

# Laboratory Investigation on Enhancement of Niger Delta Crude using Carbon Dioxide and Silicon Oxide

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## Abstract –

Enhanced oil recovery is the process of artificially stimulating a reservoir to recover more oil after primary and secondary techniques have become unable to sustain desired production volumes. It is a process that increases the volume of crude oil that can be extracted from an oil field. It is usually done by injecting water or gas into the reservoir to increase pressure and drive crude oil out of the rock. This research work focused on the use of nanoparticle and gas to enhance crude. Enhanced oil recovery using gas (carbon dioxide) with nanoparticle (silicon oxide) was used in this research. The effect of silicon oxide and carbon dioxide on the API gravity, density, flashpoint, viscosity, cloud point and volume recovered. At first the control was done with 10litres of crude oil and carbon dioxide alone for 10sec, then five different mass percent concentration (5-10%) of silicon oxide (nanoparticle) were used and each were allowed to soak for a period of 24hrs before flushing with carbon dioxide. The result shows that increase in mass percent concentration increases the density from 1.0028g/m to 1.0076g/m for silicon oxide and carbon dioxide. The API reduced with increase in mass percent concentration from 9.604°C to 8.934°C for silicon and carbon dioxide. The viscosity reduced with increase in mass percent concentration from 0.905m<sup>2</sup>/sec to 0.878 m<sup>2</sup>/sec for silicon oxide and carbon dioxide. The volume of the oil recovered reduced with increase in mass percent concentration from 8.95ml to 8.10ml for silicon oxide and carbon dioxide. The cumulative production increase with increase in mass percent concentration from 8.82 to 13.35 for silicon oxide and carbon dioxide. Therefore, based on the result obtained, silicon oxide (nanoparticle) should be tried in field scenarios as it gives a higher recovery in laboratory condition.

Keyword: Enhancement, Niger Delta Crude, Carbon Dioxide, Silicon Oxide

## INTRODUCTION

Globally, crude oil recovery is divided into three phases: primary, secondary and tertiary recoveries (Raj *et al.*, 2019). In the primary recovery, oil flows out of the reservoir depending on its own pressure (Miller and Sorrell, 2014). The three main drive mechanisms of the primary recovery include solution-gas drive (common in the production of heavy oil), gas-cap drive and water drive. During the primary recovery, the rate of oil production declines because of the continuous reduction in the reservoir pressure, which is consistent with Darcy's law (Davidsson *et al.*, 2014). In the secondary recovery, water is typically injected into the reservoir through several injection wells to maintain the reservoir pressure and displace additional oil. However, in heterogeneous reservoirs, water may start to flow in path ways of high permeability extending between the injection and production wells. Consequently, several regions in the reservoir are left unswept by the injected water. Moreover, water-oil inter-facial tension traps oil ganglia in small interstices existing between the grains of the rock, which further impedes oil flow. It is estimated that more than 50% of original-oil-in-place (OOIP) remains unrecovered after the primary and secondary phases of oil recovery (Sengupta *et al.*, 2012). Therefore, Enhanced Oil Recovery (EOR) is applied as a tertiary recovery phase to reduce the residual oil saturation utilizing various techniques such as chemical flooding, gas injection, microbial recovery and thermal recovery (Castilho *et al.*, 2020).

In an oil reservoir, EOR processes can improve the overall oil displacement efficiency, which involves both the microscopic and macroscopic displacement efficiencies (Kumar and Mandal, 2017). Such improvement is accomplished by decreasing oil viscosity interfacial tension (IFT) and capillary forces in addition to changing the mobility ratio between the displacing and displaced fluids to more favorable values (Haruna, *et al.*, 2020).

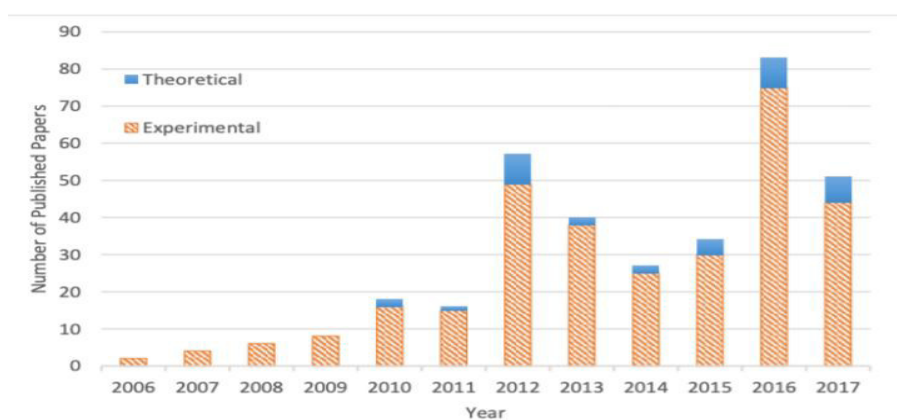
In oil and gas industry, the three traditional enhanced oil recovery method mentioned above can be used in combined form but due to challenges facing the traditional enhanced oil recovery processes such as high mobility ratio of injected gas and oil which causes the gas to penetrate quickly through the reservoirs from the injection wells to the producing wells which results to a large amount of residual oil remaining unrecovered in reservoirs, fingering and early gas breakthrough, and also high cost of chemicals, possible formation damage and loss of chemicals hinders the use of traditional enhanced oil recovery. To carry out any enhanced oil recovery processes in oil industry, petroleum engineer has searched for an

alternative way to solve these problems. More efficient, less expensive and environmentally friendliness is greatly needed in oilfield. (Neginet *et al.*, 2016)

The initial recovery occurs early in the manufacturing cycle and is powered by natural driving energy. Rock and fluid expansion, solution gas, water ingress, gas cap, and gravity drainage are some of the natural drive energy sources (Stosur, *et al.*, 2003). Secondary recovery is the process of adding energy to the reservoir after the natural drive energy has been used up. Most often, water and/or gas are injected as an extra source of energy (Sheng, 2010). To keep the reservoir pressure constant and improve the effectiveness of the volumetric sweep, they simulate the natural processes of water ingress or gas expansion (Stosur *et al.*, 2003). EOR is frequently used as a tertiary recovery technique to recover oil that has not been generated by secondary recovery (Stosur *et al.*, 2003). The infusion of chemicals, miscible gases, and/or thermal energy to enhance reservoir rock and oil system interaction is a characteristic of enhanced oil recovery techniques (Sheng, 2010).

