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Research Article

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Experimental Study on Permeability Alteration using Copper Oxide Nanoparticles with different Dispersing Agent for Enhanced Oil Recovery

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Abstract A novel concept of treating oil reservoirs by nanofluids is being developed to improve oil recovery and reduce the trapped oil in hydrocarbon reservoirs. The use of nanoparticles dispersed in fluid overcomes the limitation of conventional enhanced oil recovery (EOR) methods like high cost and degradation of chemicals. Despite their good performance in enhancing oil recovery, these nanoparticles can retain in the reservoir pore thereby reducing the permeability of the reservoir formation. This study is designed to experiment the effect of copper 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 for tertiary recovery method. The experimental result showed that the nanofluids formulated with ethanol give 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 238.14mD and 258mD 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 460.1mD and 670.76mD respectively. The use of copper oxide nanoparticle homogenously mixed with ethanol surfactant altered the properties of hydrocarbons that aided 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 good recovery and less permeability damage.

Keywords Copper oxide, nanoparticle, brine, ethanol, permeability

1. Introduction

Energy crisis and reservoirs with declining reserves even after primary and secondary oil recovery are some of the factors that led to the development of Enhanced Oil Recovery (EOR) processes. Enhanced oil recovery, also known as tertiary recovery, is the extraction of crude oil from an oil field that cannot be extracted using the traditional methods of natural drive methods. Figure 1 shows the flow chart of enhanced oil recovery techniques. Tertiary method can extract up to 30% - 60% or more of original oil in place, compared to 20% - 40% of using primary and secondary recovery [1]. The fundamental research on enhanced oil recovery (EOR) is very important in developing technologies that enable a high recovery factor from oil reservoirs, that is cheap and reliable even when the renewable energy sources are yet unavailable. Many enhanced oil recovery methods like thermal, microbial, miscible, and chemical processes have proved reliability in improving hydrocarbon recovery [1]. Enhanced oil recovery (EOR) methods applied in hydrocarbon reservoirs affects the following mechanisms, reduces interfacial tension, alters rock wettability, mobility control and gravity drainage. Due to the increase in demands of global energy market, oil companies are required to invent novel solutions to improve oil recovery, hence nanoparticles (NPs). Nanoparticles (NPs) are considered as one of the promising chemical methods in EOR applications [2].

Presently, nanotechnology have been proposed as a promising EOR method since nanoparticles can penetrate the pore throat and change the reservoir formation and fluid properties considerably to increase oil recovery [3]. Nanofluid flooding is a type of chemical enhanced oil recovery process. It is prepared by adding nanoparticles into the base fluid and stirred or agitated to have a homogeneous solution. 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. [3] state and discussed some of the factors affecting nanofluid-flooding recovery which are Size of nanoparticles, Salinity, Wettability of the nanoparticle, Concentration of the nanoparticles, Rock grain size, Clay content, Rate of injection, Reservoir permeability and Temperature.

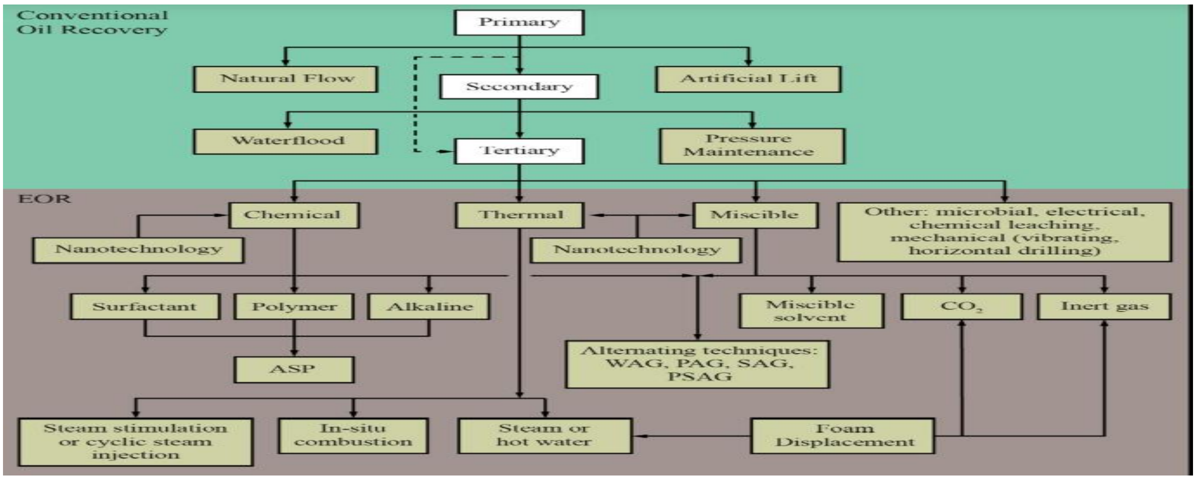

Figure 1: Enhanced oil recovery techniques [4]

