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Optimizing Alkaline Surfactant Polymer (ASP) Flooding Using Gum Arabic for Enhanced Oil Recovery: A Practical Approach to Advancing the Development of Local Material for Oil Field Chemicals in Nigeria

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ABSTRACT
Over the years, the percentage of heavy oil production continues to rise in the world as more light oil reservoirs have either depleted or reached their economic limit. However, the recovery factor from heavy oil reservoirs by both primary and secondary is low, making these reservoirs candidates for Chemical Enhanced Oil Recovery (CEOR) technologies. The applicability of ASP flooding for reasonable incremental oil recovery was studied by conducting linear displacement experiments using Engineering grade class IV glass beads. The glass beads were treated to be strongly water wet. The viscosity of oil samples used for the different experiments ranged from 3 to 140 cp. In this work, ASP flooding was optimized using a combination of 1% wt. of NaOH and Na_2CO_3*, 0.3% sodium lauryl sulphate and 15% Gum Arabic as the alkali, surfactant and polymer used respectively. The addition of alkaline and polymer to the surfactant slug helps to control mobility and increases the sweep efficiency. In this study, the rate of recovery of oil was determined using five different percentage mixtures of diesel and engine oil (Q, R, X, Y, and Z) as well as the displacement efficiencies of all five mixture samples were comparatively analyzed. The fluid flow mechanism of ASP flooding to economically mobilize the residual oil through analyzed production performance was effective. Crude Oil of API gravity 19 – 40 and viscosity of 3.5 – 140cp were used. A sequence of experimental procedure of brine saturation, oil saturation, water flooding and ASP flooding were carried out on the glass Beads. High pressure core holder, pressure transducer + digital display, digital camera and confining pressure pump were among the instruments that was used to accomplish this study. Thus, ASP flooding can recover an appreciable volume of heavier oil left behind by by-passed water. In this case, the additional recovery by ASP ranges from about 13.5% to 50.27% of the OOIP depending on the oil viscosity by this optimization after water flooding. It was found that the higher the viscosity, the higher the recovery rate while using the optimized ASP flooding technique whereas the higher the oil viscosity the lower the recovery rate using water flooding. The study shows favorable response to the ASP flooding mechanism, recovering a reasonable percentage of the OOIP of by this optimization which is definitely handy for resolving the declining marginal fields and other heavy oil reservoirs.*

KEYWORDS: *Alkaline-surfactant polymer (ASP) flooding,EOR,Surfactant flooding, local Content, Gum Arabic*

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I. INTRODUCTION

The ever-increasing global demand for energy and reducing number of discoveries of new oil reservoirs has place greater demand on new techniques to recover oil from reservoirs. Hence, enhanced oil recovery (EOR) technologies have become a viable solution to deal with world oil shortage in the future. It is generally considered that only approximately one-third of the oil present in known reservoirs is economically recoverable with primary-recovery methods using gas pressure and other natural forces in the reservoir, and secondary recovery by water flooding (Farajzadeh, et al., 2019. Ma et al., 2011). However, due to their high potential for recovering more oil from a reservoir, Enhanced Oil Recovery (EOR) processes have been studied and field tested for many years. EOR processes involve the displacement of one fluid by another in a heterogeneous reservoir. EOR processes include thermal, miscible, and chemical methods (Kumar & Mohanty, 2011, Li, 2014, Liu, 2007). Thermal methods add heat to the reservoir, while miscible methods involve the injection of solvents (e.g., carbon dioxide, light hydrocarbons, nitrogen) that is mixes with the reservoir oil to increase its mobility (Ma et al., 2011). One of the important methods in EOR is chemical EOR methods add chemicals to the injected water to reduce the interfacial tensions or create a favourable mobility ratio in order to improve the sweep efficiency of the displacement (Wang et al., 2008, Bryan & Kantzas 2008). Most chemical EOR projects have used polymer with surfactant for mobility control, and in recent years many of the projects have combined alkaline agents with the surfactant and polymer solutions (Sui, et al., 2020, Farajzadeh, et al., 2019.). Hence, it has always been the desire of the industry to improve overall recovery through tertiary recovery one of which is chemical methods which has a potential of raising oil recovery to about 40 to 65% of the total reserve after water flooding activities (Dong, et al., 2011, Bryan & Kantzas ,2009). Alkaline surfactant polymer flooding, a chemical EOR method consists of the injection of a surfactant slug to reduce the interfacial tension (IFT) between oil and water which consequently reduces the capillary force and mobilizes the residual oil trapped after water flooding (Sheng et al., 2015, Liu et al., 1995, Zhou et al., 2009). Surfactants are capable of reducing residual oil saturation to very low values approaching zero in the swept volume of an oil reservoir (Zhang & Somasundaran 2006, Sheng, 2014). Therefore, the investigation of an optimized ASP flooding technique that could improve the EOR has become imperative, thus the importance of this study which is focused on optimizing ASP flooding using the readily available polymer (Gum Arabic) present in most fields in Nigeria for the purpose of enhancing local content and improve recovery of heavy oils for better energy production in Nigeria.

