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Rheological Properties of Guar Gum for Potential Use in Enhanced Oil Recovery in Sudanese Oil Fields

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Abstract: Recovery from depleting Sudanese oil fields using Enhanced Recovery methods needs to be studied. Improved/Enhanced recovery techniques represent a potential to recover some of the oil left in place. One of these technologies is polymer flooding to increase the viscosity of the displacing water when compared to the viscosity of the displaced oil and consequently improve the displacement efficiency. This paper investigates different parameters that affect guar gum for potential use in Enhanced Oil Recovery Processes. Guar gum is as an abundant and environmentally safe material which can be utilized for increasing viscosity of injected water to improve the recovery of crude oil in certain oil fields. Rheological study was performed in the Petroleum Engineering laboratory for indigenous guar gum. Effects of concentration, salinity, thermal and biological degradation factors were thoroughly studied. For four different salinity waters, the viscosity of polymer in different salinity levels (encountered in field) was found to increase gradually in direct proportion with concentration and decreases with salinity. The critical micelle concentration, CMC (the concentration beyond which no remarkable change in viscosity is likely) of guar gum was found to be 0.6%. Bacterial growth is found to affect guar gum viscosity drastically. However, the effect of mechanical (shear) degradation as well as thermal degradation (temperatures up to 100 deg C) was found to be minimal. Based on these results, guar gum can be a good candidate for use in Sudanese oil fields, however further coreflood is required to quantify its performance.

Keywords: Rheological properties; Enhanced oil recovery; Guar Gum; Degradation.

1. INTRODUCTION

Water-soluble polymers find application in almost every aspect of oil industry [1],[2]. In primary recovery processes water-soluble polymers are used in drilling (as clay modifier in high solid mud, in foam drilling, as the primary viscosifying component in low solids mud, etc) in completion and work over and in fracturing applications. In improved recovery techniques water soluble polymer find utilitization as flow diversion agent and in mobility control buffer solutions [3].

Guar Gum (guaran) consists of linear chains of (1→4) –β-D mannopyranosy1 units with α-D- galatpyranosy1 units attached by (1→6) linkages. Enzymic hydrolysis of guaran gives mannobiose (4→0β-D mannopyranosy1 D mannose), mannotriose, and 6→0-α-D galactopyranosy1 D mannopyranose, confirming earlier methylation results and showing that β-D-(1→4) linkages are present in the mannan and that side chain D-galactose units are attached by α-D-1→6) linkages.
The ratio of D-galactose to D-mannose in guar gum is 1:2 with single D-galactopynosy unit side chains attached to every other D-mannopyranosy unit the molecular weight has been reported as 220,000^4. Fig. 1 shows chemical structure and Fig. 2 depicts a photo of guar gum plant.

2. MOBILITY CONTROL

In petroleum industry polymer usages have been grown steadily [5]. Two specific applications arise in secondary and tertiary oil recovery. The first is to increase the viscosity of water so as to affect a reduction in the mobility differences between the injected water and oil-in-place and thereby improves both areal and vertical sweep efficiencies. The second application is to utilize certain properties of polymer to control water production in oil wells. This is achieved through a combination of effects, e.g., in-situ gel formation, affinity of polymer for water and interaction between the polymer and porous medium.

A decrease in mobility can result from an increase in solution viscosity and/or a decrease in relative permeability, but each effect is influenced by different factors. Polymer characteristics (type, concentration, molecular weight and weight distribution) solvent type (salinity, pH and ionic

