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Laboratory Study on Permeability Alteration Using Silicon Oxide Nanoparticle with Different Dispersing Agent for Enhanced Oil Recovery

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Abstract:

Mobilizing and recovering crude oils from geological strata is crucial for the management and development of petroleum reservoirs. Unlike conventional oil production methods, enhanced oil recovery (EOR) processes can increase the recovery of most oil products from the reservoir above the secondary recovery baseline. Recent studies have demonstrated that nanoparticles (NPs) dispersed in different dispersing agents have the potential to improve EOR processes. This research focuses to experiment the effect of silicon oxide nanoparticles on oil recovery and permeability change using different dispersing agents of brine and ethanol. The efficiency of the nanofluids solution with different dispersing agents were tested using different seven core samples of A to G for tertiary recovery method. The laboratory result reveals that the nanofluids formulated with ethanol give higher oil recovery with lower permeability change than the nanofluids dispersed in brine. Samples-E and F with 0.4wt% and 0.6wt% silicon oxide nanoparticle in ethanol gave the highest cumulative oil recovery of 88.46% and 82.5% with lowest permeability change of 120.55 md and 258.72 md respectively. Samples- B and C that contains 0.4wt% and 0.6wt% silicon oxide nanoparticles in brine gave the cumulative oil recovery of 73.91% and 73.70% and permeability change of 752.2 md and 680.88md respectively. The use of copper oxide nanoparticle homogenously mixed with ethanol surfactant altered the properties of hydrocarbons which helped in easy sweeping of the reservoir pore throats and reduces formation damage. Reservoir engineers should consider the type of dispersing agent to be used when designing enhanced oil recovery projects as to have a higher recovery and less permeability damage.

Keywords — Brine, Enhanced Oil Recovery, Ethanol, Nanoparticle, Permeability change, Silicon Oxide

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I. INTRODUCTION

The Enhanced oil recovery (EOR) indicates any reservoir method that is used to change the properties inside the reservoir. This change could be between the displacing and displaced fluid or between the displaced fluid and rock inside the reservoir as to increase the recovery factor (RF). The change between the formation and fluids reduces the oil viscosity, the interfacial tension, increase oil swelling, and wettability alteration. The EOR period is a very important production period because more than 30 % of the oil in place can be recovered with this process [1]. Enhanced oil processes have many methods, and each process has its own considerations for use. One of the major types is Chemical method and is also the interest in this research study. Chemical enhanced oil recovery is classified into Polymer, Surfactant, Alkaline, and Nanoparticles enhanced oil recovery (Fig. 1). The Nanoparticles are small particulates less than one hundred manometers, small sized and ultrafine particles. The use of nanoparticles in EOR studies is gaining much interest due to its ability to change the reservoir properties or change the displaced and displacing fluid properties. Aluminium oxide, Tritium oxide, Calcium carbonate, Silicon oxide, Nickel Oxide, Copper oxide, Magnesium oxide, Nickel oxide and Zirconium oxide are some of the common nanoparticles popularly used in petroleum industry for enhance oil recovery [2]. The mixture of nanoparticle with dispersing agent is called nanofluids.

Recently studies have proven that nanoparticles can solve many problems in EOR studies due to the advantages of nanoparticles (NPs). The main advantages of NPs are their large surface area [3], change the wettability ([4], [5]), reduced oil viscosity [6], increased viscosity of the injecting fluid, [7], reduction of the interfacial tension agent [5] and reuse of some nanoparticles.
The NPs also have some disadvantages. The main common disadvantage of NPs is the blockage phenomena during the injection. Where, the NPs will lead to block the pores and reduce the RF due to reducingpermeability and porosity. This blockage may occur due to the high concentration of NPs [7],high salinity of the displacing NPs and reservoir fluids [8], reservoir temperature and single charge of NPs as well. Thus, many challenges are at stake to avoid the blockage or deposition phenomena while the injection.