II. LITERATURE REVIEW

Alkali-surfactant-polymer (ASP) flooding is a chemical EOR method that can be used to improve recovery of heavy oil containing organic acids by increasing sweep efficiency, and reducing interfacial tension. (Sui, et al., 2020, Farajzadeh, et al., 2019. Sun, et al., 2018, Yuan and Wang, 2018, Li, et al., 2019). The history of ASP can be traced to the earlier works of Uren and Fahmy in the year 1927, who established that an inverse relationship exists between oil-water interfacial tension and the percentage of oil recovery by water flooding (Dong, et al., 2011, Bryan & Kantzas ,2009). Based on their study, a manifest was issued to Atkinson in same year that projected the use of aqueous solutions of soap or other materials to decrease the "surface tension" between oil and the flooding medium and thereby increase the recovery of oil. Using the findings from the works of Uren and Fahmy, Clark et al., (1988), designed and applied an alkaline–surfactant–polymer recovery system for heavy oil recovery and this brought about a breakthrough for the application of ASP in recovery of heavy oils and several related studies (Salager et al., 1979, Bourrel & Schechter ,1988, Martin & Oxley 1985). Furthermore, Oluwaseun et al., (2013) investigated surfactant and surfactant-polymer flooding for light oil recovery and found that the viscosity of the oil determined the rate of recovery using a strong Alkali such as NaOH. Further studies that used Gum Arabic as polymer and NaOH as Alkali got some level of recovery from heavy oil include Onuoha & Olafuyi (2013), Shutang and Qiang (2010) and Avwioroko et al., 2014) but their study did not sufficiently examine the effective of heavy oil viscosity on the rate of recovery. Atsenuwa, et al. 2014, studied the Effect of Heavy Oil Viscosity (Class-A) on Oil Recovery in SP Flooding Using Lauryl Sulphate and Gum Arabic with NaOH or Na_2CO_3 and recovered about 7% after water flooding. Again Attah (2016) examined ASP Flooding in a Shallow Oil Reservoir in the Niger Delta and found that more oil was recovered using one Alkali and a polymer for the flooding. Whereas the above studies examine ASP flooding using NaOH or Na_2CO_3, they haven’t tried to use two Alkali and a surfactant and a polymer for the purpose of ASP flooding and the present study is focused on the use of two Alkali defer in methodology. Recent progress and evaluation of ASP flooding for EOR has been most pertinent among the chemical techniques because it has proven most promising depending on the candidate reservoir (Kumar & Mohanty 2011, Ma et al., 2011, Li 2014, Liu, 2007). The concept of using two Alkali is anchored on the stronger emulsification ability of NaOH could resulted in larger fluid production capacity loss. The weaker Na_2CO_3 react with the CO_2 that forms scale form more solution of Na_2CO_3 thereby help to reduced scaling degree and this improve recovery for heavy or waxy crude. It is therefore imperative to optimize ASP flooding to improve recovery of oil from heavy oil reservoirs, hence the main aim of this study is to optimize ASP flooding using a combination of two Alkaline in solution (one weak and the other a strong Alkali) and Gum Arabic and investigate it effect of oil recovery from heavy oil reservoirs. This study further examines the effect of the viscosity of the crude on the recovery factor using the present combination.