Nanotechnology has shown its potential in almost every industry, offering innovative solutions as a cornerstone of future technologies. In the oil and gas industry, nanofluids are expected to bring an effective, economical, and environmental-friendly method for enhanced oil recovery. The resistivity of salt, shear, and temperature promises the utilization of nanomaterials in harsh reservoir conditions. In addition, the small size endows nanomaterials with the ability to inject into and transport through the porous medium. Many researchers have dedicated to the studies of nanoparticles for enhanced oil recovery. The inorganic nanoparticles, including but not limited to nano-silica, nano-metallic oxide, and nano-clay, prefer to adsorb at the oil-water interface and reduce the surface energy irreversibly. In addition, the nano-silica could form wedge-like aggregations between oil and rock surfaces, which helps to displace the residual oil adhered to the rock surface. Since nanotechnology has been successfully applied in many facets of life, it is now regarded as the most contemporary method of producing goods with extremely high use efficiency (Paul and Robeson 2008). This nanotechnology revolution is widespread throughout the petroleum processing industry (Kapusta *et al.*, 2011). Figure 2.8 showed how the oil and gas companies' research into nanotechnology grew quickly.

In the petroleum sector, several nanoparticles have been examined and used for both upstream and downstream operations such exploration, drilling, completion, and EOR (Bera and Belhaj 2016). Inorganic nanoparticles such nano-silica, nano metallic oxide, and nano clay have gained increasing attention during the past ten years. The oil-water interface is where



nanoparticles seek to adsorb in order to permanently lower the surface energy.

Figure 1: Number of Published Papers about Nanotechnology in the Petroleum Industry (Agista, 2017).

### Nanogel Properties

Nano-sized cross-linked polymeric hydrogel, also known as nanogel, is a new generation of material with a wide range of uses in numerous industries, including biomedical engineering, pharmaceutical application, biomaterials research, cosmetics, and enzyme catalysis (Mohan *et al.*, 2007; Cheng *et al.*, 2011; Langer and Peppas 2003; Thoniyotet *et al.*, 2015). Figure 2.11 illustrates the architectures of several nanogels, which offers significant potential for a variety of uses. For drug delivery and enzyme catalyzed reactions, nanogels with improved biocompatibility, larger loading capacity, and regulated drug release property have been created (Wang *et al.*, 2016). Comprehensive research has been done on the swelling ratio and pH-responsive features of PH sensitive nanogels, including polyacrylic acid nanogels, polymethacrylic acid nanogels,

poly (2-dimethylamino ethyl methacrylate) nanogels, polyvinylpyrrolidone ( $C_6H_9NO$ )<sub>n</sub> nanogels, and chitosan nanogels (Oh *et al.*, 2008).

### Enhanced Flooding of Carbon Dioxide Reservoirs

Nowadays, Nano Particles are used extensively in a variety of scientific and practical sectors. They provide practical solutions for enhancing the wellbore performance of formation fluids and subsurface fluid injection. Because Nano Particles are good at piercing subsurface porous media, they can move quickly through reservoir formations' pore spaces and flow channels and cover large distances. They are able to target specific zones and alter the fluid-flow properties deep inside oil reserves thanks to interactions between injection and pore fluids. Due to the Nano Particle's advantageous qualities, such as its resistance to high temperatures and a variety of hydrocarbons and/or salts that are frequently present in oil reservoirs, adding Nano Particles to surfactant foam in particular tends to improve the foam's stability.

### Effects of Nano Particle Size on Carbon Dioxide Foam Performance

Foam stability has been tested using silica Nano Particles in three different sizes (20, 100, and 500 nm). The best Nano Particle for enhancing foam stability is 20 nm in size (Huang, *et al.*, 2018). To stop the foam from becoming coarser and merging, the 20 nm Nano Particles work to make the layers inside it more coherent. The stability of foam could be most effectively increased by SiO<sub>2</sub> A300 due to its greater surface area to particle size ratio when compared to SiO<sub>2</sub>, AEROSIL816 (hydrophilic and hydrophobic) and ZnO or TiO<sub>2</sub>, which were added to the MFomax surfactant. Additionally, because to their larger surface area and lower particle size, surfactants can adhere to Nano Particle surfaces and enhance their catalytic activity. As a consequence of surfactant molecules attaching to Nano Particle surfaces, they form steric layers of lamellae which tend to resist shrinkage and expansion. This feature assists foams in remaining stable during storage and transport (Massarweh and Abushaikha, 2021).

### Effects of Nano Particle Surface Wettability on Carbon Dioxide Foam Performance

The ratio between the adhesion forces of liquid molecules and molecules (or atoms) of the wetted body/surface (adhesion) and the forces of mutual adhesion of liquid molecules determines the wettability of Nano Particle surfaces (cohesion) (Raza, M. A. and Kooij, E. S, 2020). Aerosil SiO<sub>2</sub> was used as a hydrophobic component in an evaluation of the impact of Nano Particle surface wettability on the stability of foams, and the results showed that the stability of foams increased the contact angle by 26° to 56°. Fumed SiO<sub>2</sub> AEROSIL816 and SiO<sub>2</sub>, AEROSIL300 (HYDROPLIC) added to sodium dodecyl sulfate surfactant shown that the wettability of the rock surface tends to influence and govern, to a significant extent, the location, distribution, and movement of fluids within a specific reservoir (Ab Rasid, *et al.*, 2022).

