

Experimental Assessment of Guar Gum and Aluminum Oxide Nanoparticle Hybrid for Enhanced Oil Recovery

MBACHU IJEOMA IRENE¹, FAYOYIWA DAVID ADEDOTUN²

^{1,2} *Petroleum and Gas Engineering University of Port Harcourt, Rivers, Nigeria*

Abstract- Enhanced oil recovery (EOR) techniques are important for increasing oil production as to meet global demands. Polymer flooding is a commonly used EOR method, but it has issue with retention and vulnerability to degradation both at higher temperature and salinity. Nanoparticles can, therefore, be mixed with polymers to increase its recovery potential. The study compares the effect of standalone guar gum polymer solution, guar gum/Aluminum oxide hybrid and aluminum oxide nanofluid on viscosity, salinity range of 30, 000ppm and 60,000 ppm, permeability changes and oil recovery. The efficiency of the formulated fluids were tested using twelve different encapsulated plug samples. The results indicate that polymer-nanoparticle hybrid solution enhanced the viscosity, give better permeability change and higher oil recovery for both 30,000ppm and 60,000ppm salinity change. Furthermore, guar gum and aluminum oxide nanofluid hybrid exhibited non-Newtonian shear-thinning behavior maintaining stable gel strength, consistent viscosity and higher pH over time. 0.5wt% guar gum/ 0.3wt% Al₂O₃ hybrid gave the highest cumulative oil recovery of 83.04% for 30,000ppm brine concentration as to compare to the stand-alone guar gum and aluminum oxide nanoparticle that gave the cumulative oil recovery of 78% and 73.91% respectively at the same weight and salinity concentration. 0.3wt% guar gum/0.5wt% Al₂O₃ hybrid at 30,000ppm brine concentration gave lower permeability change of 53.04mD than every other stand-alone fluid concentration investigated. The combination of aluminum oxide nanoparticle and guar gum polymer enhances polymer rheological properties as to improve displacement efficiency, reduces polymer adsorption and permeability damage.

Index Terms- Aluminum Oxide, Enhanced Oil Recovery, Guar Gum, Nanoparticles

I. INTRODUCTION

The global demand for energy has become a pressing concern in the petroleum industry, as conventional primary and secondary oil recovery methods have proven to be insufficient, yielding only 10-30% and

10-40% recovery rates, respectively. However, Enhanced Oil Recovery (EOR) techniques have significantly improved oil extraction efficiency, achieving up to 80% recovery rates by increasing displacement efficiency, which increases oil recovery from pore spaces in rocks, and sweep efficiency, expands the volume of rock contacted by injected fluids. By adopting EOR methods, the petroleum industry can effectively address the energy demand concerns and maximize oil production [1]. Enhanced oil recovery processes are implemented to increase the flow of oil to the well by injecting water, chemicals or gases into the reservoir all by changing the physical properties of the oil and the rock surface [2].

Enhance oil recovery methods are classified into thermal method, chemical method, gas injection method and biological method [3]. Polymers (chemical method) are of primary focus on this study because they are environmentally friendly, cost effective, renewable and biodegradable material, and can tolerate high temperature, salinity, and share action when modify with nanoparticles [4].

Guar gum is a biopolymer produced from the *Cyamopsis tetragonoloba* plant and is composed of mannose and galactose. They are used extensively as thickener, stabilizer, and emulsifier, properties that make it potentially useful in enhanced oil recovery. It has been found to show pseudoplastic behavior when an external force is applied to it, and this behavior shows a pronounced effect with molecular weight [5]. Guar gum has been used in the oil industry due to its relative cost, resistance to thermal and mechanical degradation, and its environmental biodegradability. It has been used as a fracturing fluid, in formulating drilling muds and now in chemical flooding process [5, 6]. The use of guar gum polymer for chemical flooding can produce up to 35% of additional oil

from a reservoir after water-flooding [7, 8, 9]. The polymer achieves oil recovery by reducing the mobility of the displacing fluid. It is however believed that if guar gum is combined with a nanoparticle, the combination or nanocomposite would be able to achieve greater recovery by combining the macroscopic efficiency of the polymer with the microscopic efficiency of the nanoparticle to achieve greater overall efficiency; hence, the use of guar gum nanocomposite.

