ABUAD Journal of Engineering and Applied Sciences (AJEAS)
ISSN: 2992-5584

Volume 2, Issue 1, 20-27

Performance Evaluation of Rankiya (Grewia *venusta*) as a Polymer for Enhanced Oil Recovery-Polymer Flooding

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Date Submitted: 26/12/2023
Date Accepted: 02/03/2024
Date Published: 30/06/2024

Abstract: *Polymer Flooding is an enhanced oil recovery method where high-molecular-weight polymers are added into the injected water, in order to increase the viscosity of injection fluid, improve volumetric sweep efficiency, and finally increase the oil recovery factor. Most research studies focused on the use of partially hydrolysed polyacrylamide (HPAM), xanthan gum, SPG, HEC as flooding fluid. This work focused on investigating the potential of natural polymer - Grewia venusta plant tree in formulating flooding fluid for polymer flooding operation. The polymer was prepared from the mucilage extracted from the inner stem bark of Grewia venusta. Rheological characterization shows that the formulated Grewia venusta mucilage (GVM)-based flooding fluid maintained high viscosity under very high salinity, also exhibits shear thinning behaviour which obeys power law model with fluid behaviour index n = 0.32 and consistency index K= 6.3 at highest GVM concentration of 3000 ppm, similarly revealed that GVM-based flooding fluid was stable when subjected to high salinity of 130,000 ppm and temperature, up to 90 °C an inconsequential decrease in viscosity was experienced. These indicate its potential in enhancing oil recovery process. Core flooding analysis was carried out on an outcrop core sample with porosity and permeability of 26.1% and 218 mD respectively. Core flooding analysis revealed that: with increase in GVM concentration of 500, 750, 1000 and 2000 ppm oil recovered against time were 55.1%, 62.6%, 69.2% and 72.9% respectively, beyond 2000 ppm GVM concentration (optimum concentration), increase in polymer concentration did not bring about an increase in oil recovery, this finally resulted to an incremental recovery of 29% original oil in place (OOIP).*

Keywords: Polymer flooding, oil recovery, polymers, Grewia venusta mucilage, core flooding set-up.

1. INTRODUCTION

Primary oil recovery utilizes the energy provided by natural drive mechanisms such as an expansion of free gas, solution gas drive, natural water drive, fluid and rock expansion and gravity drainage and it can only recover around 20-30% of the oil [1, 2].

Secondary oil recovery which is the injection of water or gas is usually employed after primary production has fallen. Normally water is injected into underground reservoir rocks to maintain reservoir pressure and sweep oil into production wells which in turn recovers 10-20% additional oil recovery after primary method has fallen. This process is referred to as water flooding. But, operation only recovers less than 50% original oil in place (OOIP) due to capillary forces and immiscibility of the oil and water [1, 3, 4]

However, by means of enhanced oil recovery (EOR) techniques such as gas injection, water alternating gas (WAG), and polymer flooding, the recovery factor can account for 60-65% [5]. Injection of polymer solution into reservoirs is termed polymer flooding. This method was also applied in different places such China, Angola, Brazil etc. [6]. Polymers, such as partially hydrolyzed polyacrylamide (HPAM) and Xanthan gum, proved effective in improving oil recovery [7]. For commercial EOR project, hydrolyzed polyacrylamides (HPAMs) are still the most extensively used polymer to date due to its availability in large quantity with customized properties (molecular weight, hydrolysis degree, etc.) and low manufacturing cost. However, HPAM is extremely susceptible to reservoir conditions (temperature, salinity, shear, etc.), which as a result leads to notable loss of the thickening power [8]. The oil and gas industries have been actively searching for a polymer that can withstand high salinity and high temperature. In recent years, biopolymers have attracted the attention of petroleum industry [9, 10].

