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Effect of Silica Nanoparticles in Xanthan Gum Solutions Using Different Temperature for Enhanced Oil Recovery

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Abstract:

Enhanced oil recovery (EOR) techniques are important for increasing oil production as to meet global energy demands. Polymer flooding is a commonly used EOR method, but it has issues with polymer retention and vulnerability to degradation at both high temperature and salinity. The study compares the effect of stand- alone xanthan gum polymer solution and xanthan gum/silicon oxide hybrid using different temperature ranges of $30^{o}C$ and $45^{o}C$. The study also evaluates the effect of bare xanthan gum and xanthan gum-silicon hybrid on viscosity, permeability changes and displacement efficiency. The efficiency of the formulated fluids was tested using different twelves core samples of Niger - Delta sand. The results indicate that the presence of nanoparticle with polymer improved the functionality of xanthan gum even at higher temperature to withstand degradation. Xanthan gum/silicon oxide hybrid with 0.2wt% concentration gave higher oil recovery of 80.43% as to compare with bare xanthan gum with cumulative oil production of 73.91% at the same temperature of $45^{o}C$. The hybrid also gave a better viscosity, good permeability changes and higher oil recovery.The combination of Silicon oxide nanoparticle and xanthan gum polymer enhances polymer properties as to enhance displacement efficiency, reduce polymer adsorption and reduce permeability damage.

Keywords — **Enhanced Oil Recovery,Nanoparticle, Polymer, Silicon Oxide, Temperature,Xanthan Gum**

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I. INTRODUCTION

The primary and secondary recovery techniques are the basic ways in which oil is recovered from the reservoir. However, a considerable amount of residual oil is still present in the reservoir despite the increase in oil recovery rate brought about by the application of secondary oil recovery techniques. According to global work data, 10–25% of oil in place is recovered through the primary recovery techniques; 25–40% of oil in a place is recovered using the secondary recovery techniques[1]. To further recover the remaining oil in the reservoir, enhanced oil recovery techniques is used. Enhanced oil recovery techniques improve oil recovery by increasing the sweep efficiency and modifying the surface forces in the reservoir. Polymer flooding is an effective way of recovering oil from the reservoir as it helps to recover over 30% of the initial oil in place but under high temperature and salinity, the polymer becomes less effective. Nanoparticles are used widely with polymers to overcome this challenge.

Oil companies are working extremely hard to increase oil production by employing enhanced oil recovery (EOR) techniques like gas injection, low salinity water flooding (LSW), chemical flooding (surfactant, polymer, etc.), and thermal methods to extract the remaining residual oil ([2], [3]).The remaining oil-in-place otherwise known as residual or immobile oil is the target of enhanced oil recovery (EOR) [4]. There are extensive studies regarding the usage of nanoparticle materials in tertiary oil recovery methods even in chemical flooding, which helps the conventional methods to increase the oil production ([5],[6]).

Nanoparticles are small with the range of 1 – 100 nm. Due to their unique physical characteristics and

properties, nanoparticles (NPs) are recognized as significant nanomaterials for a wide range of industrial and scientific applications. They are in higher demand right now to be used in enhanced oil recovery operations. Using NPs can significantly improve EOR by altering the rock's wettability, enhancing the oil drop's mobility, and lowering the interfacial tension (IFT) between the oil and the water. [7] presented types of nanoparticles which includes organic, inorganic, metal oxides and non-silica nanoparticles which are shown in Fig. 1. Organic nanoparticles are carbon nanoparticles and carbon nanotube (CNT) nanoparticles. However, inorganic nanoparticles can be silica oxide (S_iO_2), while the metal oxides nanoparticles are aluminum oxide (Al_2O_3), TiO_2 and iron oxide (Fe_2O_3/Fe_3O_4). Polymer nanoparticles and polymer-coated nanoparticles are examples for non-silica nanoparticles.
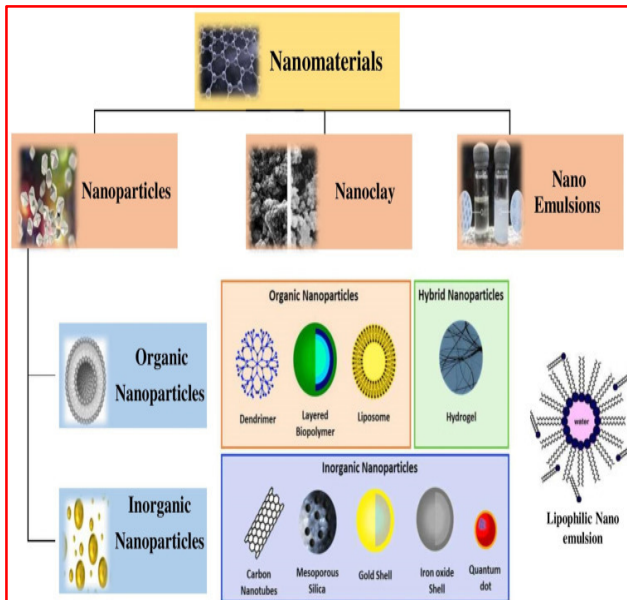

