INVESTIGATING THE EFFECTIVENESS OF DIFFERENT TYPES OF NANOPARTICLES IN ENHANCED OIL RECOVERY

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ABSTRACT

Enhanced Oil Recovery (EOR) technique has been proven to be one of the most reliable and cost-effective methods of recovering residual oil. These methods include Gas injection method, Steam Injection method, Chemical injection method (chemicals such as surfactants, polymers etc) and Microbial Enhanced Oil Recovery. This work investigates experimentally the density, viscosity, API gravity and flowrate using CuO, SiO and FeO_3 in various mass percent concentrations (5 – 25 grams). Ten (10) liters of heavy crude oil were measured and mixed with 5, 10, 15, 20 and 25 grams of CuO, SiO and FeO_3. The nanoparticles were mixed together in equal mass percent concentrations, left to soak for 24 hours, and then pumped with 1 bar of N_2 gas in a laboratory-scale enhanced oil recovery system. At various nanoparticles mass percent concentrations, the density, API Gravity, viscosity, flow rate, and heavy crude oil recovered were measured. The result shows that increase in mass percent concentration reduced the density from 1.29g/cc to 0.901g/cc for FeO_3 nanoparticles, 0.95g/cc density was also recorded for CuO and 0.88g/cc was recorded nanoparticles. Increase in concentrations from 5 – 25grams increased the API gravity of the oil from 15.54°API to 22.91°API for SiO, 27.92°API was also recorded for CuO and 27.06°API after the combination. Increase in concentration from 5 to 25grams reduced the viscosity from 1.6cp to 0.6cp for SiO, 0.54cp for CuO and 0.76cp after combination. As the mass percent concentration of the nanoparticles increased, the amount of recovered oil increased, as did the cumulative production. More nanoparticles should be investigated to know the best in enhanced oil recovery.

KEYWORDS: Effectiveness, Laboratory, Nanoparticles, Microbial and Enhanced Oil Recovery

I. INTRODUCTION

The demand for oil and gas continues to increase globally, and as a result, there is a need for more efficient and sustainable methods of oil recovery. One such method is microbial enhanced oil recovery (EOR), which utilizes microorganisms to increase the recovery of oil from reservoirs. However, the effectiveness of EOR can be limited by several factors, such as the mobility and survival of microorganisms within the reservoir. One promising approach to enhance the effectiveness of Enhanced Oil Recovery (EOR) is through the use of clay nanoparticles. During the last decade, nanomaterials have been introduced as residual oil problems in heavy and semi-heavy oil reservoirs are solved by the development of new alternative methods that are used as the new EOR techniques [8]. Nanomaterials as a technique in thermal and chemical enhanced oil recovery have proven to be a new emerging technology. Over the last several years, nanotechnology has been used widely to advance the functioning of EOR hence making it more cost-effective.

Nanotechnology refers to a technology which permits the production of practical materials, systems and devices by using nano-sized materials, as well as new phenomena and properties at nanoscale (1100 nanometers) [3]. Wettability refers to the tendency of one fluid to spread across a solid surface in the presence of another immiscible fluid. In oil reservoirs, rock wettability significantly influences fluid distribution, which directly impacts the efficiency of Enhanced Oil Recovery (EOR) processes. Due to its enormous contribution to the recovery of oil, many reviews have been made in this technical field. The wetting characteristics of a reservoir are governed by complex rock-fluid interactions, including pore-size distribution, fluid composition, and the orientation of pore surfaces. Consequently, extensive laboratory studies and case reports have been developed to evaluate how nanoparticles can be used to effectively alter these wettability profiles. Roustaei and Bagherzadeh explored how the nanoparticles of SiO2 can be used to modify the wettability of a rock composed of a carbonate reservoir [8]. Other studies have proposed the use of nanoparticles as an efficient solution to change the rock fluid system properties. The use of nanoparticles has been reported to enable many researchers to get higher oil recoveries [10]. Numerous studies have investigated the effects of various types of nanoparticles on fluid-fluid interactions and interfacial tension. For instance, metal oxide nanoparticles such as silica, alumina, and titania have been widely explored due to their stability and tunable surface properties [4]; [2]. Furthermore, [11] explored the use of graphene oxide nanoparticles to modify fluid-fluid interactions and interfacial tension. The study demonstrated that graphene oxide nanoparticles effectively reduced interfacial tension between oil and water, facilitating the displacement of oil from porous media.