### Effects of Flow Characteristics on the Performance of Nano Particle-Enhanced Carbon Dioxide Foam

The impact of fluid-flow parameters on the stability of Nano Particle-enhanced Carbon dioxide foam has been thoroughly assessed. In the presence of Nano Particles with changed surfaces, the bulk apparent viscosity of foam can be enhanced by roughly 15% (Rahim Risal, A, *et al.*, 2018). It was discovered that the apparent viscosity of foam in capillary-containing porous media was four times greater than that determined with a capillary viscometer. The higher apparent viscosity of the foam led to an increase in permeability of the porous media. Particularly in heterogeneous reservoirs, the higher apparent viscosity attained by foam stabilized with surface-modified Nano Particles can improve pore fluid diversion and pore blocking operations (Rahim Risal, *et al.*, 2018).

### Silicon Dioxide Nanoparticle

#### 2.4.1 Structure and Surface Chemistry

The molecule of silicon dioxide is [SiO<sub>4</sub>] and has four oxygen atoms joined to the silicon atom at its core. It has a tetrahedral structure, which is in contrast to the name's suggestion of a linear structure (Bergna, 2005). (Figure 2.12).

Due to the silicon atom's small size and insufficient p-orbital overlap, the double bond between silicon and oxygen does not form (P. W. Atkins & Atkins, 2006). Through Silicon-Oxygen-Silicon connection, the [SiO<sub>4</sub>] tetrahedral structure can form pairs, rings, one-dimensional chains, two-dimensional sheets, or three-dimensional networks (Salh, 2011). Figure 2 depicts the three-dimensional configuration of the amorphous silicon dioxide nanoparticles.

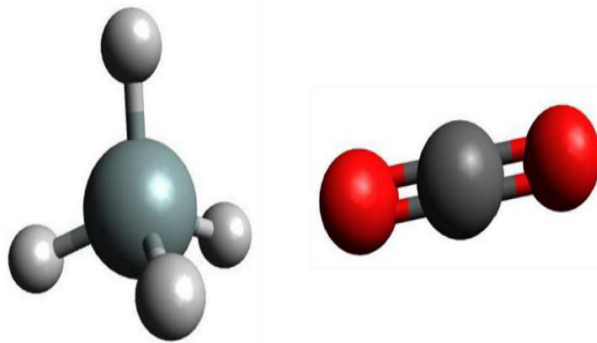


Figure 2: Tetrahedral geometry (left) and linear geometry (right)

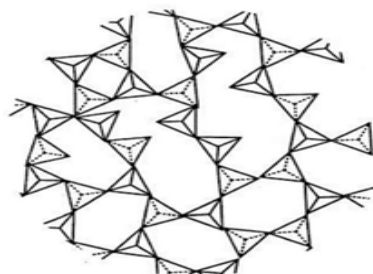


Figure 3: Three-dimensional Arrangement of Amorphous Silicon Dioxide Nanoparticles (Bergna, 2005).

Most frequently, the siloxane linkages (Si-O-Si) and silanol groups (Si-OH) are used to identify the surface of pure silicon dioxide nanoparticles (Rimola, Costa, Sodupe, &Ugliengo, 2013). When silicon dioxide is exposed to water or an aqueous solution, further silanol group production can take place via a rehydroxylation process as the free valence from the oxygen in the siloxane gains hydrogen (Zhuravlev, 2000), as seen in Figure 4.

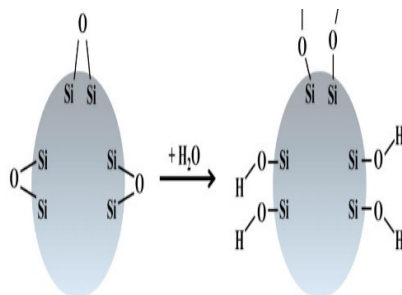


Figure 4: Formation of Silanol Group via Rehydroxylation Process (Modified after Comas-Vives, 2016)

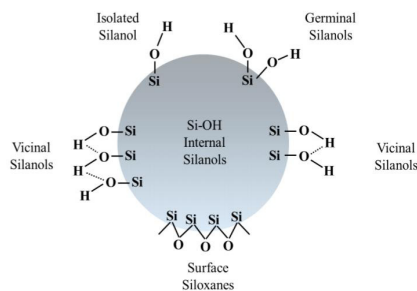


Figure 5: The Surface of Amorphous Silicon Dioxide (Modified after Comas-Vives, 2016)

Figure 5 shows the many silanol group types found on the surface of amorphous silicon dioxide, including solitary, germinal, vicinal, interacting, and internal silanol groups (Comas-Vives, 2016; Zhuravlev, 2000). The silicon dioxide's hydrophilic properties are due to the silanol groups' ability to interact with other molecules via hydrogen bonding (electrostatic attraction between molecules when hydrogen is bound to a strongly electronegative atom, such as oxygen).

**Materials and Equipment-**

**Table 3.1: Experimental Materials for Enhanced Oil Recovery Method**

<b>Equipment</b>	<b>Materials</b>	<b>Glass</b>
Crude oil	Redwood viscometer	Beaker
Silicon oxide ( <b>Nanoparticle</b> )	Stopwatch	Crucible
Carbon dioxide (Gas)	Retort stand	Pycnometer
	Measuring cylinder	Thermometer
	Air cooler chamber	
	Weigh balance	
	Enhanced oil recovery laboratory setup	
	Pemsky-Martens flash	

**3.1.1 Laboratory Apparatus and their uses**

Redwood viscometer was used to determine viscosity, Pycnometer was used in measuring and comparing the density of the crude oil. Thermometer was used to determine the various temperature of the crude oil. Weigh calibrator was used to calibrate the weighing balance before used.

Measuring cylinder was used in determining the volume of the crude oil. Crucible is a ceramic container used in carrying and weighing of silicon oxide. Stopwatch is used to measure time intervals. Retort stand was used to support the separating funnel to separate the crude oil.

Silicon oxide was used as a nanoparticle. Crude oil was gotten from a Niger delta reservoir. Carbon dioxide was used as a driving force to help flush the reservoir.

**METHODS**

**i Collection of Crude Oil Sample**

Crude oil was gotten from a reservoir in the Niger delta region. The following laboratory procedures were carefully observed to determine the necessary petro-physical properties (i.e. density, viscosity, API gravity, cloud point, flash point, specific gravity and pour point) of the crude oil.