Recently, many researchers have demonstrated the reliability of nanoparticle dispersed in different dispersing fluids in improving hydrocarbon recovery ([5], [6], [7], [8], [9]). [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 oxide are 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 nano flooding for EOR.

[6] did a research work on experimental investigation of the effect of using nanoparticle for improved oil recovery. They investigated Aluminum 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.

[7] 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.

[8] researched on the effect of Magnesium oxide, Aluminium Oxide and Silicon oxide in porous media at 45ºC and 3000 – 3500 Pisa. They reported that Aluminium oxide gave the highest recovery as to compare to other

nanoparticles investigated. The authors also mentioned that increase in nanoparticle concentration increases the oil recovery but decreases the permeability of the reservoir formation after the flooding procedures. They reported that only Aluminium Oxide is economical at 0.2wt%. The authors used brine as their dispersing agent and determined the permeability change after EOR flooding.

[9] 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 Aluminium Oxide and Silica Oxide.

[10] 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. 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], [6]). Therefore, this research work aimed at investigating copper oxide nanoparticle for enhanced oil recovery using different dispersing agents of brine and ethanol.

Factors Affecting Nano-Fluid Flooding Recovery

The choice of nanoparticles used: The choice of nanoparticles used for nano-fluid flooding determines the oil recovery factor and for typical reservoir conditions, the choice of appropriate nanoparticles is of great importance. Different nanoparticles have different characteristics on altering reservoir or fluid properties.

Concentration of the Nanoparticles: The nanoparticles concentration used when conducting a nano flooding assisted EOR process, is the most essential factor to consider irrespective of its bilateral influence on nano-fluid flooding [9]. On the other hand, an increase in the nanoparticles concentration results in a reduction in porosity and permeability of the reservoir rock due to the increased rate of nanoparticle deposition on the rock surfaces. Increase in nanoparticle concentration also increases oil displacement efficiency and this can occur due to the distribution of nanofluids on the surface and increases the viscosity of fluid ([2], [11]).

Size of nanoparticles: Size of nanoparticles and the corresponding charge density also affect the disjoining pressure. The smaller the size of nanoparticles, the higher the repulsive force and thus the higher the disjoining pressure that exist between them. The size of nanoparticles should be in the range, it cannot be big to be trapped or too small to cause log-jamming [12].

Salinity: Ideally, the stability of nanoparticles reduces as the salinity of the system increases. In fact, increasing the salinity of the system, causes a reduction in zeta potential and hence, results in agglomeration of colloidal particles. This is due to the lack of modification of nanoparticles that maintains the disjoining pressure functionality and stability in this environment. However, increasing the salinity of the system by adding different ions doesn't prevent nanoparticles from its movement, rather, it significantly increases the deposition of nanoparticles on the rock surfaces ([13], [14]).

Dispersing Agent: The type of base fluid also has effect on the functionality of nanoparticles. Some of the dispersing fluids are distilled water, diesel, brine, and ethanol. Some of this dispersing fluid has characteristics of increasing viscosity, alteration of rock wettability and aids in giving better homogeneity with nanoparticle ([5], [[6]).

Rate of injection: As the rate of injection increases, smaller molecules of water will accelerate faster than nanoparticles, resulting in agglomeration of nanoparticles, blocking pore throat, and thus reducing oil production. So, it is expected that as the rate of injection increases, the nanofluid injection effect on oil recovery will be reduced due to particle agglomeration and pore blockages and its resulting permeability decline, leading to decrease in oil recovery factor ([15], [2]).

Characteristics of Nanoparticles

Nanoparticles used for enhanced oil recovery show some important and useful characteristics when compared to the injection fluid used in conventional enhanced oil recovery applications.