A nanoparticle is a solid colloidal particle in a size range of 1 nm to 100 nm, having unique size- and shape-dependent physicochemical and biological properties. Nanoparticles can be classified based on their composition, which are organic nanoparticle, carbon-based nanoparticle and inorganic nanoparticle. Examples of Nanoparticles are zinc oxide, titanium dioxide, silica nanoparticles, silver nanoparticles, gold, polymeric and aluminum oxide [10, 11].

Aluminum oxide (Al_2O_3) nanoparticles are class of metal oxide nanoparticles (inorganic nanoparticle) that has exceptional physicochemical and structural features such as resistance towards wear, chemicals, mechanical stresses, as well as their favorable optical properties and a porous vast surface area. Aluminum oxide nanoparticle is a good enhanced oil recovery agent that can alter Rock wettability, reduce oil viscosity and reduce interfacial tension between oil and water. In addition, its ultra-small sizes allow it to move through porous media without critical permeability reduction, the high ratio of its surface area to volume help to enhance other critical properties of nanofluids [12, 13].

Nanofluids are synthesized by adding nanoparticles to fluids. This method intensifies and improves fluid properties at low volume concentrations of the dispersion medium [14, 15]. The most extensively studied nanoparticles are silica nanoparticles, which have shown promising EOR results [16, 17]. Recent research has looked into the possibilities of Al_2O_3 , magnesium oxide (MgO), and iron oxide (Fe_2O_3) in EOR applications in addition to SiO_2 nanoparticles [14].

Recently, the addition of nanoparticles to polymer fluid as injectant has been investigated by many researchers [18, 19, 20, 21, 22, 23, 24]. [18] proved in their experimental work that the presence of aluminum oxide nanoparticles in guar gum polymer improved the rheology and stability of a biopolymer for enhanced oil recovery. [19] made a detailed investigation on silica nanoparticles-induced guar gum polymer solution flooding for EOR with the focus on viscosity modification. The authors reported that the addition of silica nanoparticles to the guar gum solution increases viscosity of polymer solution which improves the sweep efficiency as well as oil recovery. [20] experimented the hybrid of guar gum and aluminum oxide nano particle under different conditions of temperature and weight percentages for rheological properties. Sowunmi and his team concluded that the addition of silicon oxide nanoparticles at different concentrations, oil recovery increased from 54 % to 67.2 % of original oil in place (OOIP). [24] in their study aimed to address the limitations of using only guar gum as EOR agent, by exploring the synergistic effects of guar gum and Silicon oxide nanoparticles in improving oil recovery efficiency at different 30,000ppm and 60,000ppm. The incorporation of Silicon oxide nanoparticles played a crucial role in increasing oil recovery at both salinity level and preserving permeability by preventing the plugging of pore spaces, thereby enabling improved fluid flow and oil displacement.

Having gone through the literature, it can be observed that few studies have been done regarding guar gum and aluminium oxide nanoparticle for EOR, hence, this study aimed to investigate the effect of guar gum and aluminum oxide nanoparticles hybrid using sandstone from Niger Delta for Enhanced oil recovery.

II. METHODOLOGY

This section focuses on the description of experimental materials, equipment and procedure used to achieve the objective of this research.

A. Equipment

Encapsulated plug sample (unconsolidated Sand-packs), Venire caliper, Density bottle, PH meter,

Hydrometer, Thermometer, Canon U-tube Viscometer, Electronic Weighing balance, Stopwatch, Retort Stand, Sieve, Stirrer and flooding loop (displacement loop, flow meter, core holder, stem heads (2), Valve (2), accumulator and pressure gauge.

B. Materials

Preparation of Brine: Two laboratory brine solutions were formulated in this study. The brine solutions were prepared with 30g and 60g of sodium chloride (NaCl) in 1000ml of water. The density of the formulated brine using different 30000ppm and 60000ppm are 1.021g/dm³ and 1.039 g/ dm³.

Preparation of Nanofluids: The aluminum oxide nanoparticles used in this study was acquired from JoeChem Chemical Shop Port Harcourt, River's state, Nigeria. 0.3g and 0.5g of aluminum oxide were dissolved in equal volume of 200ml of brine from the different concentrations of 30g/L and 60g/L. The formulated nanofluids with different 0.3g and 0.5g in 200ml of brine were added to equal concentrations of 200ml of formulated guar gum.

