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Comparative study on the effects of guar gum nanocomposite and guar gum polymer solutions on enhanced oil recovery

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Abstract. Guar gum is a polysaccharide that occurs naturally, and has useful properties in thickening and stabilizing. This makes it of interest in enhanced oil recovery, because of its ability to increase the sweep efficiency of the recovery process. Also, guar gum has an economical and reliable supply as well as flexible chemistry. Guar gum, however, cannot interact with oil-rock surface or the oil-water interface, thereby limiting its capacity to recover crude oil. Nanoparticles can, therefore, be mixed with guar gum to increase its recovery potential. Silicon oxide nanoparticles can be combined with a polymer to form a polymer nanocomposite, which can then be used to increase the overall efficiency of the crude oil recovery process. In this study, the viscosity profile of guar gum was investigated under different conditions of temperature and weight percentages. Four temperatures were investigated: 30, 50, 75, and 90℃. Six weight percentages were also investigated in the viscosity tests: 0.1, 0.2, 0.3, 0.4, 0.5, and 1. The oil recovery potential of guar gum and guar gum nanocomposite was also investigated at different weight percentages. Across the six weight percentages used in the viscosity study, it was observed that there was an average percentage loss in viscosity of 33 % as the temperature was increased from 30℃ to 90℃ at the highest shear rate of 1021 s-1. At 30℃, the viscosity of guar gum was seen to increase by close to 1000 % as weight percentage was increased from 0.1 to 1. The recovery factor observed during core flooding tests utilizing guar gum at three different concentrations indicated an increment of 48, 51, and 54% respectively. On addition of silicon oxide nanoparticles at different concentrations, oil recovery was enhanced by 54 % to 67.2 % OOIP. This validates the recovery potential of guar gum for enhanced oil recovery.

Keywords: guar gum, enhanced oil recovery, viscosity, silicon nanoparticles, nanocomposite

1. Introduction

Several challenges exist in the process of oil recovery. Such challenges include the presence of an interface between the displacing fluid and the crude oil, mobility level of displacing fluid, heterogeneity of reservoir

structure, wettability of rock surface, etc. [1]. The use of chemicals in enhanced oil recovery (EOR) has been found to reduce the impact of some of these challenges and increase oil recovery.

Chemical flooding involves the injection of solutions such as polymer, surfactant, or alkali into the reservoir, usually alongside water, to increase the sweep efficiency of the process. A combination of chemicals may also be used in the flooding process to achieve the targeted effect. Several types of biopolymers and synthetic polymers have been studied in the literature for use in the EOR process. Some synthetic polymers that have been studied include acrylic acid, comb polymers, associative polymer, polyacrylamide and NVP (N-Vinylpyrrolidone) [2]. Some biopolymers that have been tested include scleroglucan, guar gum, xanthan gum, schizophyllan, etc. Biopolymers have been found to have a higher tolerance for shear and salinity than synthetic polymers, but are more prone to biological degradation during the flooding process [3]. Nonetheless, synthetic polymers that contain ATBS monomer have been found to show the following characteristics: higher resistance to shear and salinity; lower adsorption of the polymer to reservoir rock during the flooding process, and reduced polymer precipitation in reservoirs with high temperatures. On the other hand, NVP monomers give polymers greater resistance to hydrolysis that the ATBS monomer. Guar gum polymer has been found to have good viscosifying properties which makes it a potentially good agent for chemical flooding in EOR.

Guar gum or guaran is a biopolymer produced from the plant *Cyamopsis tetragonoloba*. Guar gum is composed mostly of mannose and galactose; and has been used extensively as thickener, stabilizer, and emulsifier, properties that make it potentially useful in EOR. It has been found to show pseudoplastic behaviour when an external force is applied to it, and this behaviour shows a pronounced effect with molecular weight [4]. Guar gum has been used in the oil industry due to its relative cost, resistance to thermal and mechanical degradation, and its environmental biodegradability. It has been used as a fracturing fluid, in formulating drilling muds and now in chemical flooding process [5, 6]. The use of guar gum polymer for chemical flooding can produce up to 35% of additional oil from a reservoir after water-flooding [7-9]. The polymer achieves oil recovery by reducing the mobility of the displacing fluid. It is however believed that if guar gum is combined with a nanoparticle, the combination or nanocomposite would be able to achieve greater recovery by combining the macroscopic efficiency of the polymer with the microscopic efficiency of the nanoparticle to achieve greater overall efficiency; hence, the use of guar gum nanocomposite.

