p. 210-221.

[21] Ejedawe JE, Coker SJL, Lambert-Aikhionbare DO, Alofe KB and Adoh FO. Evolution of oil-generative window and oil and gas occurrence in Tertiary Niger Delta Basin: American Association of Petroleum Geologists, 1984; 68: 1744-1751.

[22] Ekweozor CM and Daukoru EM. Petroleum source bed evaluation of Tertiary Niger Delta--reply: American Association of Petroleum Geologists Bulletin, 1984; 68: 390-394.

[23] Tuttle M, Charpentier R, Brownfield M. The Niger Delta Petroleum System: Niger Delta Province, Nigeria, Cameroon, and Equatorial Guinea, Africa". 1999, United States Geologic Survey.

[24] NNPC. Development of Nigeria's oil industry. http://nnpcgroup.com/NNPCBusiness/BusinessInformation/OilGasinNigeria/DevelopmentoftheIndustry.aspx

[25] https://en.wikipedia.org/wiki/Niger_Delta#/media/File:NigerDeltaStates.png.

[26] https://en.wikipedia.org/wiki/Oloibiri_Oilfield.

*Corresponding author. Address: Moskovskaya 2, Krasnodar, Russia. Postal code: 350072
Email: engineaust@gmail.com. Tel: +79604783414