Applications of biopolymers for chemical EOR are gaining more significant interest due to their eco-friendly nature [11–13]. Jang *et al*. [14] assessed the effectiveness of xanthan gum polymer for EOR at various concentrations, temperatures, shear rates, and salinity.

https://doi.org/10.53982/ajeas.2024.0201.03-j

Result shows that the polymer exhibited non-Newtonian behaviour at high shear rates due to its rigid polysaccharide chains and alignment of the chains along the line of flow. As compared with partially hydrolysed polyacrylamide (HPAM), which witnessed significant viscosity reduction when subjected at the same condition, xanthan polymer was found to withstand a high salinity concentration, while the viscosity decreased marginally under the influence of temperature. Oil displacement tests show that the application of xanthan gum for heavy oil recovery with 3 wt.% NaCl and 10 wt.% NaCl produced an incremental oil recovery of 28.4% and 30.1% respectively, over waterflooding. Moreover, Xu *et al.* [15] reported that the application of welan gum resulted to a significant improvement in oil recovery and good rheological properties compared with xanthan gum.

However, *Welan* gum is unsuitable for high salinity and high temperature owing to anionic charges on the polymer backbone. Likewise, Gao [16] reported that field pilot application of schizophyllan yielded approximately 20% incremental oil recovery over the waterflooding process. Though several complexities remain in understanding the rheological properties of schizophyllan [13,17]. Olabode *et al.* [18] reported to have achieved 19.71%, 27.9%, 31.59 % incremental oil recovery after waterflooding in three different core samples using a biopolymer (B-P) formulated from Solanum tuberosum (waste) Starch (naturally occurring biodegradable polymers derived from potato peel). Similarly, Gbadamosi *et al.*, [19] investigated the potential of okra mucilage in oil recovery process their finding reveal that okra mucilage polymer exhibited pseudo plastic behaviour at varying shear rates, also recorded 12.7% incremental oil recovery over waterflooding though the viscosity of okra mucilage decline at high salinity and high temperature.

Grewia venusta mucilage (GVM) is a natural polymer extracted from the inner stem back of an edible plant called Grewia venusta. Its major monosaccharide composition is identical to that of xanthan gum: both mainly compose of glucose, Rhamnose and xylose [20-23]. These compounds are mostly polysaccharides that are characterized by the ability to produce highly viscous solutions at low concentrations [23]. *Grewia venusta mucilage* is commonly used in food industries to impart a desired slimy consistency to local soups and stew [20]. Figure 1 shows the pictorial view of Grewia venusta plant.

Figure 1: *Grewia venusta* plant

Similarly, research has shown that *Grewia venusta* has good rheological properties, and it is locally available and extensively used in Food (as food stabilizers, preservatives etc.) and pharmaceutical industries (as stabilizers, film courting of tablet, binders, etc.) however, there is little or no research work on its applicability in oil recovery process despite being inexpensive, available, good thickening ability and can tolerate high temperature and salinity [22, 23]. This paper studies the rheology of *Grewia venusta mucilage* under high salinity and high temperature conditions. Laboratory core flooding analysis was carried out to verify the effectiveness of *Grewia venusta mucilage* in the improvement of oil recovery.

2. MATERIALS AND METHODS

2.1 Materials

2.1.1 Grewia venusta mucilage (GVM)

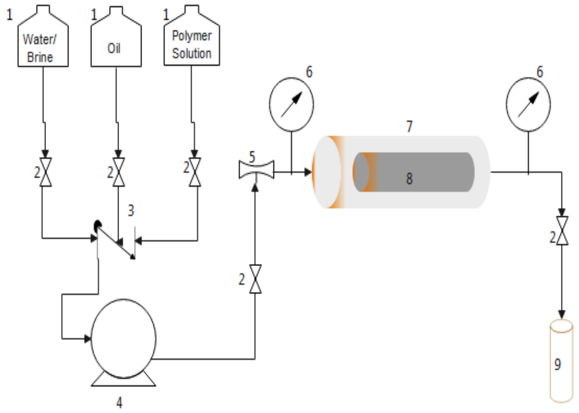
The plant material used in this study was the mucilage extracted from Grewia venusta stem bark obtained from Buskuri town of katagum local government of Bauchi State with Geographical coordinates of latitude and longitude of 10.3203215 and 11.6502121 respectively. Table 1 contains the list of equipment used in the research and their function.

