Journal of Materials and Environmental Science
ISSN : 2028-2508
e-ISSN : 2737-890X
CODEN : JMESCN

J. Mater. Environ. Sci., 2022, Volume 13, Issue 12, Page 1489-1499

http://www.jmaterenvironsci.com

Effect of Potassium Carbonate on the Viscosity of Irvingia Gabonensis

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Received 14 June 2022,
Revised 20 Dec 2022,
Accepted 27 Dec 2022

Keywords
- ✓ Reservoir
- ✓ Temperature,
- ✓ Polymer,
- ✓ Concentration,
- ✓ Additive.

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Abstract
In the petroleum industry, the viscosity of polymers is important during enhanced oil recovery (EOR) and Irvingia gabonensis extract, a biopolymer has been proposed as an EOR agent. However, viscosity of polymers deteriorates with increase in temperature, necessitating that the viscosity of polymers at elevated temperatures be studied when proposed for use as an EOR agent since oil reservoirs exist at elevated temperatures. Additives that improve viscosity at elevated temperatures can be deployed; thus in this work, the effect of potassium carbonate as an additive to enhance the viscosity of Irvingia gabonensis from 0 to 10g/l concentrations and at temperatures of 10 to 60ºC is investigated. It is observed that 10g/l concentration of potassium carbonate reduced the viscosity of the polymer at all concentrations and temperatures considered. In the presence of potassium carbonate, the viscosity of the polymer was enhanced mainly at 10 to 30ºC and at polymer concentrations of 6g/l to 10g/l. Since potassium carbonate improves the viscosity of Irvingia gabonensis only at 10 to 30ºC, it is therefore not ideal for use in EOR because most oil reservoirs exist at higher temperatures. Nevertheless, it can be useful in other fields of study.

1. Introduction

Polymers are important fluids that have various uses domestically and industrially. They are chemical compounds with macromolecules bonded together in long repeating chains. There are three classes of polymers based on source and they are natural polymers, synthetic polymers and semi synthetic polymers. The properties of polymers are largely determined by the attractive forces between the polymer chains. Ionic and hydrogen bonding between these chains emanate from the different side groups present in the polymer which gives rise to higher tensile strength and crystalline melting points. Polymers can be semi crystalline or amorphous depending on the chemical structure. Polymers are sometimes modified with additives in order to meet certain criteria and some of these additives can also alter the viscosity property of a polymer.

Biopolymers are polymers produced from natural sources such as plants and they have various uses ranging from food to industrial items such as textile, plastics and packaging materials. They are also exploited in green technology and bio-nano composites technology. One of such biopolymers is the extract from Irvingia gabonensis produced in West Africa. Irvingia gabonensis (also called Ogbono) is a species of African trees known as wild mango, African mango or bush mango and it bears fruits enclosed in a hard shell. Most of the fruits are edible and they are especially valued for their rich fat and protein. There are three varieties of Irvingia gabonensis in Nigeria of which two types produce fruits with edible pulp and turpentine like odor while the other variety bears fruits with very fibrous and inedible pulp. Studies have shown that the flow behavior curve of the viscous solution of Irvingia gabonensis is the same regardless of the variety [1] although differences between the species have been reported [2]. Some properties of the three species of Irvingia gabonensis are presented on **Table 1** [1].

Table 1: Some Properties of the Seeds of Irvingia Gabonensis

Property		Variety		
		Edible Pulp		Inedible Pulp
		Sweet	Bitter	
Kernel	Crude Protein	8.7 ±0.2	8.7± 0.2	8.30±0.1
	Crude fat	66.5±0.3	66.4±0.3	69.7±0.3
Fat	Specific gravity (40ºC)	0.85±0.03	0.84±0.01	0.91±0.02
	Refractive index (40ºC)	1.40±0.01	1.40±0.01	1.45±0.01
	Cloud point(ºC)	35.0±1	35.5±1	36.0±1
	Melting point(ºC)	39.5±0.08	39.7±0.05	39.9±0.04
	Smoking point(ºC)	213.0±0.7	214.0±0.6	215. 3±0.6
	Iodine value	4. 2±0.1	4. 2±0.1	3.5±0.1
	Peroxide value(meq/kg)	1.98±0.03	1.99±0.03	1.95±0.06
	Saponification value	219. 2±0.74	219. 2±0.03	212.7±0.43
	Unsaponifiable matter (%)	0.12±0.002	0.13±0.003	0.40±0.030
	Free fatty-acid (%)	0. 30±0.02	0. 25±0.02	0. 29±0.02

The seed of Irvingia gabonensis that is processed into a polymer is enclosed in a hard shell. Traditionally, the shell is cracked to release the seed which is sun-dried and split into two flat whitish cotyledons which after grinding and dissolved in water is very viscous, forming a polymer which is often used for preparing various dishes. The nutritional and medicinal values of Irvingia gabonensis have been reported [3-7]. The biopolymer is used as a lubricant, a binding and encapsulation agent, and it is also used in making dye, cosmetics and soap. Properties of Irvingia gabonensis polymer have been extensively studies [8-17]. Other studies conducted on the polymer include the effect of storage on its quality, its shelve life improvement and drying characteristics modeling [18-20].

