Effect of Sodium Magnesium Silicate Nanoparticles on Rheology of Xanthan Gum Polymer

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Abstract- Polymer flooding is known for its ability to assist in enhancing oil displacement during tertiary recovery stage. Most EOR polymers degrade and lose their viscosifying abilities at high salinity and high temperature reservoir conditions (HSHT). Laboratory rheological study of Xanthan gum was carried out before and after incorporating with Sodium Magnesium Silicate under certain conditions (25 and 60 ^{o}C; salinity: 0, 3.4, 10, 15 and 20-wt % NaCl). Experimental results show that viscosity of these polymers is strongly affected by salinity, temperature and shear rates. Xanthan gum displays a strong thermal and salinity resistance at low, medium and high shear rates. It was also found that the viscosity solutions increased with addition of sodium magnesium silicate nanoparticles, and exhibit better shear resistance and enduring thermal stability at high salinity than ordinary xanthan gum.

Index Terms: Nanoparticles, Polymer flooding, Salinity, Shear rate, Shear stress, Viscosity, Xanthan gum.

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1.0 Introduction.

The ever-increasing demand and consumption of energy presently is a result of skyrocketing in global population. [1] Reported that; as of 2005, the global oil consumption has risen by 3.9% (i.e. from 30.7 billion barrels to 34.6 billion barrels in 2010). There is an anticipated rise in consumption up to more than 44.6 billion barrels by the year 2020. Non- renewable energy sources such as hydrocarbon fuels are however affected the most in such crisis. Oil scarcity, mature fields reserves declining that coupled with complexity in discovering new oil fields are few reasons behind the crisis that hit non-renewable energy sector**.**

[2] The issue that needs to be addressed is finding a means by which global demand for energy can be met and sustained. Innovative technology will enable us to confront the challenges facing our energy industries.

[3] Polymer flooding is one of the major types of chemical EOR that involves addition of polymers having a very high molecular weight that will results to an increase in the viscosity of water and at the same time reducing the rock permeability to water. As a result of this, the tendency of water to by-pass the oil in parts of the reservoir with low permeability will decrease thus improving the sweep efficiency of the reservoir.

[4] Was the first person to attempt enhancing sweep efficiency in water flooding through branding various additives among which include water-soluble polymers to increase the injected water viscosity, which will consequently improve the mobility ratio for better oil recovery. [2] Polymers incorporated with nanoparticles are currently being practiced in flooding process.

In accordance with [5], Polyacrylamide, polysaccharides and ethylene polyoxide are the three main classes of polymers, however only polyacrylamide and polysaccharides are reportedly tested for EOR field applications.

[6] Categorized water soluble polymers into two main categories; those that are produced synthetically in labs (i.e. synthetic polymers) and those that are obtained from natural products such as wood, seeds, or those formed by microorganisms (bacteria and fungi); which are essentially polysaccharides (Biopolymers). Within the scope of this work, only xanthan polymer will be discussed.

2.0 Xanthan Gum

[6] Xanthan gum is a polysaccharide released by bacteria called Xanthomonas Campestris. [3] It is anionic in nature with high tolerance to salinity and a reasonable tolerance to hardness ions. Its temperature tolerance shows variation with components of water phase. Xanthan is reportedly begins to undergo degradation at temperatures around 93-121oC. Xanthan is very vulnerable to bacterial attack and doesn't withstand high pH condition.

Xanthan gum polymer solutions are exhibiting extremely high pseudo plastic behavior. For this reason, xanthan gum has many industrial applications as a suspending, stabilizing, thickening and emulsifying agent for food, cosmetics, oil recovery and many others.

2.1 Rheology of Xanthan Gum:

The effectiveness and efficiency of xanthan polymer is largely determined by its rheological properties (i.e. shear stress vs. shear rate and shear rate vs. viscosity). These properties are affected by a lot of factors such as salinity, polymer concentration, pH and most importantly temperature.