III. METHODOLOGY

3.1.1 The Porous Media

Class IV Soda Lime Glass Spheres from MO-SCI Specialty Products, L.L.C, A subsidiary of MO-SCI Corporation 4040 Hypoint North Rolia, MO 65401 USA were used as porous media in all flooding experiments. The Glass beads has a particle size distribution of -60 +80 mesh. The beads were etched with dilute H_2SO_4 in order to make it strongly water wet which is typical of the reservoirs system in Niger Delta, Nigeria and then rinsed properly with water until there were no more traces of acid on the beads. This was confirmed with a litmus paper. Then oven dried. A Transparent core holder was used to pack the Class IV Soda Lime Glass Spheres and vibrated with each incremental addition of beads. Vibration continued until the entire granular material dispersed evenly and packed closely in the core holder. The average porosity of the cores is 0.3799.

The core holder

A transparent and cylindrical core holder of diameter 2.37cm, length 25.6cm and a bulk volume of 112.9cc was used to pack the glass spheres.

Mineral Oil

The Oil used as the heavy oil was motor engine oil which as a viscosity of 140cp. The viscosity of the engine oil was altered with diesel oil of 3.5cp at different ratios of 1:3, 1:1, 3:1 of Engine oil to diesel. Different oil samples of 3.5cp (diesel), 8cp (diesel and Engine oil, 3:1), 19cp (diesel and Engine oil, 1:1), 60cp (diesel and Engine oil, 1:3), 140cp (100% Engine oil) were prepared and used. Table 1 below shows the summary of the oil samples properties used.

Table 1. Oil properties

Property	**Sample A**	**Sample B**	**Sample C**	**Sample D**	**Sample E**
API Gravity (^{o})	36.95	34.97	32.1	29.30	26.92
Temperature (^{o}c)	20-25	20-25	20-25	20-25	20-25
Viscosity@ room temperature (cp)	3.5	8.0	19.0	60.0	140.0
Oil specific gravity (Υ^o)	0.84	0.85	0.865	0.88	0.89

Brine

A synthetic brine was prepared from sodium chloride and distill water by adding 2% by weight of the sodium chloride to the distilled water and mixing thoroughly with a magnetic stirrer to obtain a concentration of 2% wt. by weight solution of NaCl.

Surfactant

The surfactants used in this study are Sodium Dodecyl sulphate (SDS or NaDS). Sodium Dodecyl sulphate (SDS or NaDS) or sodium lauryl sulphate (SLS) is an organic compound with the formula $CH_3(CH_2)_{11}OSO_3Na$, Molar mass of 288.372 g/mol. 0.3% by weight of SDS was dissolved in brine solution of 25 by weight.

Alkaline

The two Alkaline used in this study are sodium hydroxide and sodium carbonate. Dong et al., (2011) found that sodium hydroxide and sodium carbonate is a better combination to maximize oil recovery efficiency in their channeled sand packs.

Polymer (Gum Arabic)

The Gum Arabic samples were collected from different Acacia tree species (A. Senegal, A. Sieberiana and A.nilotica) found naturally in surrounding forests of Batagawara Village , Katsina state. Samples were collected from the tree barks as dry nodules or lumps. The raw samples consisted of mixtures of large and small nodules admixed with bark and organic debris. Hand picked select gum (HPSG) method (Sabah El-kheir et al., 2008) was used to separate the neat, quality gum from other constituents. The dried sample (hard nodules) was then ground into fine powder (to pass 0.4mm mesh screen). The prepared samples were kept in tight containers and stored at room temperature.

Chemical Slug Preparation

The chemical slug was prepared by first dissolving NaCl in water at 2%. wt, mixed and a 0.3% SDS in the brine, also properly mixed. Then 15% wt gum Arabic was dissolved carefully to avoid the formation of lumps which are difficult to dissolve. Failure to have a clear solution would result in the clogging of the pore spaces of the core hence impairing its permeability. The magnetic stirrer was used to stir up the solution for 30 minutes until a consistent solution was formed. The stirring was performed at a low speed (rpm) in a bid to avoid shear thinning or mechanical degradation due to shear stress. The solution was then kept and allowed to stay overnight to ensure full hydration before it was discounted to remove residue or separate the undissolved particles.

Table 2. Slug composition

Materials	Name	Concentration
Salt	Sodium chloride (NaCl)	2.0wt %
Alkali	Sodium hydroxide NaOH and sodium carbonate $Na_2 CO_3$	0.1wt %
Surfactant	Lauryl Sulphate (SDS)	0.3% wt
Polymer	Gum Arabic	150000ppm

Experimental Setup

The Pump, tubings, beakers and measuring cylinders were made ready as shown in Figure 1 below. The core holder was filled with Class IV Soda Lime Glass Spheres dry spherical glass and vibrated with each incremental addition of glass beads until the entire granular material dispersed evenly and packed closely in the core holder was mounted on the retort stand and ready to be saturated with fluids (Brine and oil). Figure 1, shows the experimental set up.