Fig. 1. Nanomaterials division breakdown[7]

Xanthan gum is widely used in the industry, including food, clothes and the oil and gas industry. According to [8] xanthan gum is an extracellular polysaccharide formed by the xanthomonas campestris. Its primary structure comprises the backbone of glucose monomers or cellulose-like

chain and trisaccharide side chain (Fig. 2). Silica nanoparticles, for instance, are cheap and easy to control their chemical behaviour by using surface modification technique[9]. Moreover, these nanoparticles are also environmentally friendly, which is another advantage of using this type of nanoparticles in EOR apart from their ability to improve production [10]. [11] stated that xanthan gum is a high molecular anionic polysaccharide that is formed by bacterium Xanthomonas campestris during the process of cellulosic backbone fermentation. This water-soluble polymer has been commonly used in EOR proving that it is able to improve sweep efficiency by controlling the mobility of water, lowering the permeability of water in the swept zones as well as contacting unswept zones.
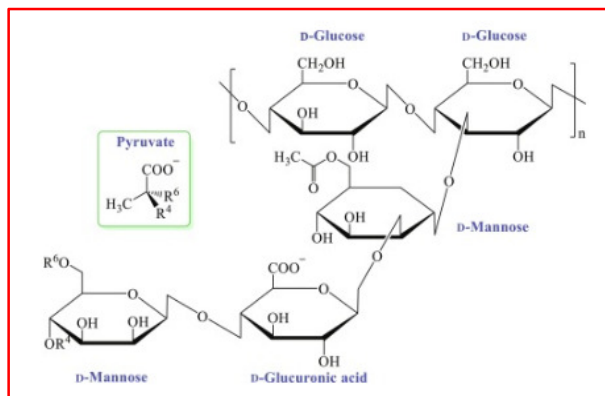

Fig. 2. Structure of Xanthan Gum [11]

In the last ten years, residual oil issues in heavy and semi-heavy oil reservoirs have been resolved using nanomaterials as innovative alternative approaches for EOR ([12], [13],[14],[15],[16]). As interdisciplinary disciplines, nanoparticles and nanofluids are very important in the areas of materials science, thermal engineering, and nanoscience. Their potential uses in EOR have been revealed as they have advanced significantly over the past ten years ([17], [18]). During the last ten years, numerous studies have demonstrated EORprocesses by NPs and nanofluids ([13],[18]). They are employed for mobility control, nano- and microspheres have shown promising results in

reducing water cut, increasing sweep efficiency, and recovering oil in a few operations ([19], [20]). Moreover, water relative permeability and capillary force can be decreased by micro and nanospheres, which ultimately alters the water flow path in porous media [20]. Additionally, in oil and gas reservoirs, nanoparticles have an appropriate resistance to degradation at high salinity and temperature. To improve oil recovery in challenging reservoir conditions, some research also investigated combining polymer solutions with nanoparticles as to withstand polymers degradation at higher salinity and temperature.

Of late, many researchers have shown that nanoparticle when mingled with polymer solution in the right proportions enhances oil recovery and positively affect reservoir formation([10], [21],[22],[23],[24]).[11] did a study on enhanced oil recovery using hydrolyzed polyacrylamide grafted with tin oxide material. They recorded that the combined effect of polymer and nanoparticle increased oil recovery by 2% as to compared to polymer alone. [21] in their study, synthesizedAmide- and alkyl-modified nanosilicas (AANPs) and introduced into xanthan gum(XG) solutionto improve the temperature/salt tolerance and oil recovery. The authors investigated the rheological behavioursof XG/AANP hybrid dispersions at different concentrations, temperatures,and inorganic salts. At high temperature of 75°C and high salinity of 10,000mgL^{-1} AANPsincrease the apparent viscosity and dynamic modulus of the XG solution, and XG/AANP hybrid dispersionexhibits elastic-dominant properties. The most effective concentrations of XG and AANP interactingwith each other are 1750 mg. L^{-1}and 0.74 wt.%, respectively. The temperature tolerance of XG solution isnot satisfactory, and high temperature further weakens the salt tolerance of XG. Yong and his team reported that the AANPssignificantly enhance the viscoelasticity of the XG solution through hydrogen bonds and hydrophobic effect.Under reservoir conditions, XG/AANP hybrid recovers approximately 18.5% more of original oil in place than AANP and 11.3% more OOIP than XG.