2.2 Shear Thinning behavior of Xanthan gum.

Xanthan polymer solutions exhibit shear-thinning behavior at different conditions. This means that,

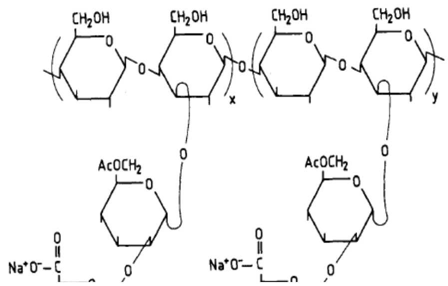
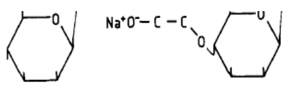


Figure 1. Xanthan gum Structure (Littmann, 1988)



at high shear rate e.g. 600 RPM, the viscosity of polymer solution becomes low whereas at low shear rate e.g. 20 RPM, the viscosity becomes high. In our case, the rheological properties of xanthan polymer solutions were obtained at different chemical and environmental conditions. High xanthan concentration increased the absolute viscosity at the same time increasing the degree of shear thinning. Addition of Sodium Magnesium Silicate Nano caused the viscosity of xanthan to increased and making it even more thermal resistant, however maintaining shear-thinning property.

[7] Use of mono- and divalent salts (e.g., Na^+, Ca^{2+}) to increase the solution ionic strength also decreased the dynamic viscosity of xanthan and the degree of shear thinning, although the effect reversed at high xanthan concentrations. A power law analysis showed that the consistency index is a linear function of the xanthan concentration. The degree of shear thinning, however, is best described using a logarithmic function.

[8] A lot of research works focus their interest in examining the salinity effect on polymer solution viscosity. They found out that there was a tremendous decline in viscosity with increasing salt concentration especially when the polymer concentration is low [10]. Divalent ions such as Ca^{2+} shows a more pronounced effect among which includes sharp viscosity decrease as well as precipitation at high temperatures [9].

3.0 Experimental Work

The focus of most experimental works in the field of EOR polymer flooding nowadays has been finding solution to the problem of polymer degradation. However, purpose of the this experimental work is to study the effect of introducing nanoparticle to xanthan polymer solution using Ofite Model 900 Viscometer. Various concentrations of xanthan gum were used at varying salinity (0 – 20-wt%) as well as temperatures (i.e. 25 – 100 ^oC) to simulate reservoir condition. In addition to that, viscosity at different shear rates was also measured.

3.1 Materials and Methods Used

Viscometer

The OFITE Model 900 Viscometer is a portable, yet fully automated system for measuring fluid viscosity at various temperatures and shear rates providing a very consistent end results. It could be used along with a computer to carry out even more sophisticated laboratory tests.

Polymers.

Xanthan gum polymer was used for this experimental work. It was purchased from a company called alpha chemicals in Egypt. It is off white colored powder. Xanthan gum solution was made by gently dissolving the xanthan gum powder 0.2 liter of fresh water to obtain a desired concentration. Since Xanthan gum forms dispersion when dissolved in water, stirrer was used to ensure total dissolution of xanthan gum and then the prepared solution is allowed to stand for some minutes before beginning the test. Two samples were prepared 1500 and 2000ppm xanthan gum and tested with nanoparticle.

Density measurement

The densities of the solutions were determined with a standardized 50-mL pycnometer. The mass of the solution was calculated from the weight difference between the empty pycnometer and the filled vessel. This is performed at different temperatures and salinities.

4.0 Results and Discussion

4.1 Shear Stress vs. Shear Rate relationship.

The relationships between shear stress and shear rate assist in determining the fluid type i.e. Newtonian or Non-Newtonian. Polymers generally are Non-Newtonians in nature. Plots of shear stress against shear rate are often used to illustrate the response of different fluids to applied forces. Shear stress and shear rate relationships are studied before and after addition of sodium magnesium silicate Nano.

Figures [2] through [5] show the plots of shear stress vs. shear rates for xanthan polymer at 1500ppm and 2000ppm at room temperature (25 ^oC) and higher temperature (60 ^oC). In general, shear stress decreases as the shear rate decreases and increasing salinity.

Increment in shear is observed as sodium magnesium silicate nanoparticle is added, the increment is however more pronounced at high polymer concentration.

Power law model best described the shear stress vs. shear rate relationship for both concentration at all temperatures.

$$\tau = \boldsymbol{K}\gamma n$$

Where:
τ is the shear stress
K is the consistency index
γ is the shear rate
n is the flow behavior index

Tables [3] through [6] show the values for K, n and R^2 for all concentrations and temperatures. It is worth mentioning that the power law index (n) is always less that 1 for non-Newtonian shear thinning fluids such as xanthan gum at all concentrations and temperatures.