**ii. Determination of Density**

The weight of the empty dry pycnometer was determined after which the pycnometer was filled with crude oil sample ensuring that there was no bubble inside the pycnometer and its weight was recorded using the weighing balance. The crude oil density was determined at every given temperature with the use of a thermometer. The procedure was repeated for crude oil at initial condition, the crude oil sample with carbon-dioxide (control), and for the different mass percent concentrations of the nanoparticle.

$$\text{Density } (\rho) = \frac{\text{weight of filled pycnometer} - \text{weight of empty pycnometer}}{\text{volume of pycnometer}} \quad (1)$$

**iii. Determination for Specific Gravity**

The specific gravity was measured using hydrometer. The operation of the hydrometer is based on the Archimedes principle which that the solid suspended in a fluid will be buoyed up by a force to the weight of the fluid displaced. During this process the cylinder was filled with the crude oil and the temperature of the crude oil sample was measured by the use of thermometer and recorded. The hydrometer was dropped into the sample slowly and carefully, away from the wall of the cylinder until a steady floatation in the center of the cylinder was observed. A hydrometer is usually made of glass and consists of a cylinder stem. The procedure was repeated for crude oil at initial condition, the crude oil sample with carbon-dioxide (control), and for the different mass percent concentrations of the nanoparticle. The equation used in calculating the specific gravity of the crude oil is;

$$\text{API Gravity} \frac{141.5}{\text{SPECIFIC GRAVITY}} - 131.5 \quad (2)$$

**v. Determination of Viscosity Using Redwood Viscometer**

The viscosity of all formulated samples was measured using redwood viscometer. The viscometer was cleaned properly and dried properly, the viscometer contained water and thermometer which was used to know the temperature of the water, the crude oil was filled into the oil cup to the required oil level indicated by the marker point, the water was heated at different uniform temperature, when the required temperature was attained by the use of thermometer the ball was lifted above the orifice hole same time the stopwatch was started then the oil was allow to pass through it inside a beaker, the measured time is in terms of the viscosity of oil measured. The procedure was repeated for crude oil at initial condition, the crude oil sample with carbon-dioxide (control), and for the different mass percent concentrations of the nanoparticle. Kinematic viscosity was calculated by multiplying the efflux time by the viscometer constant (A and B) and the dynamic viscosity by multiplying kinematic viscosity by density. The diagram for this experiment is shown in Figure B4 of Appendix B.

The equation used in calculating the viscosity of the crude oil is;

$$\left(At - \frac{B}{t}\right)\rho \quad (3)$$

Where;

$$A=0.026$$

$$B=0.188$$

t=time

$\rho$  = density

**iv. Determination of Cloud and Pour Point using Air Cooler Chamber**

Test jar was filled to the level mark, closed tightly by the cork carrying the thermometer and placed into a bath of crushed ice. The test jar was removed from the jacket quickly without disturbing the crude oil and the Inspection for cloud point was done and jacket replaced. The process was repeated without exceeding duration of three (3) seconds. Since cloud point is the temperature of a liquid when the smallest observable cluster of hydrocarbon crystals first appears upon cooling under prescribed conditions, observation was done and cloud point was reported. At this point, cloud point was observed at the bottom of the jar, which is confirmed by continued cooling. The pour point was reached when the crude oil surface stayed at a vertical position for a period of 5 seconds without sagging. At this point the thermometer was inserted to cool for 10 seconds and the temperature of the crude oil was recorded. The procedure was repeated for crude oil at initial condition, the crude oil sample with carbon-dioxide (control), and for the different mass percent concentrations of the nanoparticle.

**vi. Determine of Flash Point**

The procedure used to determine flash point in this work is the pensky-martenz closed cup test which is use for the determination of the flash point of flammable liquids. The brass test cup was cleaned, dried and filled to the marked specified dimension with the crude, the cup containing the crude oil sample was fitted into the pensky-martenz and covered to avoid spill. The electric source was put on to heat and the stirrer was turned on to enable the crude oil gain uniformity. At regular intervals, the ignition source was directed to the ignition point and checked if it flashes; if it does not, continue to heat, stir and check till it ignites. The lower temperature was recorded at which the crude ignites. The brass test cup was



cleaned and allowed to dry. The procedure was repeated for crude oil at initial condition, the crude oil sample with carbon-dioxide (control), and for the different mass percent concentrations of the nanoparticle.

**vii. Enhanced Oil Recovery Experiment**

After the properties test was done the enhanced oil recovery test was done using: The set up used for this is a laboratory set up for enhanced oil recovery, this set up can be used for various type of enhanced recovery method which includes water, air etc but in this case silicon oxide is used to enhanced the recovery of the crude. The setup is made up of series of equipment that represents the setup of a well head, the set up makes use of a Nitrogen gas cylinder (N<sub>2</sub>) that acts as the reservoir pressure, this cylinder is connected to a 10litre metal tank which stands as the reservoir, a pipe is connected to this tank which along its line comprises of a tap handles (stands as the well head valve) and a pressure gauge used to read the tank outlet pressure (reservoir outlet pressure), a condenser to condense any gas if present then a second tap handle which stands as a valve which leads to the collection container (storage tank). The tap handles were opened and the stopwatch set for 10 seconds at the same time, the inlet pressure and the outlet pressure were recorded as the fluid flowed, as the 10 seconds elapses, the Nitrogen gas cylinder was closed, the tap handles was also returned to a closed position. The volume of the crude oil and water recovered were recorded.

The reservoir was emptied totally. After the mixture settled, the water cut was recorded and the amount of water and crude recovered calculated. A sample of the recovered crude was taken and tested for its properties again. 10litres of crude oil sample was mixed with 2 grams of silicon oxide and allowed to mix properly for 24hours. After 24hours the samples were made to undergo the same procedures used for the recovery of the previous sample, the reservoir and flow lines were emptied properly, after getting the cut, the crude oil recovered was used to carry out the properties test again, The 10litres of crude oil samples was mixed with Zinc and calcium oxide nano-particles in different mass percent concentrations (5g, 10g, 15g, 20g,25g) and mixed properly before adding it to the crude sample, it was allowed for 24 hours which is also known as soaking period to mix before flooding with Nitrogen (N<sub>2</sub>). The procedure was repeated, equally recorded and calculated the quantity of oil recovered, and also testing for the crude properties of the crude recovered respectively for the different samples, the reservoir set up was emptied and its environment properly cleaned.