The application of guar gum in combination with nanoparticles for EOR has not been studied extensively. Nanoparticles range between 1-100 nm in size and are composed of a core and thin shell [10]. The core controls the physicochemical properties of the nanoparticle, while the shell is made up of inorganic material [11]. Nanoparticles that have been commonly used in the flooding process are silica and alumina. Others include oxides of copper, magnesium, nickel, zinc, iron tin, etc. Nanoparticles have the potential to change oil wettability, which is an important mechanism for increased oil recovery [12-14]. Silicon oxide nanoparticles have been found to enhance oil recovery when dispersed in ethanol [15]. Aluminium oxide nanoparticles are effective in increasing oil recovery when used in heavy oil fields because aluminium oxide can reduce the viscosity of the oil, therefore leading to increased mobility of the oil [16]. Magnesium oxide nanoparticle has been reported to control fines migration in reservoirs [17-19]. Other nanoparticles that can control fines migration have not been studied in detail. Silicon oxide was chosen in this work because of its potential in EOR, and its cost and availability. It was combined with guar gum to harness the strength of both to enhance oil recovery. Silicon oxide nanoparticle interacts with the oil-rock and oil-water interface to enhance oil recovery, while guar gum reduces the mobility of the displacing fluid. In this work, the viscosity of guar gum under different conditions of weight percentage, temperature and silica concentration was studied. The capacity of guar gum and its nanocomposite for enhanced oil recovery was also studied.

2. Experimental description

2.1. Materials

Guar gum polymer was purchased from a local dealer in Lagos Nigeria. Sigma Aldrich silicon oxide nanoparticles with the purity of 98+% and an average size of 30-50 nm were used for the experiments. Guar gum and silicon oxide nanoparticles were used in viscosity measurement and the core flooding process. Other materials used include; crude oil with API 24.8^0 gotten from Izombe Oilfield, Niger Delta region of Nigeria, and reservoir core samples.

2.1.1. Equipment

The viscosities of all samples were measured using an OFITE® 800 Model Viscometer. The enhanced oil recovery process was initiated and actualized with the use of OFITE® Reservoir Permeability Tester (RPT), and all flooding was done at 28℃. The saturation of core samples for porosity determination was done using Vinci Equipment at high-pressure.

2.2. Preparation of core samples used

Four core samples representing the porous medium were used for the core flooding equipment in the laboratory to measure the effects of testing fluids for this enhanced oil recovery process. For this experimental work, the core samples were acquired from Offshore Depobelt – Niger Delta. The core samples were cleaned in a soxhlet extractor using toluene as the cleaning solvent. Density and fluid viscosity were determined using a pycnometer and glass capillary viscometer, respectively. The core sample was saturated using Vinci Equipment's high-pressure core saturator for Porosity Studies. Table 1 shows the core sample properties.

Table 1: Petro-physical properties of core sample used

Sample	Pore Volume (cc)	Porosity	Permeability (mD)
Core 1	12	0.27	248.15
Core 2	21.8	0.31	228.4
Core 3	20.8	0.39	205.7
Core 4	5.8	0.15	215.3

2.3. Preparation of polymer fluids and polymer nanocomposites

2.3.1. Formulation of guar gum polymer

Plastic bottles were filled to 500 mL with deionized water. Respective quantities of guar gum were then measured and added to the deionized water. Guar gum was prepared to the following weight percentages for viscosity measurements: 0.1,0.2, 0.3, 0.5, and 1. These weight percentages were selected based on literature and pre-tests conducted in the laboratory. Core flooding was done using weight percentages of

0.1, 0.3 and 0.5. These weight percentages were chosen based on the requirement of the OFITE RPT machine (see table 2).

