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Enhanced Recovery of Heavy Oil in the Niger Delta: Nelson and Mcneil Model a Key Option for In-Situ Combustion Application

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Abstract

In-situ heavy oil recovery involves several field tested enhanced oil recovery methods/techniques with applicable models. Such field tested techniques include non-thermal oil recovery, hybrid oil recovery and solvent-base oil recovery. The viabilities and field successes recorded by these in-situ heavy oil recovery techniques/methods cannot be overemphasized. But, the main focus of this study is on heavy oil recovery using in-situ combustion with attention on the application of Nelson and McNeil model as documented in the in-situ combustion handbook (Partha, 1999). We subjected data(s) obtained from five (5) heavy oil reservoirs located within the same field in the Niger Delta to the correlations, equations, assumptions and calculations proposed by our study model. This enabled the research team to carry out performance evaluations while considering in-situ combustion implementation using our proposed model. Our result outcomes were further validated with a foreign heavy oil reservoir having similar reservoir properties. Our study results show how viable and profitable (with possible commercial production) heavy oil production from unconventional reservoirs in the Niger Delta would be. Currently, most of the internally generated oil revenue by the Nigeria government is from cheap/light oil obtained from conventional reservoirs (which is fast declining globally).

Key words: In-Situ Combustion ISC; Niger delta; Heavy oil; Enhanced oil recovery; Nelson and McNeil model

INTRODUCTION

Commercial production of heavy oil is a costly venture with existing high risk. But, it is also a highly viable and profitable business that can be exploited in the Niger Delta by the Nigeria government or in other heavy oil reservoirs worldwide. Heavy oil is very evident in the Niger Delta as documented by Tetede in 2006. According to Tetede (2006), there is heavy oil sand outcrop at Imeri village in Ijebu-Imushin community located in Ogun State, Nigeria. Tetede in his work also claimed that 40% of the heavy oil in the Niger Delta could come from Ogun State alone. About 30-40 billion barrels of heavy crude are contained in bituminous sand deposits located within the Southwestern region of Nigeria. This amount of heavy oil is too significant to be left un-exploited and must be considered for possible commercial exploitation/production using this study in-situ combustion ISC model. Heavy oil can be located in the following Niger Delta states:

i. Ogun
ii. Ondo
iii. Edo
iv. Lagos (most recent addition)

According to Smalley (2000), the earth contains about 6 trillion barrels of heavy oil, compared to 1.75-2.3 trillion barrels of cheap/light oil contained in conventional reservoirs with 40% of it already been produced at commercial scale globally.

(a) Heavy Oil

Heavy oil is a petroleum-like liquids or semi-solid petroleum mixtures less than 22^0 API gravity. Viscosities ranges between 100-10,000cp and are usually formed in porous formations like sands with less carbonates (at reservoir conditions). Most heavy oil exists at shallow depth (3,000ft or less) and in unconsolidated sand formations (Farouq et al., 1997).

(b) In-Situ Combustion

In-situ combustion (ISC) also known as fire-flooding involves technically burning the heavier and less mobile components of the oil, thereby reducing its viscosity via thermal effects/compositional changes. In-situ combustion is considered wrongly as the most unsuccessful thermal recovery method. This wrong assertion is as a result of failed ISC projects in the past. However, these failures resulted from inappropriate application of fire-flooding to wrong reservoir prospects. Typically, ISC can be done when the reservoir pressure is too high or the pay zone is too thin to effectively carry-out steam-flooding or when the reservoir is also too deep (PTRC Report, 2009). In-situ combustion comprises of Dry ISC, Wet ISC and Reversed ISC. Dry ISC applies only dry air as injectant. Wet ISC occurs when water is injected alongside air. The Reverse ISC is known to have less application and the burning is conducted in the reverse manner. One of the major disadvantages of ISC is the difficulty in controlling the burning front.