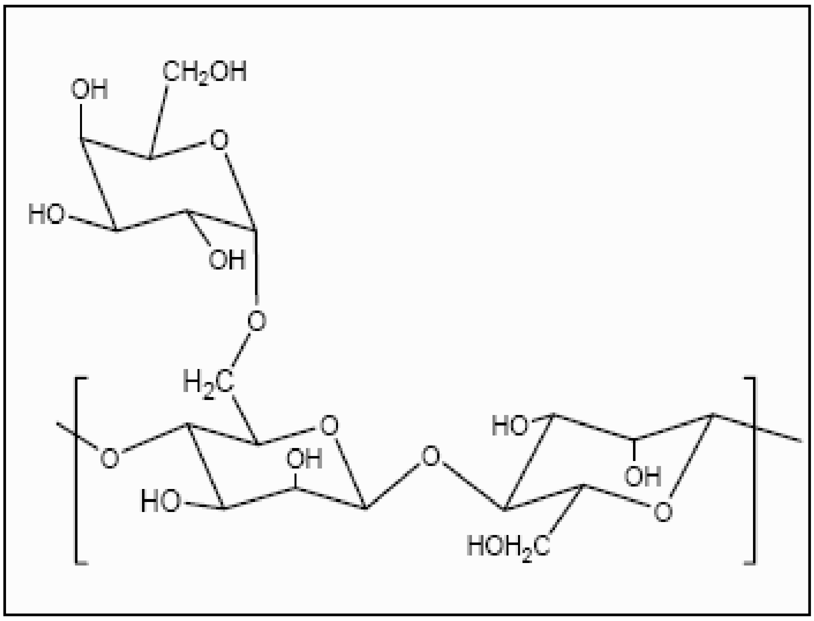

Fig. 1. Chemical Structure of Guar Gum (after Sharma [4])

Fig. 2. Photo of guar Gum Plant (after Sharma [4])

strength of solution) rock characteristics (porosity, permeability, etc.) as well as polymer rock interaction (adsorption, pore blockage by microgels or polymer molecules, etc.) can affect the mobility.

3. MATERIALS AND METHODS

3.1 Experimental set up and procedure

A. Rheology Measurements

Guar was cultivated in Guar processing complex in SINGA (SUDAN). The samples were stored in a dry condition to avoid moisture adsorption. Guar gum polymer was available from the manufacturer, Sudanese Guar Company. Specification and general properties of this polymer are given in Table 1 and the properties of different water solvent used are given in Table 2.

Glycerol solution was used to calibrate the low shear-viscometer which is based on the viscosity levels from CRC Handbook [7]. The solution was available from the manufacturer at 97% concentration. Solvents are prepared by dissolving the exact amount of salts in deionized water. Polymer solutions were prepared according to the American Petroleum Institute, API, recommended practices for ease of evaluation of polymers used in enhanced oil recovery operations [8].

Two stages for polymer preparation were followed; first a 3% by weight of the guar polymer solution was initially prepared in the specific solvent and then diluted to the required concentration level. A specific weight of polymer was added to 300 cc of deionized water under agitation.

The dispersed polymer slurries were immediately added to 700 cc of water and stirred by blade impellers until dissolution occurred. Thickened solution were left to 24 hours as to allow complete hydrolysis, then for the second case, each polymer concentration was prepared individually in the specific solvent, except when the solvent used was API brine (3% NaCl, 0.3% CaCl.H$_2$O in deionized water). The API report (1986) recommends preparation of the polymer concentration in API fresh waster first, and then dilutes the concentrate by API brine; this is simply to avoid the incomplete dissolution of emulsion in brine. Polymer solutions are stored after preparation for one day in room temperature to ensure complete hydrolysis of the polymer in 500 ml beakers.

Test of biological degradation is performed by keeping the polymer solution for several days in room temperature, and tightly sealed in a 500 ml beaker, without any addition of preservation. At every 24 hours viscosity measurement are reported for five days. To test mechanical degradation of the guar polymer solution, an over head stirrer of maximum revolution per minute equal to 1000 is used. The solution is vigorously stirred to induce shear degradation for half an hour. The solution viscosity is then measured as previously stated.

B. Apparatus Calibration

A solution of 97% glycerol is used to calibrate the Rotovisco RV2 viscometer at 20 °C. The result was plotted in Fig. 3 at three different temperatures. Fig. 4 shows the trend of shear versus shear rate at different temperatures, which indicates the Newtonian behavior of the solution, the shear stress is linearly correlated to the shear rate. When the test was repeated, it gave good reproducibility as in Fig. 5. Another Brookfield viscometer was used in calibration and to compare results obtained by the Haake Rotovisc instrument. These results are shown in Fig. 6.

