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Investigating the Effect of Copper Oxides and Alumina Nanoparticles on Enhanced Oil Recovery in Carbonate Reservoirs

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Abstract

Traditional methods of oil production like primary recovery and conventional secondary recovery mechanisms such as (Basic water flooding) cannot produce more than 35 % of OOIP. With appearing of nanotechnology lots of certain research mentioned that this technology can change and improve from traditional methods of oil production and it can help in enhanced from oil recovery factor. Then in the last few years, lots of papers are addressed the title of using nanotechnology in EOR, but until now it is not very clear.

The main objective of this paper is to investigate the effect of nanoparticle to enhance the oil recovery factor and change the wettability of formation. Nanoparticles will be applied to crude oil and porous media by flooding mechanism. These nanoparticles are copper oxide and alumina. Eight limestone core samples will be used in this experiment and the flooding process will be done by using a core flood system. The displacing fluid will be prepared by using solutions of copper oxide and alumina nanoparticles at concentrations of (0.0125, 0.025, 0.07, and 0.5 wt%) and (0.01, 0.05, 0.1, and 0.5 wt%) respectively, then it will be used in flooding the core samples containing crude oil with viscosity of 3.25 cp. The sizes of used nanoparticles are from 30 to 50 nm for copper oxide and 5 for alumina. Each case of nano flooding will be compared with the basic flooding of water injection with a salinity of 50,000 ppm.

The paper indicates that copper oxide and alumina nanoparticles at low concentrations have the best results more than high concentrations. Copper oxide at a concentration of 0.0125 wt% has a large ability to change from formation wettability to be more water wet. Alumina nanoparticle at concentration of 0.01 wt% and copper oxide nanoparticle at concentration of 0.0125% have the best results in increasing the oil recovery factor by percentage of 24%.

Keywords: *Nano; Copper; Alumina; Flooding; Carbonate reservoir; Enhanced.*

1. Introduction

The process of enhanced oil recovery shows a huge result in recovered trapped stranded oil at the pores of the reservoir after applied the recovery methods of primary and secondary techniques by using techniques of driven snap-off and capillary pressure. These techniques recover two-third of the original oil in place, methods of EOR have a big impact on oil production as increasing only 1% in recovery factor can produce about 70 billion barrels from conventional oil reserve. EOR uses lots of technologies and processes that working on increasing the recovery factor of oil from the existing reservoirs. These processes contain injection of fluids and recently injection of microbes to support the natural energy of the reservoir and make an effective displacement of oil into the production well, as a result of this injection there are interactions occurred between the fluids of injection and rocks/oil of the reservoir, these interactions make a favorable conditions for oil production [1-3].

Nanotechnology is one of the most important discoveries that have occurred in the field of industry, especially in the oil and gas industry, because this technology has revolutionized many innovations related to aspects of the oil and gas industry. The material of the Nano is characterized by having high concentrated volume and large surface area. These dimensional effects have given them distinct magnetic, mechanical, thermal, and chemical properties. The nanomaterials are also distinguished as they are treated as a chemical treatment. Their properties can be modified for a specific technical purpose [4-7].

Lots of current researchers and papers show the importance of using nanotechnology and nanomaterials in the oil and gas industry [8-10] because using this technology in this field provides many solutions to technical problems and economic problems. For example, using applications of nanotechnology in reservoir enhanced from oil recovery at 60% better than traditional methods. These enhanced oil recoveries are happened due to lots of mechanisms that occurred by nanomaterials such as the reduction in viscosity of heavy oil, oil/water wettability alteration and reduction in interfacial tension between oil and water. The nanomaterials are also used in increasing from veracity and accuracy of equipment because they are used as a coat for the surface of equipment or it can be used as a sensor for increased sensitivity of the equipment. Nanotechnology is used for reducing the volume of fluid loss and increasing the quality of mud by adding nanomaterial to drilling fluid. It also can be used for keeping the viscosity of the fluid system stable by maintaining rheological properties, and the more important is using nanomaterial to keep shale formation stable during drilling with water-based mud. Emulsifier of nanomaterial work on increase temperature of application and stability of the oil-based fluid system. All these advantages of nanotechnology make it one of the most important discoveries in the field of oil and gas industry [11-12]. The cost of nanomaterials is not cheap, but it is useful in the oil and gas industry. Therefore, this technology must be researched and developed to improve and facilitate oil and gas extraction operations**.**

2. History of nanotechnology

Nanotechnology is considered one of the most important recent scientific developments in the field of scientific research, because it's a result of great development in scientific concepts and laboratory experiments, although the evolution of its central concepts occurred over long periods. The germination of nanotechnology began in the 1980s due to concourse of experimental advance such as invented of tunneling microscope scanning in 1981 and fullerenes discover in 1985, and with the beginning of the development of nanotechnology and the knowledge of scientific importance, it was the beginning to work on the development of a framework to benefit from them in practical life. So with the beginning of 1986, a book published called engines of creation, and in the early of 2000s this field has become the focus of public awareness and With the increasing of scientific discussions in this field and work on getting the benefit of using this technology in the applications of life and various industries, governments and investors began to finance and encourage specialized research in the field of nanotechnology, and with this great development in this field, the commercial application of nanotechnology appeared in the first decade of the 2000s [13-14].