Consistency index (K) decreases with increasing temperature and salinity and adding sodium magnesium silicate Nano at 25 ^oC. (K) Starts to increase as the concentration of Nanoparticle increased i.e. (0.1-wt% to 0.15-wt%) with temperature of 60 ^oC. This is very much in consistent with [8] that K decreases with increasing temperature. [n] On the other hand increases with salinity increase.

(a)

(b)

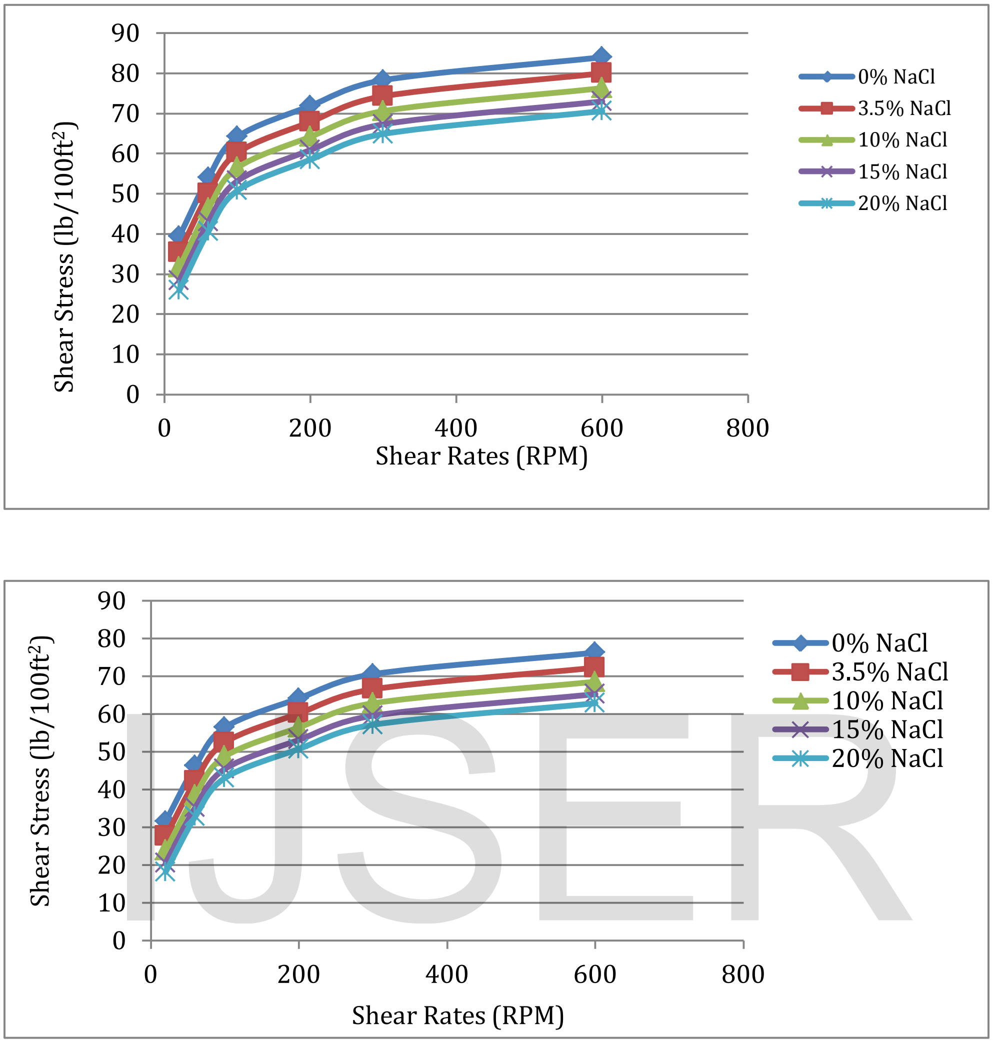


Figure 2. Shear Stress vs. Shear Rate of 1500ppm Xanthan gum polymer at (a) 25 oC and (b) 60 oC