- Nanoparticles can move easily in porous media where conventional injection fluids like polymer and, surfactant are unable to access without much retention and plugging of the pore throats when the fluid is properly formulated with the right dispersing agent.
- They are economically cheaper and have low cost of installation than the conventional injection fluid, hence they can be extensively used in petroleum industry for enhanced oil recovery application as to make more profit.
- Nanoparticles used for enhanced oil recovery application are environmentally friendly compared to the conventional chemical enhanced oil recovery and hence pollution is highly reduced.
- They can be easily modified to improve rheological properties and enhance oil recovery.
- They create wedge film or structural disjoining pressure to sweep the oil droplets from rock surface. ([15], [8]).
- Nanoparticles are resistant to degradation in oil and gas reservoirs with high temperature and salinity.
- They can remain free or bound together depending on the attractive and repulsive forces.
- Nanoparticles have both high surface-area-to-volume ratio and chemical reactivity ([16], [17])
- They have unique physio-chemical and mechanical properties ([18], [19]).
- The nanoparticles also show thermal stability at higher reservoir temperature ([20], [21]).

2. Materials and Equipment Used

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 used in conducting this experiment include Niger-Delta sand, unconsolidated sand-packs, nanofluids, copper oxide nanoparticles, aluminium foils, masking tape, industrial salt (NaCl), laboratory prepared brine and crude oil. 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 20^{o}C.

Preparation of Laboratory Brine: The brine was prepared using 29.52g industrial sodium chloride (NaCl) and 0.48g potassium Chloride (KCl) in 1000liters of distilled water. The density of the formulated brine is 1.0211g/cm^3.

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

Experimental Procedure

i. The seven unconsolidated Niger - Delta core (plug) samples labeled P1 to P7 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 2.
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 4.

v. The porosity was determined by using the result obtained from bulk volume (Table 2) and pore volume (Table 4) 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 oil recovered 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 Table 5 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 5.

Pore Volume Equation: $PV = \frac{W_{sat.plug} - Weight_{dry\ plug}}{P_{NaCl}}$ (1)

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

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

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

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

3. Results and Discussion

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

ormation Petrophysical Properties

The bulk volume for the various plug samples as indicated in Table 1 presented the total sand volume used to form the plug sample excluding the volume of the screen. 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 55.33 to 72.59 cm^3 as shown in the Table 1. The plug sample P6 has the lowest bulk volume while P5 has the highest bulk volume.

Table 1: Bulk Volume of Encapsulated Plug

Plug samples ID	Screen thickness (cm)	Total length of plug (cm)	Actual length of plug (cm)	Plug diameter (cm)	Plug radius (cm)	Bulk volume (cm^3) $\pi r^2 h$
P1	0.03	7.76	7.73	3.36	1.68	68.54
P2	0.03	7.92	7/89	3.37	1.69	70.79
P3	0.03	7.73	7.73	3.36	1.68	68.27
P4	0.03	8.07	8.04	3.34	1.69	70.4
P5	0.03	8.12	8.09	3.34	1.69	72.59
P6	0.03	6.27	6.24	3.36	1.68	55.33
P7	0.03	7.23	7.2	3.37	1.69	64.60

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 of the core samples varies from 26.71 to 33.09cm^3 (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 results as determined from Table 2 and Equation 2 is represented in Table 2.

Table 2: Pore Volume of the Plug Samples

Plug samples ID	Wt. of screen + foil (g)	Wt. of screen + foil +dry plug (g)	Wt. of dry plug (g)	Wt. of screen + foil+ saturated plug (g)	Wt. of saturation within the plug (g)	Density of sat. fluid +NaCl/KCl 30000 ppm(g/cm^3)	Pore volume cm^3	Porosity (%)
P1	33.11	149.98	116.87	179.08	29.10	1.0211	28.50	42.95
P2	32.93	156.73	123.80	187.78	31.05	1.0211	30.41	41.31
P3	33.83	152.88	123.05	185.68	28.80	1.0211	28.20	43.65
P4	32.33	160.88	128.55	192..28	31.40	1.0211	30.75	45.58
P5	30.98	156.99	126.01	190.78	33.79	1.0211	30.09	42.11
P6	25.09	124.23	99.14	148.02	23.79	1.0211	23.30	41.35
P7	29.63	139.24	109.61	166.51	27.27	1.0211	26.71	41.58