Table 1: List of equipment used and their functions

Equipment	Function of Equipment in the Experiment
Knife	Scraping stem back
Laboratory Sieve	Sieving of sample
Air oven	Sample drying
Weighing Balance	weight determination
FANN VG 35 Viscometer	Viscosity determination
Water bath	Heating of sample
Motor and pistil	Sample grinding
PH Meter	pH determination
Mud Balance	Density Measurement
Thermometer	Temperature Measurement
Hand driller	Core sample preparation

2.1.2 Description of core flooding setup

This section discusses the functions and specifications of each equipment and instrument used in the construction of the core flooding experiment setup, The core flooding setup was made up of three fluid tanks which contain brine, oil and polymer solution, it also equipped with a pump which sucks fluid from the reservoir tanks and discharges it through the flow meter, into the hassles type core holder and into the core sample and jet out at the outlet of the core holder where it is collected in a measuring cylinder located at the outlet of the core holder. The setup is also equipped with five gate valves at different points to control flow when needed and two pressure gauges at the inlet and outlet of the core holder to measure pressure drop across the core sample**.** The process flow schematic diagram is shown in Figure 2.



1- Fluid Container 2- Throttle Valve 3- Manifold 4- Displacement pump 5- Flow meter 6- Pressure gauge 7- Core holder 8- Core Sample 9- Effluent collector

Figure 2: Process engineering flow schematic for experimental setup

Figure 3: Constructed experimental setup

Figure 3 shows the fabricated core flooding setup which is made up of ATLAS 125 centrifugal suction pump with energy requirement of 372.85 W and voltage of 200-250 V, two WALFRONT Ltd model TS pressure gauges with pressure rating of 0-200 psi to measure pressure drop across the core sample, 1x 3 internal diameter cross-linked polyethylene (PEX) plastic pipe, a core holder, Sea Zhongjiang digital flow Meter model YF-B6S, with working pressure of 0.05 - 1 MPa and flow range of 2-30 litre for measurement of flow rate, Three 2 litters capacity tank and 6 mm corrosion resistance round brass tube grade CuZn37 pipe connections and 10 ml measuring cylinder for effluent collection

2.2 Method

This research work consists of two parts: *Grewia venusta mucilage* extraction and bench test which involve *Grewia* venusta stem back acquisition, GVM flooding fluid preparation and formulation**,** rheological characterization of the formulated flooding fluid and laboratory core flood experiment which involve design, construction and conducting core flood experiment.

2.2.1 *GVM flooding fluid Preparation*

The stem back of *Grewia venusta* (Rankiya) plant was obtained from Buskuri town of Katagum LGA of Bauchi State. Mucilage from the stem was removed using the procedure described by Alobo *et al.* [24], the stems was thoroughly cleaned by scrapping off the brownish powdery bark with knife and was then wash in clean water. The washed stem barks were then cut into short pieces of about 20 cm long and reduced to thin strips which weighed about 200 g. The pieces were mixed with 1.5 litres of clean water and allowed to settle for 48 hrs, after this time the sample was squeeze to release the mucilage, double folded muslin cloth was then used to filter the released mucilage which separated it from the pieces of strips. The mucilage was then dried in an air oven at 50±3 ºC for 24 h, milled, sieved using a laboratory sieve of 80 meshes, weighed and stored in air-tight containers. Figure 4 and 5 shows the dried *Grewia venusta* stem back and the Oven dried, milled and sieved *Grewia venusta mucilage*.

Figure 4: Dried stem bark of *Grewia venusta*

Figure 5: Oven dried, milled and sieved *Grewia venusta mucilage*

2.2.2 *GVM flooding fluid formulation*

The flooding fluid was formulated using the method described by API Recommend Practice 63 as procedure for the preparation of polymer solution from polysaccharide product, the amount of polymer needed to make up the appropriate amount of stock solution with polymer concentration of 5000 ppm and the make-up water was calculated, the calculated amount of GVM required was spread into the make-up water in the blending jar, while stirring with rheostat blander at low speed for 2 minutes, the mixture was then allowed to mix for 3 minutes at high speed, the formulated solution was then diluted to the desired concentration. The formulated GVM stock solution is shown in Figure 6.