In general, to clarify and understand how nanotechnology works, it can be described as materials that allow it to be controlled and not only to produce nanomaterials but also to control their operation, which means, they are influenced according to their intended purpose. Nanotechnology was mentioned in 1959 in a session of American physical society by Mr. R. Feynman that is known as “There is a lot of space down there” that cleared we can create Nano products by using atoms as building particle. nowadays this lecture is known as the origin of the nanotechnology paradigm. The word “Nanotechnology” as we known as now was mentioned for the first time by N. Taniguchi into the scientific world in a conference of industrial production in Tokyo in 1974 to show the super accuracy with nanometer of processing material and create Nano-sized material. There have been many discoveries and researches that have a clear impact on the development of nanotechnology in the period from the second half of the 1980s to the early 1990s, since then, the number of researches dealing with this subject has been increasing and the practical application of this technique has been growing [15-16].

In 1991 the first nanotechnology program of national scientific was taken place in the USA. Then in 2001 is the date of approved national nanotechnology initiative (NNI) that worked on introduced nanotechnology in the USA industry. Also, in japan nanotechnology had big attention as the USA, in 2000 Japanese Economic Association created a special department on nanotechnology under the auspices of the Technical and industrial Committee and in 2001 they worked on developed plan research of nanotechnology by increasing the research center and encourages investors to apply the result of this research in industry. And as it was in the USA and JAPENESE the other countries such as (Western Europe, South Korea, China, and else…) take the same direction of research, encourage, and invest in developing and applying nanotechnology in industries [17-18].

To realize the importance of nanotechnology and the importance of working on developing it and to realize its impact on the future of the industry and other fields, let's define the physical meaning of nanotechnology and know the technique of it. Nanotechnology define as Nanotechnology is defined as a technique that can control and reconstitute matter at different atomic and molecular ranges from 1 to 100 nanometers, this makes it able to control the properties of that substance and exploit its distinct phenomena unlike those associated with loose behavior, single atoms or molecules. These special characteristics make us able to control the geometry of the small structure of the material leading to the establishment of new devices and systems, this change is considered to be the maximum attainable in terms of economic characteristics as well as the maximum efficiency of the material in terms of molecular medicine and manufacturing. This principle is closely related to many different fields and has helped to build a unified platform for engineering, technology and different sciences on the Nanoscale, and with this technology, we have been able to change the behavior of atoms and molecules from a single behavior to collective behavior [4, 19].

3. Application of nanotechnology in the oil and gas industry

Since the discovery of nanotechnology in the 1980s, and it has had a major impact on all disciplines of biology, chemistry, physics, mechanics, and material balance to provide a new platform for solving complex problems. The nanomaterials are described as crystals, sheets, rods, and particles with size ranging from 1 to 100 nm, and it provides practical application in lots of industrial sectors, as we will see in this research their impact on the oil and gas industry. After the development of nanotechnology, it becomes reliable in the oil and gas industry to solve the complex problem in the oil field and chiefly to improve oil recovery, the trend towards the use of nanotechnology has become significant, especially in the last 5 years. Several theoretical and scientific studies have been created to develop these industries. And now we will study the effect of this technology on exploration, drilling, and extraction [20-22].

Applications of nanotechnology are applied widely in many regions of oil and gas development and exploration, And nanotechnology has surpassed many other technologies that are used in exploration, so it is constantly being developed to increase oil and gas sources and it will be applied developed to the following aspects.

- Nano-characterization and numerical simulation: this technique provides an accurate reference in the analysis and description of the reservoir and helps greatly in decision-making [6, 23].
- Nano-sensing technology: this technology using a black box decoding of the oil reservoir. Nano-robot has extremely accurate sensors, so it is the best way to detect where the oil is and how it is spreading [24-25].
- Nanomaterials: there are lots of applications on nanomaterial as it works as catalysts to facilitate the exploration, drilling and extraction process [26-28].

Nanotechnology has a significant impact on the process of drilling and completion, as it helps in solving the complex problem, especially the problem that related to formation and environment. There are some applications of using nanotechnologies and nanomaterial in drilling and completion [27]:

- Nano-fluid: adding nanomaterials into drilling fluids helps in stabilizing the wellbore as particles of Nano form filter cake on the wellbore to reduce from the wellbore collapse and water swilling, also it helps in reduce filter loss as a nanoparticle works on seal pores of the wellbore to reduce fluid losses, helps in improving rheology by increase viscosity and shearing force of the system, and finally increase the thermal stability of drilling system [29-32].

- Nanocomposite: it helps in develop equipment of drilling to be lighter and more reliable and reduces fluid invasion into shales [33-34].
- Nano coating: helps in resist corrosion of drilling equipment, higher quality of drilling component and make it stronger [11, 35-36].