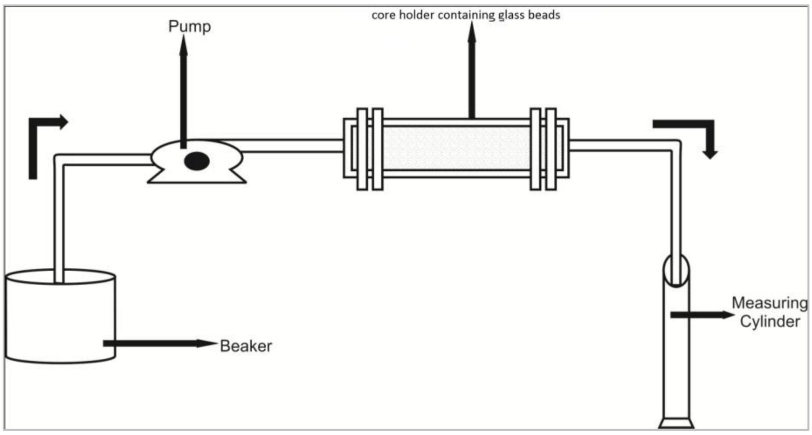


Figure1. The experimental set up.
(Source: Zhou & Liu 2007)

Brine saturation

This was carried out at a rate of 1 ml/min and it was done vertically from below so that some of the brine does not by pass the air in the pore space due to gravity segregation. The core was then flooded with oil until irreducible water saturation is reached. During this stage, pressure at the inlet and outlet packed linear cylinder core was monitored.

Oil Saturation (Drainage Process)

The main purpose of the oil flooding is to determine initial oil saturation, residual water saturation and was done at a constant flow rate of 2cc/min. The Oil flood was conducted to saturate the pore volume with oil and obtain accurate residual water saturation. The effluent fluids were collected with measuring cylinder and the total volume of displaced water which was the volume oil inside the core was recorded as the initial oil saturation. Oil flooding was continued until we could no more produce water.

Imbibition Process

The water flooding was done to displace and produced the oil in the core. Water flooding was conducted in order to determine residual oil saturation. The core was flooded until water cut was above 95%. This was done at a constant flow rate (*Q)* of 2cc/min. The effluent fluids were collected with measuring cylinder and measured. The flooding was stopped when the oil recovery was less than 5%. The residual oil saturation was estimated based on the volumes of oil in the measuring cylinder were recorded.

Alkaline Surfactant Polymer Flooding

After water flooding, remaining oil was produced by flooding the core with the ASP slug. 1.5PV of the chemical slug was pumped into the core at a constant flow rate (*Q)* of 2cc/min and the effluent collected with measuring cylinders and analyzed. The oil recovery was calculated and the residual oil obtained.

The above sets of experimental processes were carried out separately for each of the prepared oil samples to make up five separate experiments. All floods were performed at atmospheric pressure and temperature.

IV. RESULTS AND DISCUSSION

The table 3 below shows the result of the various flooding processes in terms of volume in cubic-centimeter (cc) for the five sets of experiments one for different viscosities of oil samples

Table 3 Fluid Composition

Chemical	**Composition**
NaOH and Na_2CO_3	0.1 %
NaCl for Brine	2%
Lauryl Sulphate	0.3%
Gum Arabic	15%
Viscosity	22cp

Table 4. Fluid Properties

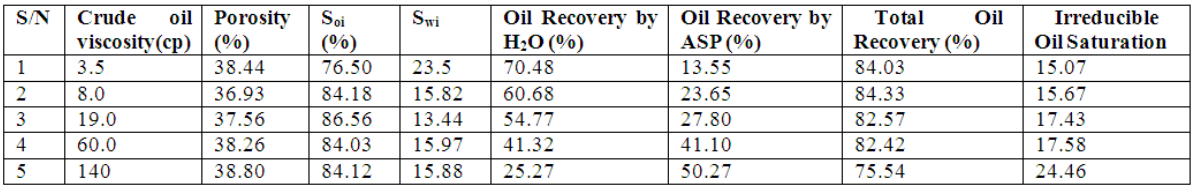
S/N	**Diesel %**	**Engine oil%**	**Specific gravity**	**Viscosity (cc)**	**Density (l.b.s./gal)**	**A.P.I**
1	100	0	0.84	3.5	7	36.95
2	75	25	0.85	8.0	7.1	34.97
3	50	50	0.865	19.0	7.2	32.1
4	25	75	0.88	60.0	7.33	29.30
5	0	100	0.89	140.0	7.55	26.92