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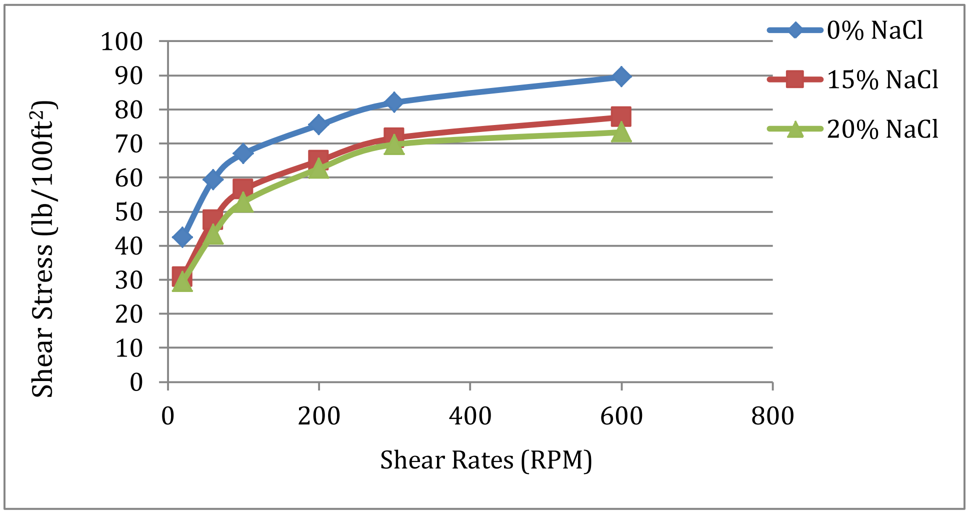
(a)



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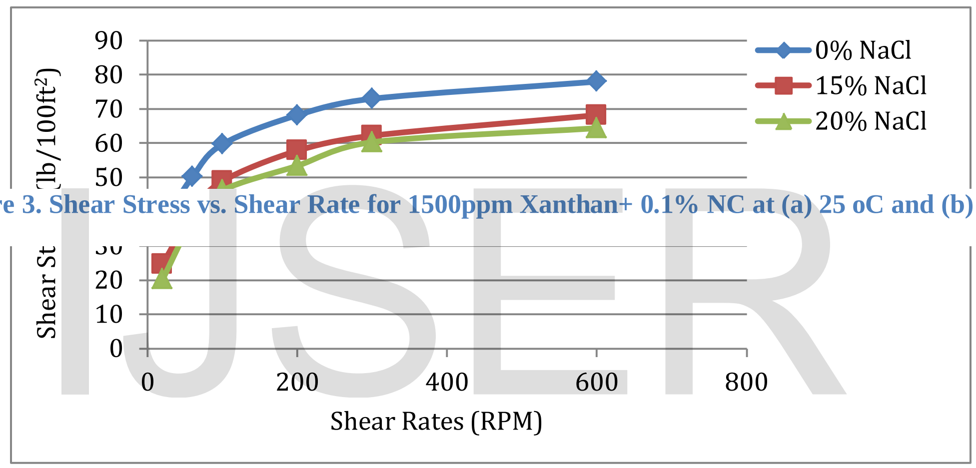

Figure 3. Shear Stress vs. Shear Rate for 1500ppm Xanthan+ 0.1% NC at (a) 25 oC and (b) 60 oC

(a)

(b)