Figure 6: Formulated GVM stock solution

2.2.3 *Rheological characterization of biopolymer (GVM)*

GVM solution of an active concentration of **5000** ppm was diluted using high salinity brine (1**30000** ppm NaCl and **50000** ppm anhydrous CaC1$_2$) to form the equivalent concentration of 500, 750, 1000, 2000 and 3000 ppm

i. Fann 35A viscometer was used to measure the viscosity of each solution to characterize its flow behavior at different revolution per minute ranging from 3 rpm to 600 rpm respectively

ii. The viscosities of each GVM solutions of 500, 750, 1000, 2000 and 3000 ppm were measured at shear rate ranged from 5.1 – 1022 s^{-1} respectively.

iii. To determine the effect of temperature and salinity, the viscosities of each GVM solution plus high salinity brine at concentration of 1000 ppm were measured at shear rates of 100 rpm, 300 rpm and 600 rpm. Starting from the lowest to the highest shear rate with temperature ranged (30 to 90 ^{o}C) for each shear rate.

2.2.4 *Core sample retrieval and characterization*

The core samples used in this study were obtained from rock surface outcrop (Bima sand Stone) located at upper Benue trough and was confirmed to have properties of a typical sandstone oil reservoir by Hamza and Hamidu [25]. The rock sample obtained was drilled using core driller into 1 inch diameter and 3 inches length which is the recommended size for laboratory analysis:

a. Porosity determination: the porosity of the core sample was obtained using wet and dry (Archimedes) method

b. Permeability determination: core flooding setup was used to determine the permeability; the core sample was placed in core holder, brine was injected into the core holder and through the core until pressure drop stabilizes the value for the pressure drop, injection rate and dimension of the core were recorded, the permeability of the core was estimated using Darcy's law.

2.2.5 *Core flooding experiment*

Core flooding tests followed standard recovery test procedures as described by Gao and Bellout [26]. Firstly, a core flooding analysis experiment was conducted to achieve oil recovery by water flooding. Brine was injected into the core until it became fully saturated; crude oil was then injected to irreducible water saturation (S_{wi}). Subsequently, the core was flooded with brine to residual oil saturation (S_{or}). The displaced effluent was collected in the measuring cylinder located at the outlet of the core holder every 3 minutes. Afterwards, the effluent collected every 3 minutes was used to determine the volume of displaced oil and the percentage of oil recovery. The second experiment assessed the potential of *Grewia venusta mucilage* in improving oil recovery. Sequential injections of 500, 750, 1000, 2000, and 3000 ppm GVM solutions were conducted until residual oil saturation for each injection cycle, and the corresponding amounts of produced effluent were collected, measured, and used to calculate the percentage of oil recovery.

3. RESULTS AND DISCUSSION

3.1 Rheological Characterization of Biopolymer (GVM)

3.1.1 Effect of shear rate on viscosity

Figure 7 demonstrates the decrease in GVM viscosity with increasing shear rate from 5.1 – 1022 s^{-1} across all GMV concentrations (500-3000 ppm); this is attributed to its pseudo plastic behaviour. At low shear rates, the high viscosity of GVM is due to the organized arrangement of polysaccharide chain entanglements. Conversely, the viscosity decreases at high shear rates due to GVM stretching and disruption of the polymeric chain network caused by significant shear forces [20]. The biopolymer shows a strong shear thinning behaviour with an increasing shear rate for all the concentrations, as a result of decrease in viscosity observed as share rate increases. Normally the Shear thinning behaviour of biopolymer is observed when the flow curve passes through the origin as shown in Figure 8.