1.1 Kinematic viscosity and dynamic viscosity

Viscosity is a very important characteristic of polymers that is exploited in different fields. It is an essential fluid property when analyzing liquid behavior and it is highly dependent on temperature. It is not appreciably affected by changes in pressure under ambient conditions however, the viscosity of some oils has been found to increase with increase in pressure [21]. There are two types of viscosity; kinematic viscosity and dynamic viscosity. Dynamic viscosity also called absolute viscosity is a measure of the internal fluid friction which causes resistance to flow; it determines the resistance to shearing stresses. Kinematic viscosity is a measure of a fluid's inherent resistance to flow when no external force except gravity is acting on it. The viscosity of interest in this work is dynamic viscosity and it is primarily caused by the cohesion and molecular momentum exchange between fluid layers, and as flow occurs, these effects appear as shearing stresses between the moving layers of the fluid [21]. The shear stress denoted as τ, is proportional to the rate of change of velocity and is mathematically defined as:

$$\tau = \mu \ (dy/dx) \quad \text{Eq. 1}$$

Where

τ = Shear stress.

μ = Dynamic viscosity, a constant of proportionality.

dy/dx = Velocity gradient

Kinematic viscosity (υ) is related to dynamic viscosity (μ) by the equation:

$$\upsilon = \mu/\rho \quad \text{Eq. 2}$$

Where

υ = Kinematic viscosity

μ = Dynamic viscosity

ρ = Density

Hence, dynamic viscosity can be obtained by multiplying the kinematic viscosity by density given as:

$$\mu = \upsilon \ \rho \quad \text{Eq. 3}$$

1.2 Irvingia Gabonensis as a Prospective Biopolymer for Enhanced Oil Recovery (EOR)

Crude oil is a major source of global energy and there are three stages of oil production; primary, secondary and tertiary recovery stages. At the tertiary recovery stage, other fluids other than water and natural gas are injected into reservoirs to enhance recovery and these fluids are called enhanced oil recovery (EOR) agents. Alkaline, surfactant and polymers are effective in enhancing oil recovery and sometimes they are all used in combination and termed Alkaline/Surfactant/ Polymer (ASP). Polymers enhance oil recovery by improving sweep efficiency thus, improving displacement efficiency of residual oil in reservoir formations. Irvingia gabonensis has been proposed as a prospective polymer for use as an EOR agent because it is locally cultivated, available and cheap in many parts of West Africa. In fact, the inedible specie can be fully utilized as an EOR polymer if its suitability as an EOR agent can be established.

There have been several studies on the suitability of Irvingia gabonensis as an EOR agent. Oduola [22] investigated how Irvingia gabonensis and other EOR agents can be blended together to form ASP for EOR. Uzoho [23] and Ojukwu [24] conducted comparative studies of several EOR agents of which Irvingia gabonensis as a polymer was also studied. Ikeagwu [25] also studied the performance of Irvingia gabonensis with other polymers and reported that its use as an EOR agent is possible with a viscosity range of 1.5 to 3.0cp. The use of Irvingia gabonensis with nanofluids for EOR has also been reported [26]. In all the investigations conducted for the use of Irvingia gabonensis as an EOR agent, the effect of temperature on the viscosity of the polymer has not been considered because all the studies to date have been carried out under ambient temperature. However, oil reservoir formations under which this polymer is intended to be subjected exist at elevated temperatures, necessitating that such studies be conducted at elevated temperatures.

Generally, the viscosity of liquids decreases with increase in temperature. This implies that if a polymer such as Irvingia gabonensis extract is injected into reservoir formations for EOR, their viscosity values will be altered which will adversely affect sweep efficiency and displacement efficiency. This emphasizes the need to investigate the effect of temperature on the viscosity of Irvingia gabonensis which is expected to decrease at higher temperatures. In order to maintain the viscosity of Irvingia gabonensis at higher temperatures, the use of potassium carbonate is proposed and investigated. Potassium carbonate is proposed because it is an alkaline which has the capacity to enhance oil recovery. Thus, the effect of the various concentrations (0 to 10g/l) of potassium carbonate on the viscosity of various concentrations (0 – 10g/l) of Irvingia gabonensis is studied in this work. If potassium carbonate can reasonably maintain the viscosity of Irvingia gabonensis at elevated temperatures of oil reservoirs, then it can serve as an ideal additive since it is an alkaline which is also desired in EOR.