The idea of this technology is to add nanomaterial into based water fluid to generate Nanofluids, it can be used with and without chemicals to improve from oil recovery. There are lots of papers and researches that are published about this mechanism and the results seem very interesting. Lots of published papers, the results of experimental works indicate the possibility of increasing and improve the recovery of oil by using nano-fluids. It also noticed that the percentage of EOR is depending on some main properties of nano-fluids such as (types of material, percentage of concentration, and size of the particle). According to there are lots of different mechanisms that can be applied in EOR by using nano-fluids. These mechanisms are: (reduction in interfacial tension, increase in the viscosity of the aqueous solution, wettability alteration, disjoining pressure changes, slug-like displacement, decrease viscosity of the oil, log jamming, and combination between different mechanisms). The next slide will analyze each of these mechanisms to define how it works and the expected problems.

4. Mechanisms of using nano-fluids in wettability alteration

Wettability [37-39] has a significant impact on the percentage of oil recovery. Some nanomaterials can change the wettability of oil-rock-water systems by buildup wedge film structure in contact of three phases. Nanoparticles create a wetting wedge between oil bubbles and solid surfaces to help in separate oil bubbles from the surface and change the wettability of the system to be water wet, as shown in Figure 1.

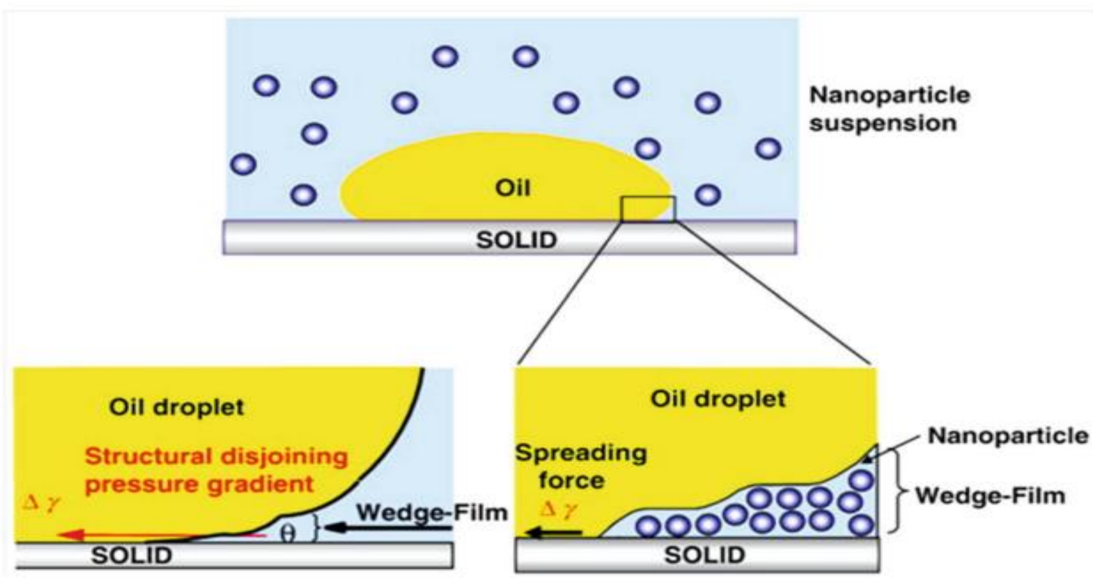

Figure 1 Nanoparticles creates wedge-film structure

The angle of contact between n-heptane and water on calcite clean plates in oil was 180 degrees. By using zirconium oxide nanoparticle (Zio2) with concentration (0.05%, and 0.10%) and size 24nm this angle between n-heptane and water is changed according to the type of concentration used in treatment from 180 to 32 degree to change the wettability of rock from oil-wet to strongly water-wet. And the experiment mentioned that angles between n-heptane and water reduce with increasing aging time and to achieve the best alteration aging time should not be less than 48hr [40].

5. Applications of nano-fluids to reduce interfacial tension

The reduction of interfacial tension between oil and water is considered one of the important factors that affect the efficiency of oil recovery. Lots of papers are mentioned that using nano-fluids in EOR shows good results in reduced interfacial tension. The effect of nanoparticles and Nio/SiO_2 nanocomposites to reduce the interfacial tension and surface tension (S.T) for a sample of heavy oil produced from Soroush field located in Iran with 1310 cP of viscosity, 0.965 g/cm^3 of density was investigated by some researchers the interfacial tension between oil/water without nanoparticles was 29.02 mN/m at 22°C, the experiment was done by injecting nano-fluid water-based of 30 wt% SiO_2/Nio and 28 wt% Fe@ SiO_2/Nio. The results of the experiment are decreased in IFT to 1.28 mN/m and less than 1 mN/m and with repeat the experiment by addition of concentration, salinity and aging time they found that the pest concentration to reduce the IFT and S.T is 30wt% of SiO_2/Nio in diluted water [22, 37].

5.1. Applications of nano-fluids to increase the viscosity of the aqueous solution

Increasing viscosity of the aqueous solution is a very important factor in EOR, as it plays an important role in increasing the efficiency of oil displacement and oil swilling. Many papers made researches about how to increase the viscosity of water by using nanoparticles. According to [41], nanoparticles could increase the viscosity of aqueous solution with 100%, for example, the viscosity of sulphanole solution increase from 1 cP to 2 cP by adding 0.01wt% of nanoparticles. Verag mentioned that nanoparticles can be used to improve interventions of water-flooding to different strong permeability zones that effect on displacement of oil, by adding capsules of nanomaterial during injection to increase the viscosity of water [42].