Crude Oil Properties: The crude oil sample was obtained from a field from Niger Delta of Nigeria and has the following properties: specific gravity of 0.860, density of 0.8958g/cm³, viscosity of 43.022cP and °API gravity of 33.99 at the 29°C.

C. Experimental Procedure

Twelve core (plug) samples were prepared for the experiment with the grain sizes of 600µm, the length and diameter were measured, cleaned and were fully dried in an oven. The plug samples were well defined with samples identification number (A1 to A12) for easy identity. The EOR fluid prepared consist of metallic oxide nanoparticles (aluminum oxide) and polymer (Guar gum) having the concentration ranging from 0.3% and 0.5% in brine solution (F3₁ - F3₆ and F6₁- F6₆ are fluid sample ID for 30000ppm and 60000ppm salinity respectively)

The weight, length and diameter of each prepared core was measured, and the result is presented in Table 1. The twelve core samples were fully saturated in a brine water of the different 30,000ppm

and 60,000ppm concentrations as to measure the saturated weight of various core samples. The Pore volume of each core sample was estimated by removing the saturated weight from dry weight and the outcome was divided by the density of the different brine solution of 30,000ppm and 60,000ppm using Equation 1 represented in Table 2. The porosity was determined by using the bulk volume result (Table 1) and pore volume result (Table 2) using Equation 2.

The flooding experiment started by injecting crude oil into the core to displace the brine solution. It should be noted that not all the brine solution was displaced, and the remaining water is known as connate water. The same quantity of oil that entered the unconsolidated core is equivalent to brine solution displaced from the core samples at constant flow rate of 0.9091cc/sec. The brine was injected (secondary recovery) into the core to displace crude oil and the amount of oil recovered was measured and recorded. The laboratory brine water injection was a control experiment. Other laboratory experiments were carried out following the above stated procedures. The water breakthrough time was recorded. The different concentrations of guar gum polymer, guar gum/aluminum oxide hybrid and aluminum oxide nanofluid at different concentrations of 0.3wt% and 0.5wt% (Table 4) were injected into the core until no oil could be recovered at the residual oil saturation.

Finally, the unconsolidated core was removed from the core-holder and re-weighted, the recovered oil was measured and permeability was determined using Equation 3.

PoreVolumeEquation:

$$PV = \frac{W_{sat. plug} - Weight_{dry plug}}{P_{NaCl}} \quad (1)$$

Where; $W_{sat. plug}$ = weight of saturated plug, $Weight_{dry plug}$ = weight of dry sample, P_{NaCl} = density of Brine

$$Porosity, \phi = \frac{P.V}{B.V} \times 100\% \quad (2)$$

Where, P.V = pore volume, B.V = bulk volume

$$\text{Permeability: } K = \frac{Q \mu_{NaCl/KCl} L_{plug} 14700}{A_{plug} \Delta P} \quad (3)$$

Where, Q = flow rate, μ_{NaCl} = viscosity of NaCl/KCl (Brine), L_{plug} = length of plug, A_{plug} = cross section area of plug, ΔP = differential pressure and K = permeability

III. RESULT AND DISCUSSION

The results of the experimental study on the assessment of polymer guar gum and polymer-aluminum oxide nanoparticle hybrid for enhanced oil recovery using different salinity concentrations of 30,000ppm and 60,000ppm are presented. The major discussion of this research findings includes petrophysical properties of the formation, fluid properties, oil recoveries and permeability damage.

A. Result for Petrophysical Properties for Various Core Samples

Bulk volume is a vital parameter in enhanced oil recovery, governing the storage capacity and fluid flow dynamics within the reservoir, thereby influencing the efficiency of recovery techniques, fluid mobility, oil saturation, and ultimately, the number of hydrocarbons that can be extracted from the formation.

The bulk volumes of the individual plug samples listed in Table1 were calculated using Equation1.