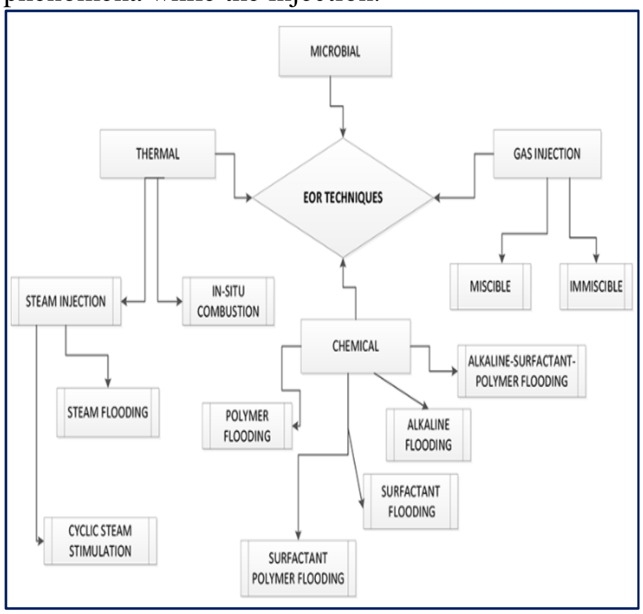

Fig. 1. Enhanced oil recovery techniques [9]

Currently, many researchers have demonstrated the reliability of nanoparticle dispersed in different dispersing fluids in improving hydrocarbon recovery ([5], [10], [11], [12], [13], [14). [5] researched on enhanced oil recovery using some selected nanoparticles like Aluminuim oxide, Zinc oxide, Magnesium oxide, Iron oxide, Zirconium oxide, Nickel oxide and Silicon oxide. They employed different dispersing agents of ethanol, distilled water, diesel, and brine. The authors reported that Aluminium oxide and Silicon oxideare good, enhanced oil recovery agent as to compare to other nanoparticle investigated using ethanol as the dispersing agent. They concluded that oxides of magnesium and Zinc dispersed in distilled water and brine cause permeability problem, which limited the recovered oil. They concluded that the dispersing agent is one of the major factors to be considered when designing nanoflooding for EOR. [10] did a research work on experimental investigation of the effect of using nanoparticle for improved oil recovery. They investigated Aluminium oxide, Copper oxide and silica using different dispersing agents of distilled water, brine, diesel, and ethanol. They investigated the effect of different nanofluids on rock wettability and oil permeability. The authors reported that the use of nanoparticles material homogenously mixed with surfactants or different dispersing agent altered the properties of hydrocarbons sweeping from pore throats of the reservoir. Their study also revealed that the mechanism of nanoparticles with different dispersing agents greatly affects interfacial tension, wettability through the contact angle and the capillary pressure of hydrocarbons. They concluded that Silica-Ethanol mixture, Copper Oxide-Distilled Water and Copper Oxide-Ethanol mixtures were found to be the three best performing mixtures and Copper Oxide-Brine and Silica-Diesel mixtures had zero effects on reservoir formation and fluid.
[11] worked on the effect of Copper Oxide and Aluminium oxide nanoparticles on Enhanced oil recovery for carbonate reservoirs using brine as the dispersing agent. Eight limestone core samples were used for flooding using different formulated nanofluids. The authors concluded that the nanoparticles gave a best recovery at low concentration than at higher concentration. The authors did not determine the change in permeability. [12] did a work on permeability alteration using silica and Alumina oxide nanoparticles for enhanced oil recovery. They conducted the experiments using core samples made with Niger Delta sand samples for both homogeneous and heterogeneous formation. The nanofluids were prepared using two different nanoparticles, with brine as the dispersing medium

and different concentrations were used to flood the core samples. They concluded from their research that the use of nanoparticles increases recovery but reduced the permeability of the formation after flooding process. They also built two mathematical regression models for predicting changes in permeability for Aluima Oxide and Silica Oxide. [13] did a work on permeability alteration using nanoparticles of Zinc oxide, Aluminum oxide, and Magnesium oxide using core plugs prepared from Niger Delta. Three different concentrations of the nanofluids were used to flood the core plugs in the laboratory using brine as the dispersing agent. The change in the permeability of the core plugs were determined before and after the flooding process. The authors reported that nanoparticles adsorption during flooding increased oil recovery to 15% and there was also permeability reduction in the formation within the range of 50 md to 612 md after the flooding process. They also developed a permeability change mathematical models for zinc and magnesium oxide using multiple linear regression. The model will help to checkmate the concentration of the Zinc and Magnesium oxide nanoparticle as to reduce the permeability reduction change during core flooding.

