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Original Research Article

Experimental Study of Oil Recovery Using Gum Arabic and Guar Gum Polymer

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ABSTRACT

Tertiary recovery methods, commonly known as Enhanced Oil Recovery (EOR) techniques, are employed when primary and secondary recovery methods become less effective. This study investigates the impact of two natural polymers, Guar Gum and Gum Arabic, on medium crude oil production to assess their recovery efficiency and suitability for light oil recovery. Core flooding experiments were conducted in two stages: water flooding, followed by polymer flooding, with 2 pore volumes (PV) of each polymer. Both polymers were formulated to have identical viscosities to ensure fair comparison. Oil recovery was measured at each stage to evaluate the polymers' performance. The results showed that both polymers enhanced oil recovery, with Guar Gum outperforming Gum Arabic. Guar Gum increased recovery by 42.4%, while Gum Arabic achieved 30.8%. These findings indicate that Guar Gum is a more effective polymer for improving oil recovery, particularly in light to medium crude oil reservoirs.

1. INTRODUCTION

Oil reservoir's recovery process involves three phases: primary, secondary, and tertiary recovery. During the primary recovery phase, oil is produced by the natural energy in the reservoir (compaction drive, solution gas drive, water drive, gas cap drive, gravity drive) the recovery usually ranges from 10-30% of the total oil in place. Secondary recovery methods, water or gas injection are for reservoir pressure maintenance and/or production increase. Additional recovery due to the application of these methods is 10-20% more (Ajayi et al., 2024; Uyoyoh et al., 2024). The average recovery factor of currently producing oil reservoirs in the world is about 35-40% (Mohaymen, 2020). Enhanced Oil Recovery (EOR), which is a tertiary recovery method has become the best solution to solve the problem of declining production and to prolong the life of a reservoir. By using this technique, the recovery performance for a reservoir can be increased by up to 60% of oil compared to the conventional method which can only recover between 20-40% of oil (Ojukwu and Taiwo, 2022). EOR comes with several methods such as injection of miscible solvents and liquid carbon dioxide (CO_2) superfluid, polymer flooding, surfactant flooding, microbial injection, and thermal methods (Amarnath, 1999).

Some experimental studies of chemical enhanced oil recovery have been carried out (Izuchukwu et al., 2018; Ogienagbon et al., 2016; Solomon et al., 2015; Taiwo, Mamudu, & Olafuyi, 2016; Taiwo, Mamudu, Adijat, et al., 2016; Taiwo, Uzezi, et al., 2016; Atsenuwa et al., 2014; Felix et al., 2015; Hillary et al., 2016; Ogienagbon et al., 2016; Onuoha et al., 2017; Solomon et al., 2015; Iserhienrhien et al., 2024).

For any EOR project, the initial stage is the screening criteria to identify the best EOR application for the candidate reservoirs in terms of incremental recovery that will be added and the economics of the project. The screening criteria is based on both reservoir rock and fluid properties such as oil gravity, oil viscosity, oil composition, remaining oil saturation (target), formation type, reservoir thickness, depth, and temperature (Ragab and Mansour 2021).

Chemical EOR techniques are usually used for hydrocarbon production due to its simplicity and its relatively reasonable additional costs of production. Water-soluble polymers are widely used in the different petroleum field operations including EOR processes. Partially hydrolyzed polyacrylamide (HPAM) is one of the most used synthetic water-soluble polymer in EOR processes but polymers like these are expensive. They also, sometimes, pose a threat to the environment and they could be limited in salinity and temperature testing. Therefore, researchers are always on the lookout for the ideal polymers to rectify those problems.

Guar gum and Gum Arabic are one of these polymers. Not only are they environmentally friendly, but it is also readily available at a moderate cost. Guar Gum plant tolerates different types of soil. It generally comprises of high molecular weight polysaccharides of galactomannans ranges between 0.1 and 2.8 million which are a linear chain of (1→ 4)-linked β-D-mannopyranosyl units with (1→6)-linked α-D-galactopyranosyl remains as side chains (Mudgil et al., 2014).

This study experimentally investigated the two polymers for light oil recovery and the polymer with more recovery was chosen to be a better option for the oil recovery.