Table 1. Bulk Volume of Encapsulated Plug

Sample plug ID	Dispersing Fluid salinity (ppm)	Length (cm)	Diameter (cm)	Radius (cm)	Bulk vol. (cm ³)
A1	30,000	7.80	3.18	1.59	61.94
A2	30,000	7.71	3.20	1.60	62.02
A3	30,000	7.44	3.18	1.59	59.09
A4	30,000	7.90	3.34	1.67	69.23
A5	60,000	6.74	3.32	1.66	58.36
A6	60,000	7.81	3.30	1.65	66.81
A7	60,000	7.52	3.16	1.58	58.98
A8	60,000	7.77	3.10	1.55	58.65
A9	30,000	6.81	3.44	1.72	63.31
A10	30,000	7.89	3.20	1.60	63.46
A11	60,000	6.93	3.28	1.64	58.56
A12	60,000	7.99	3.18	1.59	63.47

Pore volume plays a pivotal role in enhanced oil recovery, as it directly influences the storage capacity, fluid saturation, and sweep efficiency of the reservoir, thereby impacting the effectiveness of recovery techniques and ultimately determining the amount of hydrocarbon that can be extracted from the formation. The pore volumes of the individual plug samples listed in Table 2 were calculated using Equation 2.

From Table 1 and 2, Plug Sample A1 has a bulk volume of 61.94 cm³ and a pore volume of 24.91 cm³. This indicates that Plug Sample A1 has a storage capacity of 24.91 cm³, which can accommodate gas, oil, and water. Table 2 also presents the encapsulated plug's porosity, which ranges from 38.89% to 41.97%, indicates that it is highly porous.

Table 2. Pore Volume and Porosity of the Plug Samples

Sample plug ID	Dispersing Fluid salinity (ppm)	Wt. of screen + foil +dry plug (g)	Wt. of screen + foil+ saturated plug (g)	Wt. of saturation within the plug (g)	Density of sat. fluid +NaCl/KCl 1500 ppm(g/cm ³)	Pore vol. (cm ³)	Porosity (%)
A1	30,000	152.74	178.16	25.42	1.02	24.91	40.21
A2	30,000	151.92	177.45	25.53	1.02	25.02	40.34
A3	30,000	137.00	161.45	24.45	1.02	23.96	40.54
A4	30,000	154.64	182.11	27.47	1.02	26.92	38.89
A5	60,000	134.21	158.93	24.72	1.02	24.22	41.51
A6	60,000	149.86	176.77	26.91	1.02	26.37	39.47
A7	60,000	136.41	160.57	24.16	1.02	23.67	40.14
A8	60,000	149.92	174.63	24.71	1.02	24.21	41.29
A9	30,000	133.84	159.60	25.76	1.02	25.24	39.88
A10	30,000	153.69	180.87	27.18	1.02	26.63	41.97
A11	60,000	134.13	157.66	23.53	1.02	23.06	39.38
A12	60,000	154.85	181.66	26.81	1.02	26.27	41.40

Permeability is the ability of the core sample to allow fluid to flow through it. It was measured by injecting water into core at a uniform flow rate of 0.9091 cm³/sec and the pressure difference was recorded for every experiment. The viscosity of the brine was 1.0224cp which was also uniform. The permeability (K) of the sand packed was estimated using Darcy's law equation as shown in Equation 3. Permeability of the core samples were measured before and after flooding with different EOR dispersing agents as shown in Table 3 as to measure the formation damage after the recovery.

As illustrated in Table 3 the formulated encapsulated plug samples exhibit a permeability range of 100-1000 mD, indicating that they are from a highly permeable sandstone formation. Table 3 also demonstrated how permeable each sample plug is before flooding operation was carried out, meaning sample plug A1 will allow more fluid flow compare to sample A5 due to the permeability difference which are 369.79mD and 342.13mD respectively.

B. Result of Fluid Properties (PH, Density, Viscosity. shear rate and gel strength)

The results for density, pH, viscosity, shear rate and gel strength of the formulated fluids of guar gum, guar gum-aluminum oxide hybrid, and aluminum oxide nanofluid for different concentrations of

30,000ppm and 60,000ppm brine of 0.3%wt, and 0.5%wt are presented in Table 4. The pH levels of the samples ranged from 6.4 to 8.4, with pure brine having a pH of 7.8.

