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In-situ Combustion: Reservoir Candidacy/Project Selection Criteria(s) For Niger Delta Heavy Oil Reservoirs

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***Abstract*—**There is a drastic need for the oil companies operating within the onshore(s) and offshore(s) of Nigeria to critically start looking at the various possibilities of heavy oil production from the nation's various fields located in the Niger Delta region using already available Enhanced Oil Recovery techniques/methods such as In-situ combustion (ISC), CHOPS and SAGD. This study focused on In-situ combustion as a means of enhancing likely heavy oil production in the Niger Delta using the Nelson & McNeil 1961 ISC model. The study developed applicable screening criteria(s) for both reservoir candidacy and ISC project selection in the Niger Delta. Corresponding programs and flow-charts that would allow petroleum engineers in the Niger Delta to theoretically evaluate production performances using his/her computer(s) was also developed. It was discovered also during our course of work that all six reservoirs considered in both Case 1 (Venezuela reservoir) and Case 2 (Niger Delta reservoirs) met this study's reservoir candidacy selection criteria(s) for possible applicability of an ISC project performance evaluation(s) with respect to enhancing oil production. These reservoirs were further graded / ranked based on their theoretical ISC project performances as calculated and evaluated using a well known ISC model as documented in the ISC handbook.

***Keywords*—** In-situ Combustion ISC, Niger Delta, Reservoir Selection Criteria, Heavy Oil, Enhanced Oil Recovery EOR, Thermal Recovery, Nelson and McNeil ISC model

I. Introduction

The importance of crude oil production to Nigeria's economy cannot be overemphasized. However, most will agree that the time of conventional oil, oil that was easy and cheap to find and produce is coming to an end (Nigeria's light oil isn't an exemption to this fact). As conventional oil fields reach maturity and global demand for oil increases, there is a shift to production from unconventional heavy oil reservoirs. They have recently become an important resource as conventional oil reservoirs are in sharp decline. Heavy oil reservoirs are considered to be non-conventional oil reservoirs, and are sometimes ignored as a source of oil because of the difficulties and cost involved in their development, which reduces their economic viability. The main objective of an EOR method such as in-situ combustion is to achieve higher overall oil recovery and higher production rates. This study was able to demonstrate this theoretically using the Nelson & McNeil (1961) In-situ combustion model as documented in the In-situ Combustion Handbook (Partha, 1999) [10].

It is already a known fact that In-situ Combustion (ISC) is a good EOR technique that has incurred a bad reputation over the years as a result of wrong application and to wrong reservoir prospects. This study findings and development will save the oil industry both time, manpower and most especially money. It will further enhance the participation of both indigenous and multi-national oil and gas companies in boosting Nigeria's energy reserves by venturing into full scale commercial production from its heavy oil reservoirs in the Niger Delta. Applying the right EOR method like ISC to the right heavy oil reservoir prospect remains the key to boosting heavy oil production from the Niger Delta. Hence, this study's reservoir candidacy/ISC project selection and screening criteria (with its corresponding screening Program A and reservoir performance Program B) developed for the Niger Delta heavy oil reservoir will enthusiastically and practically encourage prospective oil companies to critically take steps leading to the eventual commercial production of heavy oil from unconventional reservoirs in the Niger Delta region.

a. Heavy oil Recovery

Heavy oil recovery can be achieved by injecting steam down a vertical well and into a production zone for a short period. This well is now placed on production for a longer period. This cycle is subsequently repeated provided production is still profitable (Snow et al, 1998) [14]. On the other hand, In-situ combustion (ISC) is a thermal EOR technique that involves a fire-flooding process. Usually, thermal energy is produced in the reservoir by combustion, which is initiated with either an electric heater/gas burner or may occur spontaneously. Air is by far the most common way to introduce oxygen into a reservoir. It is compressed at the surface and continuously injected into the reservoir via the injection well. In the heating and combustion that occur, the lighter parts of the oil are vaporized and moved ahead. Depending on the highest temperature reached, thermal cracking is most likely to happen, and vapor products from this reaction also move downstream. Part of the oil is deposited as a

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coke like material on the reservoir rock, and this solid material serves as the fuel in the process. Hence, as oxygen injection is sustained, a burning front slowly progresses through the reservoir, with the reaction components displacing vapor and liquids ahead toward production wells (Green & Willhite, 1998 and Prats, 1982) [4], [12].