[14] experimented on the effect of copper oxide nanoparticles on oil recovery and permeability change using different dispersing agents of brine and ethanol. The authors evaluated the efficiency of the nanofluids solution with different dispersing agents using different seven core samples for tertiary recovery method. Mbachu and Eguzoro reported that the nanofluids formulated with ethanol gave higher oil recovery with lower permeability change than the nanofluids dispersed in brine. Samples-F4 and F5 with 0.2wt% and 0.4wt% Copper oxide nanoparticle in ethanol gave the highest cumulative oil recovery of 85.71% and 82.5% with lowest permeability change of 238.14 mD and 258 mD.respectively. Samples- F1 and F3 that contains 0.2wt% and 0.4wt% Copper oxide nanoparticles in brine gave the cumulative oil recovery of 75% and 74.07% and permeability change of 460.15 mD and 670.76mD respectively. From the literature review, it can be found that permeability damage is one of the major limitations of using nanoparticle in enhancing oil recovery. Some authors have showed that using different dispersing agent other than normal brine aided in reducing permeability and increase oil recovery ([5], [10]). Therefore, this research work aimed at investigating silicon oxide nanoparticle for enhanced oil recovery using different dispersing agents of brine and ethanol for Niger Delta formation.

II. NANOPARTICLES

A. Types of Nanoparticles

Nanoparticles are divided into four categories:

Metal oxide Nanoparticles are Copper oxide (CuO), Aluminium Oxide (Al_2O_3), Nickel Oxide (Ni_2O_3), Copper Oxide (CuO), Titanium Oxide (TiO), Iron oxide (Fe_2O_3/Fe_3O_4), Magnesium oxide (MgO), Tin oxide (SnO_2), Zirconium Oxide (ZrO_2) and Zinc Oxide (ZnO).

Magnetic Nanoparticles are Ferro Nano fluids, Cobalt ferrite NPs and $NiFe_2O_4$-chitosan.

Organic Nanoparticles are Carbon NP and Carbon nanotubes.

Inorganic Nanoparticles are Hydrophobic silicon oxide (SiO_2) NPs, Silica containing NPs, Spherical fumed silica NPs, Alumina coated silica NPs, inorganic silica core/polymer-shell nano composite, Silicon oxide treated with silane NPs, Polysilicon NPs, Hydrophobic and lipophilic polysilicon NPs, naturally wet polysilicon, Nano-structured zeolite, Nano sensors Nano-Sized Colloidal Dispersion Gels, Polymer coated NPs and Polyacrylamide Micro-gel Nano-spheres.

Based on open lierature, the most used category in EOR is the metal oxide nanoparticles. The different types of metal oxide NPs have tested as an interfacial tension depressant, catalyst at the high temperature, reduce the oil viscosity, prevent condensation reactions, and oil swell as well [15], and [16] . While the potential of the other categories such as magnetic, organic, and inorganic nanoparticles have only recently come to the notice of EOR researchers ([7], [17], [5], [18]and [19]).

Most but not all the previous types of NPs have been used to test their ability to enhance oil recovery, some types of NPs have been reported to be able to enhance oil recovery such as Al_2O_3, Ni_2O_3, Fe_2O_3, etc. At the same time, some NPs have failed to enhance the oil recovery due to the reduction in permeability, such as MgO and ZnO [5]. As well as some types need further investigation in EOR such as ZrO_2, ZnO, Ferro fluids, Spinal Oxide, Magnetic Cobalt Ferrite, Carbon NPs, Carbon nanotubes. In any case, the effect of each type of NPs mainly depends on the type of the dispersing agent, the most important issue for petroleum engineers is to understand that not all the types of NPs can be dispersed in water, so different types of fluids have been used as a dispersing agent for NPs.

B. Nanoparticles Effect on the Pore Throat

A rule of thumb related to the interactions between solid particle size and pore throat diameter (suspendedsolids or accumulation solids), has been presented by [21]. This rule canbe called the "1/3: 1/7 rule". If the particle size is larger than "1/3" of the pore diameter, this will cause externalfilter cake or plugging behaviour. If the solid particle size is between 1/3 and 1/7 of the pore throat diameter, thesolid particles will pass the formation but become trapped, and an internal filter cake may be formed. This canalso be viewed as partially plugging behaviour. If the particle size is smaller than 1/7 of the pore diameter, then theparticles will flow easily through the formation, as shown in Fig. 2. The adsorption of NPs (ZnO and MgO) onsurface of the rock and small pore throats blocking may cause a reduction in the porosity and permeability [5]. Additionally, the blocking of the pore throat may occur due to the accumulationof the NPs to cross the pore at the same time, which is often called Bridge Theory (log-jamming).