2. MATERIALS AND METHODS

2.1. Materials

In this experiment, the materials used were glass beads, mineral oil, and sodium chloride for brine preparation, polymer (Guar Gum and Gum Arabic). The equipment used include: the core holder, electric oven, graduated measuring cylinder, viscometer, digital balance, beakers.

2.2. Experimental Setup

For the core holder, glass spheres were packed into a transparent core holder. The diameter of the core holder was 2.4cm, a length 25.5cm and a calculated bulk volume of 115.36 cc. A transparent core holder was used so that the flooding process could be closely monitored and visually observed. For the porous media, glass beads packed in a core holder were used as the porous media. The glass beads used had a grain size of about 60 +80micron engineering grade class IV glass spheres from MO-SCI Specialty Products, LLC, which is a subsidiary of MO-SCI Corporation. First, the glass beads were washed thoroughly with a washing powder (detergent) to make it clean. Then an acid (H_2SO_4) was added to remove any substance that would make them have an affinity for oil i.e. to make them strongly water wet. This was done to imitate the reservoirs in the Niger Delta. The beads are then properly washed with water until all traces of acid was gone. To be very sure, a litmus paper was used to confirm the acidity. The beads were then oven-dried to remove the residue water. After drying, the beads were then packed into the core holder and were vibrated from time to time to make sure they are properly packed and that there was negligible air in the core holder.

2.3. Fluid Properties

The crude oil used was obtained from a field in Niger Delta. It was characterized as a medium oil because of its API gravity (26.6) as shown in Table 1. The crude oil was dyed to be able to differentiate the oil from the polymer solution and to aid easy visualization of the flooding process. A laboratory grade Sodium Chloride (NaCl) mixed with distilled water was used to prepare a synthetic brine. A brine concentration of 2% was used. This was made by using 2% weight of NaCl that was mixed thoroughly with distilled water using a magnetic stirrer as shown in Figure 1.

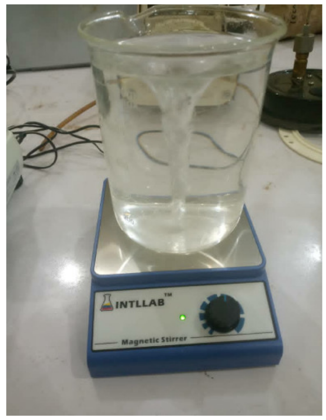

Figure 1: Preparation of synthetic brine with magnetic stirrer

Guar Gum and Gum Arabic were the polymers used. Guar Gum was used as a natural polymer in one of the experiments (Tagwa, *et al.,* 2021). To check the relevance of Guar Gum as a suitable polymer for EOR, the Guar Gum polymer was compared with another polymer, Gum Arabic. A Guar Gum polymer solution of 4%wt was prepared using a laboratory blender. This solution was mixed for 2 hours and allowed to stand overnight to ensure full hydration (Tagwa, *et al.* 2021). This process was repeated for the preparation of Gum Arabic. This polymer solution was 10%wt and was prepared using a laboratory blender and mixer shown in Figure 2. They are of different weight percentages, so that they would have nearly same viscosities.

Figure **Error! No text of specified style in document.**: Preparation of polymer slug for both Guar Gum and Gum Arabic

Figure 3: Core flooding (imbibition) set up

The core is saturated first with brine by pumping the brine through the injection point. This is done to bring the core to how the reservoir was initially before oil migrated into it. The core holder is positioned vertically so as to displace air from the pore spaces to reduce the probability of a three-phase forming. This process is also called imbibition, and it was carried out at a flow rate of 2.2 cc/min. After the imbibition process, the porosity was determined. The core imbibition setup is seen in Figure 3.

The porosity was calculated using the mass difference method as follows.

$$Mass\ of\ brine = Mass\ of\ saturated\ core - Mass\ of\ dry\ core \quad (1)$$

$$\rho_{water} = \frac{mass\ of brine(m)}{volume\ of\ brine(V_p)} \quad (2)$$

$$V_p = \frac{m}{\rho_{brine}} \quad (3)$$

Figure 4: Core flooding (drainage process) set up

To determine oil saturation, the process was carried out to try and depict how the oil came to displace the brine in the formation. The core, saturated with brine was gently positioned horizontally and the crude oil was injected at a rate of 2.2 cc/min to slowly displace the brine and attain initial oil saturation. The compressibility is assumed to be zero therefore the volume of the displaced brine was taken as the volume of the oil saturation. This process is also called a drainage process, the laboratory set up for the drainage process is illustrated in Figure 4.