Potassium carbonate (K_2CO_3) also known as potash or pearl is a salt that is soluble in water to form a strong alkaline solution. Potassium carbonate is a very stable compound, hence is found widely distributed in the earth's crust [27]. It is deliquescent, often appearing as a damp or wet solid. Potassium carbonate is used in the production of soap and glass. It is also used in reactions to maintain anhydrous conditions without reacting with the reactants and formed products. It is used as a mild drying agent where other drying agents, such as calcium chloride and magnesium sulfate are incompatible.

2. Methodology

2.1 Preparation of the biopolymer from Irvingia gabonensis

Study of the change in dynamic viscosity with temperature of grinded seeds of Irvingia gabonensis as a biopolymer in water solution is of primary interest in this study. The effect of potassium carbonate as an additive at different concentrations on the viscosity of Irvingia gabonensis at different concentrations and temperatures is also studied. Dried Irvingia gabonensis was grinded into fine powder and the required masses (0g, 2g, 4g, 6g, 8g and 10g) were weighed and poured into separate calibrated glass cylinders. The required masses of potassium carbonate powder (0g, 2g, 4g, 6g, 8g and 10g) were also weighed and poured into the various calibrated glass cylinders containing specified masses of the polymer. Each concentration of the polymer was experimented with each concentration of potassium carbonate. Hot water was poured into the calibrated glass cylinders containing the required concentrations of the polymer and additive to 1litre (1000ml), and the mixture was thoroughly stirred and agitated to aid solubility of the polymer. The mixtures were then allowed to cool down to room temperature after which they were allowed to settle for 24 hours with periodic agitation. At the end of 24hours, the mixtures were filtered to remove any solid particles present in the solution.

2.2 Experiment

Viscosity values for each mixture was determined for temperatures of 10, 20, 30, 40, 50 and 60^{o}C using the Cannon Fenske viscometer. Other materials used include a stop watch for determining the efflux time, density bottles and a Table of viscosity constants. The sample mixtures were brought to the desired temperatures using a water bath and refrigerator, and the temperatures of the mixtures were measured with a thermometer. The kinematic viscosity values were obtained by multiplying the efflux time by viscosity constants obtained from Tables, while the dynamic viscosity was obtained by multiplying the kinematic viscosity by the fluid density for each case. Each experiment was conducted at least twice and averages of the obtained viscosity values are presented graphically.

3. Results and Discussions

The experimental results are presented in Figures 1 to 18. There are three factors that affect viscosity in this work and they are temperature, the polymer concentration and concentration of the additive which is potassium carbonate. There are therefore three sets of plotted graphs; a plot of viscosity against temperature in Figures 1 to 6, a plot of viscosity against the polymer concentration in Figures 7 to 12 and a plot of viscosity against the potassium carbonate concentration in Figures 13 to 18.

3.1 Dynamic viscosity of the polymer against temperature

Figure 1 shows the viscosity of the polymer at different concentrations without potassium carbonate. As expected, the viscosity of the polymer decreases as temperature increases and the viscosity of the polymer increases as the polymer concentration increases almost in equal proportions. This set of results can be used to model the viscosity of Irvingia gabonensis with temperature at different concentrations of the polymer. The highest viscosity of Irvingia gabonensis without potassium carbonate was 2.4cp at 10g/l concentration of the polymer and at 10^{o}C. Figures 2 to 6 show that the highest viscosity of Irvingia gabonensis with potassium carbonate was 5.4cp at 10g/l concentration of the polymer, at 6g/l of the additive and at 10^{o}C. All other viscosity results for all the concentrations of the polymer and additive considered fall below 5.4cp.

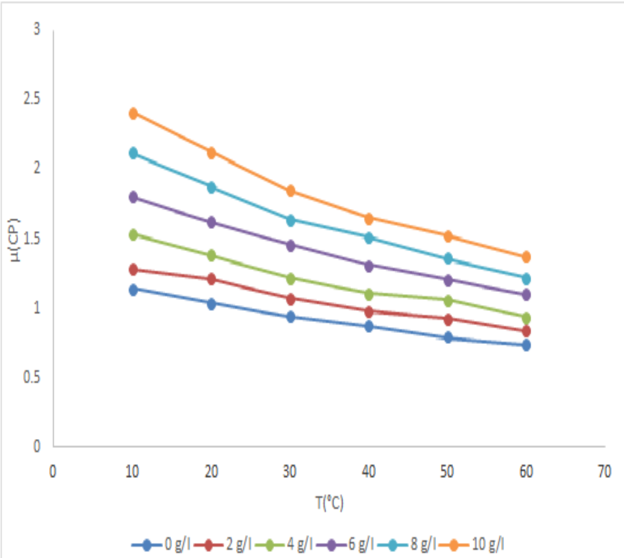

Figure 1: Viscosity of Irvingia Gabonesis at Varying Temperatures for 0g/l Potash