Density is the mass of object per unit volume. It measures how dense a fluid can be. The density measurement is important because it will be used to determine the fluid kinematic viscosity. Kinematic viscosity is a ratio of dynamic viscosity to density and dynamic viscosity is the measure of fluid's internal resistance to flow. The higher the fluid's viscosity the more it's resistance to flow. One of the characteristics of a good EOR agent is one that can increase the viscosity of the brine. The results of kinematic and dynamic viscosities of the newly formulated EOR fluids are presented in Table 4. It can be observed that the viscosity of polymer-nanofluids slug using 30,000ppm brine concentration is higher than those formulated with 60,000ppm. The fluids samples of F1₃ and F5₆, which are samples formulated with aluminum oxide nanoparticle at 30,000ppm and 60,000ppm brine concentrations have the lowest viscosity. The polymer solutions' viscosity improvement is due to the adsorption of the polymer on the aluminum oxide surface based on hydrogen-bonding based interaction. Second reason can also be attributed to the interaction between polymer and

nanoparticles through electrostatic, van der Waals and hydrophobic interaction.

In Enhanced Oil Recovery (EOR), viscosity and shear rate are intricately linked, the viscosity of EOR fluids exhibits a reciprocal relationship with shear rate, characterized by non-Newtonian behavior. This phenomenon is particularly evident in polymer solutions and nanocomposites. Viscosity, a key measure of fluid resistance to flow, significantly impacts oil displacement efficiency and sweep efficiency in EOR operations.

The viscosity of polymer-nanoparticle hybrid solutions (F9₃, F10₃, F11₆ and F12₆) were measured under different shear rates as showed in Fig. 2. Guar gum and aluminum oxide nanoparticle displayed shear-thinning performance, where viscosity decreases with increasing shear rate follows the trend of many other high molecular weight polymers [25]. The viscosity reduction is attributed to uncoiling and alignment of guar gum polymer chains as it is exposed to shear flow force [26]. Fig. 2 illustrates this relationship, demonstrating that fluid sample F9₃ (0.3% Al₂O₃/0.5% Guar gum) which has higher concentration of guar gum exhibits a higher shear rate at 3 rpm compared to sample F10₃ (0.5% Al₂O₃/0.3% Guar gum) that contains higher concentration of nanoparticle at the same salinity range of 30000ppm. This discrepancy is primarily attributed to the difference in viscosity between the two samples and the dynamic interaction between polymer chains and shear forces. The results generally suggest that optimizing the ratio of

aluminum oxide nanoparticles and guar gum can tailor the fluid rheological properties for specific reservoir conditions as to maximize recovery efficiency.

Fig. 3 provides the gel strength measurements of various hybrid fluid samples over time. Gel strength is a critical rheological property in the context of enhanced oil recovery (EOR) because it indicates the ability of a fluid to form a stable gel structure. The evolution of gel strength from 10 seconds to 10 minutes is typically driven by ongoing cross-linking reactions between Guar gum and Aluminum oxide nanoparticles, which enhance gel stability and modify viscosity for optimal oil displacement efficiency. However, high salinity levels can hinder this process due to salt hindering polymer interactions and promoting particle aggregation. The trend is observed in Fig. 3 with fluid samples of 0.3% Al₂O₃/0.5% Guar gum (F9₃), 0.5% Al₂O₃/0.3% Guar gum (F10₃), 0.3% Al₂O₃/0.5% Guar gum (F11₆), and 0.5% Al₂O₃/0.3% Guar gum (F12₆), with salt concentrations of 30,000 ppm and 60,000 ppm, exhibited identical gel strengths at 10 seconds and 10 minutes (3, 1, 3, 1, respectively), indicating that elevated salinity (up to 60,000 ppm) impedes cross-linking reactions, and preventing further development.

Table 4. Result for Density /Viscosity of the Flooding Sample and Crude

Fluid ID	Fluid conc.	Salinity (ppm)	Dynamic Viscosity (cp)	Wt. of fluids	Density (g/cm ³)	PH
F0 ₃	Brine	30000	1.020	57.66	1.02	7.8
F1 ₃	0.3% Al ₂ O ₃	30000	1.380	57.64	1.02	6.6
F2 ₃	0.3% Guar gum	30000	37.28	57.67	1.02	6.5
F3 ₃	0.5%Al ₂ O ₃	30000	1.980	57.67	1.02	7.1
F4 ₃	0.5% Guar gum	30000	74.75	57.53	1.02	6.6
F5 ₆	0.3% Al ₂ O ₃	60000	1.730	58.78	1.04	6.4
F6 ₆	0.3% Guar gum	60000	49.43	58.57	1.04	6.7
F7 ₆	0.5%Al ₂ O ₃	60000	2.980	58.77	1.04	6.9