The water flooding process was done to depict how a secondary recovery process would take place. The oil-saturated core is once again flooded with brine by injecting brine at the rate of 2.2 cc/min. The effluent was collected with a 10ml measuring cylinder at intervals of 4.5 minutes. The volume of oil produced and the residual oil saturation at the end of the water flooding was observed and recorded.

A freshly prepared polymer solution was utilized in each run. First, a polymer solution of 4%wt was prepared. The deionized was stirred using a magnetic stirrer in order to achieve a vortex initially. Then the guar gum polymer powder was added little by little at a constant rate to ensure that lumps would not form. The solution was stirred for 2 hours. After stirring, the solution was left to settle down for 24 hours to ensure that all air bubbles were absent. It was ensured that the polymer solution preparation method was done precisely and accurately to validate its efficiency over medium oil recovery experiments. The polymer slug preparation process doesn't differ much from the guar gum slug preparation. A polymer solution of 5%wt was prepared. The deionized was also stirred using a magnetic stirrer and then the guar gum polymer powder was added little by little at a constant rate to ensure that lumps would not form. The solution was stirred for 2 hours. After stirring, the solution was left to settle for 24 hours to ensure that all air bubbles were absent.

3. RESULTS AND DISCUSSION

Prior to use, the viscosity, API gravity, density, and specific gravity were examined to validate that the crude oil is classified as medium oil. As illustrated in Table 1, the API gravity and other properties match those of ordinary medium oil, confirming that it is suited for the experiment. A comprehensive understanding of the viscosity and American Petroleum Institute (API) gravity of crude oil is essential for the investigation of fluid dynamics and hydrocarbon recovery in porous media, particularly in the context of polymer flooding techniques. This knowledge establishes a foundational framework for the design and formulation of the fluid characteristics of the polymer slug to be injected, which, when considering mechanisms such as mobility control, subsequently enhances the sweep and displacement efficiency of the overall flooding operation (Izuchukwu et al., 2018; Taiwo et al., 2016; Taiwo and Ojukwu, 2022). Flooding medium with moderate viscosity oil reservoirs is challenging but it remains a feasible candidate for polymer flooding applications. Mudgil et al. (2014) provides more highlights on the significance of oil viscosity in polymer flooding efficiency. Compared to high-viscosity oils, medium oils have better recovery with polymer flooding, as observed in studies such as Taiwo et al. (2016), where polymer flooding significantly enhanced recovery.

Table 1: Summary of fluid properties

Fluid	ρ (g/cc)	Specific gravity	μ (cp)	API gravity
Crude oil	0.893	0.895	37.7	26.6
Brine	1.0204	1.0234	3.6	N/A
Gum Arabic	1.0509	1.0504	35.5	N/A
Guar Gum	1.05	1.05	35	N/A

Similarly, relevant fluid properties of the brine, Gum Arabic, and Guar gum slugs are listed in Table 1. The viscosities exhibited by Gum Arabic and Guar Gum demonstrate notable similarities, thereby facilitating a methodical comparison of their efficacy in recovery processes. The analogous viscosity metrics for these polymers, when evaluated for variances in recovery, can be attributed to the congruent molecular interactions occurring between the displacing and displaced fluids within the reservoir. Guar Gum has been recognized for its enhanced thickening capabilities, which confer increased resistance during the flooding procedure (Gordon, 2003). In alignment with the findings of Solomon et al. (2015), Guar Gum tends to surpass other natural polymers in sustaining viscosity under analogous environmental conditions. Conversely, the design phase of the polymer requires a close watch, as excessively high densities may precipitate technical complications, including gravity override and the bypassing of oil by the displacing fluid (Oluwaseun et al., 2019).

Table 2 illustrates the mass of each polymer used in the composition of the individual slug and the concentration of each polymer used in the experiment. Higher concentration of Gum Arabic was requisite to correspond with the viscosity of Guar Gum at a lower concentration, which signifies the superior thickening capability of Guar Gum. Guar Gum's configuration permits it to attain higher viscosities at lower concentrations attributable to its galactomannan content (Mudgil et al., 2014). This plays a critical role in the effectiveness of Guar Gum in lowering the oil-water mobility ratio, thereby enhancing oil recovery. This finding is congruent with Ragab and Mansour (2021), wherein Guar Gum necessitated lower concentrations in comparison to other natural polymers for efficacious oil displacement.