5.2. Applications of nano-fluids to decrease oil viscosity at reservoir conditions

Oil viscosity is one of the main factors that affect oil recovery, so many petroleum institutes are researched about how to apply nanotechnology to reduce the viscosity of heavy oil. The next slide will show some of these researches and experiments.

According to [43], they worked on research about reducing the viscosity of heavy oil by using nanoparticles. The research involved two different experiments, the first experiment depends on inject surfactant-based fluid with nanoparticles into the oil sample, and the second one depends on examined the effect of copper oxide nanoparticle without surfactant-based fluid. Copper oxide (CuO) nanoparticles are selected due to their easy availability, low cost, and high thermal conductivity. The experiment is done on two different samples of heavy oil with different viscosities produced from wells located in Oklahoma, USA. Oil samples are mixed with an emulsion of copper oxide nanoparticles at different concentrations with 50nm particle size. The results of this experiment refer to 0.1wt% of CuO nanoparticles with size 50nm give the best reduction in oil viscosity and it is expected to give a more positive result with using Cuo nanoparticles with concentration 0.02wt%.

According to [44], to solve the problems of reservoirs by using nanotechnology, they study the effect of some different materials of nanoparticles on oil reservoirs. These experiments are depending on two conducted sets. the first one is displacing the oil with injected nanofluid and the second one is to soak the sand in nanofluid for 60 days before starting displacement process.

This experiment is done by an oil sample with 0.9114g/cc of density, 53.27735cP of viscosity, and 22.44 API. The result of this experiment shows:

- Nanoparticles of aluminum oxide improve oil recovery by reducing oil viscosity.
- Saline and hydrophobic silicon oxide dispersed in ethanol improve oil recovery by change rock wettability.
- Ethanol without nanoparticle enhances oil recovery by reducing interfacial tension.
- Types of dispersion fluids very important factors to improve oil recovery.
- Magnesium and zinc oxide make permeability problems and show low recovery results.

6. Experimental work

As mentioned before, the main purpose of this paper is to find the best way to improve the oil recovery factor, and this is done by changing the properties of crude oil by applying different types of nanomaterials at different concentrations on crude oil. These nanomaterials will be applied by using the strategy of nano flooding techniques, this strategy is mentioned in lots of certain researches and it works on improving the technique of base water flood. As nanomaterials help in improve the properties of crude oil such as reducing the oil viscosity, reducing the interfacial tension, changing wettability, and…else.

6.1. Methodology

In the process of investigating the effect of nano particles on enhanced oil recovery (EOR), usually, the actual limestone cores of the reservoir are used in lab experiments to give the optimum evaluation of the effects of different displacing media and reservoir physical properties. Usually, there are three different sizes of samples in the laboratory: 3.8 cm core diameter, 2.8 cm core diameter, and full core diameter.

6.2. Core flood system

A core flood system is used to perform the flooding experiments. These experiments are helping in discover the mechanism of various flooding operations, improving the displacement efficiency, and providing a theoretical basis for oil industry development applications.

Figure 2. Core holder displacement system

The main technical parameters of the experimental flooding system with full diameter core are sample length, sample diameter, confining pressure, temperature, and displacement pressure.

The experimental flooding system with a full diameter core consists mainly of a full-diameter core holding system, a displacement system, and a metering system. The schematic diagram for the system is shown in Figure 2.

The core holding system is mainly consisting of a core holding cavity and a flip bracket. The core holding cavity is a bore designed to accommodate the core, it mainly consists of regulating plugs, sleeves of rubber, and cavity. The sleeves of rubber are in the cavity, and the core is in the sleeves of rubber. The sleeve diameter is slightly greater than the core diameter. When applied with confining pressure to the core holder, the core can be fully tightened to ensure that the displacing medium passes through the core. The system of the core holding consists of a bracket where the holder’s cavity can be flipped through. The main reason for the flip bracket is designed for cores with large diameters to make sure that the core will be fully displaced and fully saturated during the experiment.

The system of displacement consists of two kinds of displacement functions of liquid flooding and gas flooding. The system of gas flooding includes a nitrogen gas cylinder with high pressure, a relief valve, and a sensor for pressure. The gas is inserted from the high-pressure gas cylinder, and the required displacement pressure is controlled through the pressure relief valve. The process of displacement is work by press different media into the system of core holding by a pump. The flow rate and the pressure are determined by the requirement of each experiment. After the liquid passing through the core, the amount of fluid is measured at the outlet.

6.3. Sample preparation in the laboratory

The chosen samples for laboratory experiments are taken from limestone rock. Ten limestone cores are selected for cutting and grinding to make sure that each core has a cylindrical shape and the two ends are flush. According to standard of petroleum industry the cores must be washed then put in oven to be fully dried and usable.