F8 ₆	0.5% Guar gum	60000	101.59	58.92	1.04	6.8
F9 ₃	0.3% Al ₂ O ₃ /0.5% Guar gum	30000	112.75	57.97	1.03	7.1
F10 ₃	0.5% Al ₂ O ₃ /0.3% Guar gum	30000	41.79	57.9	1.03	7.3
F11 ₆	0.3% Al ₂ O ₃ /0.5% Guar gum	60000	117.34	58.85	1.04	8.2
F12 ₆	0.5% Al ₂ O ₃ /0.3% Guar gum	60000	44.13	58.81	1.04	8.4

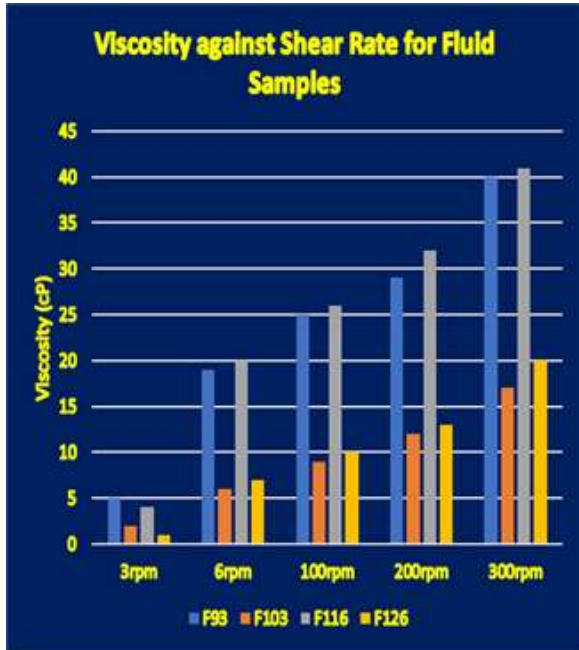


Fig 2. Viscosity against Shear Rate for Fluid Samples

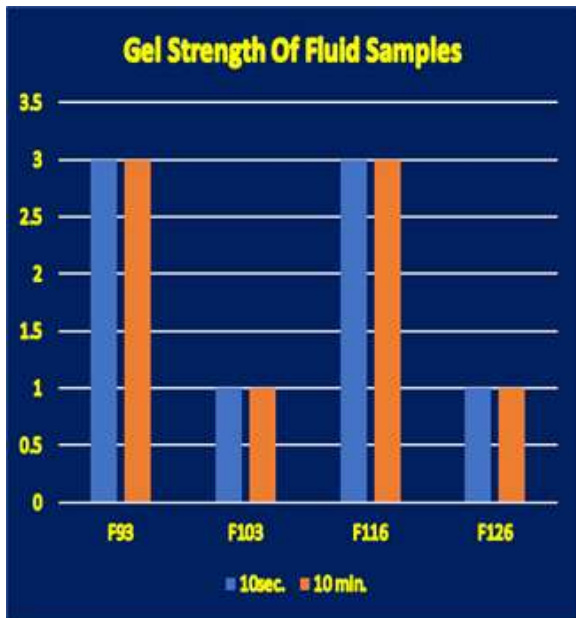


Fig 3. Viscosity against Shear Rate for Fluid Samples

C. Recovery of Crude Oil by Water and Tertiary Methods

Oil initial in Place (OIP) determines the potential oil volume available for recovery through flooding, and its effectiveness is influenced by reservoir properties (porosity, permeability), and fluid saturation, ultimately impacting the recovery factor and residual oil saturation. The results of the oil initially in place and recoveries using secondary and tertiary methods are presented in Fig. 4. The percentage of oil remaining in the pore space of the plug samples after primary and secondary oil recovery methods have been applied. Fig. 4 illustrates that Oil Initially in Place (OIP) represents the total amount of oil present in a reservoir. Secondary recovery methods, specifically brine flooding, were employed to extract oil from plug A9, resulting in a recovery of 65% of OIP.