(c) Introduction to Enhanced Oil Recovery, Eor

The four known enhanced oil recovery techniques used successfully in the field as at today are:

i. Chemical EOR
ii. CO_2 EOR
iii. Other gas EOR (HC gases and Nitrogen gas)
iv. Thermal EOR (ISC, SAGD, Steam flooding, Cyclic Steam Stimulation and THAI)

Thermal EOR techniques are known to have been successfully applied in shallow reservoirs with depth that is less than 3,000ft. It is applicable to large oil fields that have the possibilities of high return on the investments made by stakeholders. The CO_2 used for CO_2 EOR process is commonly sourced naturally or industrially based on its availability. In 2006, CO_2 EOR accounted for almost 37% of oil production from the United States alone. Other Gas EOR involves the use of other gases like HC gas and Nitrogen gas as injectants during the process. The sole purpose of injecting these gas is for gas recycling, pressure maintenance and gas lift. This process is also known to be cheaper than the CO_2 EOR process and is also non-corrosive to bottom well equipment (Muhammad et al., 2012). However, CO_2 is now alternatively dissolved in brine (this is done at the surface level) leading to inject carbonated brine as against CO_2. This technique will remove the risks that accompany the buoyant migration of free CO_2 phase. This resulted from the dissolved CO_2 carbonated brine which is denser than the native brine (Alizadeh et al., 2014). Injecting CO_2 into heavy oil reservoirs for recovery has not received much attention when compared to light oil reservoirs. It is believed that heavy oil reservoirs do not have the acceptable sweep efficient due to the high viscosity contrast between CO_2 and viscous oil. The process is also known to develop a miscible front in heavy oil reservoirs (Chukwudeme et al., 2009).

In-situ heavy oil recovery can be classified into four groups (Wang, 2010):

i. Cold Production (i.e. CHOPS)
ii. Thermal Recovery (i.e. SF, CSS, ISC, SAGD, THAI)
iii. Hybrid Recovery Process (i.e. Extended Solvent SAGD “ES-SAGD”, Thermal Solvent, SAGD with Non-Condensate Gas “NCG” Injection)
iv. Solvent-base Recovery (i.e. Vapor Extraction “VAPEX” which is a non-thermal solvent-base recovery still being developed for possible commercial application).

Heavy oil recovery has also gone electrical. Recovery of heavy oil can be done by electrical setup. It is called “Electrical Enhanced Oil Recovery” (EEOR). EEOR recovers heavy oil from oil and water bearing formation(s). It is done in a way that spaced injection and production well(s) penetrate the formation of interest and a drive fluid is then injected through the injection well(s) right into the formation. Unidirectional electrical potential gradient occurs between the anode setup of the production well(s) and the cathode setup of the injection well(s) that are adjacent to the formation of interest (Sacuta et al., 1980).

1. INTRODUCING THE STUDY MODEL

Nelson and McNeil (1961) in-situ combustion model presented mathematical formulas that allow engineers to calculate oil production rates, total oil recovery, air injection rates and the total project air requirements. The model is based on large assumptions but it is engineered by considerable field experience that can yield reasonable estimates. Assumptions made by this model in brief are:

i. Satisfactory burning rates range between 0.125 to 0.5ft/day.
ii. Maximum air rate is based on the minimum rate of 0.125ft/day.
iii. The air injection rate depends on the desired rate of advancement of the burning front.

2. RESERVOIR DATA(S) CONSIDERED (CASE 1 AND CASE 2)

Case 1:

Table 1
Venezuela Heavy Oil Reservoir Data (Partha, 1999)

Parameters	Values
Formation thickness	25ft
Formation temperature	146 F
Porosity	22.6%
Specific permeability	1000md
Oil saturation	55%
Water saturation	40%
Production well radius	0.276ft
Oil gravity	13° API
Oil viscosity	280cp

Case 2

Table 2
Five Niger Delta Heavy Oil Reservoir Data(s) From the Same Oilfield, 45miles/72km East of Port-Harcourt, Nigeria (Kerunwa et al., 2014)

Parameters parameters	Niger delta reservoir A	Niger delta reservoir B	Niger delta reservoir C	Niger delta reservoir D	Niger delta reservoir E
Pay thickness (ft)	110	152	69	71	33
Pressure (psia)	2794	3384	1,816	2,033	2,612
Temperature (°F)	128	164	113	122	127
Oil gravity (°API)	18.08	21.80	19.19	19.03	22.14
Permeabilty (mD)	600-1,500				
Oil saturation, (%)	83.40	82.10	82.60	81.40	22.20
Oil viscosity(cp)	86.75	4.76	31.81	25.49	29.31
Water saturation (%) (1-S_o)	16.40	17.60	16.70	18.30	77.03
Porosity (φ)	20% - 30%				

From the above two heavy oil reservoir data tables we compared in-situ combustion project performance/evaluations on Niger Delta heavy oil reservoirs (Case 2) using the Nelson and McNeil model and validating our findings with a foreign scenario (Case 1).