Table 2: Guar – gum polymer composition for flooding

S/N	Weight (%)	Weight (g)	Concentrations
1	0.1	0.5	GGC1
2	0.3	1.5	GGC2
3	0.5	2.5	GGC3

2.3.2. Formulation of guar gum polymer and silicon oxide nanocomposites

Guar gum nanocomposite was prepared using a similar method as the guar gum polymer. The nanocomposite is a mixture of guar gum and silicon oxide nanoparticles in deionized water. For the core flooding experiment, three weight percentages of silicon oxide nanoparticle were mixed with three different weight percentages of guar gum polymer. The three weight percentages of silicon oxide nanoparticle used are 0.1, 0.3 and 0.5 while the three weight percentages used for guar gum are 0.1, 0.3, and 0.5. In this case, silicon oxide nanoparticle was first added to deionized water before the addition of guar gum polymer. Table 3 shows the composition of guar-gum and silicon oxide nanoparticles.

Table 3: Composition of guar-gum and silicon oxide nanoparticle

S/N	Guar-gum concentration [g,%]	Silicon oxide concentrations [g,%]
1	[0.5, 0.1] ~ GGC1	[0.5, 0.1] ~ S1
2	[1.5, 0.3] ~ GGC2	[1.5, 0.3] ~ S2
3	[2.5, 0.5] ~ GGC3	[2.5, 0.5] ~ S3

2.4. Viscosity measurements

Viscosity was measured using OFITE 800 Model Viscometer. The mixture to be measured was filled into the sample cup of the viscometer. The rotor sleeve of the viscometer was immersed to the fill line of the sample cup. The viscometer was set to the required shear rate, and measurement was taken from the dial reading of the viscometer. In the case of higher temperatures, the heating mantle of the viscometer was used to achieve the desired temperature before the measurement was taken.

2.5. Core flooding

Guar-gum and Guar-gum nanocomposite flooding were implemented successively using the OFITE® Reservoir Permeability Tester. All core flooding experiments were done at 28^0C.

This setup comprises three different compartments that are either filled up with crude oil, brine or the polymer solution. For regulation of the flow of fluid, each compartment is equipped with inlet and outlet valves. The flood operates using a high precision pump to inject into one of the compartments at that instant, then acting as a driving force pushing a piston plate inside it, which drives the liquid contained in the compartment at the same time isolating the driving fluid from the displacing reservoir fluid. Figure 1 illustrates the experimental flooding setup. It shows the following parts of the core flooding equipment: pump fluid, pump, valves, displacing reservoir fluid, piston to separate the oils, crude oil, brine, polymer (Treating fluid), pressure gauge, bypass valve, hassler cell holder with core, sleeve pressure, effluent into test tubes.
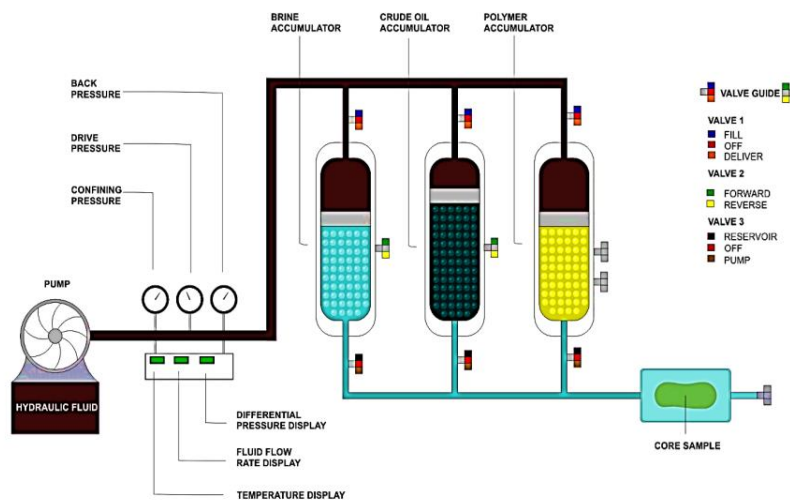