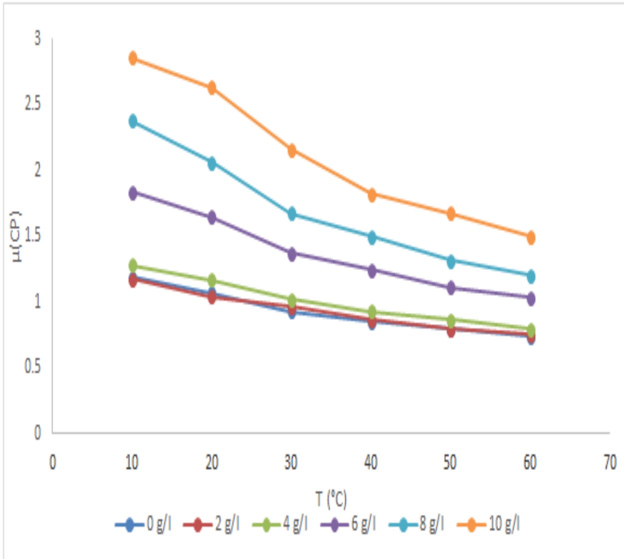

Figure 2: Viscosity of Irvingia Gabonesis at Varying Temperatures for 2g/l Potash

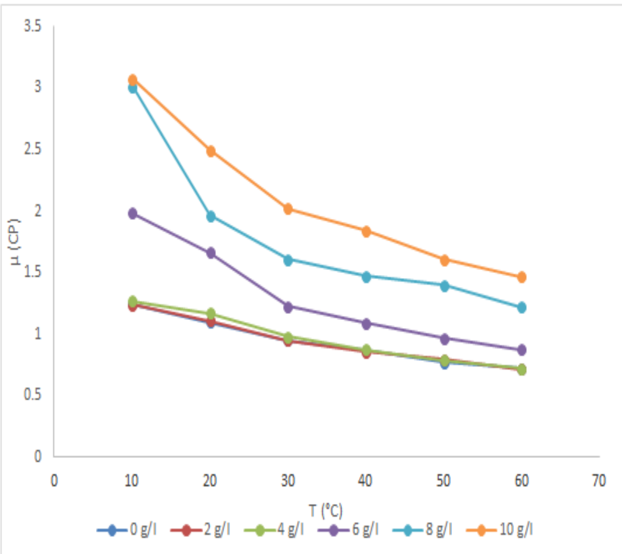

Figure 3: Viscosity of Irvingia Gabonesis at Varying Temperatures for 4g/l Potash

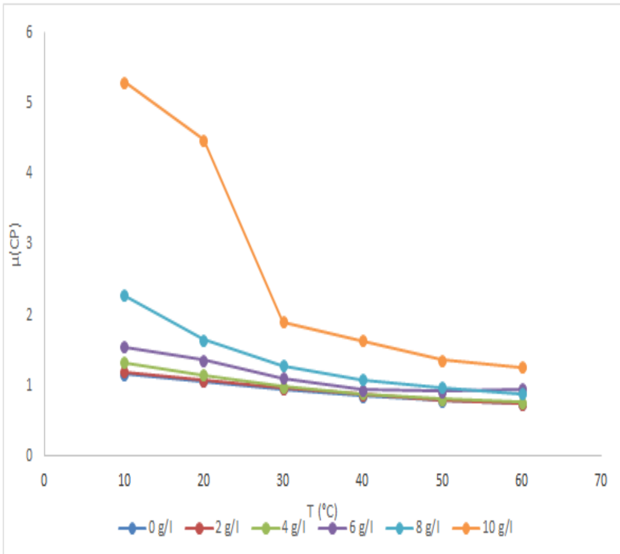

Figure 4: Viscosity of Irvingia Gabonesis at Varying Temperatures for 6g/l Potash

It can also be observed from Figures 1 to 6 that as the potassium carbonate concentration increases, it reduces the disparity in viscosity values between the different concentrations of the polymer especially at higher temperatures and starting with the lower concentrations of polymer. There are indications from Figures 2 to 6 that the viscosity enhancement with the additive is mainly at lower temperatures of 10, 20 and 30^oC. Thus, the effect of potassium carbonate on the viscosity of Irvingia gabonensis is minimal at higher temperatures of 30^oC and above but more effective at lower temperatures of 30^oC and below. 30^oC therefore seems to be a critical temperature value for the polymer.