Table 2: Slug properties

Polymer slug	Mass (g)	Water (cm^3)	Polymer slug conc.(%wt)
Guar gum slug	18.75	450	4
Gum Arabic	50	450	10

Table 3 highlights the measured properties of the cylindrical lab core in use, the porosity of the core was determined based on the stipulated pore volume in Equation (3). Determining the porosity on the other hand was essential to assess that notwithstanding the densely packed matrix, there was still an unobstructed fluid transit through the matrix, which will be advantageous to investigate the implications of polymer flooding. High permeability and porosity are imperative for Enhanced Oil Recovery (EOR) methodologies. (Oluwaseun et al., 2016) observed that cores with similar properties gave a good clean recovery. The findings of Amarnath (1999) led to comparable recovery rates, supporting the observations in this experiment.

Table 4 illustrates results recovered from the drainage process; pressure and flow rates. To imitate initial reservoir conditions, this step is necessary. The pressure difference facilitates the determination of the core's response to flooding. This is consistent with Izuchukwu et al, (2018), where drainage processes were employed to mimic oil displacement. Similar drainage processes and pressure drops were reported by Choi et al. (2014), confirming that this methodology effectively simulates reservoir conditions.

Table 3: Petrophysical data

Petrophysical Data	Values
Length(cm)	25.50
Diameter (cm)	2.40
Bulk Vol (cm3)	115.36
Dry weight(g)	550.00
Wet Weight(g)	600.00
Pore Vol. (cc)	49.02
Porosity	0.42
Permeability(D)	4.56
Length(cm)	25.50

Table 4: Drainage process

Properties	Values
Initial Pressure	-3.50
Final Pressure	-1.10
Pressure (psig)	2.40
Pressure (atm)	0.16
Flow Rate (cc/min)	2.20
Flow Rate (cc/sec)	0.04

Tables 5 illustrates the initial fluid saturations; oil saturations (S_{oi}) and water saturations (S_{wi}) in the reservoir prior to both polymer flooding. The drainage and imbibition processes outlined in Figures 3 and 4 produce these saturations. The procedure was conducted individually and separately for the polymers flooding. Table 6 shows the enhanced oil recovery and residual oil saturations for the individual polymer flooding experiments. Guar Gum demonstrated a higher total recovery, pointing to a probable superiority in performance as compared to Gum Arabic. Guar gum's higher recovery could also be attributed to a better thickening ability which keeps maintains favorable mobility ratios (Solomon et al. 2015). Similarly, (Farouq and Thomas 1996; Alhammadi et al. 2017; Ogienagbon et al. 2016), found excellent and comparable recovery enhancements with the use of Guar Gum in polymer flooding and attributed it to better viscoelastic properties in Guar gum, which in turn improves the sweep efficiency of the residual oil.

Table 5: Drainage and inhibition procedure results

Properties	PV Oil	PV Water	Initial oil saturation (S_{oi})	Initial water saturation (S_{wi})
Guar Gum	41	9	82%	18%
Gum Arabic	38.6	10.41	79%	21%

Table 6: Summary of the core flooding experimental results in percentage (%).

Experiment	Gum Arabic	Guar Gum
Recovery by waterflooding (%)	59.6	48.8
Total recovery with polymer %	30.8	42.4
Total recovery %	90.4	91.2
Residual oil saturation %	9.6	8.8
Displacement Efficiency %	90.4	91.2

The results for recovery using waterflooding prior to polymer injection is illustrated in Figure 5 as a plot of the cumulative oil recovery in both cores against time. The amount of oil produced over time grows steadily until there is a water breakthrough, and eventually negligible oil recovery with time as the waterflooding continues. The high recovery confirms that primary and secondary recovery processes such as waterflooding can recover 45-55% of the initial saturation of hydrocarbon (Izuchukwu et al, 2018; Taiwo and Olafuyi, 2015). The remaining reserve has to be recovered by EOR methods such as polymer flooding. The drop in oil production with time could be attributed to channeling and by-passing of the oil as water is injected over time. This is a major challenge with waterflooding (Farouq and Thomas, 1996; Izuchukwu et al, 2018; Taiwo & Olafuyi, 2015, 2017, 2019).