Figure 1: Schematic of the Experimental setup for core flood apparatus (Ojo et al., 2019)

2.5.1. Data collection using core flooding equipment

In carrying out this experiment, the actual reservoir system has to be reproduced at the laboratory scale. The core samples used for this experiment were already saturated 100 % with brine after the cleaning procedure; therefore, there was the need to introduce oil into the core plugs. At a flow rate of 3cc/min, oil was injected into the core plugs draining out the initial brine in the core sample until no more brine was produced. This process enabled the establishment of the initial water saturation, S_{wi}. After injecting oil into the core plugs and establishing an initial water saturation value, at a rate of 3 cc/min water was injected into the core plugs. This was done in the representation of the secondary recovery process.

However, Polymer fluids and polymer nanocomposites Flooding were conducted after water flooding considering the concentration of the recovery agents, and each value was collected every 4mins and recorded. To measure the oil recovery, the experiment was monitored closely all through the duration of each flooding and manually recording the amount of fluid produced at various time intervals.

2.5.2. Polymer fluids and polymer nanocomposites flooding analysis

All individual core plugs were flooded using the same method. Core plug was first injected with oil at a flow rate of 3 cc/min, displacing the brine already 100 % saturated in the core sample. This drainage process was done to attain initial water saturation and oil saturation values. This was followed by the injection of

water at 3 cc/min to displace the oil in the core sample till no more oil can be produced via the water being injected. The back pressure set at 200 psi and the confining pressure having built to 700 psi at the end of the flooding.

The production of oil from the core sample into the receiving tube was monitored by observing the level of the oil-brine interface. Movement of the interface level indicated the continuous production of fluid. When oil production stopped, it implied that the core content has reached its residual oil saturation. The volume of the produced oil was oil was recorded in cc. This concluded the secondary recovery process for the core sample, thereby making it viable for tertiary recovery.

After water flooding, the core sample was injected with guar-gum polymer at different concentrations, and the flooding continued until no more oil was produced from the core sample. This was done to investigate the capacity of the guar-gum polymer to recover the residual oil left in the reservoir after water flooding. The flooding process recovered oil continuously till only brine was being produced.

3. Results

3.1. Viscosity profile of guar gum polymer

3.1.1. Effect of weight percent on the viscosity of guar gum

Figure 2 shows the viscosity of guar gum polymer at different weight percentages of guar gum, ranging from 0.1 to 1.0.
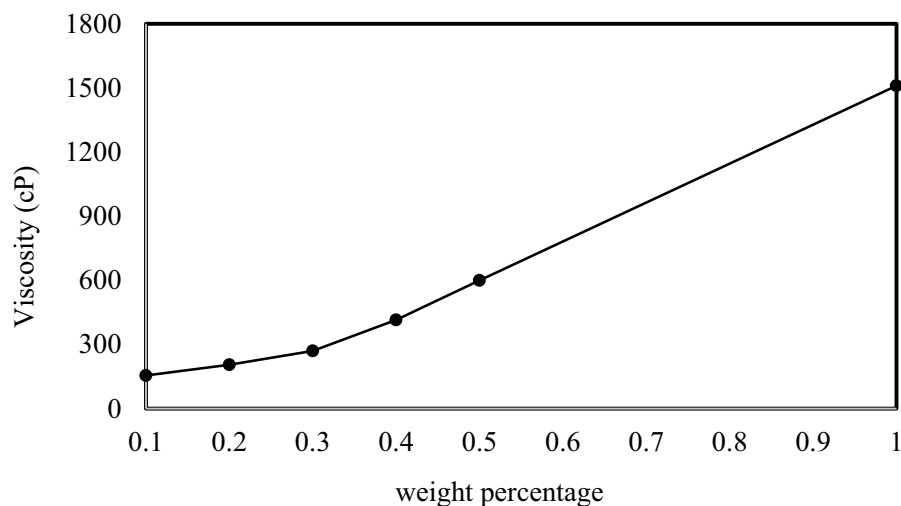