[22]did study onevaluating the capability of synergised Xanthan gum and silicon oxide nanoparticles solutions to improve the solution viscosity, interfacial tension (IFT) reduction and analyse the effects on the recovery factor. The authors prepared theirsamples with 4000 ppm XG and five concentrations of1000, 3000, 5000, 7000 and 9000 ppm silicon oxide nanofluids. The samples were tested for viscosity and IFT reduction to determine the optimum concentration of the synergised solution. The flooding test was conducted using a sand pack to measure oil recovery factors when different slug ratios of polymer and brine were injected. Results show viscosity of the solution increased with increasing S_iO_2 concentrations. The synergy has shown IFT reduction from 75.5 mN/m to 55 mN/m with increasing concentrations of the S_iO_2 added into the polymer solution. They revealed that 4000 ppm of XG synergised with 3000 ppm S_iO_2 nanoparticles was chosen as the optimum concentration as the IFT reduction is achieved and can be correlated with the viscosity result. A slight viscosity difference is observed when 5000 ppm S_iO_2 nanoparticles were added to 3000 ppm S_iO_2 nanoparticles. Oil recovery increased from 27.5% to 56% using 4000 ppm XG, while the oil recovery was increased to 57.5% using the synergised solution with a similar slug ratio. Maximum oil recovery was 66.3%, using an optimum synergised solution with the highest slug ratio of 0.5:0.5 PV polymer flooding to water slug.

[23] used hydrophilic Silica nanoparticle and Xanthan gum (XG) to improve the emulsion stability of heavy crude oil. Saha and his team showed from the flooding experimental study they did that hydrophilic Silica in polymer reduced the interfacial tension and changed the wettability of the formation from oil-wet to water-wet and thus improving the recovery of oil between 18% and 20% at 30 and 70°C. The wettability alteration from the oil-wet to more water-wet causing the oil to

move/flow easier by lowering the capillary forces which retain the oil in the pores.

[24] conducted research as to compare the impact of a bare polyacrylamide (PAM) polymer solution and a polyacrylamide-alumina nanoparticle (PAM/Al$_2$O$_3$ NP) hybrid in terms of viscosity, pH, efflux time, and oil recovery. The authors indicated from their experimental study that the hybrid solution showed higher oil recovery efficiency (83.81%) compared to the bare PAM solution (72.22%) at a concentration of 0.3wt%. The hybrid solution also exhibited higher viscosity, efflux time, and pH (57.15cP, 1543sec, and 7.9, respectively) compared to the bare PAM solution (49.68cP, 1342sec, and 6.1, respectively) at the same concentration. Mpakaboari and Mbachu showed that the addition of Aluminum Oxide nanoparticles to the PAM solution modifies its properties, reduces PAM adsorption, preserves polymer chains, and maintains entanglement. The enhanced oil recovery mechanism of the XG/AANP hybrid is mainly increasing the sweep coefficient, the contribution from the reduction of oil-waterinterfacial tension is less.

In addition to the literature above, some authors like [25], [26] have shown that addition of nanoparticles with surfactants or polymer prevents the occurrence of blocking in the pores of the reservoir rock by the aggregation of solid nanoparticles. It has been proved that viscosity of the Xanthan gum is affected by various parameters such as salinity, pH, temperature, and hardness. This research is proposed with the aim to evaluate the capability of the S$_i$O$_2$ nanoparticle with Xanthan Gum solution in improving the solution's viscosity, permeability, and oil recovery.