Table 5. Oil recovery for Water Flooding and ASP Flooding Compared in (cc)

S/N	**Crude oil Viscosity(cp)**	**Pore volume(cc)**	**IOIP (cc)**	**Recovery by H_2O (cc)**	**Recovery by ASP (cc)**	**Total Oil Recovery**	**Irreducible Oil Saturation**
1	**3.5**	**43.4**	**33.2**	**23.4**	**4.5**	**27.9**	**5.3**
2	**8.0**	**41.7**	**35.1**	**21.3**	**8.3**	**29.6**	**5.5**
3	**19.0**	**42.4**	**36.7**	**20.1**	**10.2**	**30.3**	**6.4**
4	**60.0**	**43.2**	**36.3**	**15.0**	**14.9**	**29.9**	**6.4**
5	**140.0**	**43.8**	**36.8**	**9.3**	**18.5**	**27.8**	**9.0**

**IOIP- Initial Oil I Place, ASP- Alkaline Surfactant Polymer Flooding

Table 6. Oil recovery for Water Flooding and ASP Flooding Compared in (%)



S/N	**Crude oil viscosity(cp)**	**Porosity (%)**	**S_{oi} (%)**	**S_{wi}**	**Oil Recovery by H_2O (%)**	**Oil Recovery by ASP (%)**	**Total Oil Recovery (%)**	**Irreducible Oil Saturation**
1	3.5	38.44	76.50	23.5	70.48	13.55	84.03	15.07
2	8.0	36.93	84.18	15.82	60.68	23.65	84.33	15.67
3	19.0	37.56	86.56	13.44	54.77	27.80	82.57	17.43
4	60.0	38.26	84.03	15.97	41.32	41.10	82.42	17.58
5	140	38.80	84.12	15.88	25.27	50.27	75.54	24.46