Nanoparticles have also been investigated for their potential to enhance microbial enhance oil recovery (MEOR) processes. Various types of nanoparticles have been used, including clay nanoparticles, metal oxide nanoparticles, and carbon-based nanoparticles [6].

[12] investigated the effects of interfacial interactions on the thermal properties of polymer-nanoparticle hybrids. They synthesized polyvinyl alcohol (PVA)-coated graphene oxide (GO) nanoparticles and incorporated them into a PVA matrix. The results showed that the interfacial interactions between the PVA matrix and PVA-coated GO nanoparticles significantly enhanced the thermal conductivity of the hybrids. [13] evaluated the potentials of clay nanoparticles as an additive for MEOR in a laboratory setting. The researchers conducted core flooding experiments to measure the impact of clay nanoparticles on oil recovery using microbial consortia. The study found that the addition of clay nanoparticles improved the efficiency of MEOR by enhancing the growth and activity of microorganisms.[5] evaluated the effect of clay nanoparticles on MEOR using Bacillus subtilis as the microbial agent. The researchers conducted core flooding experiments to measure the impact of clay nanoparticles on oil recovery under different conditions. The study found that the addition of clay nanoparticles improved the efficiency of MEOR by enhancing the growth and activity of Bacillus subtilis.

II. MATERIAL AND METHOD

2.1 Materials and Equipment used in the course of the laboratory investigation includes the following:

i. Nanoparticle (CuO, SiO and FeO_3)
ii. Crude oil
iii. Pycnometer
iv. Redwood Viscometer
v. Measuring cylinder
vi. Air coolant
vii. Pensky Martins Flash Point Tester

2.2 Method

This laboratory research was conducted in three stages phases

i. To investigate the effectiveness of nanoparticles on the petrophysical properties of crude oil. In the initial stage, petrophysical tests on the crude oil to identify its properties and establish a baseline for any changes that may occur.
ii. Preparation of nanoparticles (CuO, SiO and FeO_3)

Crude oil was gotten from a Niger delta field. The following laboratory tests were closely followed so as to obtain the requisite petro-physical properties such as density, viscosity, API gravity, cloud point, flash point, specific gravity and pour point of crude oil.

2.2.1 Density and API Gravity Determination

A clean and dry pycnometer was acquired. The buoyancy of the empty pycnometer was recorded by weighing the pycnometer to find the mass using a weighing balance, which was then recorded as (W1). The pycnometer was then filled with crude oil. Care was taken to avoid the formation of air bubbles, and the pycnometer was weighed on the weighing balance, which was then recorded as (W2). The density of the crude oil could then be calculated from the recorded mass and known volume of the pycnometer (V) using eqn 1.

$$Density\ (g/cm^3) = \frac{filled\ pycnometer\ (W2) - empty\ Pycnometer\ (W1)}{Volume\ of\ pycnometer (V)} \quad (1)$$

$$Specific\ gravity\ (S.G) = \frac{Density\ of\ crude\ oil}{Density\ of\ water} \quad (2)$$

$$API\ gravity = \frac{141.5}{S.G} - 131.5 \quad (3)$$

2.2.2 Viscosity Determination

Viscosity measurements for the crude oil samples were conducted using a Redwood viscometer. Prior to the experiment, the viscometer was thoroughly dried and cleaned. The viscometer was filled with water up to the required level, and then the crude oil poured into the oil cup of the viscometer, aligning it with a specific mark on the cup. The orifice ball in the viscometer was removed to allow the crude oil to flow through. The time taken for the flow was recorded.

$$\mu\ (cp) = (At - \frac{B}{t})\rho \quad (4)$$

Where;

A=0.026
B=0.188
t=time
ρ = density

2.2.3 Determination of Cloud and Pour Point using Air Coolant

The test jar was filled up to the calibration point, and a cork was placed over the test jar with the thermometer associated with the test jar immersed in the air coolant. To test the cloud point, the test jar was quickly withdrawn from the jacket (being careful not to disturb the crude oil and the thermometer was used to measure the cloud and pour point. The above step was repeated everyone minute. As the definition of cloud point is that of the temperature at which the faintest apparent amorphous accumulation of hydrocarbon crystals was first formed during cooling under prescribed conditions, the experiment was conducted and the cloud and pour point observed. The point of cloud was recorded as the temperature at which the white precipitate was at the top of the jar or test tube and the point was confirmed by further cooling it to make sure it loses its flow abilities. The test was also done on the crude oil in its initial state and sample of the crude oil with nitrogen as the control as well as there are different mass-percent concentrations of nanoparticles.