**RESULTS**

**i. Effect of Silicon and Carbon dioxide on the Crude**

The effect of carbon dioxide in the physical properties of the crude oil is presented in figure 6

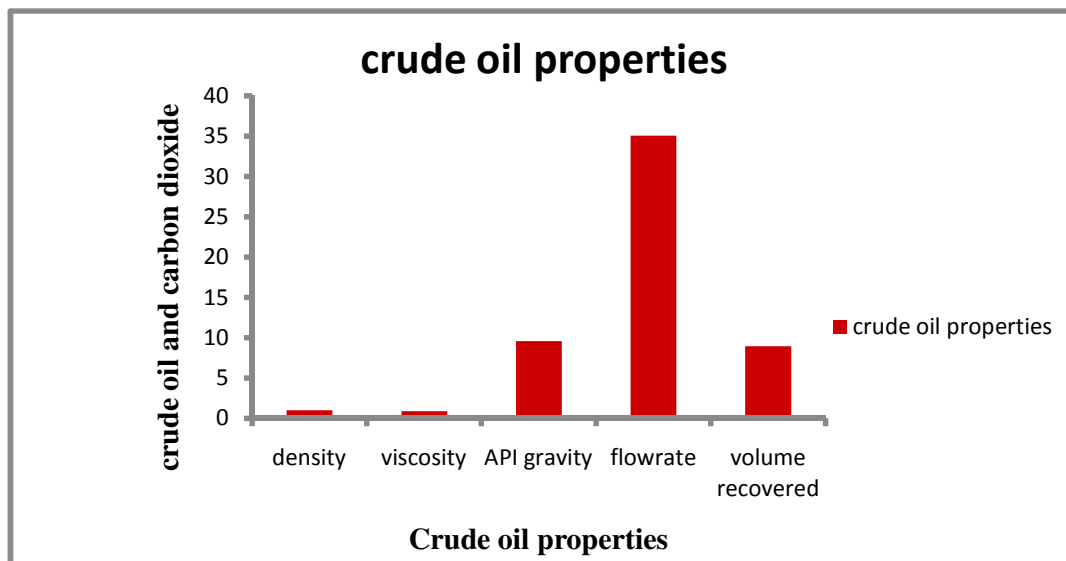


Figure 6: A Chart of carbon dioxide against Crude Oil Properties

Figure 6, shows a bar chart of carbon dioxide against crude oil properties, which shows that the flow rate was 35m<sup>3</sup>/s of the crude which was the highest property followed by API gravity 9.604°C and volume recovered 8.95ml. The density 1.0028g/m and viscosity 0.905M<sup>2</sup>/s were the lowest crude oil property.

**ii. Effect of Silicon and Carbon dioxide on the density of the crude**

The effect of silicon and carbon dioxide on density at different mass percent concentration is presented in figure 7

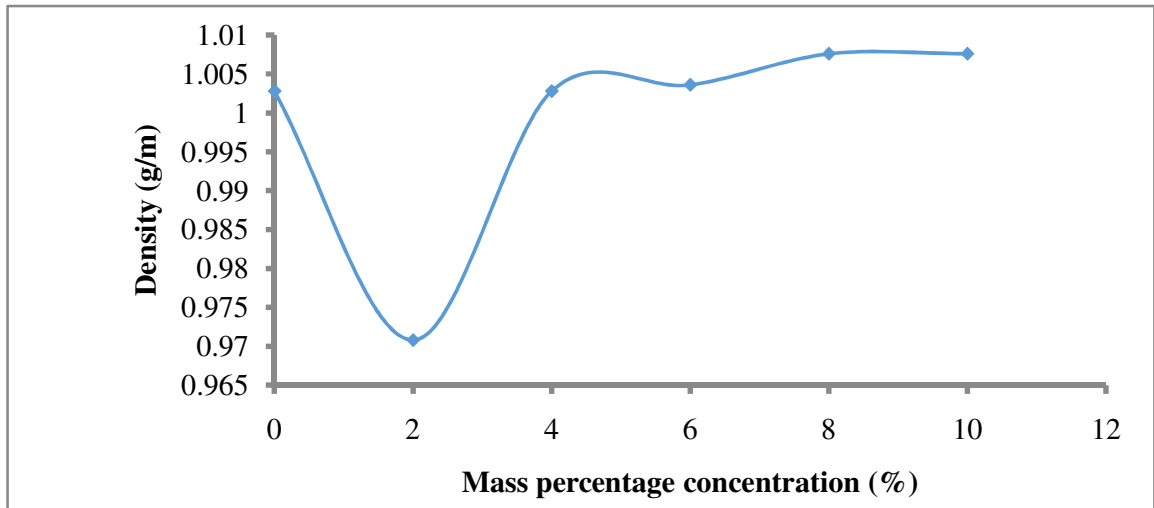


Figure 7: A Plot of Density against Mass Percent Concentration

The Figure 7 above shows the graphical representation of density. When the crude was flushed with carbon dioxide the density was 1.0028. When 2g of Silicon oxide (nanoparticle) was introduced it reduced to 0.9708 and rapidly increases to 1.0028 when 4g of same nanoparticle was introduced. At 6g of same nanoparticle the density was 1.0036, and increased to 1.0076 when 8g of same nanoparticle was introduced. When 10g of same nanoparticle was introduced the density became 1.0076 which indicates that there was a slight.

**iii. Effect of Silicon oxide and carbon-dioxide on the API Gravity of the crude**

Figure 8 shows the effect of silicon oxide and carbon dioxide on the API Gravity of the crude at different mass percent concentration.