Generally, the application of Guar gum-Al₂O₃ nanocomposite at concentrations of 0.5wt% and 0.3wt%, at 30,000ppm, yielded a significantly higher recovery as to compare to that solution with brine of 60000ppm. Fig. 4 showed the results of enhanced oil recovery capabilities of Guar gum-Al₂O₃ nanocomposite compared to ordinary Guar gum and aluminum oxide solution. Specifically, the fluid sample with ID F9₃ (0.3% Al₂O₃/0.5% Guar gum) outperformed with 83.04% the fluid samples with ID F4₃ and F7₆ which comprises 0.5 wt% standalone Guar gum and aluminum oxide that recovered 78% and 72.73% OIP. The polymer-nanofluids hybrid gave over 5% increase in oil recovery efficiency at 30,000ppm brine and 2.5% at 60,000ppm concentration. This remarkable enhancement underscores the importance of polymer-nanoparticles hybrid as EOR techniques in extracting the residual oil.

This comparative analysis proved the benefits of modifying Guar gum with Al_2O_3 nanoparticles, which improves viscosity, thermal stability, salt tolerance, and oil-water interfacial tension reduction. Consequently, incorporating Al_2O_3 nanoparticles into Guar gum enhances its performance in saline reservoirs for Enhanced Oil Recovery (EOR), leading to increased oil recovery efficiency.

From this experimental study, it can be found that the synergy effect of guar gum and aluminum oxide as a hybrid both in 30,000ppm and 60,000ppm increase oil recovery better than standalone polymer guar gum and aluminum nanofluids. Fig. 5 shows the pie chart representing the cumulative oil recovery and different fluid concentrations. These results match with findings of [27] who showed that additional oil recovery can be obtained with a high concentration of polymer solutions but reduces at a very high concentration due polymer adsorption on the rock surface. nanoparticles concentration adversely affects the oil recovery owing to impairment of the reservoir. rock permeability.

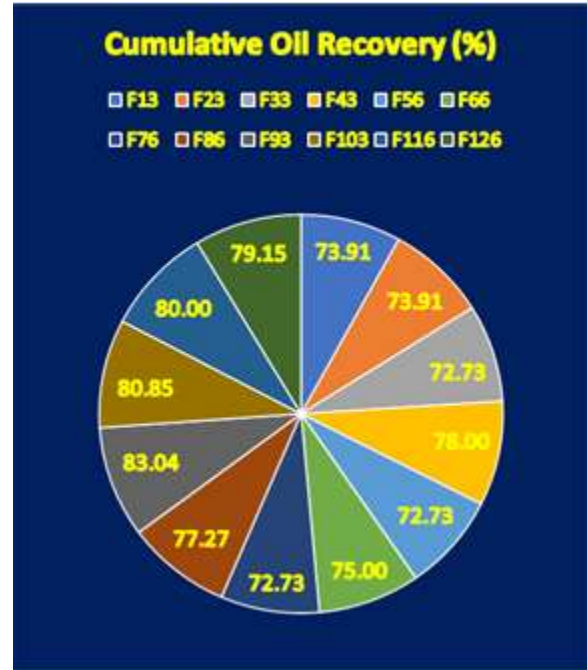


Fig. 5. Cumulative Oil Recovery against Fluid concentrations

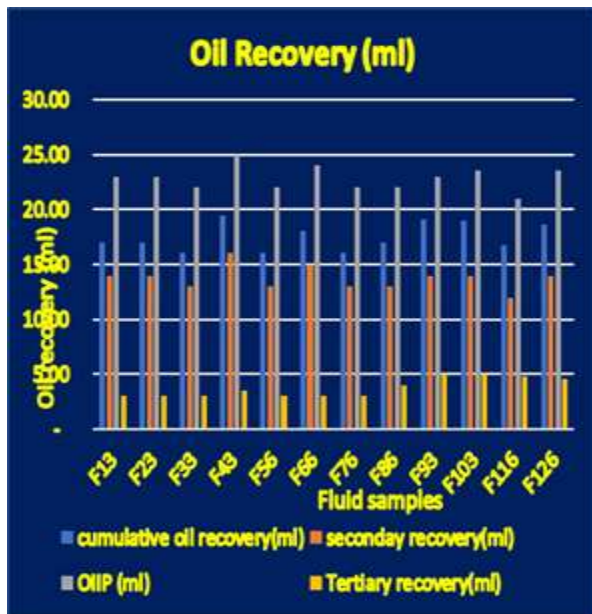


Fig. 4. Secondary, Tertiary, Cumulative recovery against Fluid Concentrations

D. Result for Permeability Change of Plug Samples

After the secondary and tertiary flooding, the permeability of the core was measured as to evaluate the extent of formation damage caused by various EOR agents for the different brine concentration of 30,000ppm and 60,000ppm. Fig. 6 showed that there is a decrease in permeability of the reservoir formation after the tertiary flooding most especially with guar gum fluids and the fluids that contains higher concentration of aluminium oxide nanoparticle as observed in samples A4 (174.94md) and A8 (190.36md).