6.4. Petrophysical properties for each limestone core sample

The core samples are dried and the length, the diameter and the dry weight are measured for each core sample and then the bulk volume is calculated. By using sodium chloride for preparing the brine with a concentration of 50,000 ppm, then this brine is used on the process of initiating the core sample to make it fully saturated with this brine. After making sure that the core became fully saturated with brine, measure the saturated weight of the core sample. By using the saturated weight and the dry weight of core, the pore volume is calculated and then the porosity is calculated.

To calculate the absolute permeability of the core, the core sample is put inside the core holder and the water is injected into the core sample by using the same brine water for 1 minute and using constant pressure, after 1minute measure the displaced water. Now calculate the absolute permeability of core sample by using this equation:

$$(absolute\ permeability\ (md) = \frac{\frac{water\ volume}{time}\times water\ viscosity\times length}{\frac{\pi}{4}d^2\times\frac{\Delta p}{14.7}}\times 1000$$

6.5. Core sample initiation

After finishing the first run, put crude oil in displacement tank (the viscosity of crude oil is 3.25 cP) to make oil displaces the brine water, this step is very important to simulate the initial conditions of the reservoir. The volume of displaced brine water equal to volume of crude oil enters to the core sample. to calculate the connate water of core sample, subtract the amount of oil enter to core sample from the total amount of water that injected initially to saturate the core sample. Now the core sample is having the same condition of reservoir and ready for the flooding.

6.6. Procedures of the experiment

1. Clean the core samples and put it in the oven to be fully dried
2. Measure the dry weight of each core, then measure the length and the diameter of each core.
3. Put the cores in the prepared brine water and put them with brine in a vacuum to be fully saturated with brine water. Measure the saturated weight of each core sample.
4. Calculate the pore volume of each core by subtracting the saturated weight from dry weight and divide the result on the density of brine water
5. Simulate the core sample with the reservoir, by injecting crude oil into the core to displace the brine water. Not all amount of water is displaced, the remaining water called connate water. The amount of oil entered the core is the same amount of water displaced from the core.
6. Inject displaced fluid into the core to displace crude oil. Measure the amount of oil recovery and recorded the time with each fraction of injected pore volume, to determine the flow rate and the effective permeability.
7. Determine the oil recovery factor and the change in wettability.

7. Results analysis and discussions

7.1. Water flooding scenario

This run considers the base run case, as it represents the conventional scenario of water flooding. In this scenario, the brine water is injected into the core sample to displace the oil. The injected brine water is divided into phases, these phases are (0.2, 0.4, 0.6, 0.8. 1. 1.2 1.4, 1.6) of the pore volume. After completing the brine injection, determine the amount of oil that is displaced at each stage to calculate the recovery factor, then construct relative permeability curve to determine if the formation is oil-wet or water-wet. This scenario is a reference scenario for each following case.

7.2. Nano-fluid scenarios

After constructing the reference scenario (conventional water flooding), the solutions of copper oxide and alumina nanoparticles are prepared to start the nanofluid flooding. The solutions of copper oxide and alumina are injected into the core samples at 4 different concentrations of (0.0125, 0.025, 0.07, and 0.5 wt %) for copper oxide and at concentrations of (0.0, 0.05, 0.1, and 0.5 wt %) for alumina. The flooding scenarios are done at 8 phases which are (0.2, 0.4, 0.6, 0.8, 1, 1.2, 1.4, 1.6) of pore volume. After completing each run, the oil recovery factor is calculated, and the relative permeability curve and fractional flow curve are constructed. Then each run is compared with the base run of the waterflooding case and the changes at each run and the effect of these changes on oil recovery are determined.

Nanotechnology has a large effect on alternate the wettability of formation. In this paper, the effect of injecting a solution of copper oxide and alumina nanoparticles at concentrations of (0.0125, 0.025, 0.07, and 0.5 wt%) and (0.01, 0.05, 0.1, and 0.5 wt%) respectively was investigated. The effect of each concentration is compared with the waterflood effect using three parameters. These parameters are oil recovery factor, relative permeability and fractional flow curve. It is founded that the copper oxide and alumina nanoparticles have a clear impact on wettability alteration, displacement efficiency and hence the oil recovery factor. The concentration of copper oxide and alumina nanomaterials play an important role in wettability alternation as shown in Figure 3. All alternation values are positive and these changes indicate to lead the rock to be more water wet than basic water flooding scenario. Copper oxide at concentrations of 0.07 and 0.025 wt%, and alumina at concentration of 0.01 wt% have all a great impact on changing the wettability of rock to be more water wet. But as shown in Figure 3, the better nanomaterial that made the highest changes in wettability of rock to be strongly water-wet is copper at the lowest concentration of 0.0125 wt%.