Note: Details of the model's formula(s) and calculations used in generating the results in the tables below are as documented in the in-situ combustion handbook (Partha, 1999)

3. RESULT(S) IN SUMMARY

Details of the correlations, equations, formulas and calculations used in deriving the below result tables for this study can be found as documented in the ISC Handbook (Partha, 1999). There is a direct proportionality between maximum oil productions (bbl/day), compressor horsepower requirements (bhp/day) and maximum air injection demands (Ossai et al., 2017).

Table 3
Calculated Oil Recovered (bbl/MMscf) and Overall Recovery Efficiency, E_R (%)

	Venezuela reservoir	Niger delta reservoir A	Niger delta reservoir B	Niger delta reservoir C	Niger delta reservoir D	Niger delta reservoir E
Oil recovered per mill.scf injected air (bbl/MMscf)	45.8	63.9	62.8	63.3	62.2	106.4
Overall recovery efficiency, E_R (%)	50.3	52.2	52.1	52.0	52.0	93.7

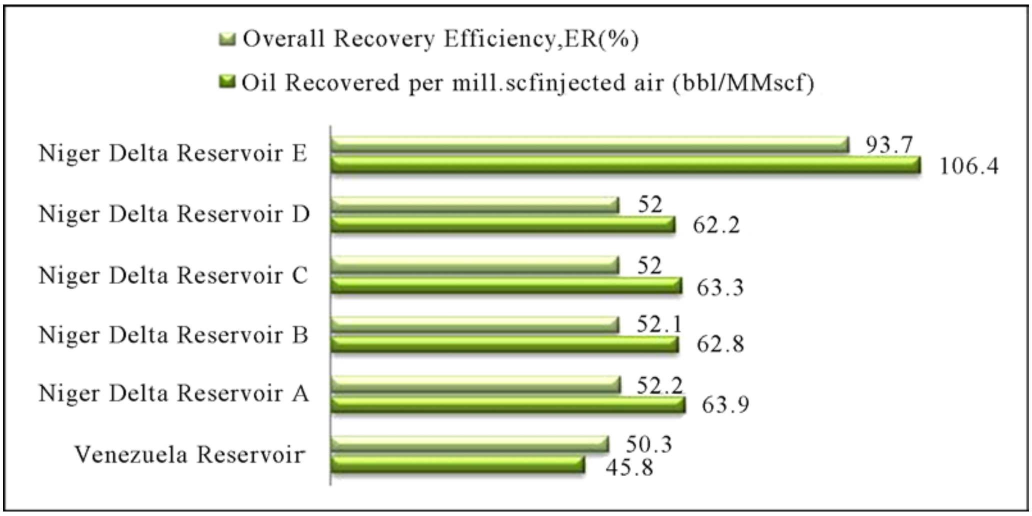

Figure 1
A Plot of Oil Recovered Per Million Standard Cubic Feet (bbl/MMscf) and Overall Recovery Efficiency, E_R (%)

4. RESULT DISCUSSION AND INTERPRETATION(S)

From Table 3 and Figure 1 it can be seen that the overall recovery efficiency for all six reservoirs considered is above 50% with the Niger Delta reservoir E yielding as high as 93.7%. Oil recovery per million standard cubic feet of injected air for the Niger Delta reservoirs yielded better results compared to the Venezuela reservoir by almost 70%. Niger Delta reservoir E yielded the highest result of 106.4 bbl /MMscf.

Table 4
Calculated Total Oil Recovery, N_{P2} (bbl/acre-ft) and Maximum Air Injection Pressure (psia)

	Venezuela reservoir	Niger delta reservoir A	Niger delta reservoir B	Niger delta reservoir C	Niger delta reservoir D	Niger delta reservoir E
Total oil recovery, n_{p2} (bbl/acreft)	485	676.4	664.8	669.4	658.4	1,125.6
Maximum air injection pressure (psia)	429	546	562	539	543	498