II.   Chemical Enhanced Oil Recovery

The target of tertiary recovery is the residual oil left behind after the secondary recovery process has become uneconomical. An EOR process may involve injection of miscible gases, chemicals, and thermal energy into the reservoir to displace additional oil. Three main classes of enhanced oil recovery currently being applied in the oil and gas industry are thermal, chemical, and microbial methods. Chemical process is enhancedoil recovery of interest in this study. Fig. 3 gives the broad classification, challenges, and mechanism of enhanced oil recovery.
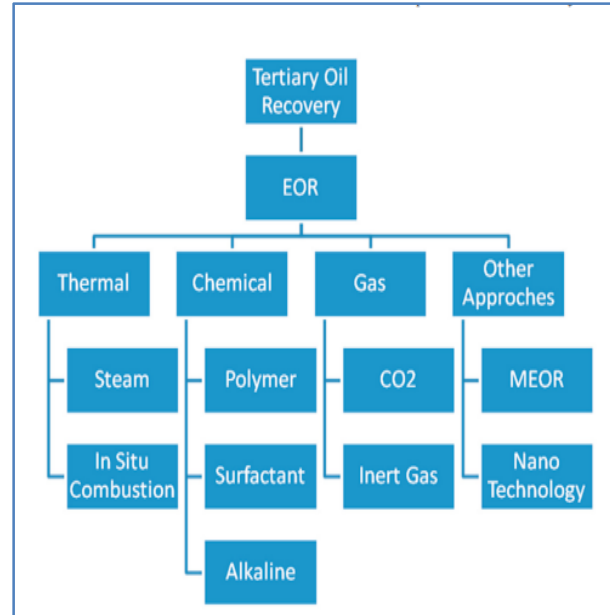

Fig. 3. Enhanced Oil Recovery methods [20]

A.   Polymer Flooding

Polymers are used to reduce the mobility ratio of water – oil by increasing the water viscosity which improves the volumetric sweep efficiency during EOR processes. There are two main groups of polymers in conventional polymer flooding: synthetic and biopolymer. Partially hydrolyzed polyacrylamide (HPAM) is the most widely used synthetic polymer for polymer flooding and is a linear water-soluble polymer. The implementation of HPAM is relatively easy and can significantly improve oil recovery rate under standard reservoir conditions. Natural and biopolymers are gaining significant interest for their application in chemical EOR because of their eco-friendly nature [27]. A few of the recently used biopolymers are xanthan gum, gum Arabic, guar gum. Advance in research is leading to combining polymers with nanoparticles mainly xanthan gum and partially hydrolyzed polyacrylamide for better performance due to their synergy effect.

B.   Alkaline Flooding

It is a type of chemical enhanced oil recovery method where synthetic chemicals such as sodium hydroxide, sodium orthosilicate or sodium carbonate are injected into a reservoir to enhance oil recovery. The injected alkaline reacts with the naturally occurring organic acids in the oil and forms surfactants inside the reservoir. The surfactants eventually play a big role by reducing interfacial tension between oil and water which contributes to increase oil recovery [27]. Alkaline flooding agent has an advantage over surfactant flooding agent because of its cost effectiveness.

III.   MATERIALS AND METHODS
A.   Equipment and Materials

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, Pump, Flooding Pump Setup, Core-holder, Sieve and Stirrer.

Materials: The materials utilized in this research work are xanthan gum, silicon nanoparticle, brine (mixture of industrial salt, Potassium Chloride, and water), encapsulated cores, crude oil.

Brine Preparation: Laboratory brine solutions was formulated in this study. The brine solution was prepared using 30g of sodium chloride (NaCl) in 1000ml of distilled water. The density of the formulated brine is 1.0191g/dm^3 .

 Nanofluids Preparation: The silicon oxide nanoparticles used in this study was acquired from JoeChem Chemical Shop Port Harcourt, River's state, Nigeria. 0.1g, 0.2g and 0.3g of silicon oxide were dissolved in equal volume of 100ml of the formulated 30g/L brine.

Polymer-Nanofluids Hybrid Preparation: The polymer used in this study is xanthan gum. 100ml equal volume of Xanthan gum was mixed with 0.1wt%, 0.2wt% and 0.3wt% of Silicon (ii) oxide

formulated solution. The formulated nanofluids with different 0.1g, 0.2g and 0.3g in 100ml of brine were added with equal concentrations of 100ml of formulated xanthan 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/cm^3, viscosity of 43.022cP and ^{o}API gravity of 33.99 at the 30°C.

B.   Experimental Procedures
- The twelves unconsolidated Niger - Delta core (plug) samples were prepared, cleaned, and fully dried in an oven.
- The weight, length and diameter of each prepared core was measured, and the result is presented in Table 1.
- The twelves core samples were fully saturated in a brine water of 30,000ppm concentrations as to measure the saturated weight of various core samples.
- 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 brine solution of 30,000ppm (Equation 1 and Table 2).
- Porosity determination was done 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 procedures for different temperature of 30°C and 45°C. The water breakthrough time was recorded.
- 0.1wt%, 0.2wt% and 0.3wt% concentrations of xanthan gum polymer stand-alone and xanthan gum/SiO$_2$ hybrid were injected into the core until no oil could be recovered at the residual oil saturation (Table 4).
- Finally, the unconsolidated core was removed from the core-holder and re-weighted, the recovered oil was measured and change in permeability was determined using Equation 3.