2.2.4 Determine of Flash Point

The apparatus used to determine the flash point is called Pensky-Martens. The crude was poured into the brass test cup to the specified marked level after that, the crude oil sample was transferred into the cup and the Pensky-Martens apparatus positioned and covered to prevent spillage. The power source was switched on for heating, and the stirrer was turned on to maintain the homogeneity of the crude oil. The ignition source was intermittently lit to the ignition point, and a flash was observed. If no ignition was produced, the heating, stirring and ignition source was checked until ignition resulted. The lowest temperature at which the crude ignited was recorded. The test cup of brass was rinsed again and left to dry. This procedure was repeated for the crude oil sample with nitrogen as a control, and in the various mass percent concentrations of the nanoparticle.

2.2.5 Evaluation of the Effectiveness of Nanoparticles on Enhanced Oil Recovery

After the physical properties of the crude oil was checked (density, viscosity, API gravity etc), the enhanced oil recovery was done using a laboratory set-up for enhanced oil recovery. This set-up can be used for various enhanced oil recovery processes which are water flooding, gas injecting, polymer flooding etc. But in this research CUO, SiO and FeO_3 were used alongside nitrogen gas as the driving force of the reservoir. The laboratorial EOR set-up is made up of series of equipment that represents the set-up of a well head with a cylinder which contains nitrogen N_2 gas that provide pressure to connected tanks. The cylinder is connected to a 10-liter metal tank which stands as the reservoir were the crude oil was poured, with a horizontal pipe that is connected to the tank which comprises of a tap handle (stands as the well head valve) and a pressure gauge that is used to read the tank outlet and inlet pressure, a condenser to condense any gas that tends to escape. Before flooding, the tank was emptied to make sure that there is no residue oil left from pervious experiments, then 10 liters of crude oil was measured and poured into the tank and flooded with N_2 after which the recovered volume was measured and the exact time of recovery was also recorded using the stopped watch and its properties was re - evaluated. Thereafter another 10 litres of heavy crude oil was measured and different mass percent concentrations (5,10,15,20 and 25 grams) of nanoparticles (CuO, SiO and FeO_3) were introduced into the crude oil and mixed properly before turning the mixture into the reservoir (tank), the mixture was allowed for 24 hours which is known as the soaking time or period before flooding with Nitrogen gas (N_2). The procedure was repeated equally, and values recorded the physical properties of the crude oil was analyzed after each flooding.

III. RESULTS AND DISCUSSION

3.1 Effect of CuO, SiO and FeO_3 Nanoparticles and on Density of the Heavy Crude Oil

The effects of mass percent concentration of nanoparticles on the density of the crude is presented in Figure 1.

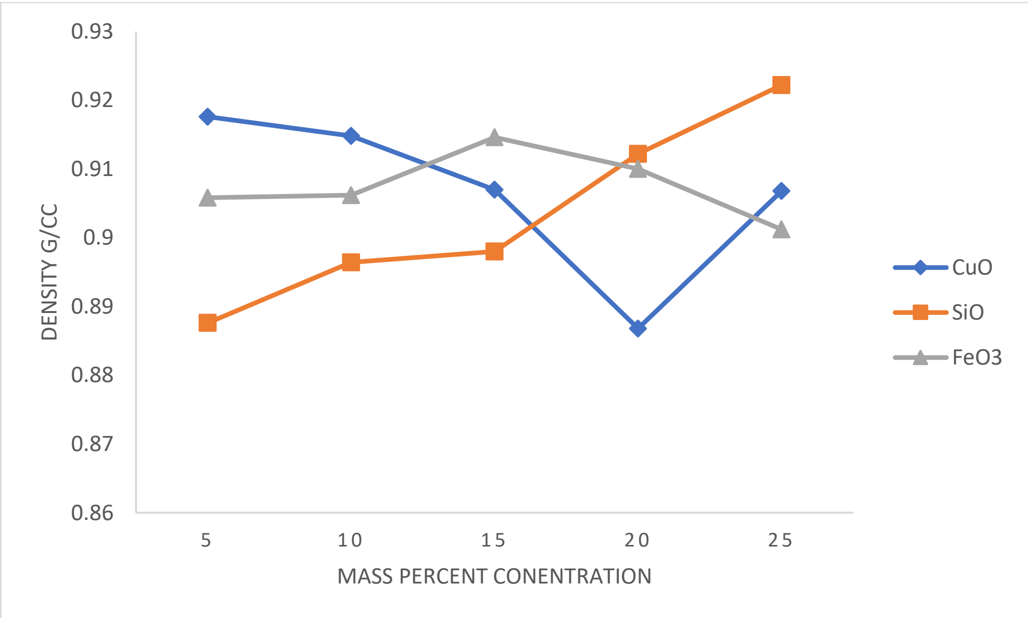

Figure 1: Effect of Mass Percent Concentration of CuO, SiO and FeO_3 on the Density of the Crude Oil.