As at today we have three types of in-situ combustion methods and they are:

1. Dry in-situ combustion: This occurs where air (oxygen) is the only injectant into the well.
2. Wet in-situ combustion: This takes place when water is injected along with air. Water effectively picks up energy in the burned zone behind the burning front.
3. Reverse in-situ combustion: This type has less application and the burning is carried out in a reverse manner. Combustion is usually initiated at the production wells. Oxygen is still injected at injection wells and so the burning zone tends to move in the direction opposite to the fluid flow (Green & Willhite, 1998) [4].

Injected gases and water, from both the water of combustion and re-condensed formation water, pick up energy as they pass through the burned zone and move toward the combustion front. A hot water-flood usually exists in this region, much in the same manner as in a steam injection process. Ahead of the steam plateau, the temperature decreases to the original reservoir temperature (Green & Willhite, 1998 and Al-Wadhahi et. al., 2005) [2], [4]. One common major problem with in-situ combustion is the difficulty in controlling the progression of the burning front. Sequel to the reservoir properties and fluid distributions the burning front may likely progress non-uniformly throughout the reservoir, but with poor volumetric contact. If proper conditions are not sustained at the burning front, the burning reaction can become weaken and stop completely. The process usefulness is lost if this takes place. Finally, due to the high temperatures produced, major equipment issues can take place at the wells (if such well are poorly designed to withstand thermal stresses). When in-situ combustion is applied in high temperature oxidation mode, the following reactions are expected to take place (Xia et al., 2001) [17]:

I. Thermal Cracking:

Crude heavy ends → Crude light ends + Coke

II. Oxidation of coke:

Coke + Oxygen → $CO + CO_2 + H_2O$

III. Oxidation of heavy residual:

Crude heavy ends + Oxygen→ $CO + CO_2 + H_2O$

b. Eor Displacement Mechanisms

Thermal EOR methods depend on various displacement mechanisms to recover heavy oil. The relative significance of each mechanism relies on the type of heavy oil being displaced and the related recovery processes involved. For in-situ combustion processes, the mechanisms are closely related to the thermal and temperature effects of the reservoir rock and fluid properties. The oil displacement is as a result of the following:

1. Decrease in oil viscosity.
2. Thermal expansion of the reservoir fluids and rocks, thereby decreasing their densities.
3. Thermal cracking and distillation of the oil.
4. A solution gas drive from generated gas that promotes the flow of fluids within the reservoir toward the production wells.
5. Increased pressure gradient caused by the injected air and produced gases.
6. Effect of Gravity drainage: Mechanisms such as distillation drives and thermal expansion of the heated oil add to recovery as crude distillation leads to reduction in residual oil saturation.

Other important parameters to be considered during an EOR process include but not limited to the following:

I. Reservoir Porosity and Oil Saturation: Economic oil recovery depends on this. This must be high enough to support commercial production. The product of both parameters (i.e. φ X S_o.) should be greater than 0.08 for combustion to be economically successful.
II. Reservoir Oil Gravity: This parameter is not critical. But, the in-situ viscosity should be low enough to permit air injection that will result in oil production at the desired rate.
III. Oil Nature of the reservoir: In heavy oil projects the oil has to be readily oxidizable at reservoir and rock matrix conditions. Laboratory experiments can determine the quantity of air required to burn a given reservoir volume (It was determined as 87,120lb/acre-ft. for a 5-acre 5-spot pattern for a heavy oil reservoir located in Venezuela). This is expedient when considering profitability of the process.

Note: *The minimum air flux required to maintain higher temperatures at the burning front is projected as 0.125 ft. /day (0.04 m/day) for a successful ISC process. (Partha, 1999)*

Table 1: Screening parameters for thermal recovery processes (Green & Willhite, 1998) [4].