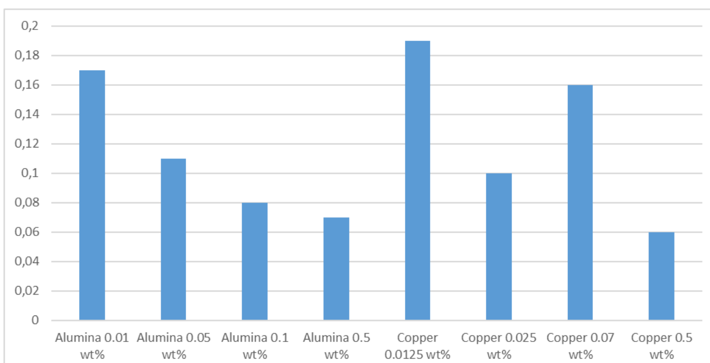

Figure 3. Percentage of rock wettability alteration

After completed the alumina flooding run at a concentration of 0.01%, the oil and water relative permeability curves are drawn. The intersection point of the two curves lies at water saturation of 69%. The results of relative permeability curve for the waterflooding case are compared with the results of the 0.01 wt% alumina flooding case, it is noticed that the wettability of reservoir is changed by 17% to be more water wet as shown in Figure4.

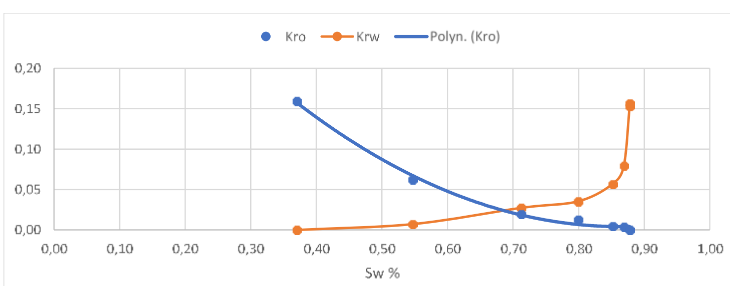

Figure 4. Relative permeability curve for 0.01 wt% alumina flooding

Also, the effect of copper oxide nanomaterial at a concentration of 0.0125 wt% on changing the wettability of formation is very clear, as the intersection point of the two curves changes from 61% for waterflooding scenario to 80% for 0.0125 wt% copper oxide flooding case and this indicates the wettability of formation becomes strongly water wet as depicted in Figure 5.

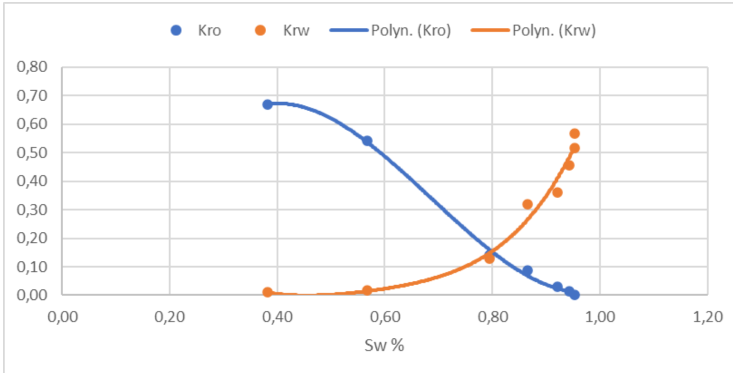

Figure 5. Relative permeability curves at 0.0125 wt% copper oxide

As shown in Figure 6, nanofluid has a good effect on enhanced oil recovery, but with a difference in the degree of enhancement according to the type of nanomaterial and its ability to enhance the reservoir rock and fluid properties on and according to the degree of the concentration. Figure 6 shows that nanofluids with low concentrations have more effect on enhanced oil recovery than nanofluid with high concentration.

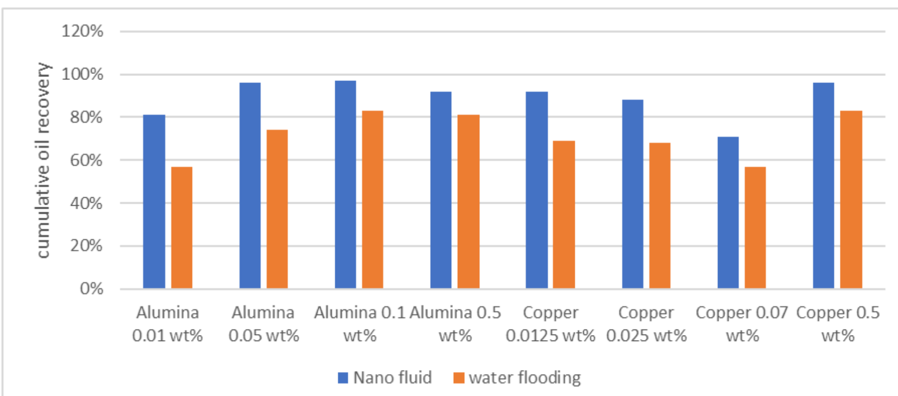

Figure 6. Water flooding VS Nano flooding

The effect of copper oxide nanomaterial at a concentration of 0.0125 wt% is very clear, as it is increasable from the ultimate oil recovery with a percentage up to 23% as shown in Figure 7.