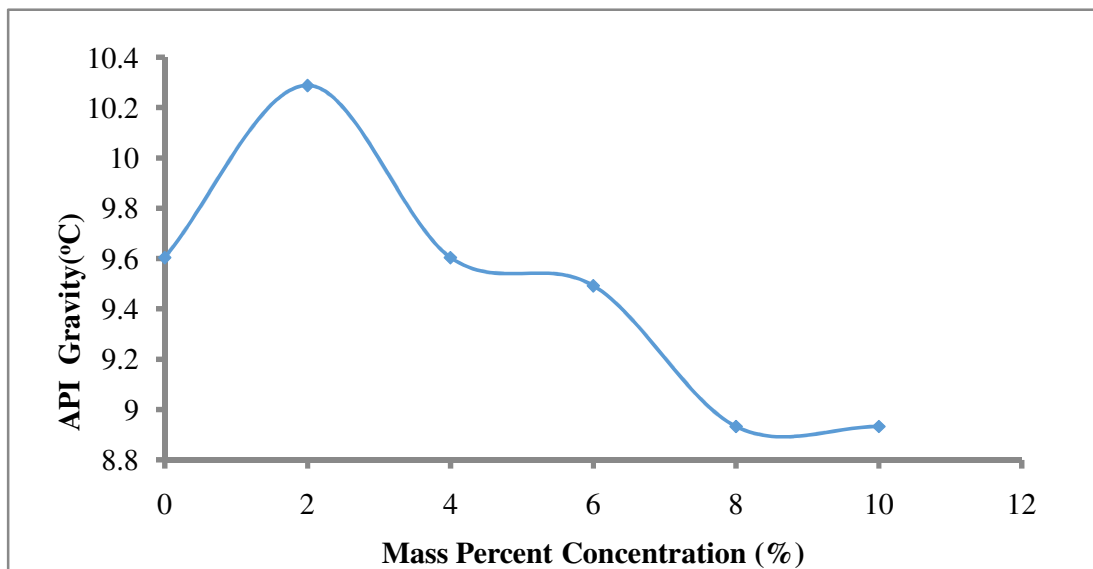


Figure 8: A Plot of API Gravity against Mass Percent Concentration



API gravity is a measure of how heavy or light petroleum liquid is compared to water. If its API gravity is greater than 10, it is lighter and floats on water, if less than 10, it is heavier and sink. The Figure 8 above shows the graphical representation of concentration. When the crude was flushed with carbon dioxide the API gravity was 9.604. When 2g of Silicon oxide (nanoparticle) was introduced it increase to 10.283, when 4g of same nanoparticle was introduced the API gravity reduced to 9.604. At 6g of same nanoparticle the API gravity reduced 9.492, and reduced to 8.932 when 8g of same nanoparticle was introduced. When 10g of same nanoparticle was introduced the API gravity reduced to 8.10.

**iv. Effect of Silicon and carbon dioxide on the Flow Rate of the Crude Oil**

Figure 9 shows the effect of carbon dioxide and silicon oxide nanoparticle at different mass percent concentration

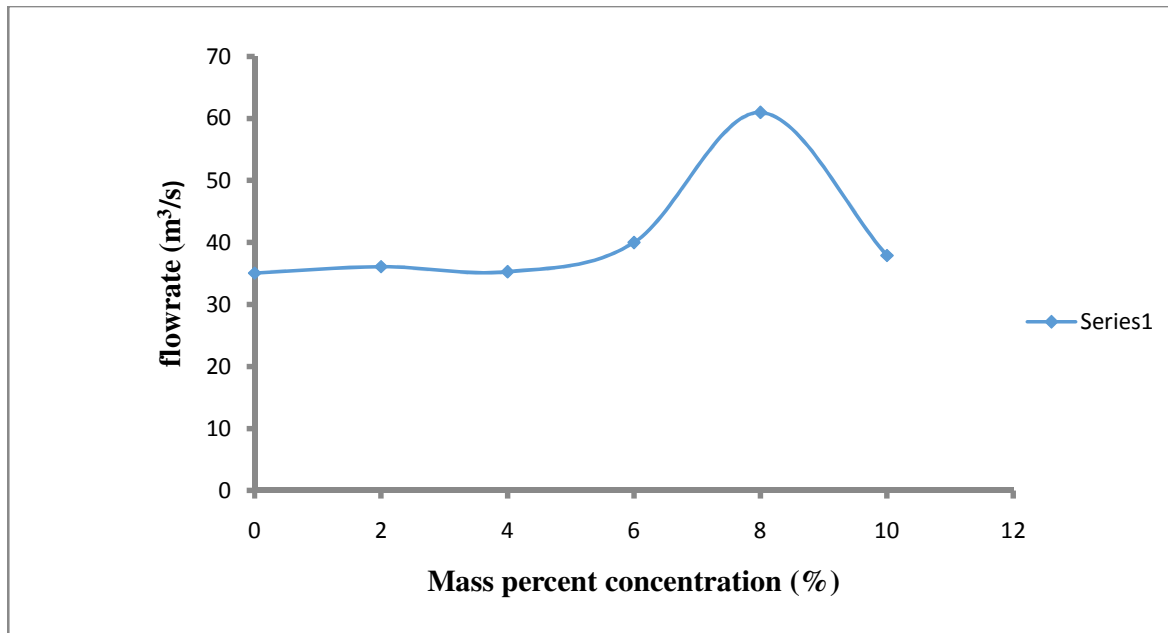


Figure 9: A Plot of Flow Rate against Mass Percent Concentration

Flow rate is the speed at which fluid in a pipe moves. The Figure 9 above shows the graphical representation of flow rate against mass percent concentration. When the crude was flushed with carbon dioxide the was 35.06. When 2g of Silicon oxide (nanoparticle) was introduced it increased to 36.09, when 4g of same nanoparticle was introduced the flow rate became 35.28. At 6g of same nanoparticle the flow rate reduced 40.61 and reduced to 37.90 when 8g of same nanoparticle was introduced. When 10g of same nanoparticle was introduced the flow rate reduced to 34.45.