The results of the waterflooding experiments displayed a trajectory similar to that depicted in Figure 5, while Figure 6 presents an additional representation of cumulative recovery throughout the entirety of the flooding process, encompassing both primary and tertiary recovery phases. Furthermore, it is evident that the implementation of polymer flooding across all scenarios enhances oil recovery. The profuse increase in recovery observed in the core flooded with Guar gum slug, as illustrated in Figure 6, is further corroborated by the intersection of the cumulative recovery plot of the Guar gum and Gum Arabic, which continues to ascend. The boost in oil production attributable to polymer flooding can be attributed to the increased viscosity of the injected fluid, thereby resulting in an improved mobility ratio and a consequent reduction in fingering phenomena. The utilization of Gum Arabic and Guar gum has demonstrated significant efficacy in diminishing the residual oil saturation during the polymer flooding process. Although Gum Arabic does not attain the elevated recovery rates observed with other natural polymers such as Xanthan Gum, its overall performance remains comparable (Solomon et al., 2015; Ogienagbon et al. 2016, Ojukwu and Taiwo, 2021; Taiwo and Olafuyi, 2015). It can be deduced that Guar Gum serves as an exceptionally effective mobilizer of residual oil, thereby rendering it a superior alternative to Gum Arabic for medium oil recovery via polymer flooding. Guar Gum exhibits enhanced viscoelastic characteristics, which facilitate increased cumulative oil production through improved sweep efficiency during the polymer flooding process (Mudgil et al. 2014) and illustrating the efficacy of Guar Gum in bolstering oil recovery by maintaining a stable displacement front. Furthermore, Guar Gum outperformed Gum Arabic in terms of cumulative recovery (Taiwo et al. 2016), as experimental results from polymer flooding consistently demonstrated Guar Gum's preeminence.

Figure 7 and 8 illustrate the variations in oil production for the both scenarios. An initial surge in oil production occurs, followed by a gradual decline post-breakthrough. The decrease in production rate highlights the limitations of polymer flooding and underscores the necessity of injectivity management for optimal recovery. The abrupt change in production rate can be attributed to the depletion of easily accessible oil, with remaining oil located in more challenging areas. This phenomenon is typical during polymer flooding, characterized by significant recovery alongside marked reductions in production rates (Barnes and Dimiter, 2004; Taiwo et al. 2016; Ojukwu and Taiwo, 2022). The work by by Solomon et al. (2015) corroborated these findings, demonstrating similar trends of peak production rates followed by subsequent declines over time. The higher production rate indicates that Guar Gum results in higher sweep efficiency that leads to more recovery in the early phases than what is obtained with Gum Arabic.