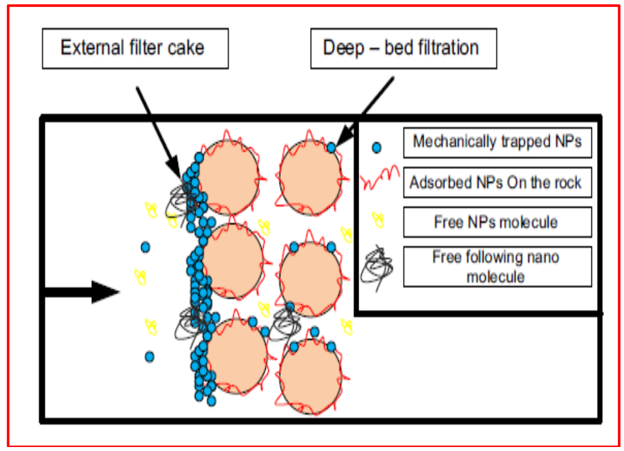

Fig. 2 Deep bed formation and external cake formation for NPs around the wellbore [20]

III. MATERIALS AND METHODS

A. Materials and Equipment

Materials

The materials used in carrying out this experimental research are Niger-Delta sand, unconsolidated sand-packs, silicon oxide nanoparticle, ethanol, aluminium foils, masking tape,industrial salt (NaCl), laboratory prepared brine and crude oil. The crude oil sample was gotten from Niger Delta of Nigeria and the properties are shown Table 1.

The crude oil sample was obtained from a Niger Delta field of Nigeria and has the following properties: specific gravity of 0.860, density of 0.8896g/cm^3, viscosity of 16.61 cp and ^{o}API gravity of 27.566 at the temperature of 31^{o}C.

Preparation of Laboratory Brine: The brine was prepared using 30g industrial sodium chloride (NaCl) in 1000 litres of distilled water. The density of the formulated brine is 1.0211g/cm^3.

Nanofluids Preparation: The silicon oxide nanoparticles used in this study was acquire from JoeChem Chemical Shop Port Harcourt, River's state, Nigeria. 0.2g, 0.4g, 0.6g and 0.8g of silicon oxide were dissolved in equal volume of 100ml of brine and ethanol respectively to give a homogeneous mixture of different enhanced oil recovery agents.

Equipment

The encapsulated plug sample or unconsolidated Sand-packs, Venire calliper, 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.

B. Experimental Procedures

i. The seven unconsolidated Niger - Delta core (plug) samples identified as A to G were cleaned and fully dried in an oven.
ii. The various core's weight, length and diameter were measured, and the results are presented in Table 1.
iii. The cores were fully submerged or saturated in a laboratory brine water as to measure the saturated weight of the individual core samples.
iv. The pore volume of each core sample was calculated using Equation 1, by subtracting the saturated weight from dry weight and the result was divided by the density of the brine solution and result is shown in Table 1.
v. The porosity was determined by using the result obtained from bulk volume (Table 1) and pore volume (Table 1) using Equation 2.
vi. 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.
vii. The same quantity of oil that entered the unconsolidated core is equivalent to brine solution displaced from the core sample at constant flow rate.
viii. The brine was injected (secondary recovery) into the core to displace crude oil and the amount of oilrecovered was measured and recorded.The laboratory brine water injection was a control experiment.
ix. Other laboratory experiments were carried out following the above procedures. The water breakthrough time was recorded.
x. The different concentrations of nanofluid EOR agents as presented in Table 4 were injected into the individual core until no oil could be recovered at the residual oil saturation.
xi. 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 and was presented in Table 4.

Pore Volume Equation:

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

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

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

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

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

IV. Results and Discussion

The results of the experimental evaluation of silicon oxide nanoparticle for enhanced oil recovery using different dispersing agents of brine and ethanol are presented.

A. Petrophysical Properties of the Formation

Proper understanding of the physical properties of the plug samples is very important in interpreting the flow behaviour and fluid-rock interactions during enhanced oil recovery (EOR) processes. This result section shows a detailed characterization of the encapsulated plug samples used in this research which includes, bulk volume, pore volume, porosity, and permeability.

The bulk volume for the various plug samples as indicated in Table 1 presents the total sand volume used to form the plug sample. The grain size of the sieved formation used in preparing the unconsolidated core is of about 445μm. The measured bulk volume of each plug samples varies from 62.84 to 76.04cm^3 as shown in the Table 1. The plug sample A has the lowest bulk volume while D has the highest bulk volume. The pore volume is the total volume of small openings/spaces in the bed of the adsorbent particle. It indicates 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 of the core samples varies from 24.06 to 29.51cm^3 (Table 1). 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 results as determined from Table 1 and Equation 2 is represented in Table 1.

Permeability is the ability of the core sample to allow fluid to flow through it. The higher the permeability of the reservoir formation the more oil will be displaced from the pore. 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 and Table 2.