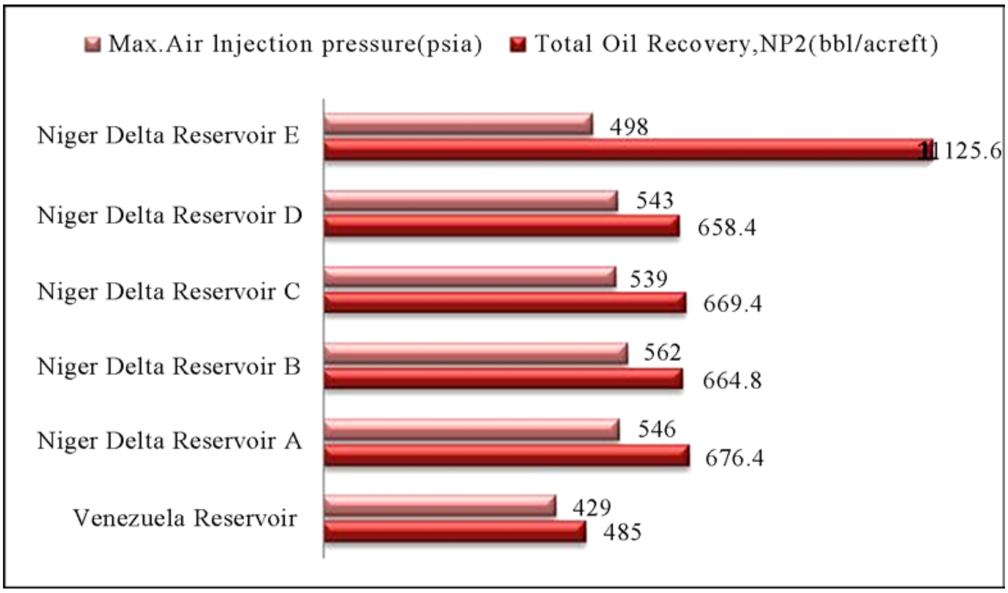

Figure 2
A Plot of Total Oil Recovery (bbl/acre-ft) and Maximum Air Injection Pressure (psia)

5. RESULT DISCUSSION AND INTERPRETATION(S)

From Table 4 and Figure 2 you will see likewise that the Niger Delta reservoirs yielded higher total oil recovery (bbl/acre-ft) results than the Venezuela reservoir. The Niger Delta reservoir E also yielded the highest total oil recovery of 1,125.6 bbl /acre-ft at a maximum air injection pressure of 498 psia. And the total oil recovery result for all six reservoirs considered was achieved at an average maximum air injection pressure of 520 psia.

Table 5
Calculated Duration of Constant Rate Period (Days) and Maximum Air Rate Time (Days)

	Venezuela reservoir	Niger delta reservoir A	Niger delta reservoir B	Niger delta reservoir C	Niger delta reservoir D	Niger delta reservoir E
Duration of constant rate period (days)	567.33	567.66	567.94	567.30	567.71	567.50
Maximum air rate time (days)	125.30	125.20	125.20	125.30	125.20	125.30

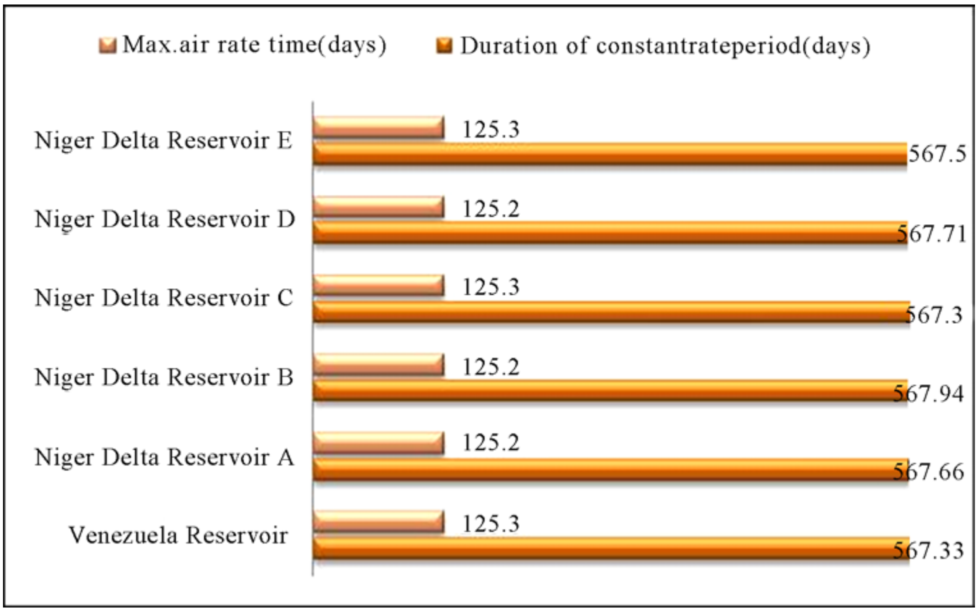

Figure 3
A Plot of Duration of Constant Rate Period (Days) and Maximum Air Rate Time (Days)

6. RESULT DISCUSSION AND INTERPRETATION(S)

From Table 5 and Figure 3 it can be deduced also that the average duration of the constant rate period for all six reservoirs considered was at 567 days. And the average maximum air rate time for these six reservoirs considered was also at 125 days. This validates the similarities in the properties of these reservoirs irrespective of their locations.