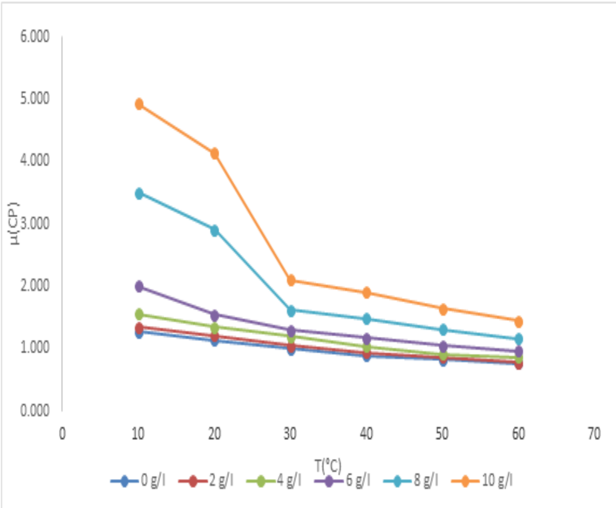

Figure 5: Viscosity of Irvingia Gabonesis at Varying Temperatures for 8g/l Potash

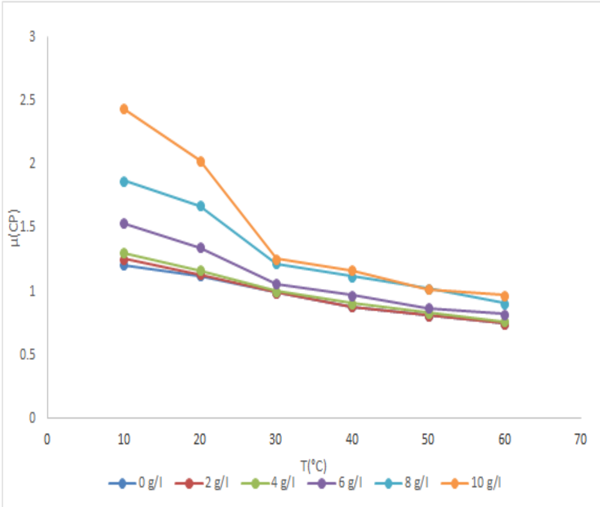

Figure 6: Viscosity of Irvingia Gabonesis at Varying Temperatures for 10g/l Potash

3.2 Dynamic viscosity of the polymer against polymer concentration

In Figures 7 to 12, it is clear that viscosity increases as the polymer concentrations increase for all temperatures as expected. It is observed that the viscosity of the polymer decreases as temperature increases. These two observations show that the effects of temperature and concentration on the polymer were not drastically altered by the presence of potassium carbonate. Another important observation is that the lowest values of viscosity in the presence of potassium carbonate are attained at a concentration of 10g/l in all the results. Probably 8g/l or 9g/l might be the highest concentration limit of potassium carbonate that will not be detrimental to the viscosity values of Irvingia gabonensis; this constitutes an area for further research.

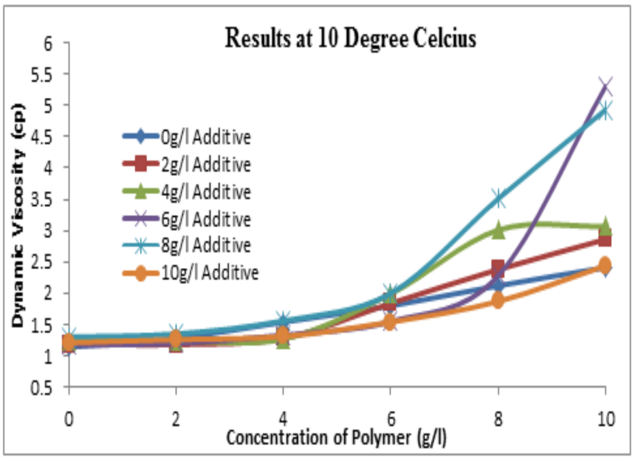

Figure 7: Viscosity of the Polymer at Varying Concentrations for 10^oC

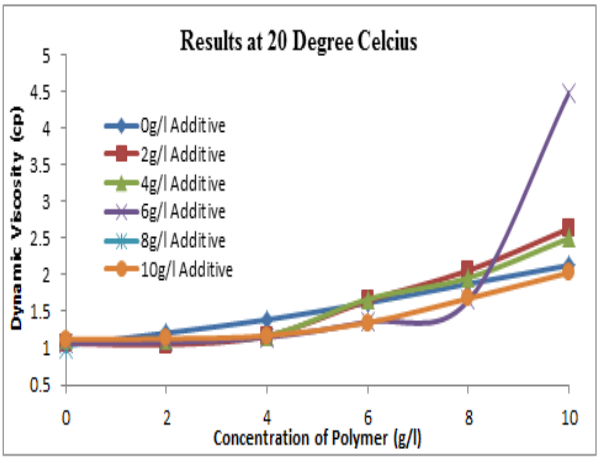

Figure 8: Viscosity of the Polymer at Varying Concentrations for 20^oC

It is speculated that different temperatures might have an optimum concentration of potassium carbonate that gives the highest viscosity value for the polymer. For example, at 10 and 20^oC (Figures 7 and 8), 6g/l of potassium carbonate gives the highest viscosity values while at 30 and 40^oC (Figures 11 and 12), 2g/l of potassium carbonate gives the highest viscosity values (but closely followed by 4 and 8g/l). However, at 30 and 40°C (Figures 9 and 10), the viscosity results for 2, 4 and 8g/l of the additive are very close and are the highest viscosity values.