**v. Effect of carbon dioxide and silicon oxide nanoparticle on viscosity**

The effect of carbon dioxide and silicon oxide nanoparticle on viscosity is shown if figure 9

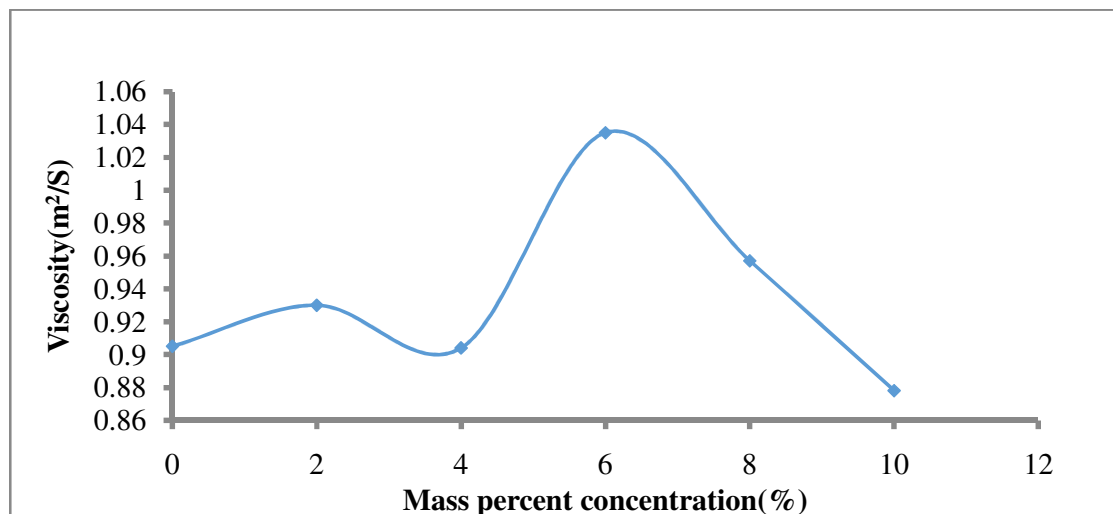


Figure 10: A Plot of Viscosity against Mass Percent Concentration

Viscosity is a measure of a fluid’s resistance to flow. A fluid with large viscosity resists motion because its molecular makeup gives it a lot internal friction. The Figure 10 above shows the graphical representation of volume recovered against mass percent concentration. When the crude was flushed with carbon dioxide the viscosity was 0.905 m<sup>2</sup>/s. When 2g of Silicon oxide (nanoparticle) was introduced it increased to 0.930 m<sup>2</sup>/s, when 4g of same nanoparticle was introduced the viscosity reduced to 0.904 m<sup>2</sup>/s. At 6g of same nanoparticle the viscosity increased to 1.035 m<sup>2</sup>/s, and reduced to 0.957 m<sup>2</sup>/s when 8g of same nanoparticle was introduced. When 10g of same nanoparticle was introduced the viscosity reduced to 0.878m<sup>2</sup>/s.

vi. **Effect of carbon dioxide and silicon oxide nanoparticle on volume recovery**

Figure 11 shows the graphical representation of the effect of carbon dioxide and silicon oxide nanoparticle on the recovered volume.

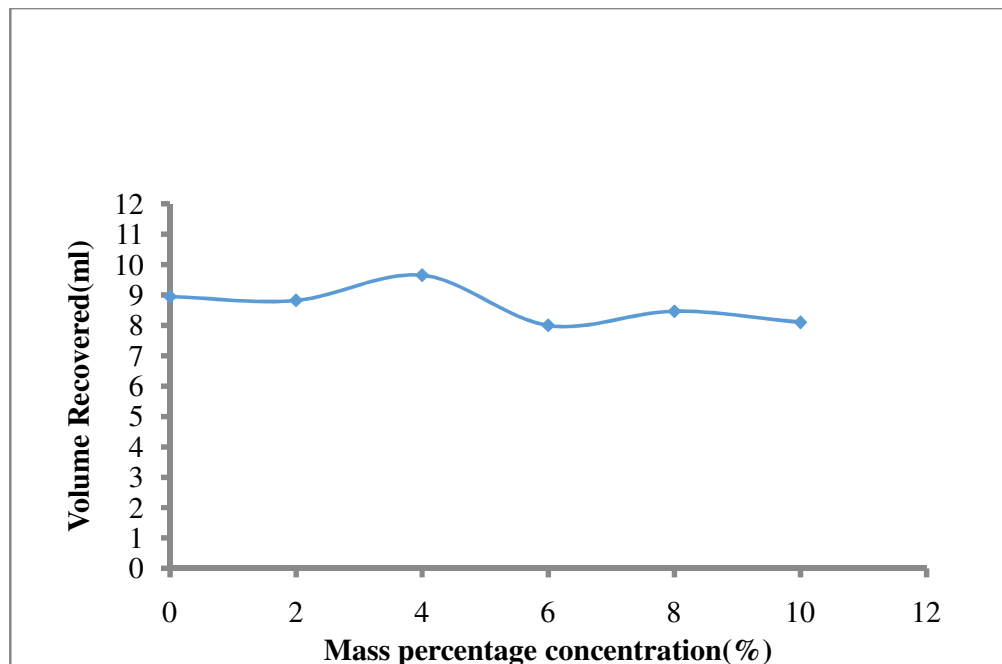


Figure 11: Plot of Volume Recovered against Mass Percent Concentration

The Figure 11 above shows the graphical representation of volume recovered against cumulative production, cumulative production was gotten using the formula ( $N_p = \text{initial volume} - \text{volume recovered}$ ). When the crude was flushed with carbon dioxide the cumulative production was 8.82 and 2g of Silicon oxide (nanoparticle) was introduced it increased to 0.930 when 4g of same nanoparticle was introduced the cumulative production increased to 10.83. At 6g of same nanoparticle the cumulative production increased to 12.51, and increased to 12.98 when 8g of same nanoparticle was introduced. When 10g of same nanoparticle was introduced the cumulative production increased to 13.35.