Table 6
Calculated Volume of Air Injected at the Constant Rate Period (MMscf) and Total Air Requirements (MMscf)

	Venezuela reservoir	Niger delta reservoir A	Niger delta reservoir B	Niger delta reservoir C	Niger delta reservoir D	Niger delta reservoir E
Volume of air injected at constant rate period (MMscf)	1,084	4,767	6,588	2,900	3,077	1,430
Total air requirements (MMscf)	1,323	5,819	8,041	3,650	3,756	1,746

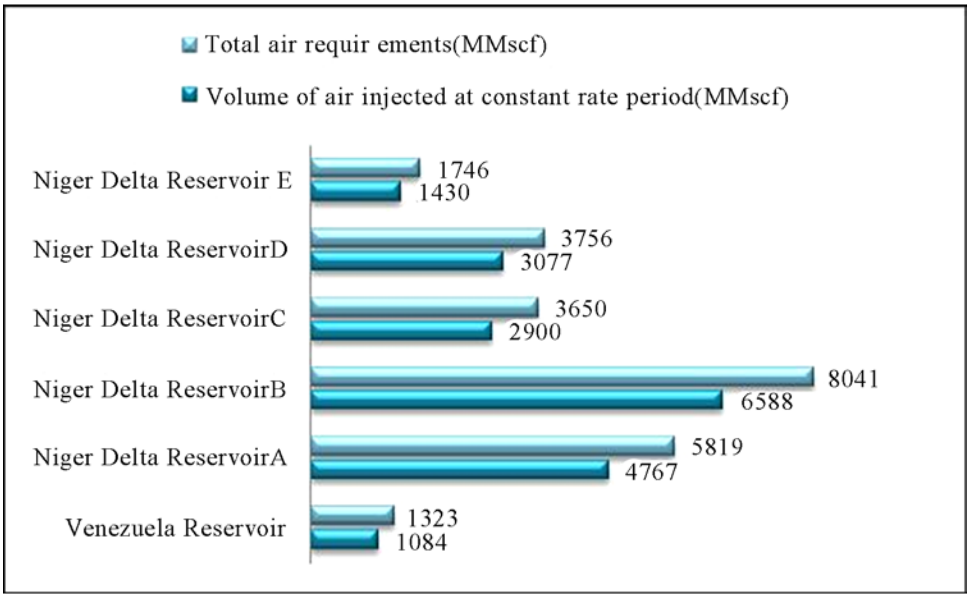

Figure 4
A Plot of Volume of Air Injected at Constant Rate Period (MMscf) and Total Air Requirement (MMscf)

7. RESULT DISCUSSION AND INTERPRETATION(S)

From Table 6 and Figure 4 we can also observe that the volume of air injected at the constant rate period (MMscf) increases with increase in total air requirements. A direct proportionality relationship exists between these two results as well.

CONCLUSION

This work has shown a better performance evaluation for the five heavy oil reservoirs considered in the Niger Delta over the Venezuela heavy oil reservoir which is already under commercial scale production while that of the Niger Delta isn't receiving any attention at all from relevant stake holders/authorities. This study has shown also from its results that there is a dare need for all relevant stake-holders operating onshore and offshore of Niger Delta to critically start looking at the very possibilities of heavy oil production at commercial scale within the region. And if this is to be done, then using Nelson and McNeil in-situ combustion model is a key option to be considered for ISC application in the Niger Delta, South of Nigeria.

RECOMMENDATION

There is a serious need for the attention of stake-holders in the oil industry to be drawn to possible commercial production of heavy oil from Niger Delta fields, South of Nigeria. Despite the diversification drive by the Nigerian government most of her internally generated revenue is still derived from production of light/cheap oil from conventional reservoirs. It is already a known fact that light/cheap oil from these conventional reservoirs are fast declining globally. Hence, production of heavy oil on commercial scale is the way forward for sustaining the ever growing need for energy consumption in the future along with sustainable green energy drives.

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