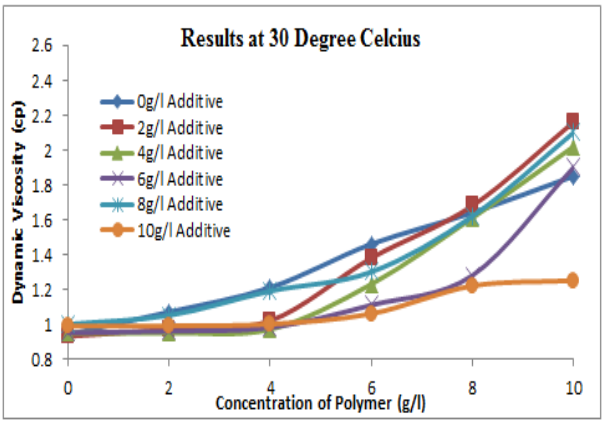

Figure 9: Viscosity of the Polymer at Varying Concentrations for 30°C

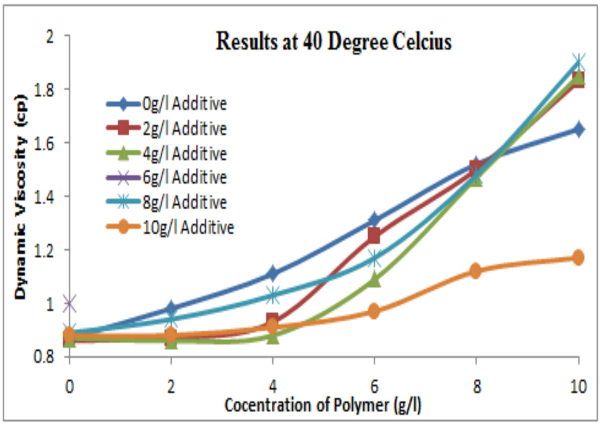

Figure 10: Viscosity of the Polymer at Varying Concentrations for 40°C

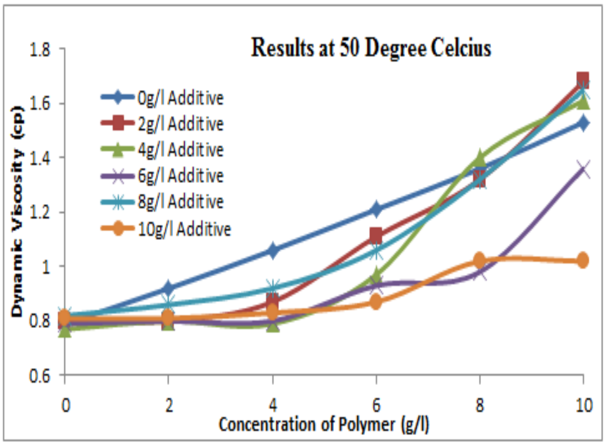

Figure 11: Viscosity of the Polymer at Varying Concentrations for 50°C

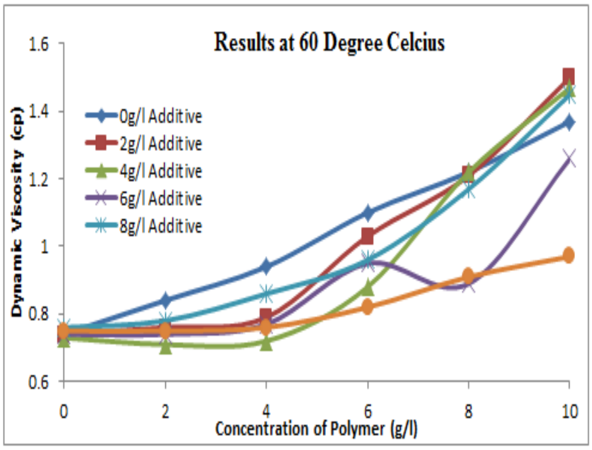

Figure 12: Viscosity of the Polymer at Varying Concentrations for 60°C

3.3 Dynamic viscosity of the polymer against additive concentration

A common trend can be observed in Figures 13 to 18 showing the effect of potassium carbonate on the viscosity of the polymer at different concentrations. There is a regular pattern of viscosity increase and decrease with the polymer concentrations and potassium carbonate concentrations (with only few exceptions at few points). Such patterns enhance the understanding of polymer behavior especially at different temperatures.