The density of the crude oil decreased rapidly from 1.29/cc to 0.901g/cc after 5g of copper oxide nanoparticle was introduced into the system. The density then decreased by 0.0028g/cc when 5grams of the constituent (CuO) was added. A further decrease of about 0.0078g/cc was recorded at 15gram of the same nanoparticle, however at 20g, a further decrease of 0.0202 g/cc was observed. The density increased to 0.90680g/cc from 0.88680g/cc for 25 grams, the reason for the sudden increase in density could be because the optimum density has been reached.

For silicon oxide nanoparticles, it shows that the density of the crude oil decreased rapidly from 1.29g/cc to 0.90580g/cc after 5 grams of the stated nanoparticle was introduced into the system. The density remained steady when another 5 grams of the constituent was added. A decrease of 0.91460g/cc was recorded at 15 grams of the same nanoparticle, however at 20 grams, the density decreased by 0.0046 and further decreased by 25 grams. Iron oxide nanoparticle, on the density shows that the density of the crude decreased from 1.29g/cc to 0.88760g/cc after 5grams of the stated nanoparticle was introduced into the system, signifying the nanoparticles had high effect on the oil. However, for 10grams of the mass percent concentration of the nanoparticles shows that the density increased to 0.89800 from 0.88760. Similarly, for 15g, the density increased to 0.91220 from 0.88760. An increase of 0.91260 was recorded for 20g and 0.91260 for 25grams.

3.2 Effect of CuO, SiO and FeO_3 Nanoparticles on API Gravity of the Heavy Crude

The impact of mass percent concentration of nanoparticles on API Gravity of the crude oil is presented in Figure 2

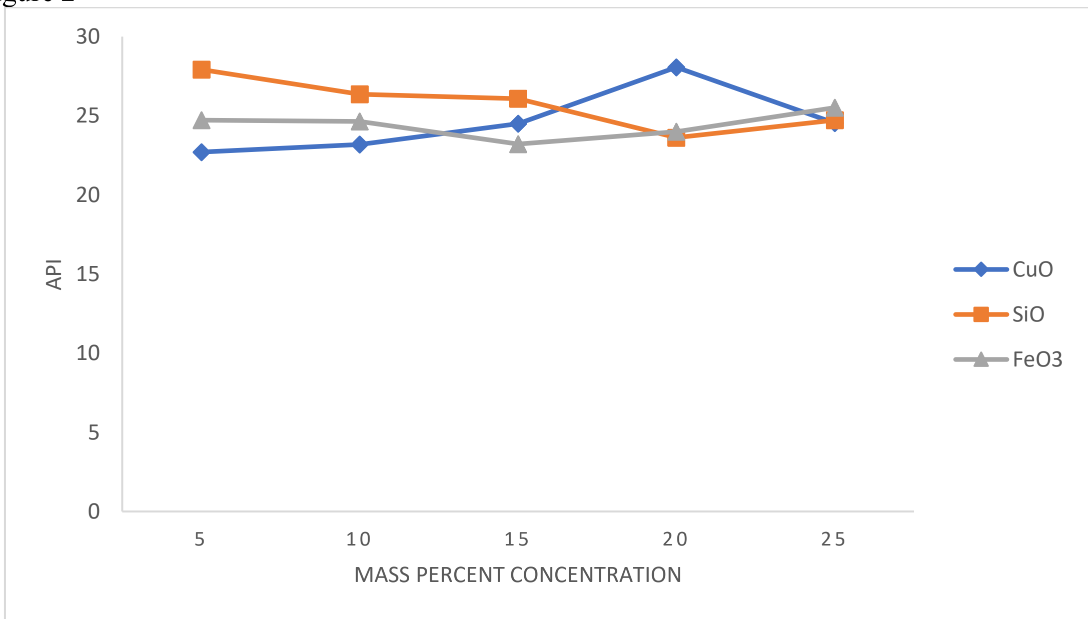

Figure 2: Effect of Mass Percent Concentration of CuO, SiO and FeO_3 on the API Gravity of the Crude Oil.