It can also be proved from Fig. 6 that plug samples A1 (61.63md), A12 (53.02md) and A5(57.02md) has relatively lower permeability alteration because they are flooded with lower concentration of Aluminum oxide nanoparticle and a well-balanced mixture of polymer and nanoparticles.

Fig. 6 also showed that the salinity range of 30000ppm and 60,000ppm did not really have much impact on the permeability change considering plug samples of A12 and A5 that were flooded with salinity of 60,000ppm and A1 and A11 that were flooded with 30,000ppm salinity respectively. It is

proved from this study that the concentrations of both polymer and nanoparticles have a strong impact on the permeability change as reported by other researchers (). Reservoir engineer must consider the concentration of both polymer and nanoparticle of paramount important in designing EOR projects as to avoid blocking of reservoir's pore space.

Generally, from Fig. 6, the combination of Aluminum oxide nanoparticle in guar gum polymer reduced formation damage and increased oil recovery as observed in the plug's samples with A9 (83.03%), A10 (80.85%), A11 (80%) and A12 (79.15%). Plug samples flooded with 30000ppm (A9 and A10) gave a higher recovery as to compare with the plug samples flooded with 60000ppm salinity (A11 and A12).

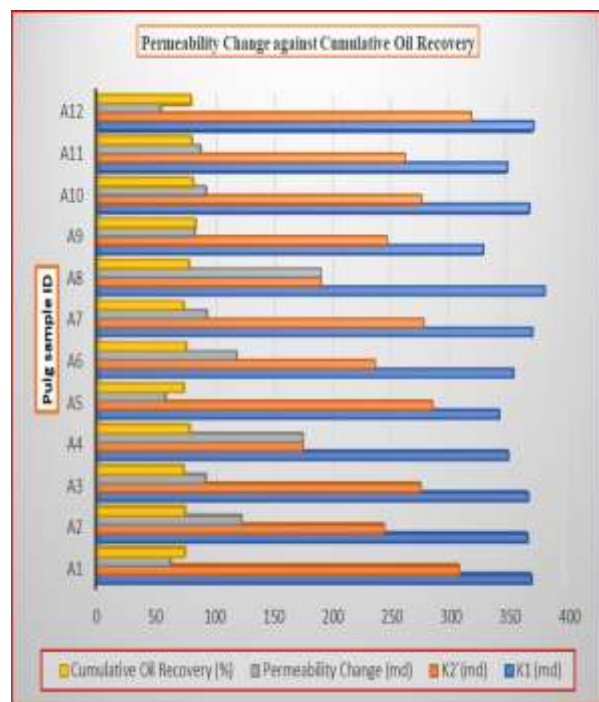


Fig. 6 Permeability change of the plug samples

IV. CONCLUSION

The results from the experimental tests have proved the effectiveness of the synergy of the aluminum oxide nanoparticles and guar gum polymer in improving oil recovery in both 30,000ppm and 60,000ppm brine concentrations. The presence of aluminum oxide in guar gum improved the viscosity of polymer solution, which reduced the mobility ratio

between the injected fluids and the oil in the reservoir. Secondly, this synergized polymer-nano-alumina solution reduced the permeability damage of the formation. Among the hybrid compositions studied, the least altered permeability values were observed in plug samples A9 (67.05md), A10 (91.95md), A11 (87.25md), and A12 (53.02md). All the hybrid fluid compositions showed relatively lower permeability change with a higher oil recovery. The optimum concentration was gotten from fluid with sample identity F9₃ (0.3wt%Al₂O₃/0.5 wt. % guar gum @ 30000ppm) that gave the best cumulative oil recovery of 83.04%. Generally, the guar gum/ aluminum oxide hybrid in both 30,000ppm and 60,000ppm gave higher oil recovery than standalone polymer and alumina nanofluids for the different brine concentrations investigated. All the concentrations that are based on 30,000ppm brine performed relatively better than 60,000ppm based on viscosity, rheological, permeability change, and oil recovery.

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