Figure 2: Viscosity of guar gum polymer at different weight percentages

3.1.2. Effect of temperature on viscosity of guar gum

Figure 3 shows the effect of temperature on the viscosity of 1 wt% guar gum at different weight percentages.
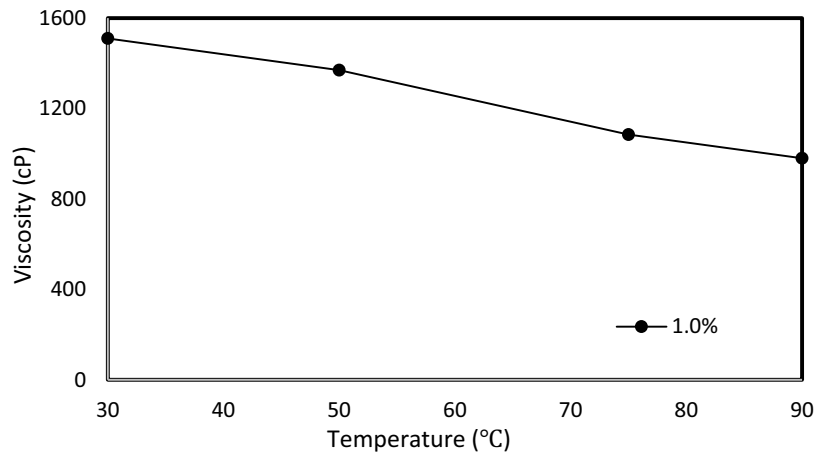
Figure 3: Temperature effect on viscosity of guar gum polymer

3.1.3. Effect of silicon oxide nanoparticle on the viscosity of guar gum

Figure 4 shows the effect silica nanoparticle on the viscosity of guar gum polymer at different weight percentages of silica.
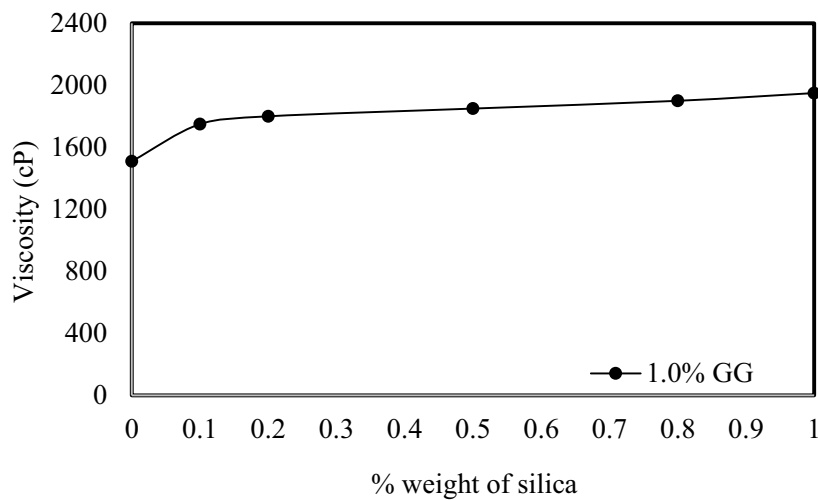