C. Concentration Effect

The shear viscosity vs. shear rate is plotted for different concentration in Fig. 7, for ten different levels of concentration of guar gum polymer in deionized water. The critical misceller concentration (CMC) for guar gum polymer in deionized water was found to be 6000 ppm obtained from the plot of shear viscosity against the polymer concentration shown in Fig. 8. CMC is explained as the value of concentration after which no changes in shear viscosity will occur for further increase in polymer concentration. This critical parameter is of important indication; it shows the degree of association between neighboring molecules. Viscosity increases with concentration as expected up to concentration of 0.6% (6000 ppm) where the increase of concentration has little or no effect on the guar solution viscosity.

D. Salinity effect

Plot of shear viscosity versus shear rate for solutions of 1.0% guar gum polymer at five different salinity levels is drawn in Fig. 9. Shear viscosity tends to decrease rapidly as the shear rate increase for all solutions in the range of shear rate (0-150 sec^{-1}). For higher shear rates (>300 Sec^{-1}) a linear relationship observed, and there is no great change in shear viscosity with shear rate for all solutions. This result is in consistence with different reports in the literature [9]–[11]. Also with increasing salt concentration, there is no change observed in shear viscosity for the studied salinity levels.

Table 1. General properties of the polymer used in experiments

Polymer *	Viscosity (cp)	Molecular Weight
Guar gum (Food grade)	4599/5000	220,000

**Source*: form the Sudanese Guar Company Limited: Guar Powder Specification, Season 2000/2001

Table 2. Properties of Solvents used at 25 °C

Solvent	Density (g/cc)	Viscosity
Deionozed water	0.996	0.888
Low Salinity Water (0.05% NaCl, 0.005% CaCl2.2H2O in deionized water)	0.966	0.889
API Fresh water (0.1% NaCl,0.01% CaCl2.2H2O in deionized water)	0.998	0.891
API brine (3%NaCl, 0.3% CaCl2.2H2O in deionized water)	1.020	0.933