Screening Parameters	In-situ Combustion	Steam
Oil Gravity, Deg API	9 - 25	10 – 34
In-situ oil viscosity, μ (cp)	≤ 5000	≤ 15000
Depth, D (ft)	≤ 11500	≤ 3000
Pay-zone thickness, h (ft)	≥ 20	≥ 20
Reservoir temp, T_r (DegF)	Not Specified	Not Specified
Porosity, Φ (fraction)	≥ 0.20	≥ 0.20
Average permeability, k (mD)	≥ 35	250
Transmissibility, kh/μ (mD-ft/cp)	≥ 5	≥ 5
Reservoir pressure, P_r (psi)	≤ 2000	≤ 1500
Minimum oil content at start of process, S_o (fraction)	≥ 0.08	≥ 0.10
Salinity of formation brine (ppm)	Not Specified	Not Specified
Rock type	Sandstone or Carbonate	Sandstone or Carbonate

Many of the criteria(s) in Table 1.0 above do have similar characteristics for steam and in-situ combustion. Consequently, it is not uncommon to find a reservoir that can satisfy these criteria for both processes during an EOR process. Three criteria where there are significant differences include depth, reservoir pressure, and average reservoir permeability. In-situ combustion can be applied in reservoirs that have lower permeability than the permeability limit for steam injection because the air injection rates are sufficient to sustain the combustion front. Table 2.0 below compares recovery efficiency of ISC to other enhanced oil recovery EOR methods.

Table 2: Recovery Efficiency of ISC compared to other EOR methods (Hasiba and Wilson, 1975)[5].

Process	(A) Process Displacement Efficiency (%)	(B) Areal Sweep Efficiency (%)	(C) Vertical Sweep Efficiency (%)	(D) Compound Recovery Efficiency (%)
In-situ Combustion	95	70	85	56
Steam-flood	65	70	85	39
Cyclic Steam	--	--	--	20
Micro-Emulsion flood	90	70	80	50
CO_2 Water-flood	80	50	80	32
NaOH Water-flood	35	70	80	20

Note: (D) = (A) X (B) X (C), and Volumetric Sweep Efficiency = (B) X (C)

c. Screenting and Reservoid Candidacy Slection Criteria (A)

Thermal EOR processes like any other EOR process involves tremendous planning, man-power, expertise / professionalism, expenditures and high cost of execution. Hence, the need of applying ISC process to the right reservoir prospect is the key to the success of the whole thermal EOR process. To this end, the importance of screening and selecting the right reservoir candidacy for the applicability of ISC process cannot be overemphasized. Below is a table showing details of program 'A' developed to screen each reservoir properties based on minimum model selection criteria(s). If the reservoir properties pass the screening processes by program 'A' then it will be further considered for ISC applicability using program B. Based on similarities of reservoir properties we subjected Case 1 (Venezuela Heavy oil reservoir) and Case 2 (Five Heavy Oil reservoirs located in a Niger Delta Field that is about 45 miles or 72km East of Port-Harcourt, Rivers State, Nigeria (Kerunwa et al., 2014)) [6] to program A (screening and selection processes) & program B (ISC project performance evaluation using the Nelson and McNeil model) respectively. See the appendix section below for a combined flowchart that shows the processes for both programs. Below Table 3.0 details the minimum screening criteria(s) that can be inputted into our study model's program 'A'.

Table 3: Program A' input data detailing the minimum In-situ combustion screening criteria(s) and Reservoir Candidacy/ Project Selection for Niger Delta heavy oil reservoirs

Input	Input Description with units	Minimum Model Screening Criteria(s)
A	Porosity ϕ, (%)	> 20
B	Permeability k, (mD)	> 50
C	Oil Gravity (deg API)	>6 < 25
D	Oil Viscosity μ, (cp)	< 5000
E	Oil Saturation So, (%)	> 50 < 100
F	Net Pay Thickness h, (ft.)	> 10 < 200
G	Reservoir Depth H, (ft.)	< 3500
H	Reservoir Temperature Tf, (deg F)	>100 < 135
I	Air Flux (ft/day)	> 0.125
J	Transmissibility "k.h/ μ", (mD.ft/cp)	>5
K	Relationship "ϕ.So" (%)	> 0.08
L	Compressor Pattern Sequence	>4
M	Compressor Number of Stages	>3
N	Burning rate (ft./day)	> 0.125 < 0.5
O	Frontal Advance Rate (ft./day)	>0.125< 0.5
P	Reservoir Area Extent (acres)	>1<5

II. Performance Evaluation using Program "B"

After a successful reservoir screening and candidacy selection process using program 'A' there is the need to theoretically evaluate the ISC project performances for these reservoirs using a suitable ISC model.

a. Introducing the Study Model

Program B was tailored to carry out ISC performance evaluation theoretically using a particular ISC model (see table 4.0 below for program 'B' details). This is done after a particular reservoir has been screened and selected as a potential candidate for ISC project by our study program 'A'. At this point, this study looked at the applicability of Nelson & McNeil ISC model as documented in the ISC handbook for ISC performance evaluation (Partha, 1999) [10]. In 1961, Nelson & McNeil gave engineering details (backed with equations) on how to evaluate the performance of a dry ISC project. Despite the large number of assumptions made, the model's method and its applicability is centered on considerable field work/expertise. Hence, it can deliver reasonable production estimates as shown in this study results.