Figure 4: Viscosity profile of guar gum nanocomposite

3.2. Crude oil recovery potential of polymer and nanocomposite

3.2.1 Guar-gum polymer flooding analysis

Figure 5 shows the result for the core flooding experiment conducted using three weight percentages of guar gum polymer. The core flooding of the three weight percentages was done sequentially after water flooding, and result shown in the plot.
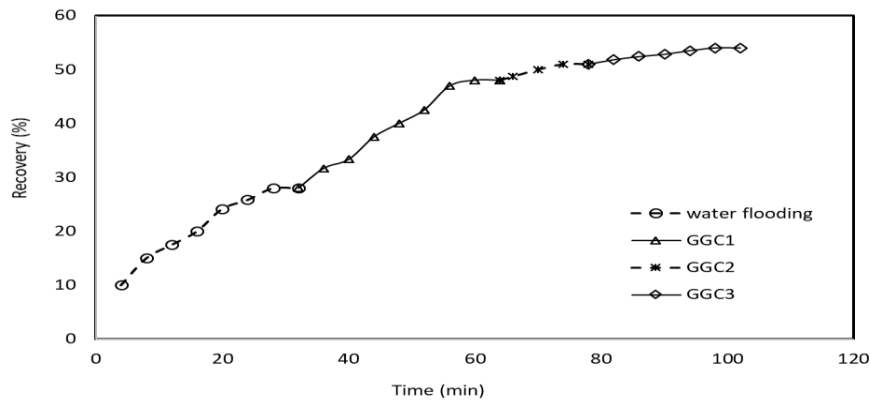
Figure 5: Recovery for guar gum on core sample 1

3.2.2. Guar-gum nanocomposites flooding analysis.

To enhance polymer flooding, nanoparticles were added to the polymer solution to test for improved recovery. The results are presented in Figures 6-8. The lowest weight percentage of guar gum (GGC1) was first used in combination with three weight percentages of silicon oxide nanoparticles incrementally (Table 3). The result is illustrated in Figure 6. Table 4 shows the properties of the core plugs used.

Table 4: Petro-physical properties of core sample 2 used for a new solution (GGC1 and silicon oxide)

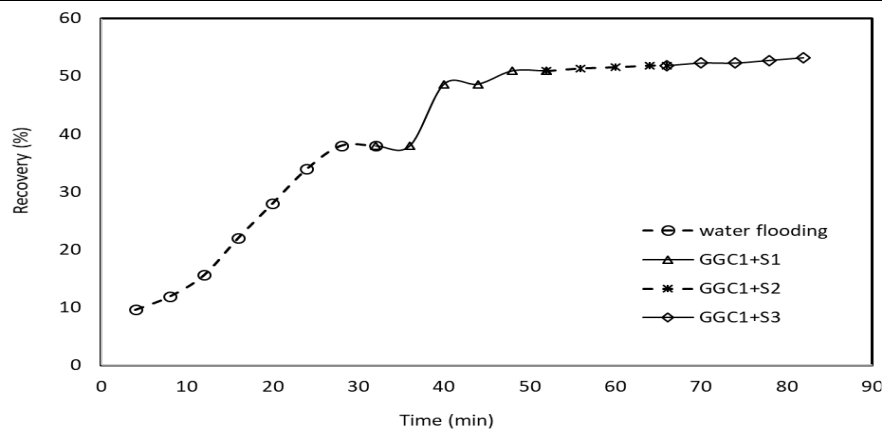| Permeability (mD)	228.4	Porosity	0.31
Pore volume	21.8	Length	4.7
Core sample	2	Diameter	2.2

Figure 6: Flooding result of guar gum (GGC1) and silicon oxide nanoparticle
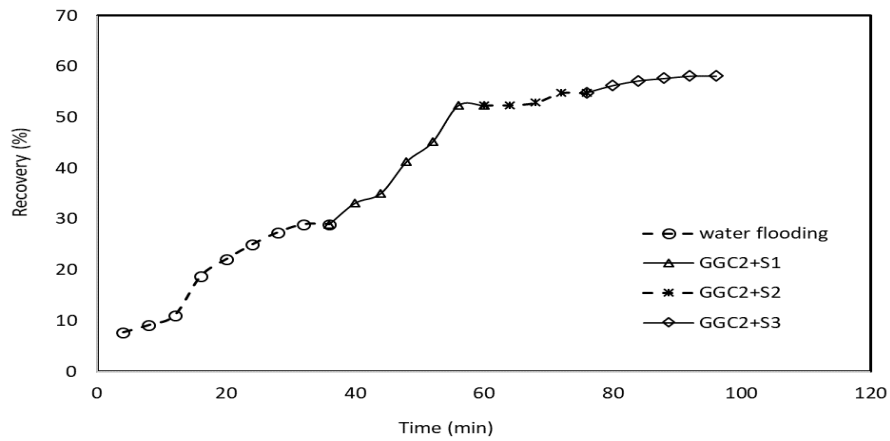
Figure 7: Flooding result of guar gum (GGC2) and silicon oxide nanoparticle