The API gravity of the crude oil increases rapidly from 15.54^0 to 22.91^0 after 5g of CuO, nanoparticle was added into the system. The API gravity then increased by 0.47197^0 when 10g of CuO was added. Then the API gravity increased to 24.50882 ° for 15grams. However, at 20g, the API gravity increased from 24.50882 to 28.06247 and a slight decrease of 3.51924 was observed for 25grams.

For calcium oxide nanoparticle, the API gravity increased from 15.54° to 27.91866 ° for 5grams. When 10 grams of SiO was added the API gravity decreased from 27.92 to 26.35364 °. The API gravity further decreased by 0.28126 ° for 15grams. A decrease of 23.9945° was recorded for 20g of the same nanoparticle, however at 25g, the API gravity increased from 23.9945 to 24.5128 °.

For FeO_3 nanoparticle at same mass percent concentration the API gravity increased from 15° to 27.0663 when 5grams was added. An increase of 23.1786 ° was observed when 10grams was added. For 15grams, the API gravity further increased from 23.1786 to 23.2124. For 20grams, a reduction of 0.7821 was observed and later increased to 24.5128 when 25grams was added.

3.3 Effect of CuO, SiO and FeO_3 Nanoparticles on Viscosity of the Heavy Crude Oil

The impact of mass percent concentration of nanoparticles and on viscosity of the crude oil is presented in Figure 3.

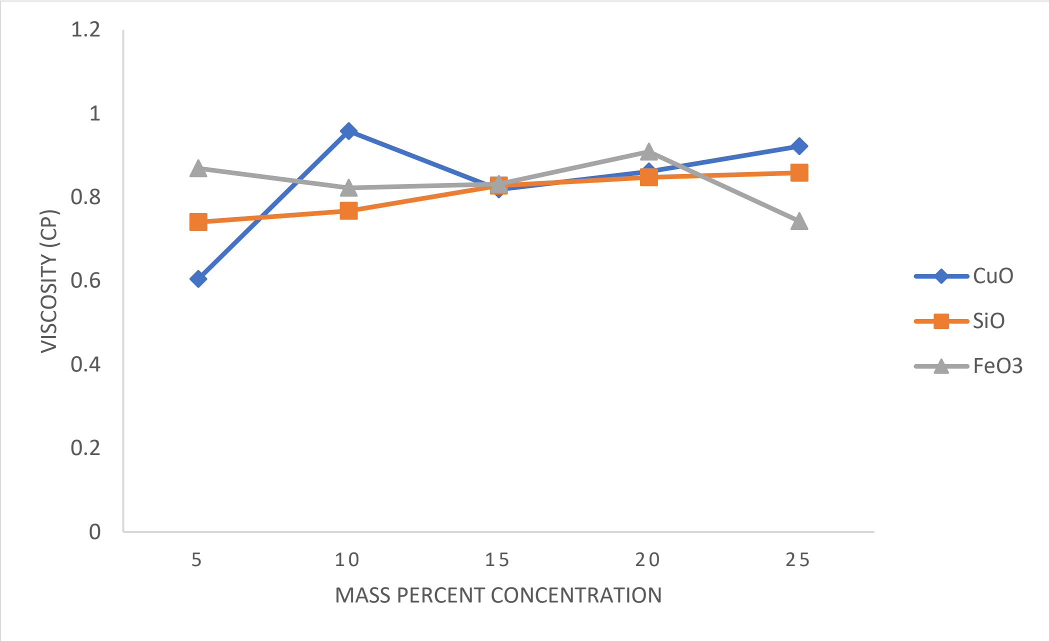

Figure 3: Effect of Mass Percent Concentration of CuO, SiO and FeO_3 on the Viscosity of the Crude Oil.

When 5 grams of copper oxide (CuO) nanoparticle was added, the viscosity decreased from 1.6cp to 0.6045 cp. The viscosity increased by 0.054cp when 10 grams of CuO was added and further decreased from 0.65808 to 0.63836 when 15 grams was added. A decrease of 0.62134 was observed for 20grams and 0.60199 for 25 grams.
when 5-gram of silicon oxide nanoparticle was added to the viscosity decreased from 1.6cp to 0.54047. For 10 grams, the viscosity increased from 0.54047 to 0.541729, the viscosity decreased from 0.541729 to 0.53762 for 15 grams of SiO. The viscosity further decreased to 5.21494 by 25grams. For Iron oxide, the viscosity decreased from 1.6 cp to 0.76891cp when 5grams was added, when 10-gram the viscosity decreased from 0.76891 to 0.72262. For 15 and 25 grams of nanoparticles, the viscosity increased to 0.73168 and later decreased to 0.70884.