In almost all the cases and for all the temperatures except a few cases like 10g/l polymer concentrations at 10 and 20°C, a drop in viscosity value at 6g/l of the additive is observed and the highest viscosity values were attained at 8g/l concentration of the additive. For all the concentrations of polymer and temperatures considered, the viscosity of the polymer dropped at 10g/l of the additive. The effect of increasing the concentration of potassium carbonate beyond 10g/l on the viscosity of the polymer is not certain until further work in the area is conducted. Note that 6g/l additive at 10g/l concentration of the polymer at 10°C and 20°C gave the highest viscosity values of 5.4cp and 4.6cp respectively in this work. However, 6g/l additive in all other cases gave the lowest viscosity values; the reason for this irony with respect to 10°C and 20°C is not clear. Note also that 8g/l of the additive gave the highest viscosity values in most other cases but not for 10g/l concentration of the polymer at 10°C and 20°C. Further work is required in these areas to explain why the general trends observed in almost all other cases is disrupted for 6g/l and 8g/l concentration of additives at 10g/l polymer concentration for 10°C and 20°C. It will be interesting to conduct these experiments at temperatures lower than 10°C and higher than 60°C as well as increasing the additives beyond 10g/l.

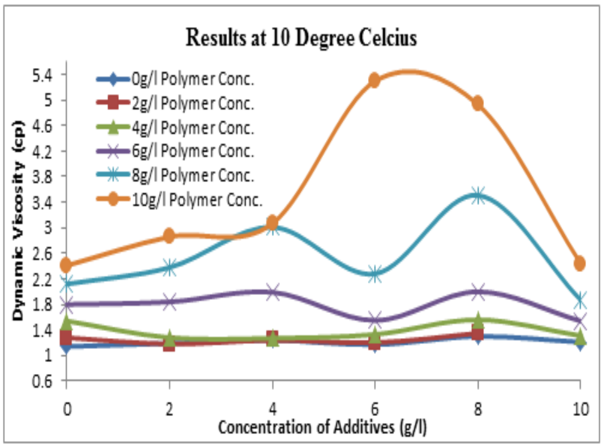

Figure 13: Viscosity of the Polymer at Varying Concentrations of the Additive for 10°C

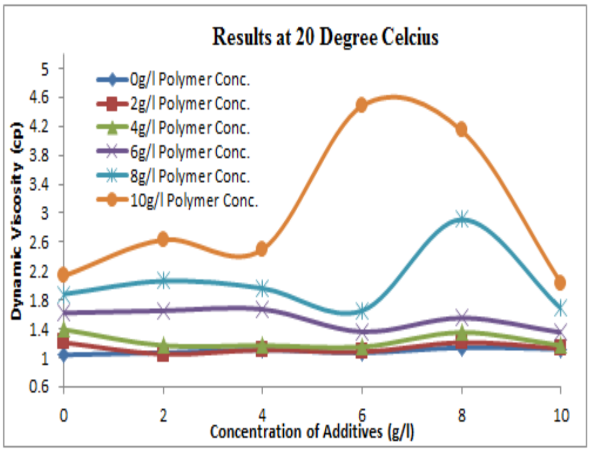

Figure 14: Viscosity of the Polymer at Varying Concentrations of the Additive for 20°C

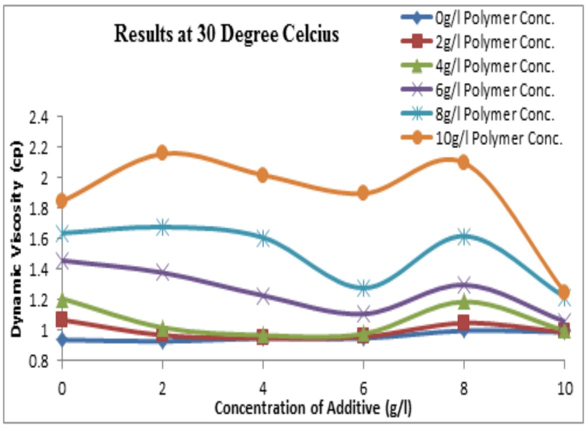

Figure 15: Viscosity of the Polymer at Varying Concentrations of the Additive for 30°C

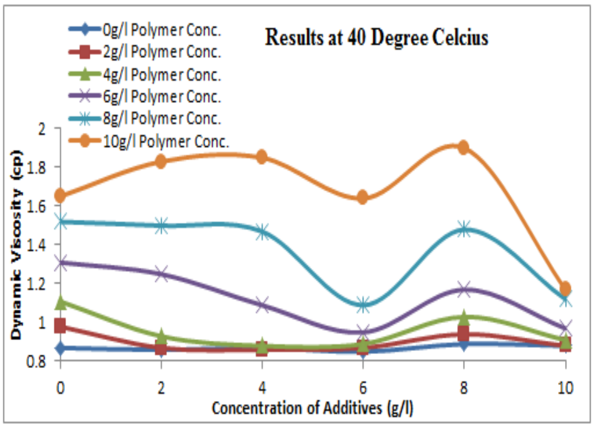

Figure 16: Viscosity of the Polymer at Varying Concentrations of the Additive for 40°C