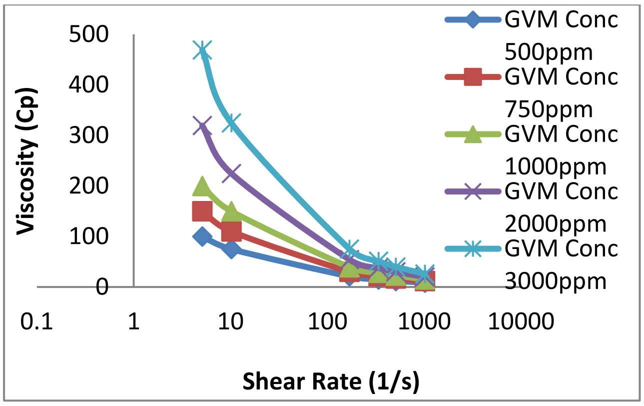


Figure 7: GVM solution viscosities vs. shear rate

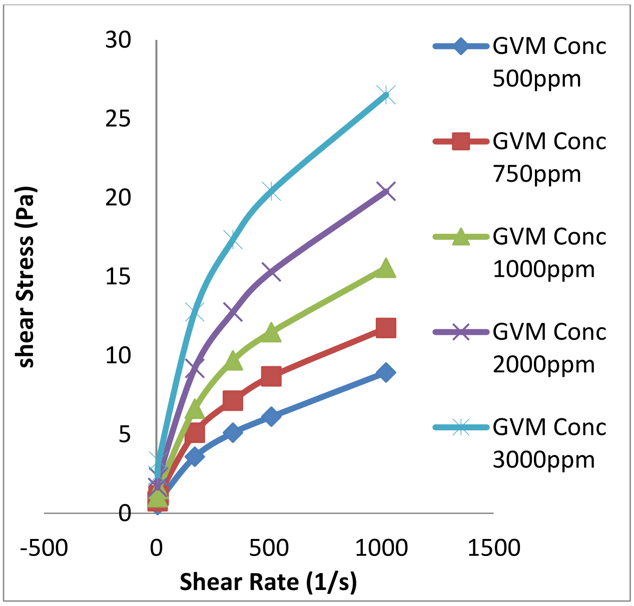


Figure 8: Shear stress vs. shear rate

By and large, the viscosity against shear rate curve of the polymer is almost linear in the double-logarithmic coordinate graph, unveiling the features of power law fluids shown in Figure 9. Generally, for power law fluids, the value of the flow behaviour index (n) is 1 for Newtonian fluids and less than 1 for shear-thinning fluids such as polymer solutions. As the value of (n) deviates from 1, the tendency of the fluid to be non-Newtonian increased. The power-law parameters (n and K) were calculated at different concentrations of GVM solution, as shown in Figures 10 and 11 respectively. It can be seen that with an increase in biopolymer concentration, the values of the fluid behaviour index (n) decrease while the values of the consistency index (K) increase. This justifies that the fluid (GVM solution) exhibits non-Newtonian behaviour.