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

Fluid samples ID	Fluid conc.	Wt. of density bottle (g)	Wt. of bottle + fluid (g)	Wt. of fluid (g)	Volume of density bottle (ml)	Density of fluid (g/cm^3)	PH Values
F1	0.2wt% CuO /brine	23.31	79.95	56.64	56.05	1.0105	8.1
F2	0.4wt% CuO/brine	23.31	79.97	56.66	56.05	1.0109	8.4
F3	0.6wt% CuO/brine	23.31	79.98	56.67	56.05	1.0111	8.4
F4	0.2wt% CuO/ethanol	23.31	77.60	54.29	56.05	0.9686	8.1
F5	0.4wt% CuO/ethanol	23.31	75.21	51.90	56.05	0.9260	7.3
F6	0.6wt% CuO/ethanol	23.31	75.27	51.90	56.05	0.9270	7.4
F7	0.8wt% CuO/ethanol	23.31	75.75	52.44	56.05	0.9356	7.5
Brine	30,000ppm	23.31	80.54	57.53	56.05	1.0211	7.3
Oil	33.99^{0}API	23.31	73.48	50.17	56.05	0.8951	-

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 4. The crude oil sample has the viscosity of 43.0224cp, brine has 5.2053cp, the viscosity of various nanofluids concentration ranges from 15.148 to 2.9858cp. It was also observed that the viscosity of ethanol nanofluids has higher viscosity than brine nanofluids.

Table 4: Experimental Result of Viscosity of the Nanofluids Samples and Crude Oil

Fluid samples ID	Temp. (^OC)	Efflux time (sec)	Density of fluid g/cm^3	Viscometer constant 150/60lb	Kinematic viscosity	Dynamic viscosity Cp
F1	30.00	82.00	1.0105	0.03641240	2.9858	3.0172
F2	30.00	131.0	1.0109	0.03641240	4.7700	4.8220
F3	30.00	163.0	1.0111	0.03641240	5.9352	6.0011
F4	30.00	158.0	1.0125	0.03641240	5.7532	5.5725
F5	30.00	170.0	0.9260	0.03641240	6.3358	5.8669
F6	30.00	247.0	0.9270	0.03641240	8.9939	8.3373
F7	30.00	416.0	0.9256	0.03641240	15.1476	14.172
Brine	30.00	140.0	1.0211	0.03641240	5.0977	5.2053
Oil	30.00	1320	0.8951	0.03641240	48.064	43.022

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 0.9091 cm^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 5.

Table 5: Result for Permeability of the Plug Sample

Plug sample ID	Q cm^3/sec	Viscosity of brine 15000 ppm (cp)	Length of plug (cm)	Plug radius (cm)	Area (cm^2)	Δρ (psi) Before EOR	Δρ (psi) After EOR	Permeability K(md) x 14700	
P1	0.9091	5.2053	7.75	1.68	99.33	2.5	3.0	0.1231	2165.31
P2	0.9091	5.2053	7.70	1.68	99.01	2.5	3.5	0.1246	2163.93
P3	0.9091	5.2053	7.89	1.69	101.73	2.5	3.0	0.1474	2157.96
P4	0.9091	5.2053	8.04	1.67	101.87	3.0	3.0	0.1476	1830.05
P5	0.9091	5.2053	8.09	1.69	103.85	3.0	3.0	0.1474	1830.05
P6	0.9091	5.2053	6.24	1.68	83.60	2.5	3.0	0.149	2706.89
P7	0.9091	5.2053	7.20	1.69	94.40	2.5	3.0	0.147	2122.78