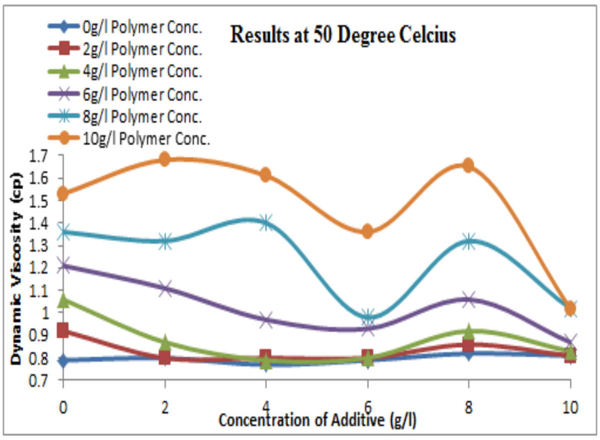

Figure 17: Viscosity of the Polymer at Varying Concentrations of the Additive for 50°C

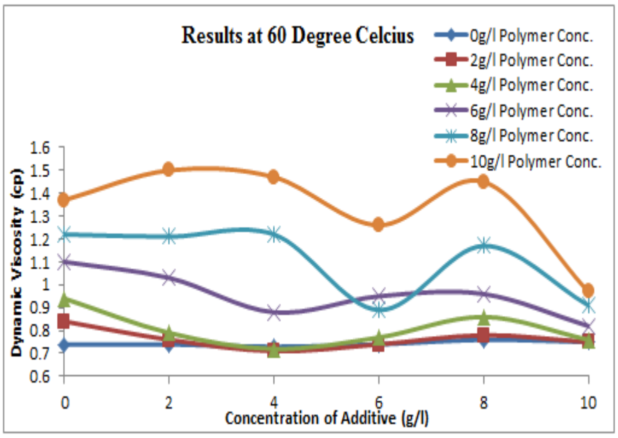

Figure 18: Viscosity of the Polymer at Varying Concentrations of the Additive for 60°C

Petroleum reservoir formations exist at high temperatures and pressures. Thus, the proposal of using potassium carbonate to maintain or improve the viscosity of Irvingia gabonensis at higher temperatures for EOR may not be effective considering the results from this work. The effect of pressure on the viscosity of Irvingia gabonensis has not yet been studied, it is necessary to also conduct this study in order to determine the suitability of this polymer for EOR. Since petroleum reservoirs are under high temperature and pressure conditions, a cheap and readily available polymer that can reasonably maintain its viscosity values under high temperature and pressure is highly sort for as an EOR agent. However, the viscosity results of this work especially in the presence of potassium carbonate may be useful in other fields of study such as the cosmetic and pharmaceutical industries. The results can also be used to model the viscosity of Irvingia gabonensis at different concentrations with temperature since the results for the cases without additive seem to differ at regular intervals.

Conclusion

The dynamic viscosity of Irvingia gabonensis polymer increases as concentration increases and decreases as temperature increases. The presence of potassium carbonate tends to have minimal effect on the viscosity of Irvingia gabonensis at temperatures above 30ºC; it mainly improves the viscosity of the polymer at lower temperatures of 10 to 30ºC and at higher concentrations of 6g/l to 10g/l of the polymer. The maximum viscosity of Irvingia gabonensis at 10g/l in the absence of potassium carbonate is 2.4cp while the maximum viscosity in the presence of potassium carbonate is 5.4cp and this was attained at a concentration of 6g/l of the additive. Generally, it is observed that a concentration of 10g/l of potassium carbonate drastically drops the viscosity of Irvingia gabonensis while a concentration of 8g/l tends to increase the viscosity to a maximum value at a temperature range of 10 to 60ºC. Using potassium carbonate to enhance the viscosity of Irvingia gabonensis as a polymer for EOR is not feasible because the viscosity of the polymer is enhanced only at lower temperatures of 10 to 30ºC while most oil reservoirs exist at higher temperatures. A concentration of 10g/l of potassium carbonate should be used if the viscosity of Irvingia gabonensis is required to be decreased in the presence of potassium carbonate within 10 to 60ºC temperature. However, the use of potassium carbonate for viscosity enhancement of Irvingia gabonensis is not ideal for formulation of enhanced oil recovery agents in the petroleum industry.

Disclosure statement: *Conflict of Interest:* The authors declare that there are no conflicts of interest. *Compliance with Ethical Standards:* This article does not contain any studies involving human or animal subjects.

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