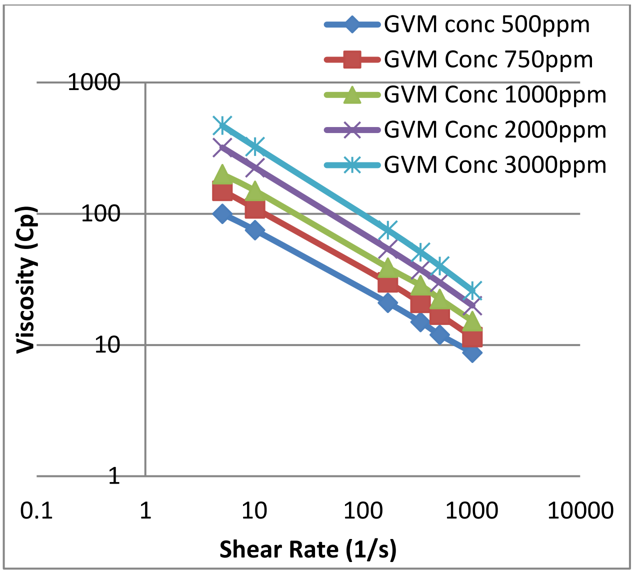


Figure 9: GVM solution viscosities vs. shear rates and polymer concentration

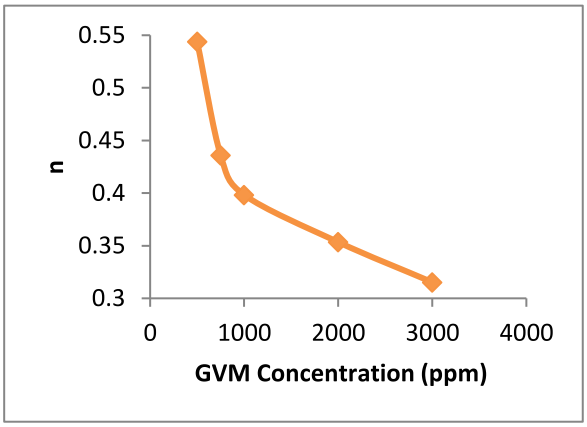


Figure 10: Power law or flow behaviour index (n) vs. GVM concentration

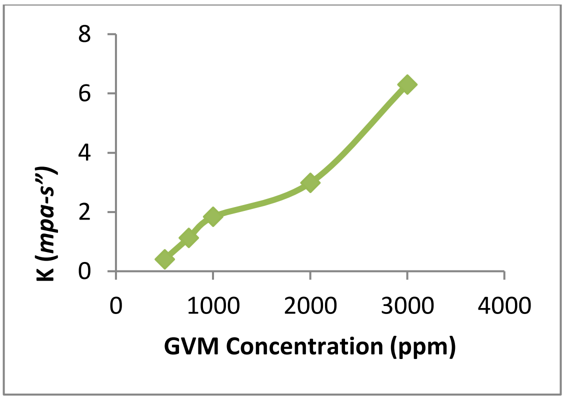


Figure 11: Power law consistency index (k) vs. GVM concentration

3.1.2 *Effect of polymer concentration on viscosity*

The viscosity of GVM solution increases with increase in biopolymer concentration as observed in Figure 12. This attributes to the increase in the number of biopolymer chains in a given volume, which then interact with each other resulting in more frictional effects, thus increasing the solution viscosity [27]. It can be concluded that high concentrations resulted in high viscosity value at the same shear rate.

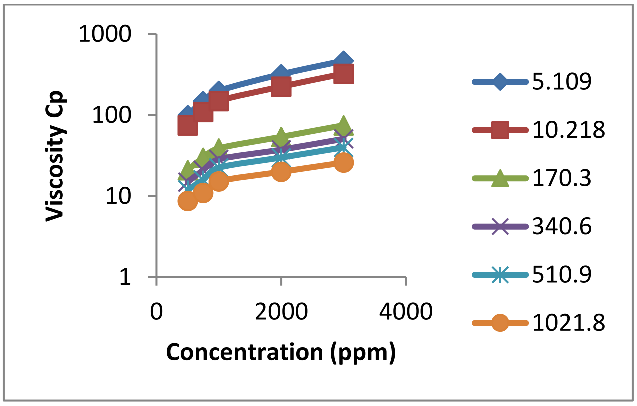


Figure 12: GVM solution viscosities vs. concentration at various shear rates

3.1.3 Effect of temperature on viscosity

The biopolymer solution (1000 ppm) was prepared using a brine with a salinity value of 180,000 ppm, and temperature sweeps (30 to 90 °C) were performed at various shear rates (5.1, 10.2, and 170 s^{-1}) using a Fann 35A Viscometer. Figure 13 presents that the polymer has temperature stability up to 90 °C without any significant decrease in viscosity, unlike HPAM, which does not withstand temperatures above 70 °C. Figure 13 shows no significant change in slope observed with increased temperature on the viscosity values, which is a key aspect for its performance in an elevated reservoir temperature [28].