Table 1. Bulk Volume, Pore Volume and Porosity of Encapsulated Plug

Plug samples. ID	Length of plug (cm)	Plug diameter (cm)	Bulk volume (cm^3)	Pore volume cm^3	Porosity (%)
A	5.00	4.00	62.84	28.73	45.75
B	5.00	4.10	66.02	29.51	44.69
C	5.20	4.20	72.05	25.37	35.21
D	5.00	4.40	76.04	24.06	29.01
E	4.80	4.20	66.51	28.88	42.19
F	5.10	4.30	74.07	28.47	38.43
G	5.10	4.00	64.10	26.73	41.70

Table 2. Result for Permeability of the Plug Sample

Plug sample ID	Length of plug (cm)	Plug diameter (cm)	Differential Pressure (Psi)	Permeability (md)
A	5.00	4.00	0.70	1749.53
B	5.00	4.10	0.80	1516.68
C	5.20	4.20	1.00	1190.44
D	5.00	4.40	1.80	615.03
E	4.80	4.20	1.40	829.81
F	5.10	4.30	2.50	459.01
G	5.10	4.00	2.20	554.67

B. Fluid Properties Result

Fluid properties govern fluid flow, displacement mechanisms, and interactions with the rock matrix, ultimately shaping the effectiveness of EOR strategies. An examination of the Table 3 will illuminate trends and variations in fluidproperties, sparking insights into their potential impact on oil recovery. Table 3 shows the measured values for density and pH for each nanofluid examined.

Density is the mass of object per unit volume. It measures how dense a fluid can be. The results of density of the formulated fluids using different concentrations of silicon oxide nanoparticles with different dispersing agents of brine and ethanol are showed in Table 3. The density measurement is important because it will be used to determine the fluid kinematic viscosity. Table 3 also shows the PH values of various nanofluid concentrations used in this study. The PH values for silicon oxide in ethanol are higher than the silicon oxide in brine solution.

The measure of fluid's internal resistance to flow is dynamic viscosity while kinematic viscosity is a ratio of dynamic viscosity to density. 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 nanofluids used in this study are showed in Table 3. The crude oil sample has the viscosity of 16.61cp, brine has 5.0977cp, the viscosity of various nanofluids concentration ranges from 0.864 to 1.059cp. It was also observed that the viscosity of ethanol nanofluids has higher viscosity than brine.

Table 3. Experimental Result for Density Samples of the Nanofluids /Crude Oil (g/cm^3)

Fluid samples ID	Fluid concentration	Temp. (^{O}C)	Viscometer constant 150/60lb	Density of fluid (g/cm^3)	Dynamic viscosity Cp	Kinematic viscosity	PH Values
S1	0.2wt% S_iO_2 /brine	31.00	0.03640989	1.126	1.0945	0.864	8.5
S2	0.4wt% S_iO_2/brine	31.00	0.03640989	1.130	1.017	0.900	8.7
S3	0.6wt% S_iO_2/brine	31.00	0.03640989	1.134	1.043	0.918	9.1
S4	0.2wt% S_iO_2/ethanol	31.00	0.03640989	1.126	1.036	0.920	8.6
S5	0.4wt% S_iO_2/ethanol	31.00	0.03640989	1.128	1.1483	1.018	9.3
S6	0.6wt% S_iO_2/ethanol	31.00	0.03640989	1.130	1.194	1.057	9.6
S7	0.8wt% S_iO_2/ethanol	31.00	0.03640989	1.132	1.199	1.059	9.7
Brine	30,000ppm	31.00	0.03640989	0.978	4.986	5.0977	7.3
Oil	33.99^{0}API	31.00	0.03640989	0.8896	14.776	16.61	-