Pore Volume Equation:

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

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

Porosity: $Porosity, \emptyset = \frac{P.V}{B.V} \times 100\% \qquad (2)$

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

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

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

IV. RESULTS AND DISCUSSION

The results of the experimental study on the effect of polymer (Xanthan Gum) and polymer-Nanoparticle hybrid (Xanthan Gum/Silicon Oxide) for enhanced oil recovery using different temperature ranges of 30°C and 45°C are presented in this section. The polymer and polymer-nanoparticle used are Xanthan gum (XG) and silicon oxide respectively.

A. Petrophysical Properties of the Formation

Table 1 shows the result of bulk volume for each core sample used in this study. The plug samples with identities of C31, C32, C33, C34, C35 and C36 were flooded at 30°C temperature while those with C41, C42, C43, C44, C45, and C46 identities were flooded at 45°C temperature. Bulk volume is the total sand volume used to form the core sample excluding the volume of the screen. The grain size of the sieved formation used in preparing the encapsulated plug is between 425μm-625μm. The results obtained from measurement of bulk volume for the plug samples of C31-C36 ranges from 57.46 to 62.68cm^3 and 57.82 to60.64cm^3 for core samples of C41-C46 respectively as shown in Table 1.

The pore volume is the total volume of small openings/spaces in the bed of the adsorbent particle. It's an indication of the volume of fluid that can be occupied by the pore space. The higher the pore volume /porosity the higher the volume of fluid that can be contained in the core and the better the reservoir formation. The results of the calculated pore volume using Equation (1) for the core samples C31-C36 varies from 25.86to 28.97cm^3 and 25.69 to 27.87cm^3 for core samples of C41-C46 (Table 2). The porosity of the porous medium (Sand pack) was calculated from the bulk volume (Table 1) and pore volume of the samples using Equation 2. The porosity and pore volume result are presented in Table 2.

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 flow rate of 0.9091cm^3/sec and the pressure difference was recorded for every experiment. 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. This is done to evaluate the effect of enhanced oil recovery agent on formation damage.

Table 1. Bulk Volume of Encapsulated Plug

Sample Plug ID	Temperature Range (ºC)	Plug Length (cm)	Plug Diameter (cm)	Plug Radius (cm)	Bulk Volume (cm^3)
C31	30ºC	7.05	3.3	1.65	60.3
C32		6.8	3.28	1.64	57.46
C33		7.24	3.32	1.66	62.68
C34		7.07	3.3	1.65	60.47
C35		6.78	3.3	1.65	57.99
C36		7.3	3.28	1.64	61.68
C41	45ºC	7.09	3.3	1.65	60.64
C42		6.89	3.3	1.65	58.93
C43		6.98	3.32	1.66	60.43
C44		6.84	3.3	1.65	58.5
C45		6.76	3.3	1.65	57.82
C46		6.86	3.28	1.64	57.96

Table 2. Pore Volume and Porosity of the Plug Samples

Sample Plug ID	Temperature Range ºC	Wt of Dried plug + screen + foil	Wt of Sat. plug + screen + foil	Wt of fluid within the pores	Density of Sat. Fluid (g/cm^3)	Bulk Volume (cm^3) $\pi r^2 h$	Pore Volume (cm^3)	Porosity (%)
C31	30ºC	136.67	164.7	28.03	1.0191	60.30	27.51	45.62
C32		133.75	160.11	26.36	1.0191	57.46	25.86	45.01
C33		137.43	166.62	29.19	1.0191	62.68	28.64	45.69
C34		135.64	163.75	28.11	1.0191	60.47	27.58	45.61
C35		136.00	163.54	27.57	1.0191	57.99	27.02	46.59
C36		138.48	168.01	29.53	1.0191	61.68	28.97	46.97
C41	45ºC	131.80	158.9	27.1	1.0191	60.64	26.59	44.38
C42		133.97	162.3	28.33	1.0191	58.93	27.8	45.84
C43		132.28	158.46	26.18	1.0191	60.43	25.69	43.59
C44		136.56	164.95	28.4	1.0191	58.50	27.87	47.64
C45		134.81	162.67	27.86	1.0191	57.82	27.35	47.30
C46		132.23	159.1	26.87	1.0191	57.96	26.37	45.50