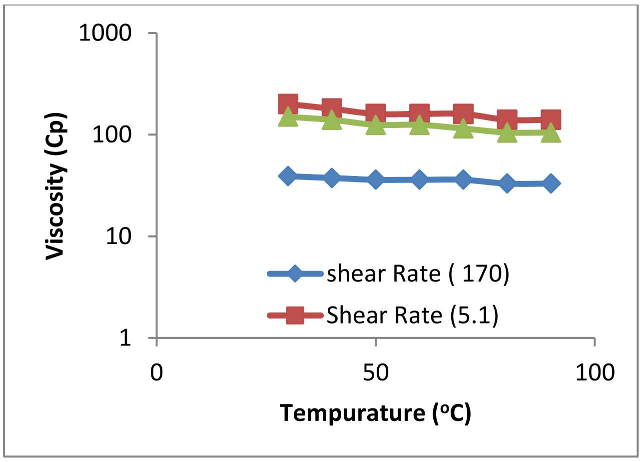


Figure 13: Temperature sweeps of GVM at various shear rates

3.2 Laboratory Core Analysis

3.2.1 Core sample properties

Table 2 shows the measured parameters of the core sample used for the study. The porosity of the core sample was obtained to be 26.1% using wet and dry (Archimedes) method and the average permeability of the core sample was obtained to be 214 mD using Darcy equation.

Table 2: Core sample parameters

Parameter	**Size**	**Unit**
Weight of dry core	63.42	g
Weight of saturated core	79.85	g
Diameter of core	2.54	cm
Length of core	7.62	cm
Pore Volume	15.58	cm^3
Bulk volume	60.81	cm^3
Porosity	26.1	%
Brine/ polymer injection rate	0.003	L/min
Pressure drop	5	psi

3.2.2 Injectivity test result

Core flooding was conducted on an outcrop sandstone core with a porosity of 26.1% and permeability of 218 mD to evaluate polymer injection after attaining residual oil saturation. The imbibition process was conducted for up to 21 minutes. Crude oil was collected in the measuring cylinder. The oil and brine interface of the effluent produced during injection period was monitored and amount of crude oil produce at each injection cycle was obtained. After several flooding with different concentrations of bio-polymer (500, 750, 1000, 2000 and 3000 ppm) on the core sample, it was observed that at 500, 750, 1000, 2000 ppm GVM concentration, oil recovered against time were 55.1%, 62.6%, 69.2% and 72.9% respectively, and each injection cycle was carried out until no additional crude oil was produced from the core. Oil recovery after water flooding for core was 43.9%.

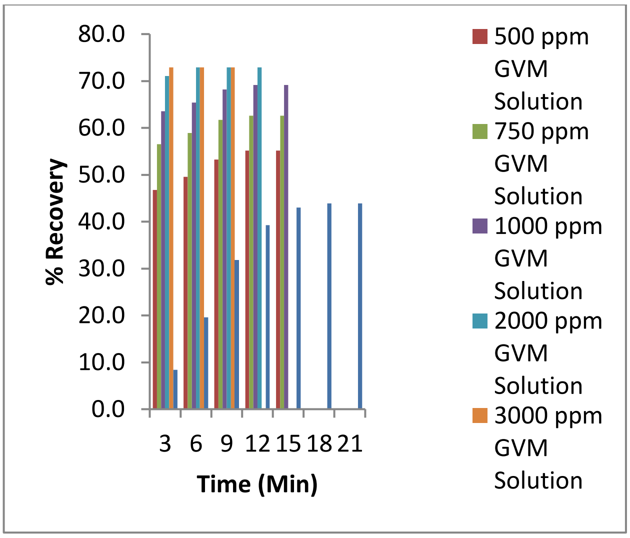


Figure 14: Percentage oil recoveries vs. time for water and polymer flooding

Figure 14 shows the trend of incremental oil recovery results from water flooding to various biopolymer concentrations. However, due to viscous fingering, water by-passed some oil before bio-polymer was injected and was trapped in the core plug, with an increment in concentration, polymer assisted its mobility. This indicated a huge mobilization of the trapped oil after injection of 500, 750, 1000 and 2000 ppm polymer concentration into the core sample; meanwhile after the 2000 ppm (optimum concentration), increase in polymer concentration was not able to produce more oil. This totally brings an incremental recovery of 29% OOIP after polymer flooding process. This is comparable with the result obtained by Oluwasanmi *et al.*,[18] whom achieved 19.71%, 27.9%, 31.59 % incremental oil recovery in three different core samples using a biopolymer (B-P) formulated from Solanum tuberosum (waste) starch and that of Gao [16] who achieved 20% incremental oil recovery after water flooding using biopolymer (SPG). The result from water and biopolymer flooding for core is recorded in Tables 3, while Figure 15 compares the oil recoveries of the core sample with the total effluent produced.