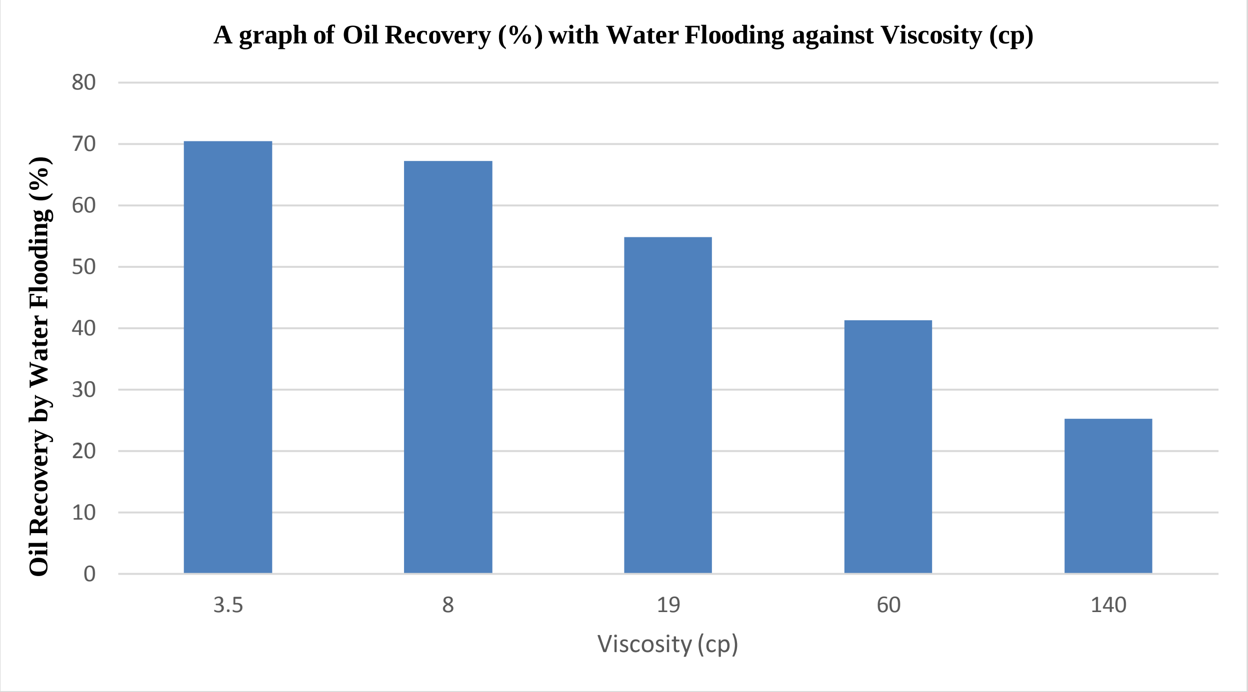


Figure 8. Recovery by water flooding

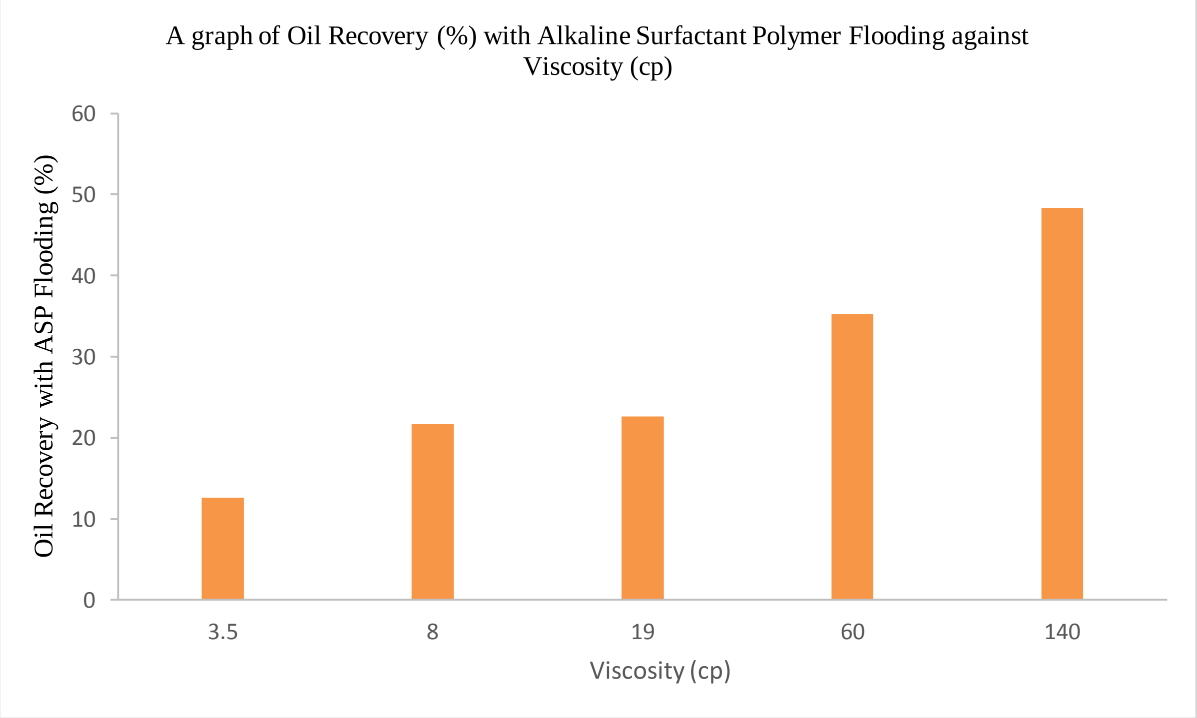


Figure 10. Recovery by ASP flooding

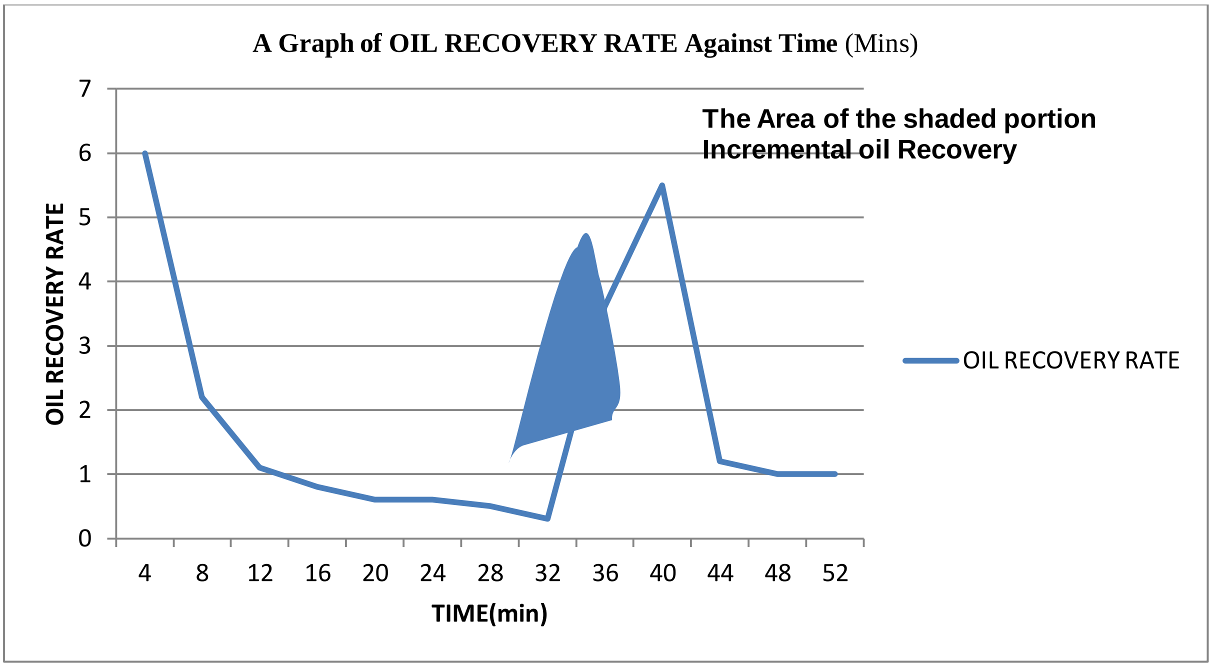


Figure 11. Rate of Oil Recovery with Time

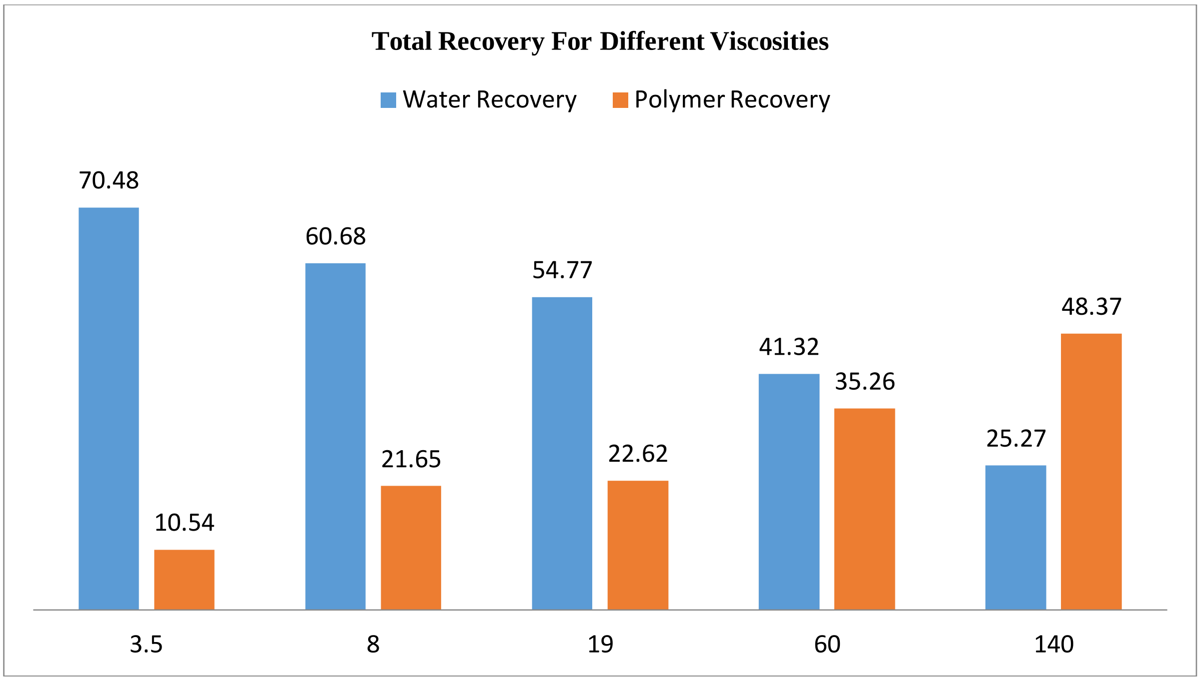


Figure 12. Total Rate of Recovery Against Viscosity

V. CONCLUSION

The objective of this study is to develop a practical and effective approach for implementing ASP flooding using Gum Arabic that is inexpensive and readily available in Nigeria in heavy oil fields and to give the oil industry a new alternative for improving oil recovery from heavy oil reservoirs and encourage in country development of oil field chemicals from local content development in Nigeria. However, this has been done by evaluating the effect of change of viscosity of heavy oil on ASP flooding using lauryl sulphate and Gum Arabic and by comparing the effectiveness of the conventional water flooding and Alkaline Surfactant Polymer flooding, from the five sets of core flood experiments, the following significant conclusions are drawn.

1. The rate of oil recovery significantly reduces after water breakthrough during water flooding and this is more rapid for heavy oil samples.
2. Water flooding is more suitable for light or less viscous oil flooding than for heavy oil.
3. Water flooding of heavier oil leaves a huge volume of oil behind as residual oil.

4. Capillary force between water and heavier oil is higher than that of water and light oil.