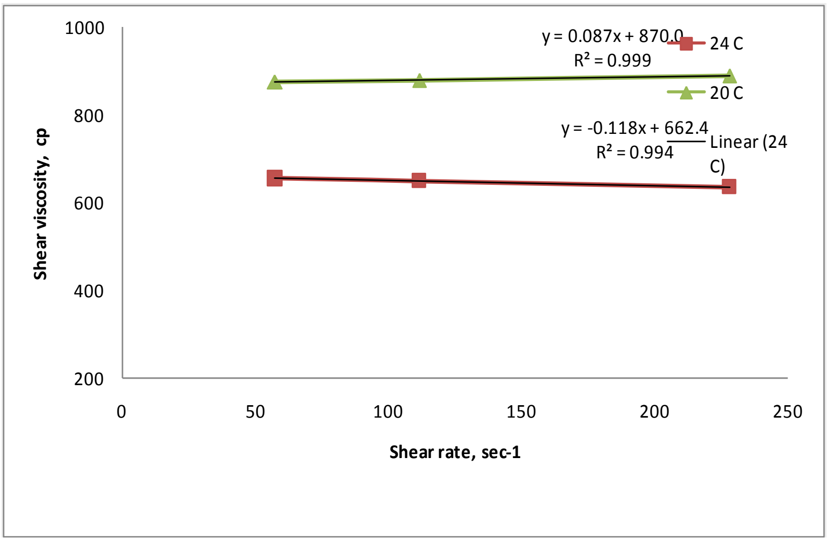

Fig. 3. RV2 Calibration

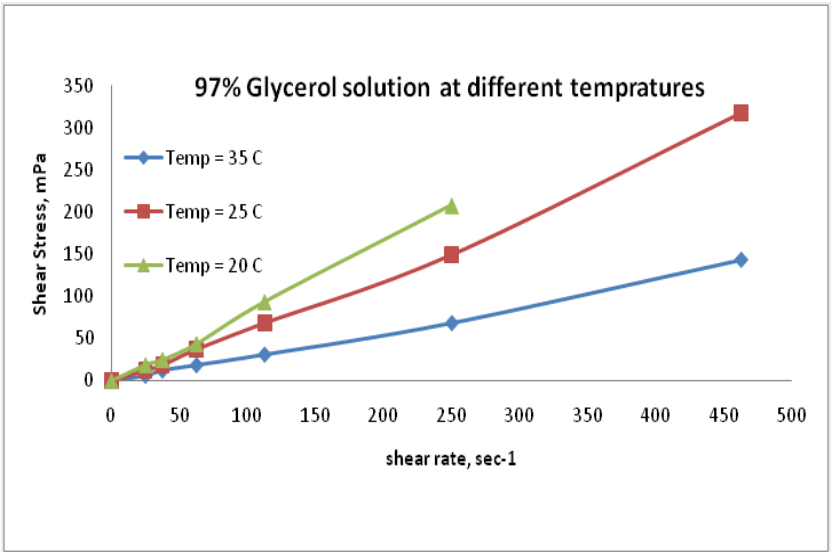

Fig. 4. Trend of shear stress versus shear rate at different temperatures

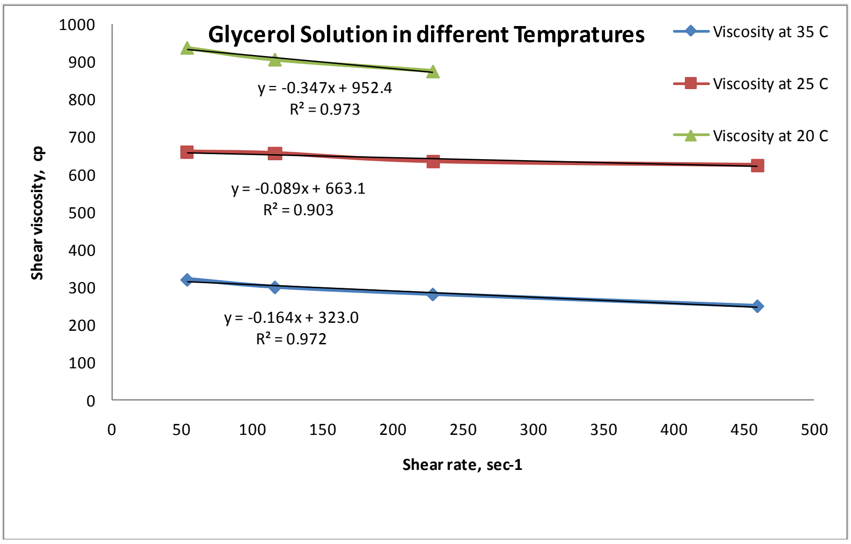

Fig. 5. Glycerol Solution in different temperatures