Table 3: Core flooding result

Concentration	Time	Oil Recovery	Cumulative Oil Recovered	Percentage Oil Recovery
Water Flooding	3	0.9	0.9	8.4
	6	1.2	2.1	19.6
	9	1.3	3.4	31.8
	12	0.8	4.2	39.3
	15	0.4	4.6	43.0
	18	0.1	4.7	43.9
	21	0	4.7	43.9
500 ppm GVM Solution	24	0.3	5	46.7
	27	0.3	5.3	49.5
	30	0.4	5.7	53.3
	33	0.2	5.9	55.1
	36	0	5.9	55.1
750 ppm GVM Solution	39	0.15	6.05	56.5
	42	0.25	6.3	58.9
	45	0.3	6.6	61.7
	48	0.1	6.7	62.6
	51	0	6.7	62.6
1000 ppm GVM Solution	54	0.1	6.8	63.6
	57	0.2	7	65.4
	60	0.3	7.3	68.2
	63	0.1	7.4	69.2
	66	0	7.4	69.2
2000 ppm GVM Solution	69	0.2	7.6	71.0
	72	0.2	7.8	72.9
	75	0	7.8	72.9
	78	0	7.8	72.9
3000 ppm GVM Solution	81	0	7.8	72.9
	84	0	7.8	72.9
	87	0	7.8	72.9

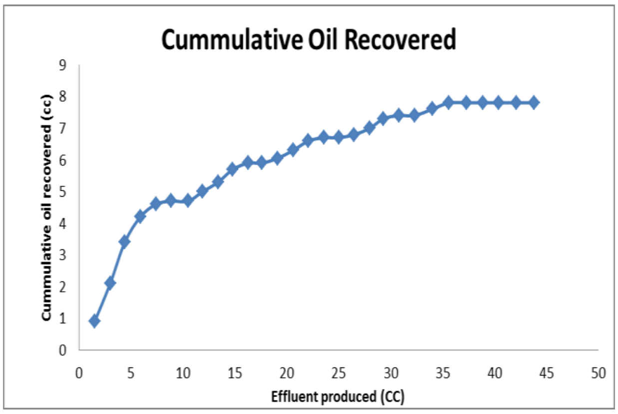


Figure 15: Oil recoveries from the core vs. total effluent produced

4. CONCLUSION

Rheological characterization shows that the fluid exhibit shear thinning behaviour which obeys power law model with power law index n = 0.32 and K= 6.3 at highest GVM concentration of 3000 ppm. In addition, GVM revealed high thermal stability and good rheological properties

Core flooding analysis revealed that, at 500, 750, 1000, 2000 ppm GVM concentration, oil recovered against time were 55.1%, 62.6%, 69.2% and 72.9% respectively, after the 2000 ppm (optimum concentration), beyond 2000 ppm increase in polymer concentration was not able to produce more oil. This resulted in an incremental recovery of 29% OOIP after polymer flooding process. Core flooding analysis revealed reasonable oil recovery by injecting GVM flooding fluid.

Recommendations

i. It's strongly recommended that in the future work to evaluate the GVM performance on in situ reservoir core samples using core flooding.
ii. Analysis of oil recovery of GVM at different concentrations should be made by incorporating the rheological properties of the crude samples and biopolymer concentration in a reservoir simulator.
iii. Further analysis should be done on reservoir cores on polymer retention to ascertain the exact level of absorption that may possibly cause permeability reduction after flooding process.

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