Recovery of Crude Oil Using Brine and Ethanol as Dispersing Agents

At the end of secondary and tertiary flooding, results obtained from the laboratory experiments for copper (11) oxide nanoparticle using different dispersing agents of brine and ethanol are showed in the Table 6. The percentage of oil recovered during the secondary flooding process ranges from 45% to 60% indicating that up to 35% - 50% 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 85.71% to 74.84% than those nanoparticles prepared with brine which gave a cumulative oil recovery of 75% to 74%. The result from tertiary recovery showed that sample- F4 with the concentration of 0.2wt% of copper (11) oxide dispersed in ethanol gave the highest cumulative recovery of 85% as to compare to samples- F1 that contain 0.2wt% of copper (11) oxide dispersed in brine that gave cumulative recovery of 75%. Sample- P5 that contain 0.4wt% of copper (11) oxide in ethanol equally performed better than sample- P2 that has the same concentration both in terms of oil recovered and permeability change. This is because copper (11) oxide alters the wettability of the rock and ethanol helped in reducing the interfacial tension between oil and water. The experimental work also revealed that ethanol gave a better homogeneity than brine, which helped in proper sweeping of reservoir pore throats, and accounts for good behavior in reducing formation damage. The result also shows that increasing nanoparticles in both dispersing agents of brine and ethanol reduces the oil recovery. Sample- P7 (0.8wt%CuO/ethanol) which has the highest concentration of nanoparticle in ethanol gave the lowest recovery of 75.58% and sample- P3 that contains 0.6wt%CuO brine has the lowest recovery of 74%. The result agrees with the findings of ([5], [6]) that ethanol is a very good surfactant nanofluids formulations.

Table 6: Summary of the Oil Recovery Processes

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 (%)
P1	24.00	52.00	7.50	15.00	F1	3.00	18.00	6.00	75.00
P2	27.00	60.00	8.00	16.00	F2	4.00	20.00	7.00	74.01
P3	25.00	56.00	7.80	16.00	F3	2.50	20.00	5.00	74.00
P4	21.00	61.00	8.00	16.00	F4	3.00	19.00	8.00	85.71
P5	29.00	62.00	8.00	18.00	F5	5.00	22.00	7.00	82.50
P6	20.00	41.00	7.00	13.00	F6	3.50	16.00	4.00	78.26
P7	23.00	47.00	7.80	15.00	F7	3.00	18.00	5.00	75.84

From this experimental study, it can be found that the dispersing agents has a big effect on hydrocarbon properties and reservoir rock formation. (Figures 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. Figures 2 and 3 show that at higher concentrations of nanoparticle, oil recovery decreases and higher permeability damage due to blockage of pore volume with aggregated nanoparticles. It was also observed that copper oxide when dispersed in brine and ethanol increased the PH value and it affected recovery quit positively (Figure 4).