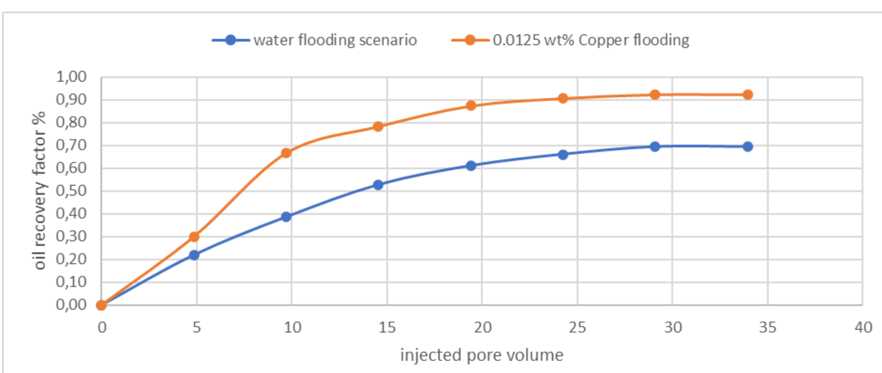

Figure 7. Effect of water flooding and 0.0125 wt% copper oxide on oil recovery

As shown in Figure 8, Alumina nanofluid has a noticeable effect on increasing the amount of production as it was able to produce 81% of the oil in the sample, and this percentage exceeds the traditional water injection with a difference of 24%.

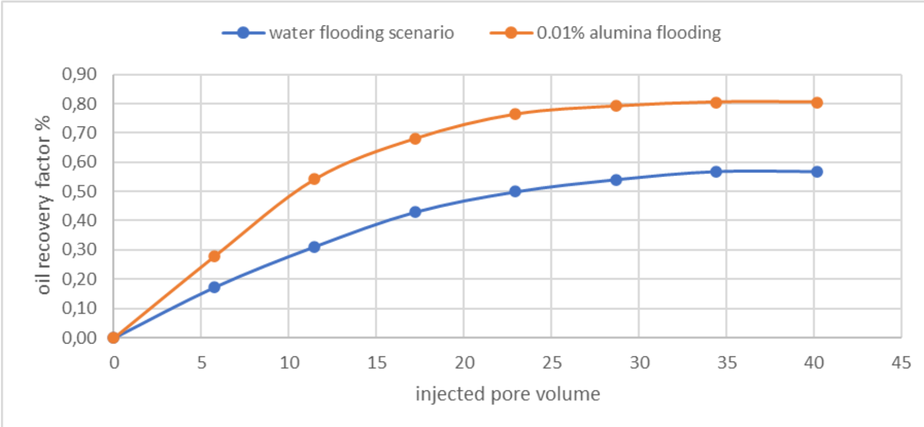

Figure 8. Effect of water flooding scenario and 0.01 wt% alumina on oil recovery

Figure 9 depicts that alumina flooding at a concentration 0.01 wt% and copper oxide flooding at concentration 0.0125 wt% have the highest enhanced to oil recovery factor, by increasing in oil recovery with a value up to 24% more than water flooding.

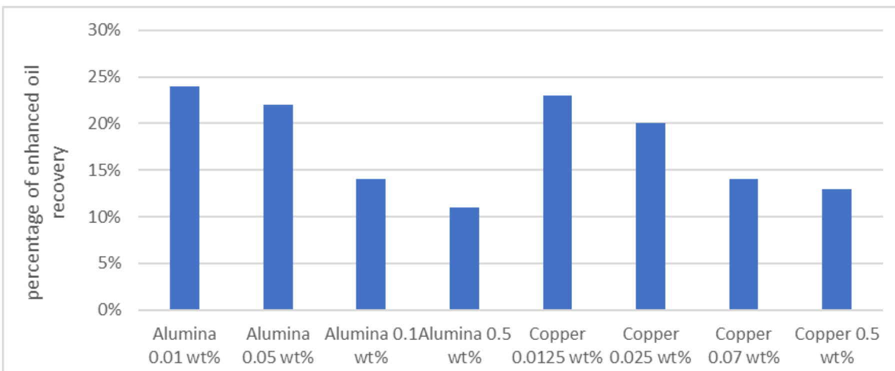

Figure 9. Incremental increase in oil recovery

As shown in Figures 10 & 11, nanoparticles have a big effect on improving the efficiency of displacement. The effect of nanoparticles is clear in the scenario of 0.0125 wt% copper oxide flooding and 0.01 wt% alumina flooding.

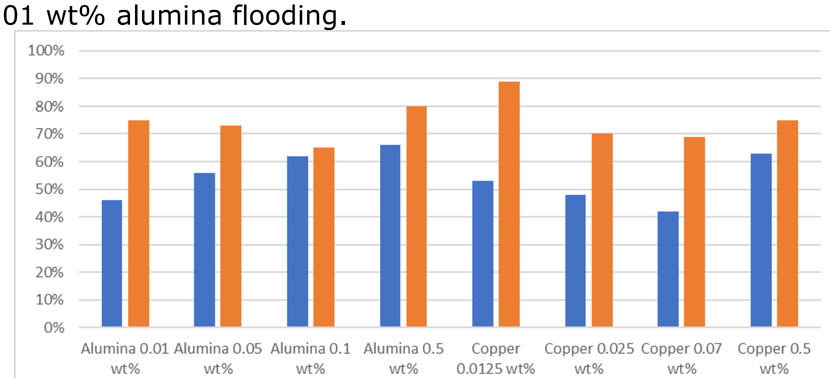

Figure 10. Displacement efficiency

At the scenario of 0.0125 wt%, copper oxide flooding the displacement efficiency was enhanced by 36% and in the scenario of 0.01 wt%, alumina flooding the displacement efficiency was enhanced by 29%.