3.4 Effect of CuO, SiO and FeO_3 Nanoparticles on Flowrate of the Heavy Crude Oil

The impact of mass percent concentration of nanoparticles on Flowrate of the crude oil is presented in Figure 4.

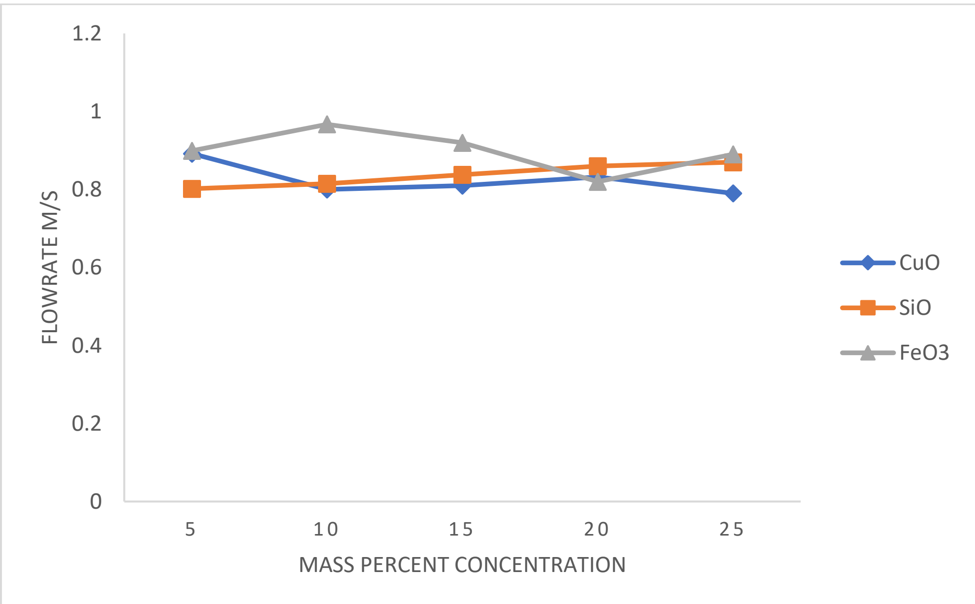

Figure 4: Effect of Mass Percent Concentration of CuO, SiO and FeO_3 Oxide on the Flowrate of the Crude Oil.

The flow rate is seen rise sharply from 0.7litres to 0.896 liters when 5g CuO of the constituent was introduced to the system. The flowrate increased gradually to 0.9 liters for 10g of the constituent before slowly dropping to 0.88 liters for 15g, 0.84 liters for 20g and 0.78 liters for 25g respectively.
The effects of the constituent of SiO on the flowrate of the recovered oil are shown in Figure 4. The flow rate is seen to rise gradually from 0.7 liters to 0.8 liters when 5g of the constitute was introduced to the system. The flowrate continued to increase slowly to 0.81 liters for 10g of the constitute and further upwards to 0.83 liters for 15g, 0.86 liters for 20g respectively before recording a slight decrease of 0.83 liters for 25g.
This shows the effect of constituent on flowrate of recovered crude with Iron nanoparticle. The line signifies the flowrate increased with increasing amount of constitute. From the plot, 5g of the constituent increased the flowrate from 0.7 liters to 0.89 liters. The flowrate increased substantially from 0.89 liters to 0.97 liters at 10g and from 0.97 liters to 1.15 liters at 15g. However, a decline from 1.15 liters to 1 liter was observed for 20g before a sharp upward movement was seen at 25g.

IV. CONCLUSION

In this research work, Investigation of the Effectiveness of different types of nanoparticles in Enhanced Oil Recovery was carried out and the following conclusions were drawn;

i. Increase in mass percent concentration of the nanoparticles (copper, Iron and silicon Oxide) decreases the density of the crude oil.
ii. The viscosity of the heavy crude decreased with increase in mass percent concentrations of (copper, Iron and silicon Oxide nanoparticles).
iii. The API Gravity increased with increase in mass percent concentration of (copper, Iron and silicon Oxide) nanoparticles.
iv. Increase of mass percent concentration increased the flowrate of the crude oil.

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