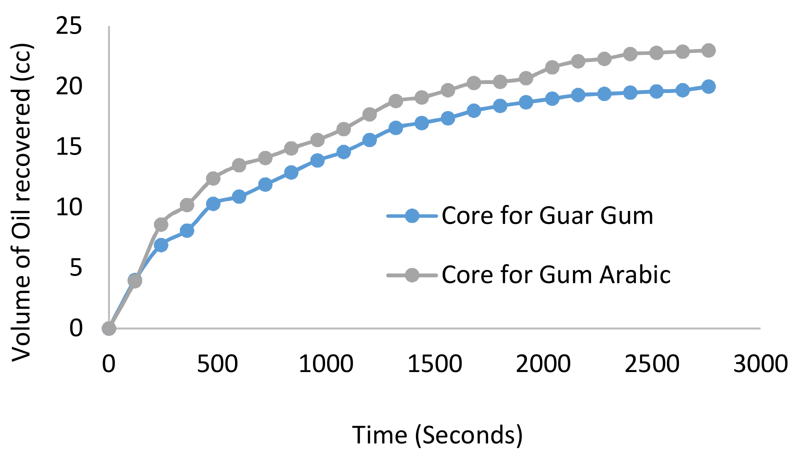

Figure 5: Waterflood cumulative oil production for both cores

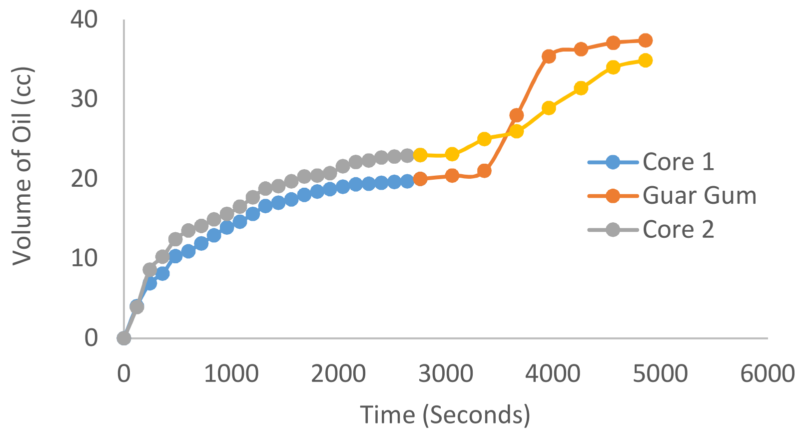

Figure 6: Waterflood and Gum Arabic polymer flood cumulative oil production

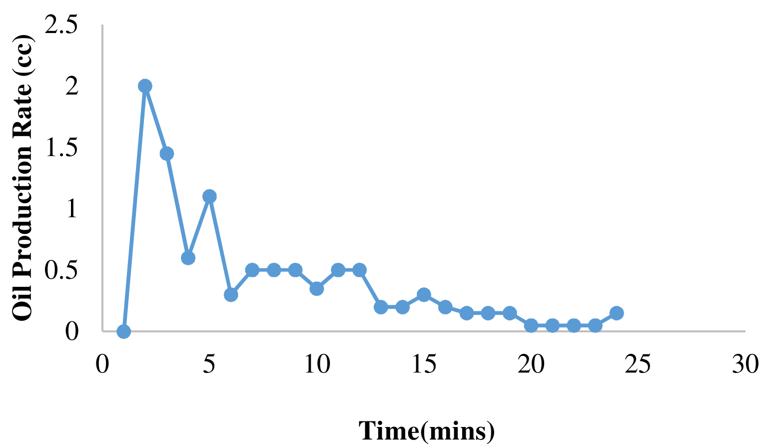

Figure 7: Oil production rate for Gum Arabic core

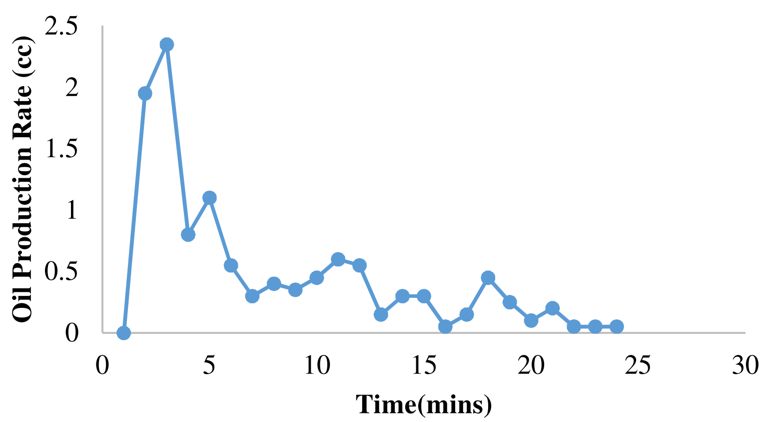

Figure 8: Oil production rate for Guar Gum core

4. CONCLUSION

This study aimed to evaluate Guar Gum and Gum Arabic as viable candidates for polymer flooding, aimed at maximizing recovery of light crude oil. Following the experimental procedures and subsequent analysis of the data, it can be conclusively asserted that both polymers demonstrate commendable recovery rates, with Guar Gum enhancing recovery by 42.4% and Gum Arabic yielding an improvement of 30.8%. The viscosity of the polymer solution exerts a significant influence on oil extraction efficiency. In this investigation, the Guar Gum exhibited high viscosity with a relatively modest quantity, whereas to achieve a comparable viscosity with Gum Arabic, a greater quantity was required. The utilization of Guar Gum is projected to be more economically advantageous, as it achieved superior recovery at a lower concentration (4%wt) in comparison to Gum Arabic (10%wt).

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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