Table 4: Program B input data for applicability of the Nelson & McNeil model and its ability to predict ISC performance with respect to enhancing heavy oil production from oil reservoirs

Input	Input Description with Applicable units
A1	Total Air Requirement @ a sweep efficiency of 62.6% (MMscf/acre-ft)
B1	Total Air Volume needed for the 5-spot @ a sweep efficiency of 62.6% (MMscf)
C1	Air Flux needed to sustain the burning front advancement @ 0.125ft/day (scf/ft2day)
D1	Maximum Air Rate (MMscf/day)
E1	Time needed to reach maximum air rate (days)
F1	Volume of injected air during period (MMscf)
G1	Volume of injected air @ constant rate period (MMscf)
H1	Duration/time of the constant rate period (days)
I1	Total time for the entire burning period (years)
J1	Maximum Air injection period (psia)
K1	Compressor Horsepower Requirements for a 4 pattern sequence with 3 stages
L1	Fuel consumption during combustion (lbs/ft3)
M1	Volume of Oil displaced per acre-ft burned (bbl/acre-ft) "Np_1"
N1	Volume of Oil displaced per acre-ft for unburned portion of the reservoir (bbl/acre-ft) "Np_2"
O1	Total Volume of Oil Recovery (bbl/acre-ft) "Np_3"
P1	Overall Recovery Efficiency (%) "ER"
Q1	Oil Recovered per millions scf of injected air (bbl/MMscf)
R1	Maximum Oil Production (bbl/day)
So	Oil Saturation (%)
Φ	Porosity (%)
H	Net pay thickness (ft) (> 30ft)
L	Spacing between injection and production well (> 330ft)

b. Assumptions

(i) Model's Assumptions:

- The air injection rate depends on the desired rate of advance of the burning front.
- Satisfactory burning rate ranges from 0.125-0.5 ft. / day.
- Maximum air rate is based on the minimum burning rate of 0.125 ft./ day

Note**:** Details of the formulas and calculations used in achieving the below result tables for this study (considering Case 1 & 2) can be found as documented in the ISC Handbook (Partha, 1999).

Case 1 and 2 tables below details the various reservoir(s) parameters subjected to our study's model and its performance evaluation equations/assumptions.

Case 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^{0} API
Oil Viscosity	280cp

Case 2: Five Niger Delta Heavy Oil Reservoir Data from same Oilfield 45miles/72km East of Port-Harcourt, Nigeria (Kerunwa et al., 2014) [6].

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	1816	2033	2612
Temperature (°F)	128	164	113	122	127
Oil Gravity (°API)	18.08	21.80	19.19	19.03	22.14
Permeability (mD)	600 – 1500				
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%				

c. Result(s) in Summary

Table 5: Calculated Maximum Oil Production (M.O.P) and Compressor Horsepower Requirements (C.H.R) (P.G.O OSSAI et al., 2017) [9].

	Venezuela Reservoir	Niger Delta Reservoir A	Niger Delta Reservoir B	Niger Delta Reservoir C	Niger Delta Reservoir D	Niger Delta Reservoir E
M.O.P (bbl/day)	87.6	536.9	728.9	333.4	337.3	268.1
C.H.R (bhp/day)	2017	8868	12249	5565	5724	2661

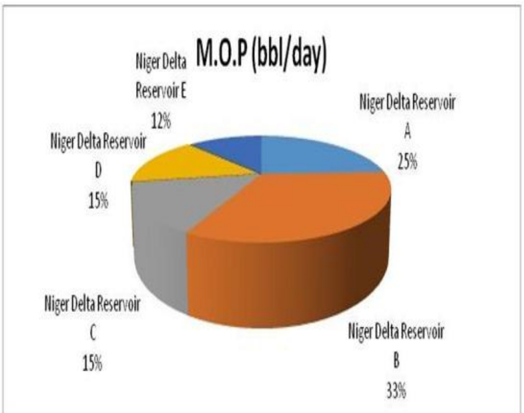

Figure 1: Pie chart showing the percentages of maximum oil productions, M.O.P (bbl/day) for the five Niger Delta reservoirs considered using the ISC model