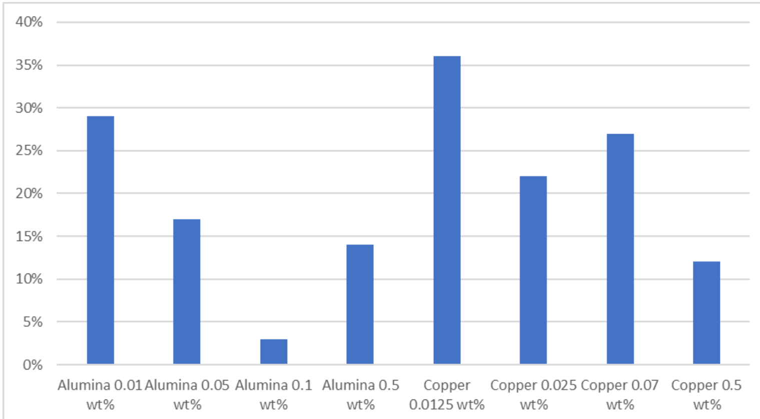

Figure 11. Changes in displacement efficiency

As shown in Figure 12, nanoparticles have a large effect on improving the initial water breakthrough.

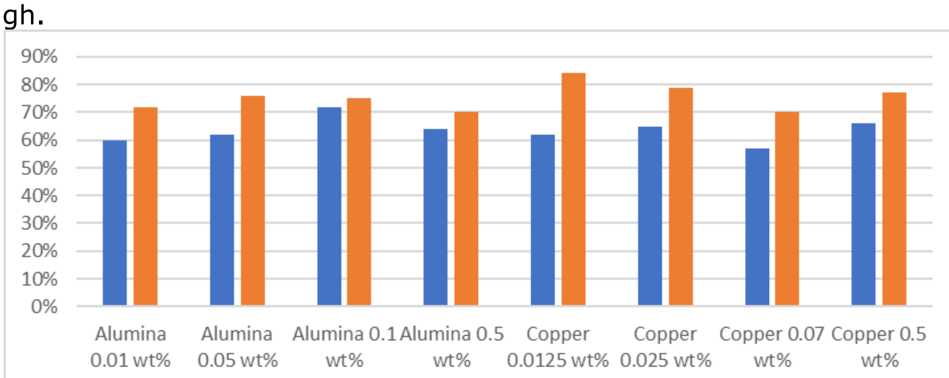

Figure 12. Water breakthrough

Fractional flow curve showing the displacement efficiency of 0.01% alumina scenario at 75% and the first water breakthrough at 71% as shown in Figure 13. Fractional flow curve for 0.0125 wt% copper oxide flooding shows the displacement efficiency is 89% and initial water breakthrough is 84% as shown in Figure 14.

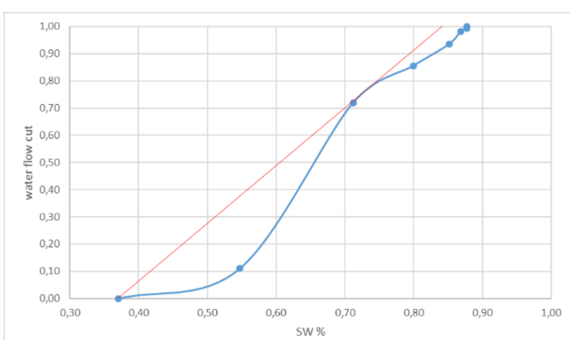

Figure 13. Fractional flow curve for 0.01 alumina flooding

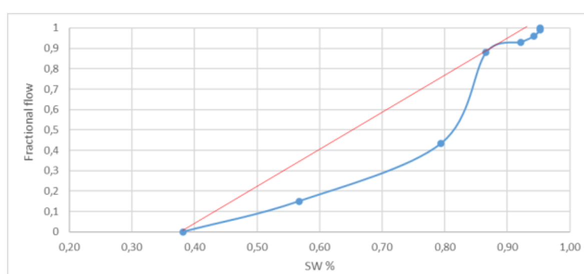

Figure 14. Fractional flow curve of 0.0125 wt% copper at core S56

8. Conclusions

Two types of nanomaterials at four different concentrations are used in this paper to investigate their effects on enhanced oil recovery. These materials are alumina nanoparticle and copper oxide nanoparticle at concentrations of (0.01, 0.05, 0.1, and 0.5) wt%, (0.0125, 0.025, 0.07, and 0.5) wt % respectively.

Alumina nanoparticle at concentration of 0.01 wt% and copper oxide nanoparticle at concentration of 0.0125% have the best results in increasing the oil recovery factor by percentage of 24%. Copper oxide nanomaterial at concentration of 0.0125 wt% has the best effect on changing wettability of the reservoir to be strongly water wet.

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