C. Recovery of Crude Oil by Water and Tertiary Methods

After performing the secondary and tertiary oil recovery, results obtained from the laboratory experiments for Silicon oxide nanoparticle using different dispersing agents of brine and ethanol are presented in the Table 4. The percentage of oil recovered during the secondary flooding process ranges from 14.5 to 16ml indicating that up to 9ml to 10.50ml oil is remaining in sand pack, hence, the need for tertiary recovery. It was observed that nanofluids prepared by ethanol gave the highest recovery in the range of 88.46% to 75% than those nanoparticles prepared with brine which gave a cumulative oil recovery of 73.91% to 70%. The result from tertiary recovery showed that sample- F with the concentration of 0.6wt% of silicon oxide dispersed in ethanol gave the highest cumulative recovery of 88.46% as to compare to samples- C that contain 0.6wt% of silicon oxide dispersed in brine that gave cumulative recovery of 73.91%. Sample- E that contain 0.4wt% of silicon oxide in ethanol equally performed better than sample- B that has the same concentration both in terms of oil recovered and permeability change. The superior behaviour of silicon oxide dispersed in ethanol than the one dispersed in brine is because the mixture changes the wettability of the rock from oil wet to water wet. The presence of ethanol reduced the interfacial tension and capillary pressure between oil and water. The experimental work also revealed that ethanol gave a better homogeneity during mixing than brine, thereby helping in proper sweeping of reservoir pore throats and reduction of formation damage.Theresult also shows that at a higher concentration of nanoparticles in both dispersing agents of brine and ethanol reduces the oil recovery due to blockage reservoir pore space by the nanoparticles. Table 4 shows that sample G with 0.8wt% in silicon/ethanol which has the highest concentration of nanoparticle in ethanol gave the lowest recovery of 75% and samples B and C that contains 0.4 and 0.6wt% silicon oxide in brine have the recovery of 73.07% and 73.91%, showing that beyond those concentrations, there will be a reduction in recovery.The result agrees with the findings of ([5], [10], [14]) that ethanol is a very good surfactant nanofluids formulations.

Table 4. Summary of Recovery

Plug samples ID	OIIP	Break thru. Time (sec)	Δρ at drainage (psi)	Secondary. Recovery (ml)	Conc. of fluid for tertiary recovery (%)	Tertiary recovery (ml)	Cumulative recovery (ml)	Residual oil (ml)	Percentage Recovery (%)
A	25.00	55.00	8.00	14.50	S1	3.00	17.50	7.50	70.00

B	26.00	59.00	7.80	15.50	S2	3.50	19.00	7.00	73.07
C	23.00	64.00	7.80	15.00	S3	2.00	17.00	6.00	73.91
D	22.00	51.00	8.00	15.00	S4	3.00	18.00	4.00	81.81
E	26.00	53.00	8.00	15.50	S5	6.50	22.00	4.00	82.50
F	26.00	47.00	7.50	16.00	S6	7.00	23.00	3.00	88.46
G	24.00	49.00	7.50	15.00	S7	3.00	18.00	6.00	75.00

From this experimental study, it can be found that the dispersing agents has a big effect on hydrocarbon properties and reservoir rock formation. (Figs. 2 and 3). For enhanced oil recovery design project, reservoir engineers should put into consideration the type of dispersing agents to use in formulating the nanofluid as to get best optimum results of high recovery and less formation damage. The concentration of nanoparticle in the dispersing fluid is another paramount factor to consider when designing EOR projects. Figs. 2 and 3 show that at higher concentrations of nanoparticle, recovery decreases and higher permeability damage due to blockage of pore volume with aggregated nanoparticles. It was also observed that silicon oxide when dispersed in brine and ethanol increased the PH value and it affected recovery quit positively (Fig. 4).