Table 6: Calculated Max. Oil Production, M.O.P (bbl/day) and Maximum Air Injection Requirement(s), M.A.R (MMscf/day)

	Venezuela Reservoir	Niger Delta Reservoir A	Niger Delta Reservoir B	Niger Delta Reservoir C	Niger Delta Reservoir D	Niger Delta Reservoir E
M.O.P (bbl/day)	87.6	536.9	728.9	333.4	337.3	268.1
M.A.R (MMscf/day)	1.910	8.398	11.600	5.270	5.420	2.520

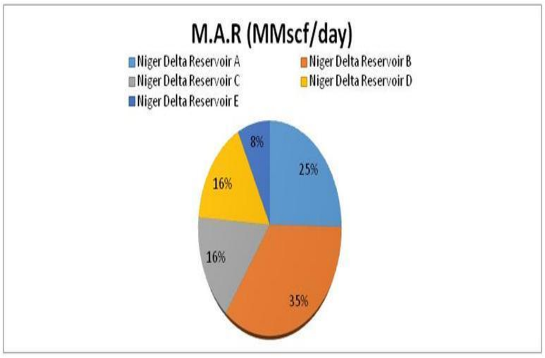

Figure 2: Pie chart showing percentage details of maximum air injection requirements, M.A.R (MMscf/day) for the five Niger Delta reservoirs considered using the ISC model

Table 7: Calculated Oil Displaced (from the burned zone) and Oil Displaced (from the unburned zone)

	Venezuela Reservoir	Niger Delta Reservoir A	Niger Delta Reservoir B	Niger Delta Reservoir C	Niger Delta Reservoir D	Niger Delta Reservoir E
Oil Displaced "burned zone" (bbl/acre-ft)	716	1046	1026	1034	1015	952
Oil Displaced "Unburned zone" (bbl/acre-ft)	386	518	510	513	506	1200

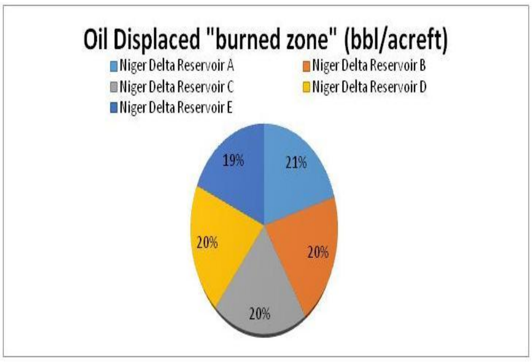

Figure 3: Pie charts showing percentage details of oil displacement from burned zones for the five Niger Delta reservoirs considered using the ISC model

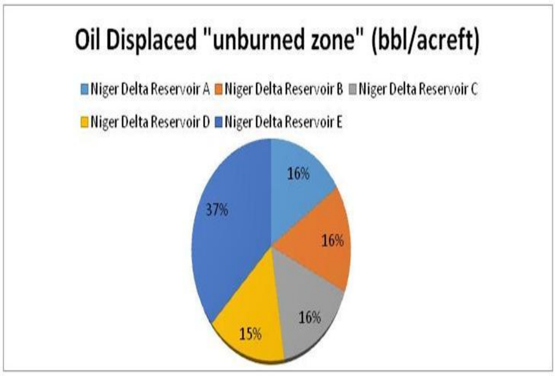

Figure 4: Pie charts showing percentage details of oil displacement from the unburned zones for the five Niger Delta reservoirs considered using the ISC model

Table 8: Calculated Total ISC Period (Time) and Total Oil Recovery

	Venezuela Reservoir	Niger Delta Reservoir A	Niger Delta Reservoir B	Niger Delta Reservoir C	Niger Delta Reservoir D	Niger Delta Reservoir E
Total ISC Period/Time (years)	2.24	2.24	2.24	2.24	2.24	2.24
Total Oil Recovery (bbl/acre-ft)	485	676.4	664.8	669.4	658.4	1125.6