5. ASP flooding can recover an appreciable volume of heavier oil left behind by by-passed water. In this case the recovery by ASP ranges from about 13.5% to 50.27% of the OOIP depending on the oil viscosity.
6. It was found that the higher the viscosity, the higher the recovery rate while using the optimized ASP flooding technique whereas the higher the oil viscosity the lower the recovery rate using water flooding.
7. Sodium Hydroxide, Sodium Carbonate is a Lauryl sulphate is an effective surfactant for ASP flooding for heavy and light crude recovery.
8. Gum Arabic is a suitable Polymer for polymer enhanced oil recovery methods.
9. The experimental study clearly established that the use of ASP flood using Lauryl Sulphate and Gum Arabic is feasible and effective in recovering heavy oil (class-A) than a convention water flood.

This experiment deals with the variation of interfacial tension with varying surfactant concentration. The experimental data were analyzed to find a critical surfactant concentration. This is very important from the economic point of tertiary recovery (chemical flooding) since the use of surfactants is expensive. The economics of surfactant flooding is a complex function of many elements, such as surface facilities, well operations, reservoir parameters and chemical cost.

Based on the experiment the following conclusions are made:

- There was a decrease in interfacial tension with an increase in IL-10 concentration.
- From the results obtained a critical micelle concentration IL-10 surfactant was obtained at 0.02 wt% of IL-10 which is significantly effective for implementation of the surfactant EOR