The third concentration of polymer solution from table 2 was mixed with different weight increments of silicon oxide nanoparticle. Table 5 shows the properties of the core plug used and Figure 8 shows the result obtained from polymer (GGC3) and silicon oxide nanoparticle.

Table 5: Petro-physical properties of core sample 4 used for guar gum (GGC3) and silicon oxide nanoparticle

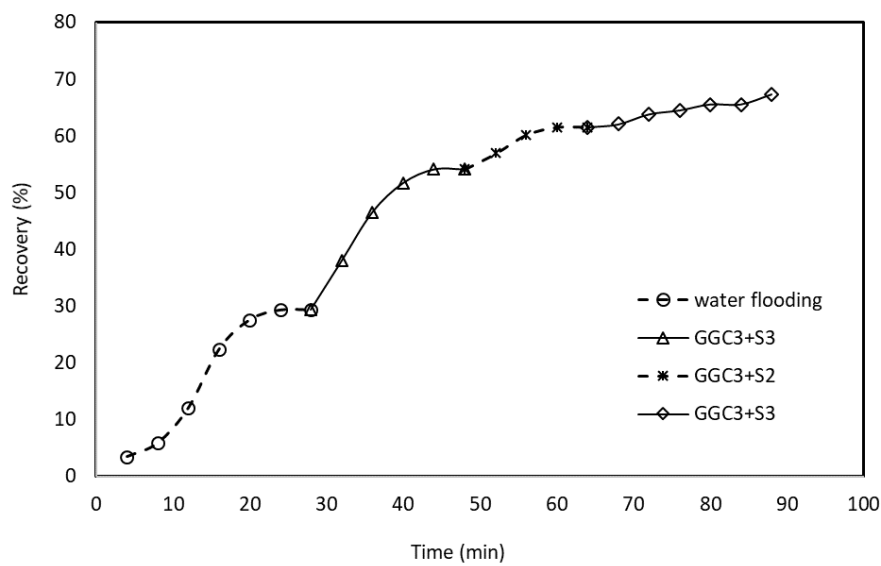|			
Permeability (mD)	215.3	Porosity (%)	0.15
Pore volume	5.8	Length (cm)	4.5
Core sample	4	Diameter (cm)	2.2

Figure 8: Flooding result of guar gum (GGC3) and silicon oxide nanoparticle

4. Discussion

4.1. Result for viscosity tests of guar gum polymer

The viscosity of guar gum showed a proportionate increase with weight percentage, up to about 1600 cP at 1 weight percent. Also, as the weight percentage increased tenfold, the viscosity was observed to increase by about ten times. From figure 3, it is observed that the viscosity of guar gum reduces with temperature. This means that as the temperature increases, its intermolecular entanglement loosens up and reduces. The viscosity of guar gum dropped by about 25 percent at the temperature was increased from 30 to 90℃. Silicon oxide nanoparticle was observed to have produced a slight increase in the viscosity of guar gum polymer. The viscosity of guar gum increased by about 29 % as the weight percentage of silica was increased to 1 wt%.

4.2. Result analysis for guar-gum polymer flooding

Guar gum polymer flooding was successfully conducted on core sample 1 at different concentrations. The values obtained from the core flooding experiment show some level of recovered oil increment after each flooding. The different concentrations used for guar gum polymer were GG conc 1, GG conc 2 and GG conc 3 selected from table 1.