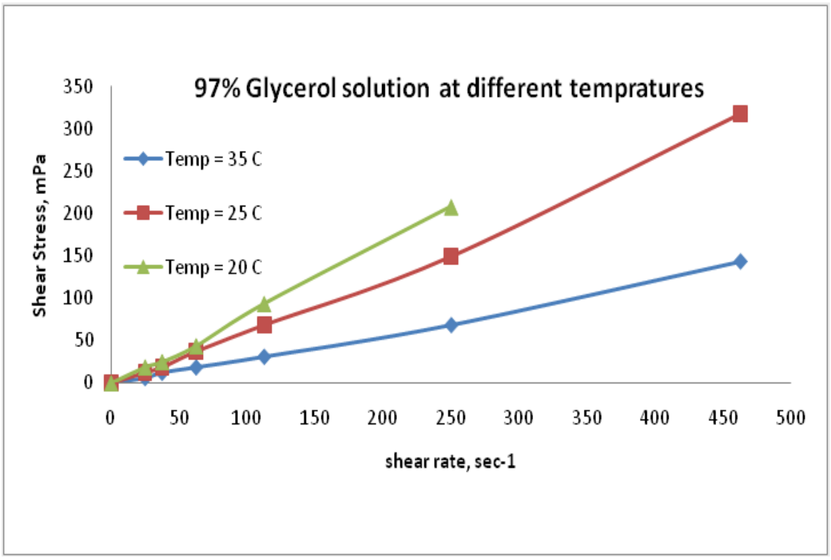

Fig. 6. Trend of shear stress versus shear rate at different temperatures

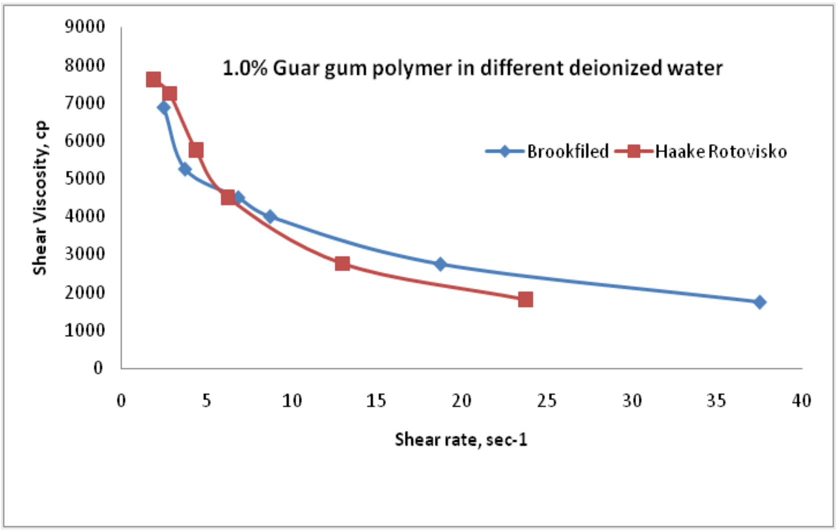

Fig. 7. Guar Polymer viscosity and shear rate in different instruments

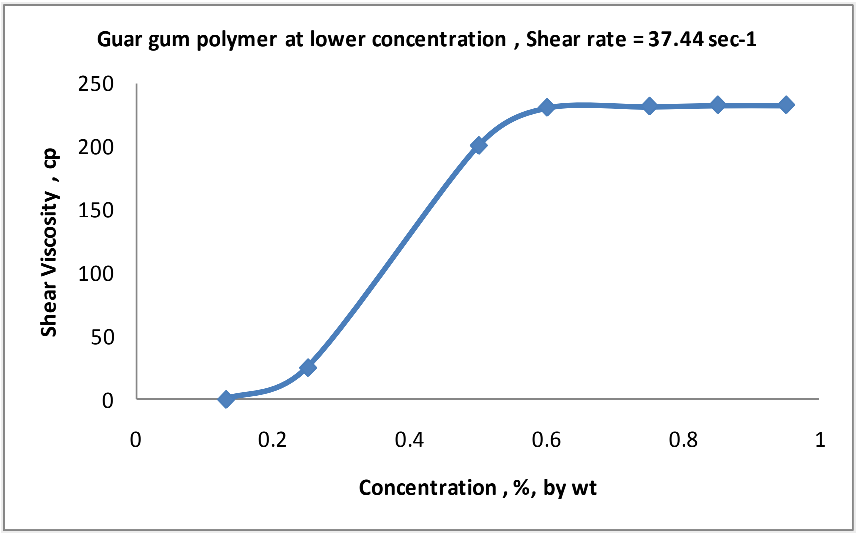

Fig. 8. Critical miscellar concentration (CMC)