Table 3. Result for Permeability of the Plug Sample

Plug ID	Fluid Concentration	Temperature ºC	K_i (mD)	K_f (mD)	ΔK (mD)
C31	XG-0.1wt%	30ºC	342.55	256.91	85.64
C32	XG-0.2wt%		341.78	256.33	85.45
C33	XG-0.3wt%		340.71	243.34	97.37
C34	XG/S_iO_2-0.1wt%		380.12	323.26	56.86
C35	XG/S_iO_2-0.2wt%		376.34	320.91	55.43
C36	XG/S_iO_2-0.3wt%		343.28	283.24	60.04
C41	XG-0.1wt%	45ºC	343.99	257.99	86.00
C42	XG-0.2wt%		343.67	257.75	85.92
C43	XG-0.3wt%		340.53	254.8	85.73
C44	XG/S_iO_2-0.1wt%		450.1	378.08	72.02
C45	XG/S_iO_2-0.2wt%		341.31	270.97	70.34.
C46	XG/S_iO_2-0.3wt%		339.63	263.72	75.91

B.   Rheological Result

Density is the mass of object per unit volume. It measures how dense a fluid can be. The results for both density and viscosity using formulated EOR agents of bare xanthan gum and xanthan-silicon oxide hybrid, for different temperatures at 30^oC and 45^oC using 0.1wt%, 0.2wt% and 0.3wt% are presented in Table 4. 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 polymer and polymer – nanoparticles hybrid is presented in Table 4. It can be observed that the viscosity of polymer-nanofluids slug has higher viscosity at both the temperatures of 30^oC and 45^oC knowing fully that viscosity varies inversely to temperature.

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

Fluid ID	Fluid Concentration	Temperature Range (ºC)	Efflux time	Viscometer constant 150/60lb	Density of Sat. Fluid (g/cm^3)	Kinematic viscosity	Dynamic viscosity (cp)
T31	XG-0.1wt%	30^oC	24.88	0.036415	1.0159	0.9060	0.9204
T32	XG-0.2wt%		27.38	0.036415	1.0171	0.9970	1.0141
T33	XG-0.3wt%		28.28	0.036415	1.0164	1.0298	1.0467
T34	XG/S$_i$O$_2$-0.1wt%		29.91	0.036415	1.0148	1.0892	1.1053
T35	XG/S$_i$O$_2$-0.2wt%		30.28	0.036415	1.0153	1.1026	1.1195
T36	XG/S$_i$O$_2$-0.3wt%		29.91	0.036375	1.0157	1.0880	1.1050
T41	XG-0.1wt%	45^oC	19.34	0.036375	1.0159	0.7035	0.7147
T42	XG-0.2wt%		24.2	0.036375	1.0171	0.8803	0.9742
T43	XG-0.3wt%		26.35	0.036375	1.0164	0.9585	0.8953
T44	XG/S$_i$O$_2$-0.1wt%		26.02	0.036375	1.0148	0.9465	0.9605
T45	XG/S$_i$O$_2$ 0.2wt%		28.02	0.036375	1.0153	1.0192	1.0348
T46	XG/SiO2-0.3wt%		29.91	0.036375	1.0157	1.0880	1.1050

C.   Recovery of Crude Oil by Water and Tertiary Methods

Xanthan gum solution and xanthan gum/S$_i$O$_2$ hybrid chemical-enhanced oil recovery (CEOR) was conducted using twelves (12) plugs samples of Niger Delta sand pack. The core flooding was done at a temperature of 30°C and 45^oC. The results of the polymer hybrid flooding experiment were compared to those of the xanthan gum solution alone after waterflooding process. The bare xanthan gum solution, and xanthan gum/S$_i$O$_2$ hybrid increased oil recovery after the waterflooding process at both temperature of 30^oC and 45^oC. The flooding done at 30° temperature gave higher recovery in the range of 83.33% to 73.19% than the flooding did at 45^oC temperature with the recovery varies from 80.43% to 70.45% (Table 5).The Xanthan gum/S$_i$O$_2$ hybrid demonstrated a better cumulative oil recovery even at a higher temperature of 45^oC with recovery of 80.43%% at 0.2wt.% as to compare to bare Xanthan gum that recovered 73.91% OOIP at the same temperature and concentration. (Table 5).