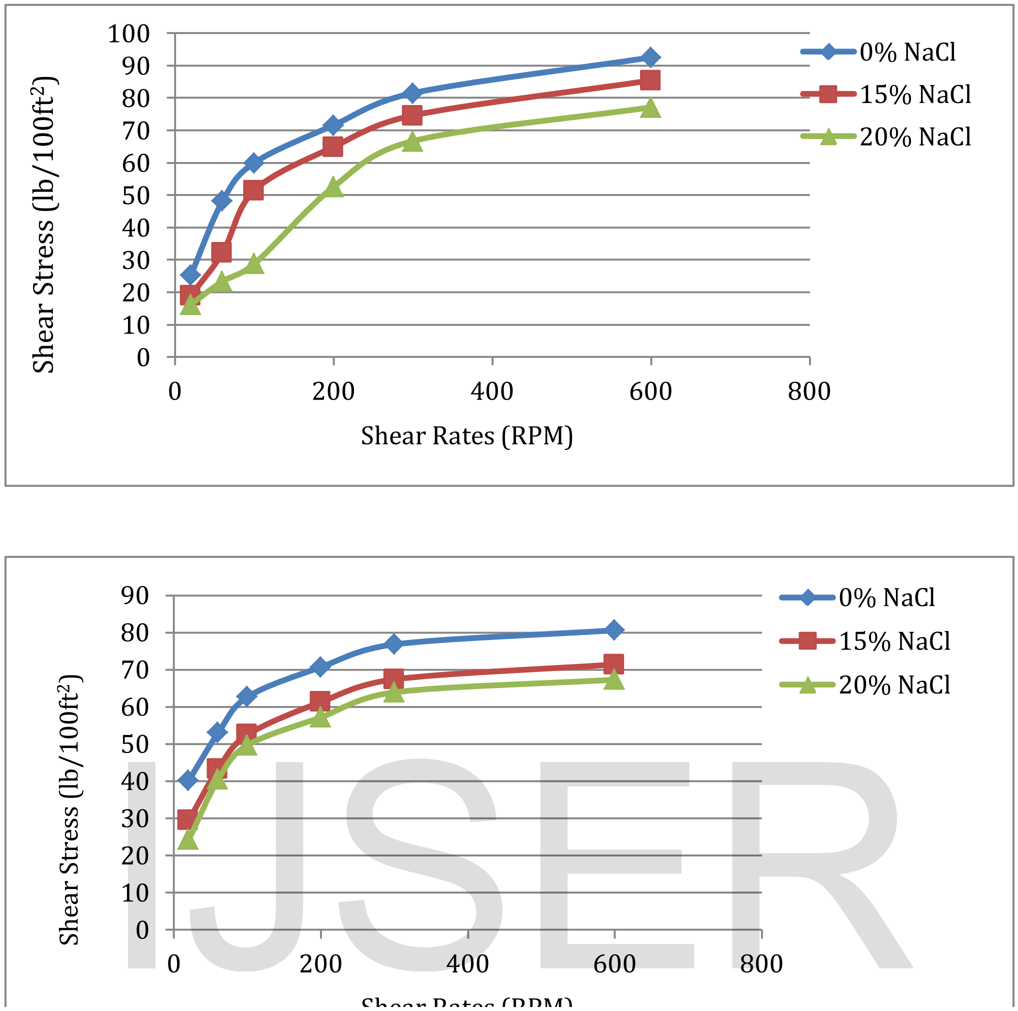

Figure 4. Shear Stress vs. Shear Rates for 1500ppm Xanthan + 0.15%NC at (a) 25 oC and (b) 60 oC

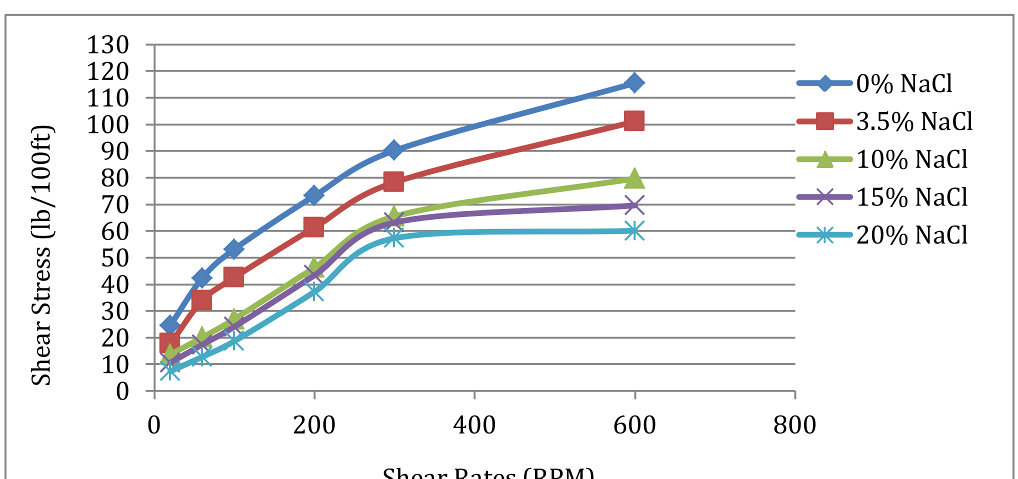

Figure 5. Shear Stress vs. Shear Rate for 2000ppm Xanthan at 25 oC

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Coefficient of determination (R^2) approaches unity value (1) in all cases and so this shows the accuracy of power law model in describing the flow behavior of xanthan polymer solution at all conditions of temperatures, concentrations, salinities and even in the presence of sodium magnesium silicate Nano (NC).