## CONCLUSION

The primary aim for this work is to enhance oil production using carbon dioxide (CO<sub>2</sub>) with silicon oxide (nanoparticle). The injection of carbon dioxide in this work is used to increase the overall pressure of the reservoir, forcing the oil towards the production well. The application of silicon oxide (nanoparticle) was used to alter the wettability, viscosity, API, physical and interfacial tension between oil and water interface and lower the chemical adsorption onto reservoir rock surface which enables the enhancement of oil production

From the enhanced oil recovery experiment carried out with a laboratory set up, the result is concluded as follows;

- i. When 2g and 6g of silicon oxide (nanoparticles) were introduced into crude oil and carbon dioxide respectively, the oil recovered was low compared to when other grams of silicon oxide were introduced.
- ii. When 8g and 10g of silicon oxide (nanoparticles) were introduced into crude oil and carbon dioxide respectively, the oil recovered was more compared to when 2g and 6g of SiO was introduced.
- iii. When 4g of silicon oxide (nanoparticle) was introduced into crude oil and carbon dioxide, it had the highest oil recovered.

## REFERENCE

- Raj, I., Qu, M., Xiao, L., Hou, J., Li, Y., Liang, T., Yang, T. & Zhao, M. (2019). Ultralow Concentration of Molybdenum Disulfide Nanosheets for Enhanced Oil Recovery, *Fuel* 251 514e522, <https://doi.org/10.1016/j.fuel.2019.04.078>.
- Miller, R. G. Sorrell, S. R. (2014). The future of oil supply, *Philos. Trans. R. Soc. A Math. Phys. Eng. Sci.* 372, 20130179, <https://doi.org/10.1098/rsta.2013.0179>.
- Davidsson, S., Höök, M., Johansson, S. and Tang, X. (2014), Decline and depletion rates of oil production: a comprehensive investigation, *Philos. Trans. R. Soc. A Math. Phys. Eng. Sci.* 372 20120448, <https://doi.org/10.1098/rsta.2012.0448>.
- Sengupta, B. Sharma, V. P. and Udayabhanu, G. (2012). A study of the effect of the concentration of constituents on the characteristics of a cross-linked polyacrylamide gel, *Petrol. Sci. Technol.* 30, 1865e1881, <https://doi.org/10.1080/10916466.2010.493907>.
- Haruna, M. A., Gardy, J., Yao, G., Hu, Z., Hondow, N. and Wen, D. (2020). Nanoparticle Modified Polyacrylamide for Enhanced Oil Recovery at Harsh Conditions, *Fuel* 268 117186, <https://doi.org/10.1016/j.fuel.2020.117186>.
- Negin, C., Ali, S. and Xie, Q. (2017). Most Common Surfactants Employed in Chemical Enhanced Oil Recovery. *Petroleum* 3, 197–211.
- Stosur, G. J., Hite, J. R., Carnahan, N. F. and Miller, K. (2003). The Alphabet Soup of IOR, EOR and AOR: Effective Communication Requires a Definition of Terms. *SPE International Improved Oil Recovery Conference in Asia, SPE 84908*, 1–3. <https://doi.org/10.2118/84908-MS>
- Sheng, J. (2010). *Modern Chemical Enhanced Oil Recovery: Theory and Practice*. Gulf Professional Publishing.
- Zhang, Y.; Zhu, Z.; Tang, J. (2021). Research on Polyether-Based Hydrocarbon Thickener for CO<sub>2</sub>. *Fluid Phase Equilib.* 532, 112932.
- Irvine, Randy, Davidson, John, Baker, Mark et al. 2015b. Nano Spherical Polymer Pilot in a Mature 18° API Sandstone Reservoir Water Flood in Alberta, Canada. *Proc., SPE Asia Pacific Enhanced Oil Recovery Conference*.
- Agista, MadhanNur. (2017). *A Literature Review and Transport Modelling of Nanoparticles for Enhanced Oil Recovery*, University of Stavanger, Norway.
- Sharma, Gaurav and Mohanty, Kishore. (2013). Wettability alteration in high-temperature and high-salinity carbonate reservoirs. *SPE Journal* 18 (04): 646-655.

- Langer, Robert and Peppas, Nicholas A. (2003). Advances in biomaterials, drug delivery, and bionanotechnology. *AIChE Journal* 49(12): 2990-3006.
- Yu, W. and Kanj, M. Y. (2022). Review of Foam Stability in Porous Media: The Effect of Coarsening. *J. Pet. Sci. Eng.* 208, 109698.
- Zhang, Y.; Zhu, Z.; Tang, J. (2021). Research on Polyether-Based Hydrocarbon Thickener for CO<sub>2</sub>. *Fluid Phase Equilib.* 532, 112932.
- Huang, D., Hu, N., Li, Y., Wu, Z., Lu, K. & Liu, W. (2018). Foams Stabilization by Silica Nanoparticle with Cationic and Anionic Surfactants in Column Flotation: Effects of Particle Size. *J. Taiwan Inst. Chem. Eng.*, 88, 62–69.
- Raza, M. A. and Kooij, E. S. Toward, (2020). Superhydrophobic Surfaces. *Surf. Interface Sci.* 391–440.
- Risal Rahim, A., Manan, M. A., Yekeen, N., Mohamed Samin, A. and Azli, N. B. (2018). Rheological Properties of Surface-Modified Nanoparticles-Stabilized CO<sub>2</sub> Foam. *Journal Dispersion Science. Technology.* 39(12), 1767– 1779.
- Zhuravlev, L. T. (2000). The surface chemistry of amorphous silica. Zhuravlev model. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 173(1–3), 1–38. [https://doi.org/10.1016/S0927-7757\(00\)00556-2](https://doi.org/10.1016/S0927-7757(00)00556-2)
- Comas-Vives, A. (2016). Amorphous SiO<sub>2</sub> Surface Models: Energetics of the Dehydroxylation Process, Strain, ab Initio Atomistic Thermodynamics and IR Spectroscopic Signatures. *Physical Chemistry Chemical Physics: PCCP*, 18(10), 7475–82. <https://doi.org/10.1039/c6cp00602g>