However, the effectiveness of each concentration was monitored, and the amount of oil recovered, and the recovery was plotted against time, as illustrated from figures 5 to 8. Figure 5 shows a plot of crude oil recovery considering guar gum polymer (Conc 1, Conc 2, Con 3) flooding against the time of core contacted by the solution at 28℃ on core plug.

For the lowest concentration of GG conc 1 in figure 5, water flooding performance gave a recovery of approximately 28 % OOIP leaving a huge amount of oil in the core. Sequel to water flooding at figure 2, GG conc 1 was then introduced, and it recovered additional oil up to 48 % accumulated recovery.

When GG, conc 2 was then introduced, figure 5 shows that it recovered additional oil up to 51% OOIP accumulated recovery.

Finally, in figure 5, GG conc 3 was later used for the flooding to check for more oil and it recovered an additional 54 % OOIP. This gave the optimum recovery since any further increment in polymer concentration did not recover more oil.

4.3. Result analysis for guar-gum nanocomposite flooding

To enhance the recovery of polymer flooding, nanoparticle was introduced to polymer flooding. The addition of silicon nanoparticle to each guar gum polymer was done on three different sandstone core plugs. The flooding process was conducted at 28℃, and the pressure was a buildup of 700 psi. Table 2 shows the composition of each nanoparticle mixed with polymer solutions.

The lowest concentration of guar gum (GG conc 1) was mixed with different concentrations of silicon oxide nanoparticle i.e. 0.1, 0.3, and 0.5 wt%. The effectiveness of this new mixture was tested on core sample 2, and the amount of oil recovered was improved and illustrated in figure 6. The recovery increased gradually with each weight percentage achieving 50, 51 and 53 % recovery of OOIP respectively.

Figure 7 shows the result for GG conc 2 mixed with three weight percentages of silicon oxide nanoparticle respectively. Recoveries of 52, 55 and 58 % OOIP were achieved respectively for the three weight percentages. The improvement in mobility ratio and reduction in the interfacial tension between the reservoir fluids added this additional increment.

The highest concentration of guar gum (GG conc 3) was as well mixed with three concentrations of silicon oxide nanoparticle. The effectiveness of this new mixture was tested on the core sample 4 and the amount of oil recovered was improved and illustrated in figure 8. The recovery increases gradually at each weight increment achieving the highest recovery of 67.22 % at the highest concentration of silicon oxide nanoparticle.

5. Conclusion

Polymer nanocomposite worked as a dual oil recovery agent with good rheological behaviour. Several experimental runs were performed to examine the activity of each solution. A rheology device and core flooding equipment were used to obtain results adopted in this article to investigate the EOR potential and rheological behaviours of each solution. Several conclusions are obtained as follows:

(1) The viscosity of guar gum polymer increased proportionately with weight percentage and it reduced by 25 % when the temperature was increased from 30 to 90℃.
(2) Silicon oxide nanoparticle can increase the viscosity of 1 wt% of guar gum by 29 %. The selected system can provide resistance for the polymer under harsh reservoir conditions
(3) The optimized formulation of the guar gum nanocomposite flooding system at 28°C achieved enhanced oil recovery of 67.22 % OOIP while the guar gum polymer of equivalent weight percentage achieved a recovery of 54 %. The improved recovery is attributed to an improvement in mobility ratio and a reduction in the interfacial tension between the reservoir fluids.

As more and more guar gum molecules are trapped in the throat, the intramolecular association of polymers progressively alter into intermolecular condensation, creating a denser network structure. The network structure in the throat plays an important role in increasing flow resistance and changing the direction of liquid flow, and its viscoelasticity contributes to the discharge of residual oil.

Under the synergistic effect of silicon oxide nanoparticle and guar gum polymer, hydrodynamic residual oil, membrane residual oil, and residual oil droplets can be mobilized, thus helping to enhance oil recovery.

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