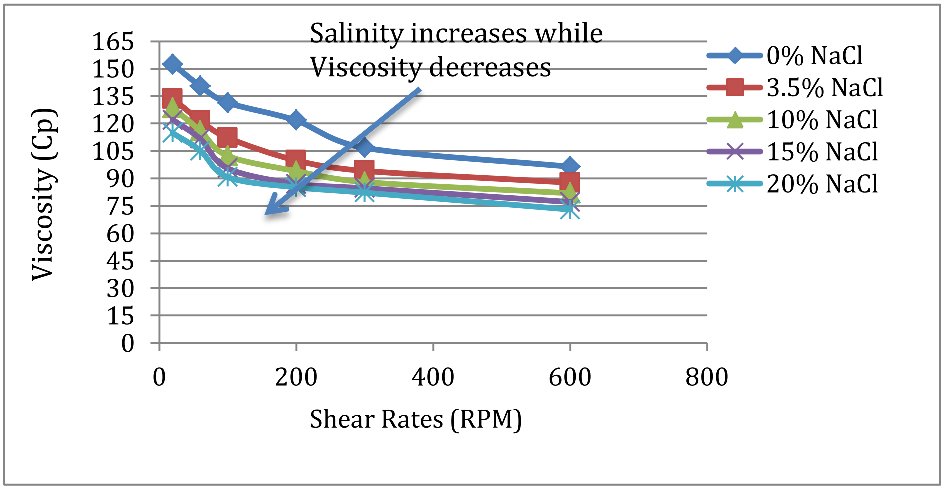
4.2 *Influence of Sodium Magnesium Silicate Nano on Viscosity Dependency of Xanthan polymer on Temperature, Salinity, Shear rate and Concentration*.

4.2.1 Influence of Nano on Temperature Effect on Viscosity

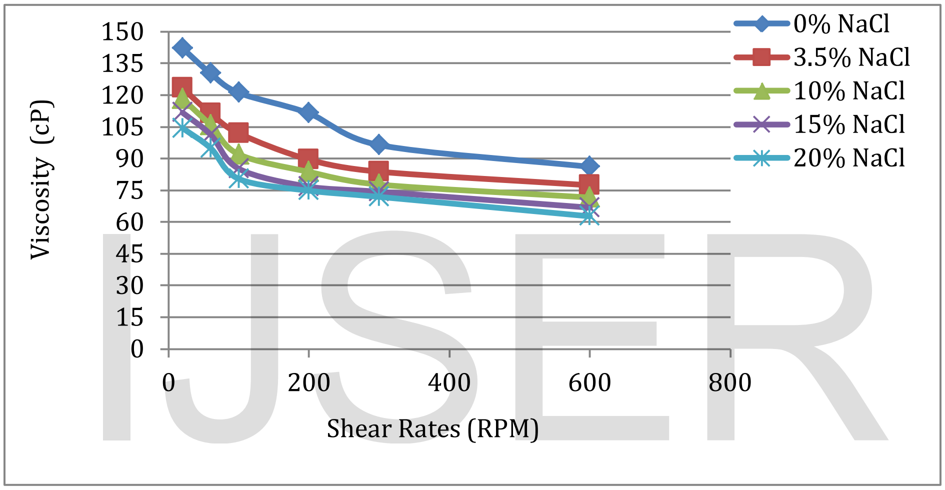
Xanthan gum solutions are generally exceptional in their capability to maintain their viscosifying property until certain critical temperature is reached after which they become thermally degraded. At this temperature, sharp decline in the viscosity in observed which is attributable to reversible molecular conformation change. Addition of Nanoparticle to the Xanthan gum solution would increase the viscosity even when the temperature is high, changing the nanoparticle concentration i.e. (0.1-wt% to 0.15-wt%) would result to a further increase in viscosity at low temperatures while sharp decrease in viscosity at high temperature

Influence of Nano on Effect of Shear Rate and Salinity on Viscosity

Xanthan gum solution exhibited shear thinning behavior at all concentrations and temperatures likewise addition of nanoparticle shows no effect on this shear thinning behavior. Xanthan polymer solution displays the following viscosity trends with regards to salinity, at polymer concentration less than or equal to 1500ppm, viscosity sharply decrease with increasing salinity. Fig. 7 (a) and Fig.7 (b) At polymer concentration greater than or equal to 2000ppm, polymer solution viscosity decreases slightly.