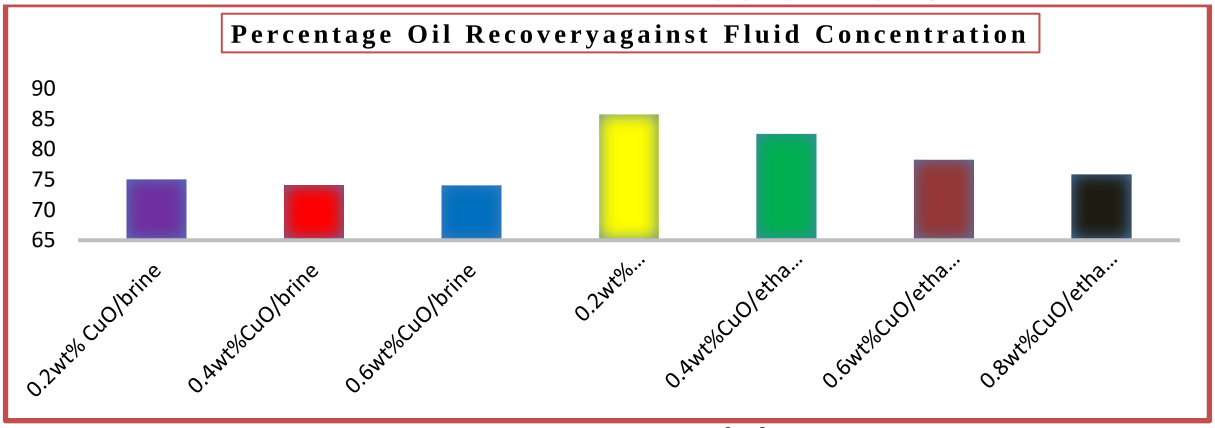

Figure 2: Percentage recovery against Fluid concentrations

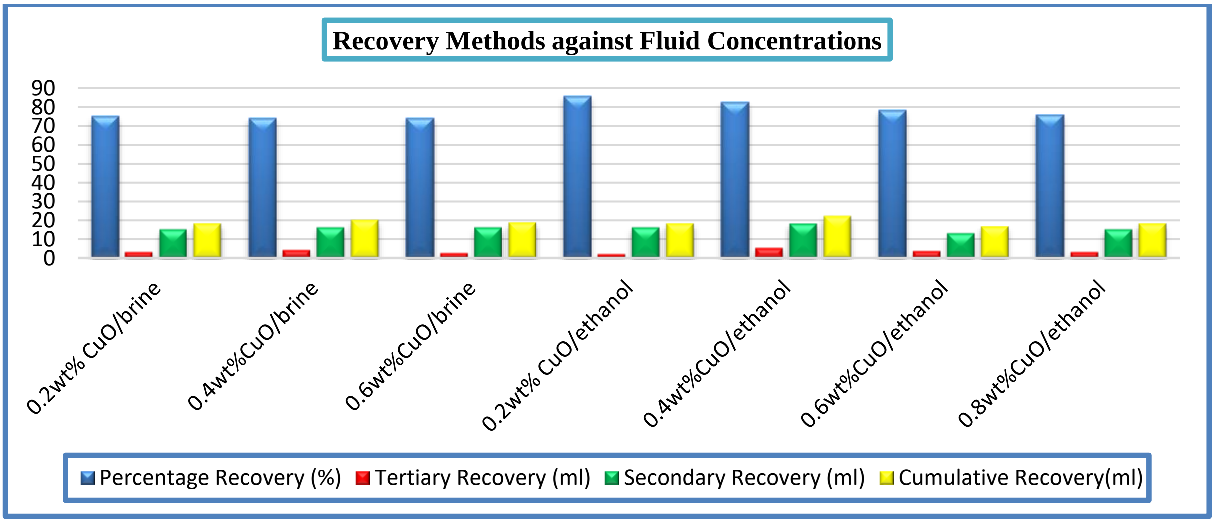

Figure 3: Secondary, Tertiary, Cumulative recovery against Fluid concentrations

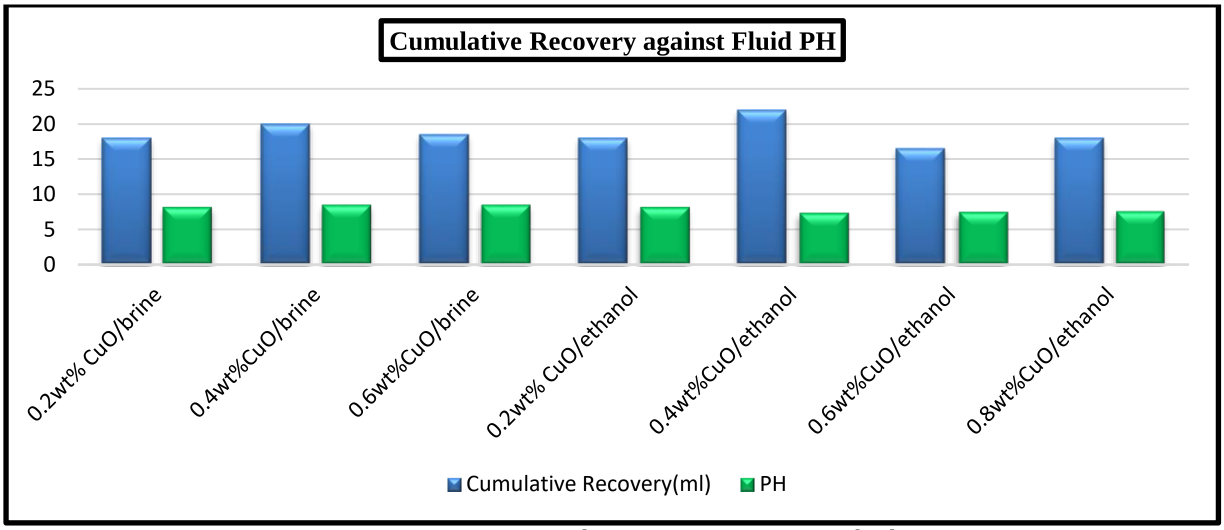

Figure 4: Percentage Cumulative Recovery against Fluid PH

Permeability Change Result

After the secondary and tertiary flooding, the core's permeability change was determined as to evaluate the extent of formation damage caused by nanoparticles. There is a significant decrease in permeability of the reservoir formation after flooding with different nanofluids. The nanofluids with brine dispersing agent has high reduction in permeability as to compare to the nanoparticle dispersed in ethanol. Figure 5 shows the change in permeability for all the EOR agents studied. Permeability alteration for all the nanofluids concentrations evaluated ranges from 238.14 md to 815.93 md. The lowest value of 238.14 md permeability change was gotten from concentration of 0.2wt% of copper oxide in ethanol and the highest permeability change value was gotten from 0.6wt% of CuO in brine. 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.