The cumulative oil recovered increased from 0.1wt.% to 0.2wt.% for both bare xanthan gum and xanthan m/silicon hybrid at both temperature of 30^oC and 45^oC. It was observed that at 0.3wt.% concentration, the cumulative oil recovered dropped for both the bare xanthan gum and the hybrid at the temperature

of 30°C and 45°C. The cumulative oil recovered using the EOR formulations with T44 to T46 identities are higher with numerical values of 77.27%, 80.43% and 73.91% when compared with those of T41 to T43 that gave 72.73%, 73.91% and 70.45% respectively.

Table 5 and Fig. 4 illustrate that the xanthan gum/S_iO_2 hybrid outperformed the bare Xanthan gum in terms of oil recovered, at both temperatures of 30°C and 45°C. This can be attributed to the synergy effect of xanthan gum/S_iO_2 hybrid, such as viscosity, stability, and mobility control, which enable more efficient mobilization of the oil, particularly at 0.2wt% fluid concentration. This show that the presence of silicon oxide nanoparticle in xanthan gum reduces its degradation at a higher temperature. This higher thermalresistance of

xanthan gum/silicon oxide nanoparticleis due to many reason such as;formation of an intramolecular association between silanol group of silicon oxide and formation water cations, formation of reinforced three-dimensional hybrid network [28], enrichment of endothermic intramolecular interaction [29] and also the formation of hydrogen-bonding between silanol groups (Si–OH) and carbonylgroups (C=O) of ester inxanthan gum form compacted, roughstructure which can resist high salinity and temperature. These observations are in great compliance with the work done by [20],[23] andthat showed that silicon oxide nanoparticles when combined with polymer canimproves thermal resistance and reduces the polymerdecomposition at high temperature.

Table 5. Summary of the oil recoveries from samples

| Fluid ID	Fluid Concentration		Oil initially in Place	Breakthrough Time @Drainage	Secondary. Recovery (ml)	Tertiary recovery (ml)	Cumulative recovery (ml)	Percentage Recovery (%)
T31	XG-0.1wt%	30°C	23	60.45	14.5	2.5	17	73.91
T32	XG-0.2wt%		22	57.92	14	3	17	77.27
T33	XG-0.3wt%		24	63.81	15	2	17	70.83
T34	XG/S_iO_2-0.1wt%		21	56.51	13	4	17	80.95
T35	XG/$S_iO_2$0.2wt%		24	63.82	15	5	20	83.33
T36	XG/S_iO_2-0.3wt%		21	57.23	13	3	16	76.19
T41	XG-0.1wt%	45°C	22	58.26	13.5	2.5	16	72.73
T42	XG-0.2wt%		23	61.2	14.5	3.5	17	73.91
T43	XG-0.3wt%		22	57.93	13.5	2	15.5	70.45
T44	XG/S_iO_2-0.1wt%		22	59.46	14	3	17	77.27
T45	XG/S_iO_2-0.2wt%		23	61.1	14	4.5	18.5	80.43
T46	XG/S_iO_2-0.3wt%		23	61.14	15	2	17	73.91
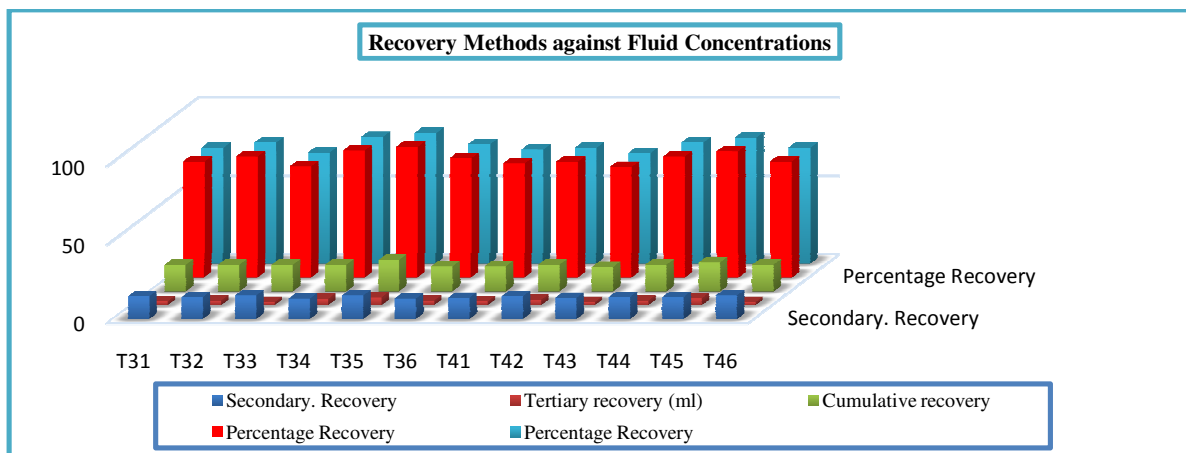
Fig. 4. Secondary, Tertiary, Cumulative recovery against Fluid concentrations