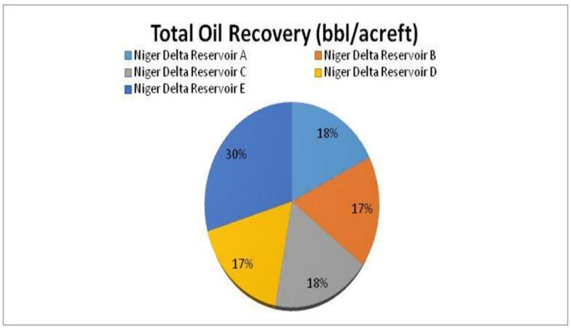

Figure 5: Pie chart showing percentage details of the total oil recovered from the five Niger Delta reservoirs considered using the ISC model

d. Reservoir Selection Hierarchy/Ranking based on ISC Performance Evaluation Results

The performance of each reservoir (considering Case 1&2) is depicted in percentages from figure 1 to figure 5 depending on specific evaluation results calculated via the applicability of the ISC model. Below also are Table 9 and Table 10 showing the performance grading/positions for these reservoirs. Figure 6 gives the final ISC project selection rankings for each reservoir considered using the Nelson and McNeil ISC model.

Table 9: Reservoir grading using 1st to 6th based on ISC performance/evaluated outcomes for Case 1&2 considered respectively

OUTPUT(S)	Venezuela Reservoir	Niger Delta Reservoir A	Niger Delta Reservoir B	Niger Delta Reservoir C	Niger Delta Reservoir D	Niger Delta Reservoir E
Max. Oil Prod.(bbl/day)	6th	2nd	1st	4th	3rd	5th
Max. Air Inj. (MMscf/day)	1st	5th	6th	3rd	4th	2nd
Oil Displaced "burned zone"(bbl/acreft)	6th	1st	3rd	2nd	4th	5th
Oil Displaced "Unburned zone"(bbl/acreft)	6th	2nd	4th	3rd	5th	1st
Total Oil Recovery (bbl/acreft)	6th	2nd	4th	3rd	5th	1st

Table 10: Final Reservoir selection rankings for the ISC project based on grading/position frequencies

	1st (FREQ)	2ND (FREQ.)	3RD (FREQ)	4TH (FREQ.)	5TH (FREQ.)	6TH (FREQ.)	Final Reservoir Selection Rankings
Venezuela Reservoir	1	0	0	0	0	4	6th
Niger Delta Reservoir A	1	3	0	0	1	0	1st
Niger Delta Reservoir B	1	0	1	2	0	1	5th
Niger Delta Reservoir C	0	1	3	1	0	0	3rd
Niger Delta Reservoir D	0	0	1	2	2	0	4th
Niger Delta Reservoir E	2	1	0	0	2	0	2nd

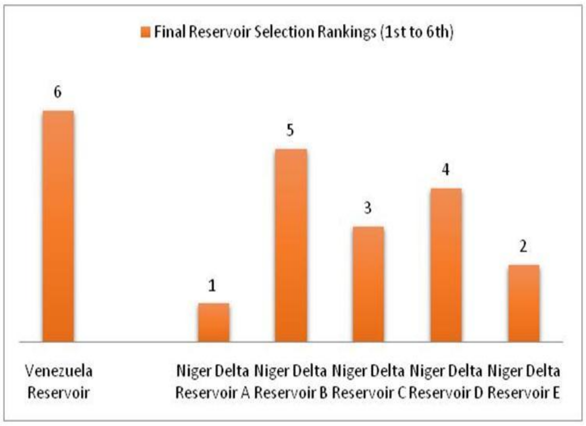

Figure 6: Reservoir Rankings based on ISC performance evaluations for all six reservoirs considered using the Nelson and McNeil ISC model

e. General Result Discussion(s) and Interpretation(s)

From result table 5 and Figure 1, the benefits of achieving maximum oil production (bbl/day) using the Nelson & McNeil ISC model came with an increasing cost of compressor horsepower requirements (BHP). Hence, the success, viability and profitability of the ISC project for achieving higher oil production isn't without paying the price of increasing compressor horsepower demands.

From the result table 6 and Figure 2, it can be seen also that a successful thermal EOR project of achieving profitable maximum oil production rates (bbl/day) from all six reservoirs considered using the Nelson & McNeil ISC model also came with an increasing maximum air injection requirements (MMscf/day) at an additional cost. Theoretically, we can see clearly that maximum oil productions (bbl/day) has direct proportionality with compressor horsepower (BHP) and maximum air injection requirements (MMscf/day) for the thermal EOR process.