Table 7: Permeability Change with Difference Nanofluids Concentrations

Nanofluids Concentrations	k_i (mD)	k_i (mD)	$\Delta K = K_i - K_f$ (mD)	Cumulative Oil Recovery (%)
0.2wt% CuO/Brine	2165.31	1705.16	460.15	75.00
0.4wt%CuO/Brine	2163.95	1493.19	670.76	74.07
0.6wt%CuO/brine	2157.96	1342.02	815.93	74.00
0.2wt% CuO/ethanol	1830.05	1568.49	238.14	85.71
0.4wt%CuO/ethanol	1806.63	1547.91	258.72	82.50
0.6wt%CuO/ethanol	2706.89	2374.76	332.13	78.26
0.8wt%CuO/ethanol	2122.68	1768.41	354.27	75.86

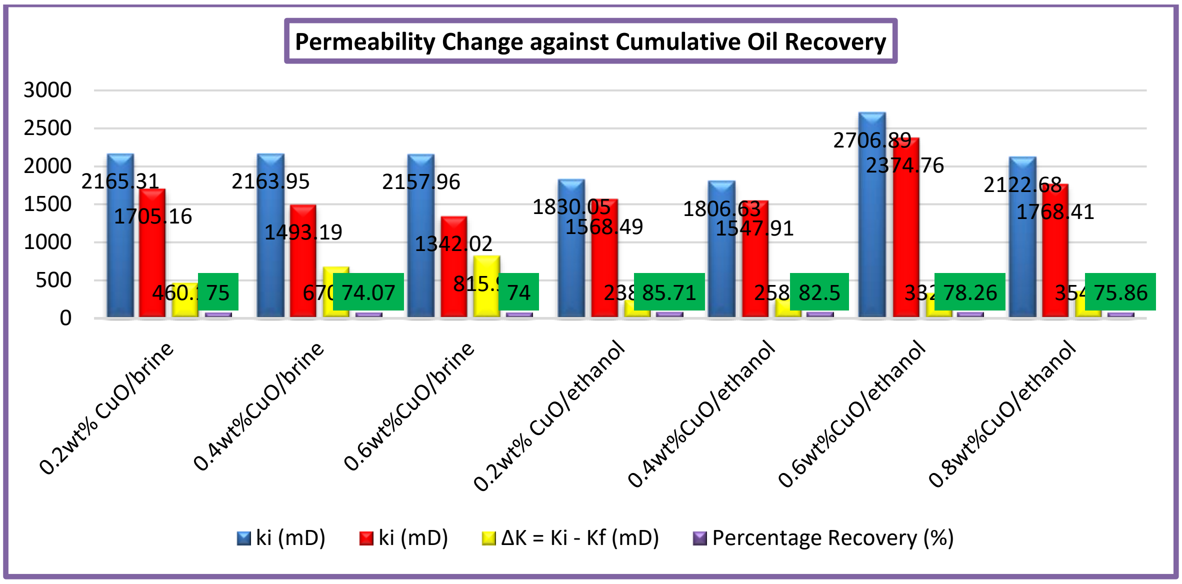

Figure 5: Permeability Change against Recovery against Different Nanofluids

4. Conclusion

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

- Dispersing agent has effect on the use of nanoparticle for EOR.
- The nanofluids of copper 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 0.2wt% of copper oxide in ethanol gave the highest recovery of 85.71% and lower saturation value 238.14mD.
- Increase in concentration of nanoparticle for both dispersing agents of brine and ethanol reduces oil produced and increases permeability change.
- Increase in concentration of nanoparticle for both dispersing agents of brine and ethanol reduces oil produced and increases permeability change.
- 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, for enhanced oil recovery design project.
- The concentration of nanoparticle in the dispersing fluid is a paramount factor to consider when designing EOR projects nanoparticles.

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