D.   Result for Permeability Change

After the secondary and tertiary flooding, the core's permeability was measured as to evaluate the extent of formation damage caused by various EOR agents for the different temperature ranges at 30^oC and 45^oC. There is a decrease in permeability of the reservoir formation after the tertiary flooding most especially with stand-alone polymer fluids and the formulations that contains higher concentration of nanoparticle.   From Table 3 and Fig. 5 polymer/nanoparticle synergy reduces permeability alteration for all the polymer concentrations evaluated from 97.37md to 55.43md at the temperature of 30^oC and 45^oC. The lowest value of 55.43 md permeability change was gotten from fluid concentration of 0.2wt% of xanthan gum/S_iO_2 hybrid at the temperature of 30^oC as to compare to 85.45md obtained at the same temperature using bare xanthan gum. There was not much difference for permeability change for polymer/nanoparticle synergized hybrid at both temperature but the permeability change at temperature of 30^oC is better than that of 45^oC. The trend is expected because [30], has shown that temperature does not have significant effect on retention of nanoparticles. However, [31] showed that the zeta potential of nanoparticles is said to decrease with increase in temperature, which will result in decrease in the stability of nanofluid but increase in agglomeration of the nanoparticles, and this invariably can lead to reduction in oil recovery.
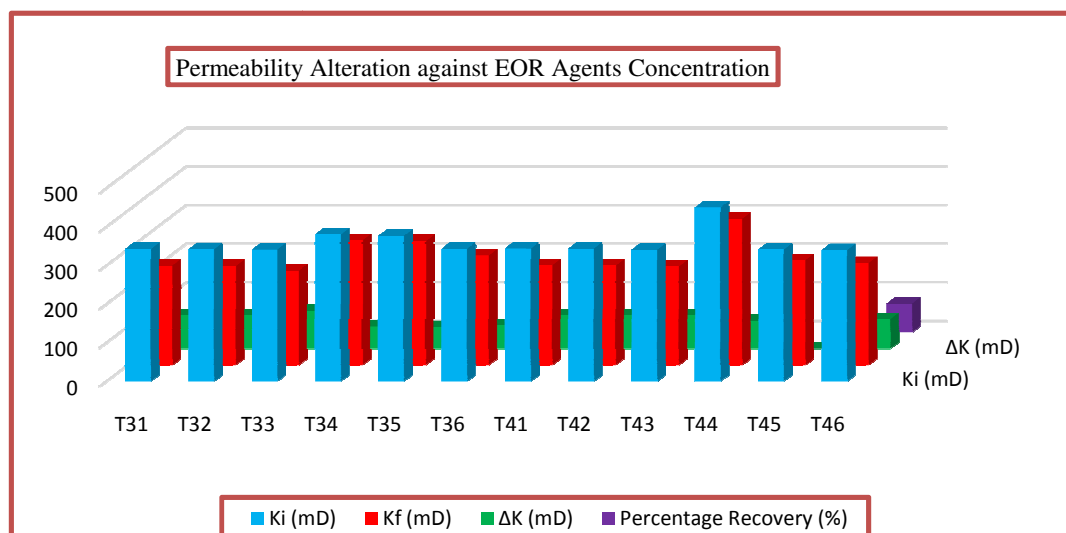
Fig. 5. Permeability Alteration for different concentration of EOR agents

V. CONCLUSION

Biopolymer solution modification is very crucial methodto boost their ability in Enhance oil recovery process at high temperature.In this study, Silicon oxide nanoparticle was successfully mixed with xanthan gum and the flooding was done at 30°C and 45°C temperature. The xanthan gum/ silicon oxide hybrid at the temperatures of 30°C and 45°C gave higher oil recovery than standalone polymer at the same temperature. The results indicate that the presence of nanoparticle in xanthan gum enhanced

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the polymer to withstand degradation at higher temperature, thereby increasing the cumulative oil recovery from 77.27% to 70% for 0.1wt% at 45°C for hybrid and xanthan gum respectively. There was not much change for the permeability change of the hybrid at 30°C and 45°C but permeability change increased more for bare xanthan gum. Xanthan gum as a natural-source polymer was chosen in this studyas Enhanced Oil Recovery agent due to its availability, eco-friendly, and biodegradable.

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