From our study's result table 7, Figure 3 and 4, and its corresponding ratio analysis it will be seen that oil displaced from the burned zone of the six reservoirs considered (irrespective of their locations) is almost 50% higher than the oil displaced from the unburned zone of these reservoirs. The drastic reduction in the oil viscosity in the burned zone is due to the high temperature created by the intense in-situ burning process. This accounts for the higher oil displacement from the burned zone over the unburned zone of these six reservoirs considered using the ISC model. Reduction in oil viscosity within the burned zone during the ISC process means increase in its oil flow properties. But, oil displacement from both zones contributes to the overall daily oil production resulting from the thermal EOR process.

From result table 8 and Figure 5, the total oil recovery (bbl/acre-ft) was achieved at the same period of 2.24years for all six reservoirs considered irrespective of the reservoir locations (Nigeria or Venezuela) using the Nelson & McNeil ISC model.

Furthermore, all six reservoirs (case 1 &2 respectively) considered by this study was observed to have passed the reservoir candidacy and selection processes for ISC project implementation. Hence, these reservoirs are all viable for subjection to ISC project performance evaluations as documented in this study for possible enhanced oil recovery with heavy oil production at commercial scale. But, ISC project/Investment priorities should first be given to Niger Delta reservoir A because of its highest ISC performance selection ranking, followed by Niger Delta reservoir E and then Niger Delta reservoir C. These three reservoirs have the highest selection rankings and are most likely to yield the fasted return on investments made on the production outcomes resulting from the ISC project(s).

Conclusion

This study findings and developments will allow oil companies and other relevant stakeholders in the oil industries to subject their heavy oil reservoirs to our reservoir candidacy/ISC project selection processes (Program A), and subsequently to the study's production performance evaluations using program B respectively. It will invariably reduce ISC project/process risks involved in the thermal EOR process. It will also save the oil industry both time, manpower wastage and most especially in the area of cost reduction. Finally, the Nigeria government as at today despite their diversification drives still depend on internally generated revenue from light/cheap oil produced from conventional reservoirs in the Niger Delta region, south of Nigeria (Ossai PGO et al., 2017) [11]. Hence, we can say invariably that "if in-situ combustion projects and its processes are applicable at commercial scale in Venezuela then why not in Niger Delta region of Nigeria?"

Recommedndation(s)

Despite the enormous challenges associated with thermal EOR processes like ISC it is also expedient that heavy oil reservoirs be selected more carefully before embarking on any thermal EOR project. The importance of willingness to do it, the right expertise, adequate funding and the need to subject each reservoir samples to combustion tube test cannot be ignored for ISC projects. Hence, applying the right thermal EOR method like ISC to the right oil reservoir prospect remains the key to boosting oil production from conventional and unconventional oil reservoirs. There are potential heavy oil reservoirs in the Niger Delta and in other regions worldwide that deserves possible thermal EOR attention at commercial scale from all relevant stake holders in the oil industry for future energy sustainability.

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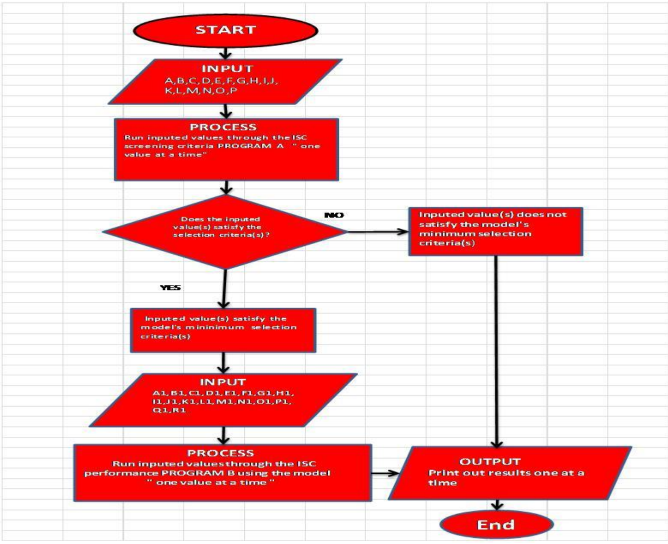
APPENDIX



A combined flow chart of program A and B to demonstrate the applicability of the whole process (reservoir screening/selection and ISC project performance evaluation).