- Below the critical micelle concentration (CMC), the added surfactant helps to greatly reduce the IFT in a brine-oil solution system. Above the CMC, the added surfactant keeps the IFT increasing and eventually remains less constant.

In conclusion, this study has developed effective methods for implementing ASP flooding using Gum Arabic that is vastly available in Nigeria in heavy oil fields and also given the oil industry a new alternative for improving oil recovery from heavy oil reservoirs. Consequently, this is a practical approach to advancing the development of local material for oil field chemicals and advancing local content in Nigeria**.** Therefore, it's sufficed to say that the optimized ASP flooding exemplified in this study would be handy to improve oil recoveries from many marginal oil fields in Nigeria or those that face shut-down due to uneconomic operating cost, but still contain significant amount of oil.

Nomenclature

μ = Viscosity.
Δ= Oil-water interfacial tension (IFT).
Q = Flow rate in standard condition unit.
q_o= Rate of oil production.
K = Permeability.
S_{wi} = Initial water saturation.
S_{ro}= Residual oil saturation.
μ_o= Oil viscosity.
Φ = Porosity
PV = Pore volume
SP = Surfactant polymer.
EOR = Enhance oil recovery.
L = Length.
T = Temperature.
Υ= Specific gravity.
Υ_o= Oil specific gravity.
$\boldsymbol{\lambda}$ = Mobility.
$\boldsymbol{\lambda}_w$ = Mobility of water phase.
$OIIP$ = Oil initially in place.

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