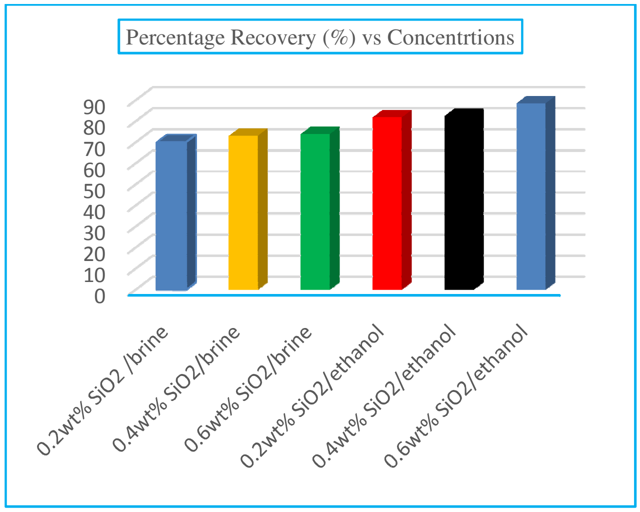

Fig. 2. Percentage recovery against Fluid concentrations

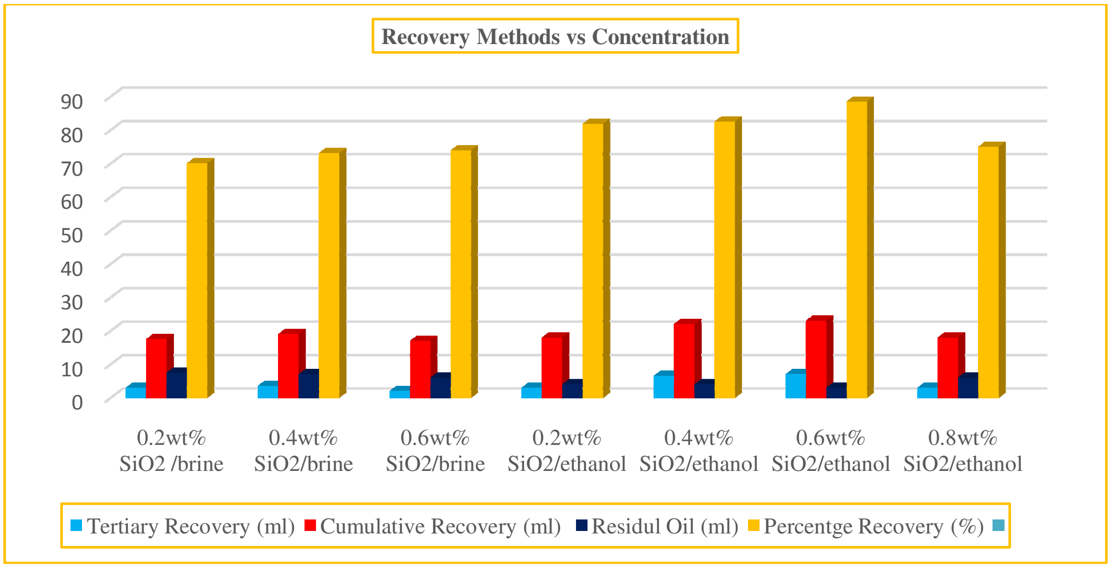

Fig. 3 Secondary, Tertiary, Cumulative recovery against Fluid concentrations

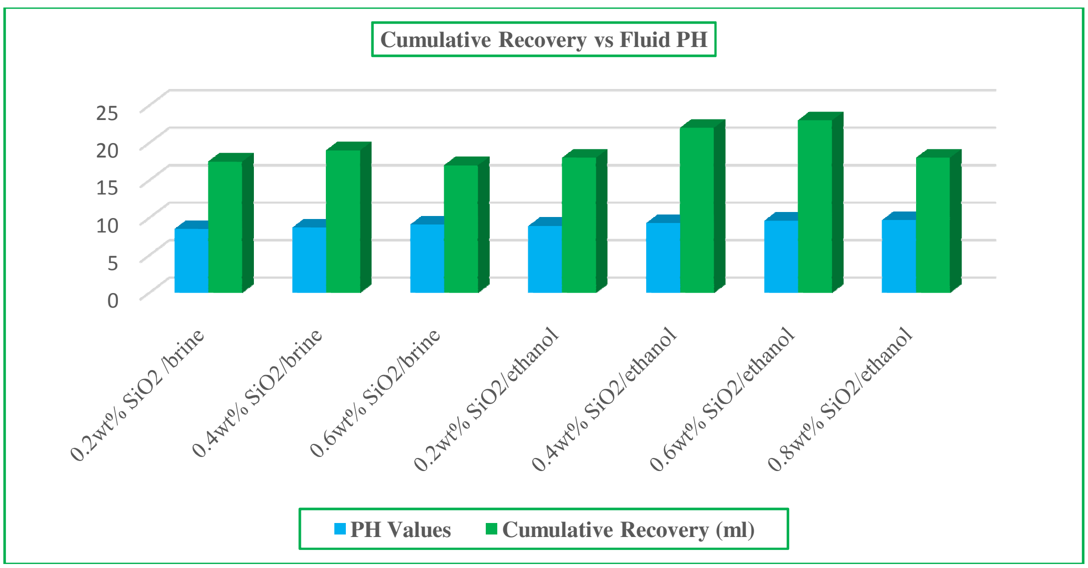

Fig. 4. Percentage Cumulative Recovery against Fluid PH

D. Result for Permeability Change

When the secondary and tertiary flooding is over, the core's permeability change was determined as to ascertain the extent of formation damage caused by nanoparticles. The permeability before and after the flooding was calculated as to get permeability change There is a significant decrease in permeability of the reservoir formation after flooding with different nanofluids. The nanofluids formulated with brine dispersing agent has high reduction in permeability as to compare with those nanofluids prepared with ethanol. Table 5 and Fig.