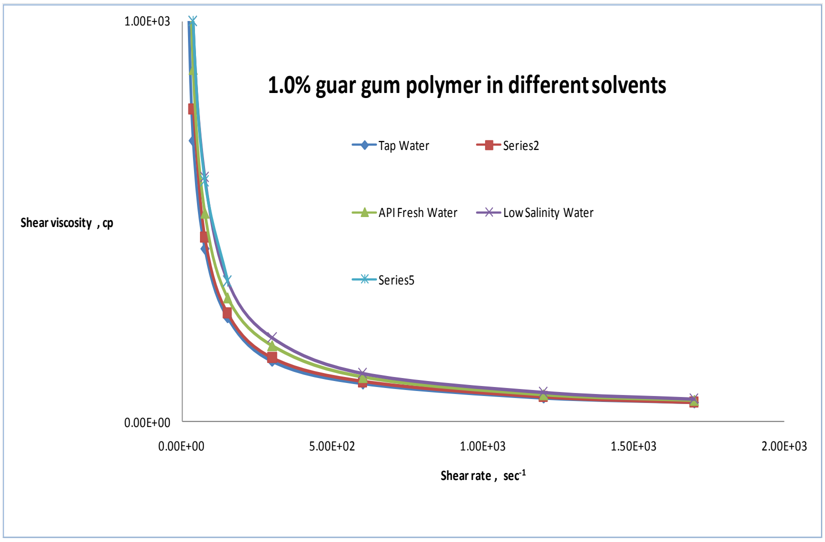

Fig. 9. Salinity effect

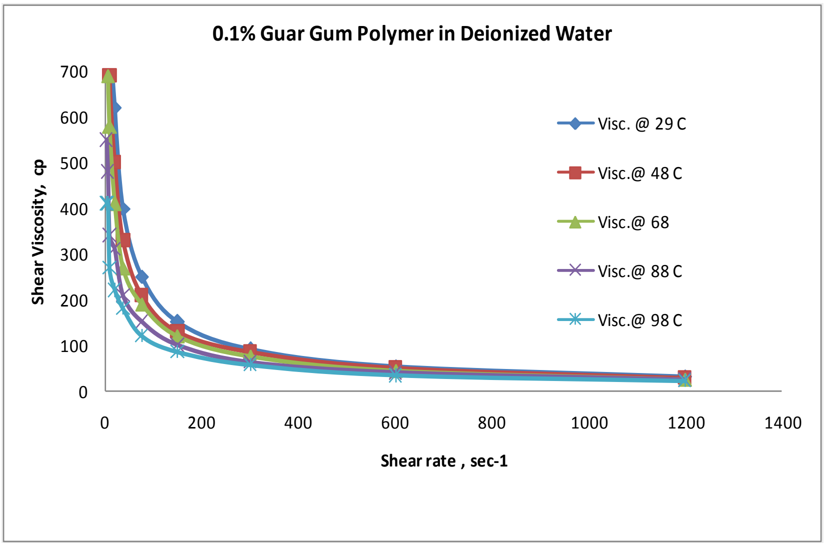

Fig. 10. Thermal Degradation

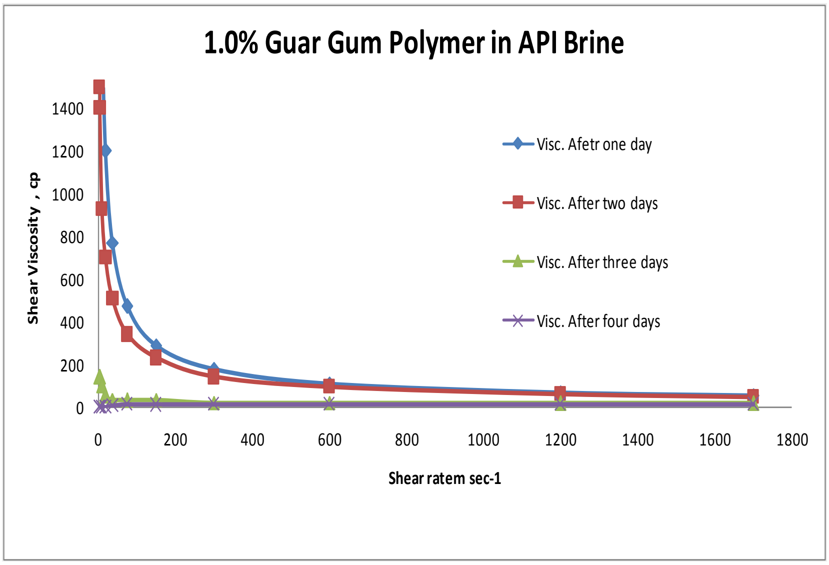

Fig. 11. Biological effect

Table 3. Biological degradation

n, min-1	S, Skt	S/n, Skt.min	τ, dyne/cm^2	γ, sec-1	ŋ1, cp	ŋ2, cp	ŋ3, cp	ŋ4, cp
1.00E+00	2.50E+00	2.50E+00	8.10E+00	2.30E+00	3.40E+03	1.50E+03	1.40E+02	NA
2.00E+00	3.50E+00	1.80E+00	1.10E+01	4.70E+00	2.40E+03	1.40E+03	1.40E+02	NA
4.00E+00	5.20E+00	1.30E+00	1.70E+01	9.40E+00	1.80E+03	9.30E+02	1.00E+02	NA
8.00E+00	7.00E+00	8.80E-01	2.30E+01	1.90E+01	1.20E+03	7.00E+02	5.20E+01	NA
1.60E+01	9.00E+00	5.60E-01	2.90E+01	3.70E+01	7.70E+02	5.10E+02	3.40E+01	8.60E+00
3.20E+01	1.10E+01	3.40E-01	3.50E+01	7.50E+01	4.70E+02	3.40E+02	3.00E+01	1.30E+01
6.40E+01	1.40E+01	2.10E-01	4.30E+01	1.50E+02	2.90E+02	2.30E+02	3.20E+01	1.10E+01
1.30E+02	1.70E+01	1.30E-01	5.30E+01	3.00E+02	1.80E+02	1.40E+02	2.10E+01	1.40E+01
2.60E+02	2.10E+01	8.00E-02	6.60E+01	6.00E+02	1.10E+02	9.40E+01	2.00E+01	1.30E+01
5.10E+02	2.60E+01	5.00E-02	8.30E+01	1.20E+03	6.90E+01	6.20E+01	1.80E+01	1.20E+01
7.20E+02	2.90E+01	4.00E-02	9.30E+01	1.70E+03	5.50E+01	4.90E+01	1.70E+01	1.20E+01
ŋ1	viscosity value after one day		ŋ3	viscosity value after three days		NA	Not detected	
ŋ2	viscosity value after two days		ŋ4	viscosity value after four days				

E. Degradation Effect

1) Thermal Degradation

A solution of 0.1% guar gum polymer is subjected to thermal degradation to study the effect of temperature as in Figure 10. Shear viscosity varies with shear rate in a decreasing manner, for shear rates (< 300 Sec^{-1}) a sudden drop in shear viscosity is obvious, after which shear viscosity changes slightly with increasing shear rate (>300 sec^{-1}). The viscosity of 1.0% guar gum polymer solution varies almost directly with changes in temperature over the range 25^{o}C – 90^{o}C. The maximum viscosities that can be obtained when dry gum is dispersed in water at various temperature for periods up to two hours is found to be 1200 cp. After maintaining the temperature at 60 $^{\circ}$C, the solution viscosity exhibit good stability towards prolonged heating for periods