5 show the alteration in permeability for all the enhanced oil recovery agents evaluated. The change in the permeability for all the nanofluids studied ranges from 120.55 md to 752.20 md. The nanofluids formulated with ethanol has the permeability change from 120.55 md to 298.08 md and the highest damage was gotten from 0.8wt% S_iO_2/ethanol concentration. The brine formulated fluids have the permeability change from 752.2 md to 510.19md and 0.6wt% S_iO_2/brine concentration having the highest damage. It was because some of the nanoparticles dispersed in brine entered the core pore throat in a larger aggregate form thereby blocking the pore space and hence permeability and recovery are reduced. The nanoparticle dispersed in ethanol entered the core in tinier, separated form which formed a sort of wedge film that reduced the formation damage caused by nanoparticles plugging the pores of the core. This reduced the permeability change and thus increased recovery.
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Table. 5 Permeability Change with Difference Nanofluids Concentrations

Nanofluids Concentrations	$k_{i\ (mD)}$	$k_{i\ (mD)}$	$\Delta K = K_i - K_{f\ (mD)}$	**Percentage Recovery (%)**
0.2wt% S_iO_2 /brine	1749.53	1239.34	510.19	70.00
0.4wt% S_iO_2/brine	1516.68	835.80	680.88	73.07
0.6wt% S_iO_2/brine	1190.44	438.24	752.2	73.91
0.2wt% S_iO_2/ethanol	615.03	378.85	236.18	81.81
0.4wt% S_iO_2/ethanol	829.81	571.09	258.72	82.50
0.6wt% S_iO_2/ethanol	459.01	338.46	120.55	88.46
0.8wt% S_iO_2/ethanol	554.67	256.59	298.08	75.00

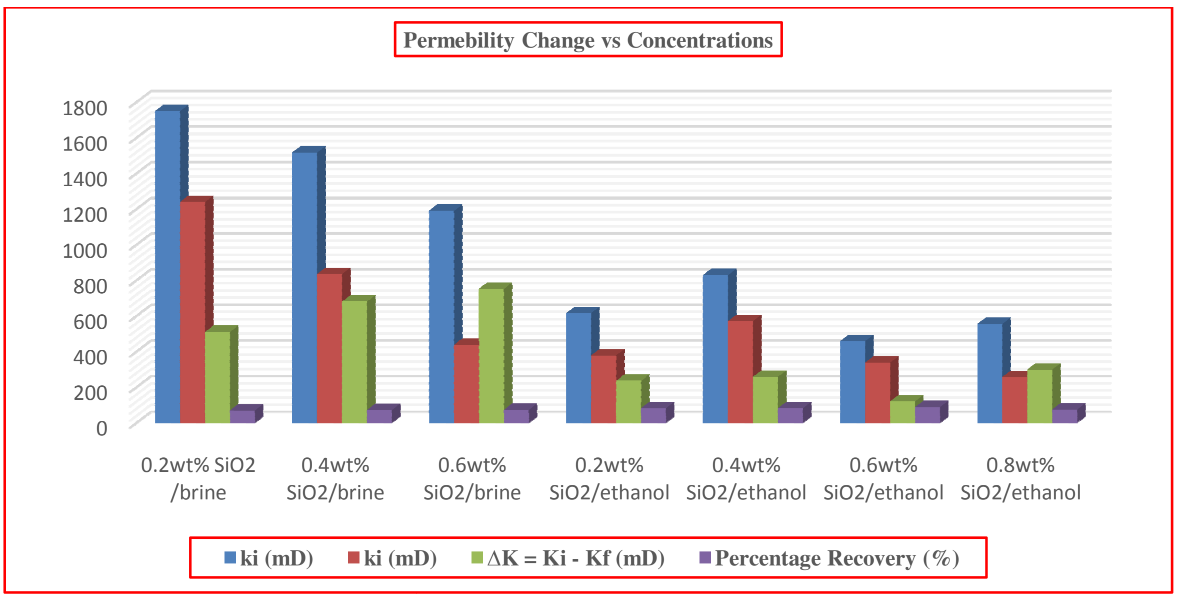

Fig. 5. Permeability Change against Recovery against Different Nanofluids

V. CONCLUSION

Based on the experimental results obtained from this study, the following conclusions are reached.

- Dispersing fluids has very big impact on the application of nanoparticle for enhanced oil recovery

- The nanofluids formulated using silicon oxide in both brine and ethanol increases oil recovery.
- Application of nanofluid prepared with ethanol generally performed better than the ones prepared with brine in terms of oil recovery and permeability alterations.
- The nanofluid that contains 0.6wt% of silicon oxide in ethanol gave the highest recovery of 88.46% and lower saturation value 120.55 md.
- Increase in concentration of nanoparticle for both dispersing agents of brine and ethanol reduces oil produced and increases permeability change.

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