up to two hours. Maximum viscosity of guar gum dispersion is achieved with temperature of 25^{o}C-40^{o}C. Temperature increase caused sharp viscosity decrease, Fig. 10 in a deionized water solvent. Where the decrease is slowly in saline solution (API brine), it may be due to multivalent salt effect of non ionic guar polymer i.e., shrinkage of the polymer coil at higher salinity levels.

2) Biological Degradation

A solution of 1.0% guar gum polymer was investigated for variation of shear viscosity with time at fixed shear rate. Table 3 contains the experimental results obtained at 25 $^{\circ}$C. Plots of shear viscosity versus shear rate were illustrated in Fig. 11. For the case when the solution is API fresh water, there is no significant change observed in viscosity measurement in the range of one to two days. This shows that there is no biological degradation took place. But the viscosity is seriously affected in the third day and dropped dramatically. In the case of API brine, the decrease in shear viscosity is observed in lower shear rates (<50 sec^{-1}).

4. CONCLUSIONS

For environmentally safe chemicals use in rich and resourcefulness areas where most Sudanese oil fields are located, this study was carried out and the following conclusions can be drawn:

- Guar gum viscosity is comparable to synthetic polymers and therefore can viscofy injected water in a reasonable concentration.
- The critical miscellar concentration (CMC) was found to be 6000 ppm
- The viscosity of guar gum polymer is not very sensitive to increase salt concentration (within the studied salinity levels).
- The solutions of guar polymer are not sensitive to thermal degradation up to 90 degree C.
- As expected, the polymer viscosity is severely affected by biological degradation after passing of certain time (3 days).

The future of enhanced recovery in Sudan depends on availability of natural and environmentally safe materials. Fortunately, these materials can be indigenously produced resulting in sustainable oil recovery. For this work coreflooding is required to study guar gum behaviour in porous media.

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