(a)



(b)

Figure 6. Viscosity vs. Shear Rate for Xanthan at 1500ppm at (a) 25 oC and (b) 60 oC

(a)

(b)

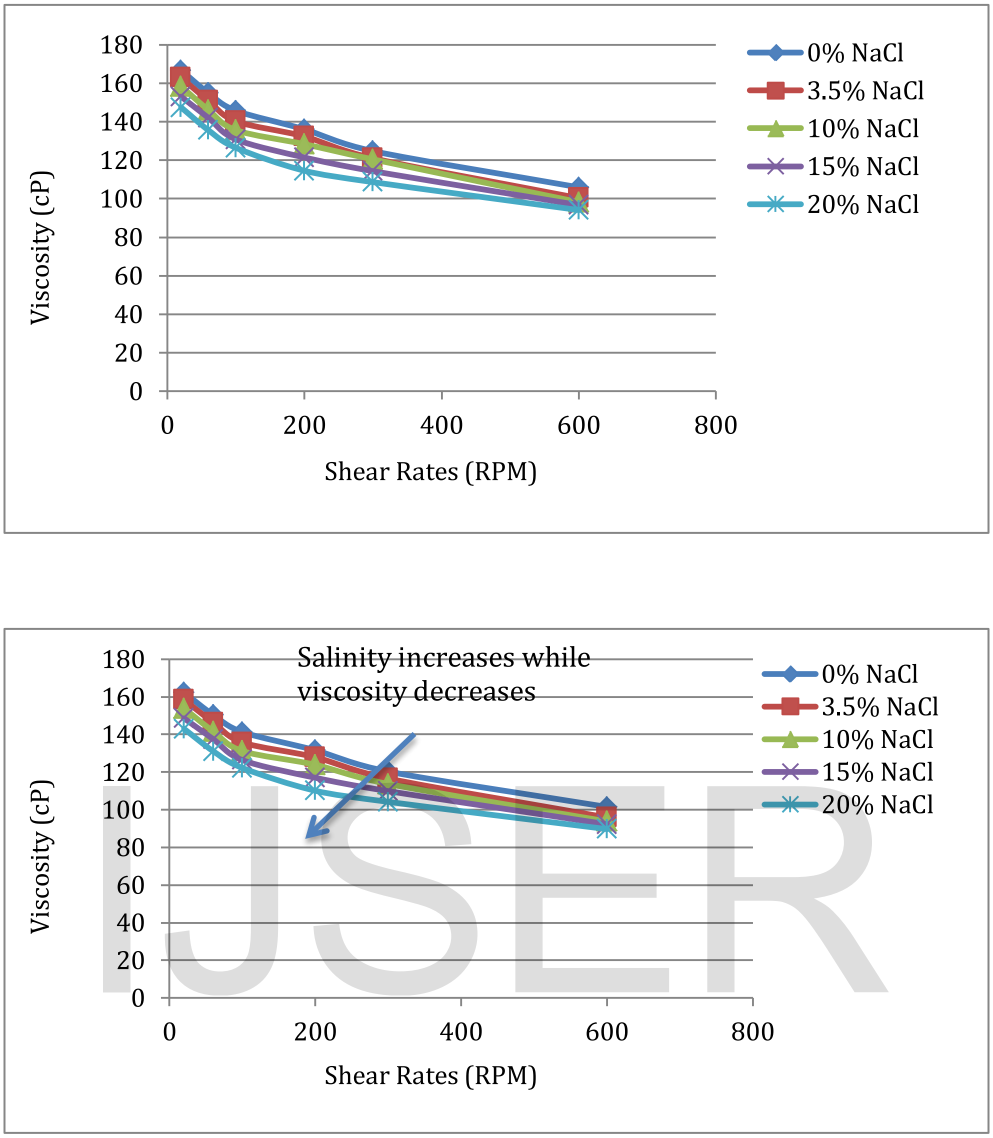


Figure 7. Viscosity vs. Shear Rate for Xanthan at 2000ppm at (a) 25 oC and (b) 60 oC

As we move from fig.6 (a) to fig. 6(b), temperature increases from 25 ^oC to 60 ^oC and it is therefore evidently clear that viscosity of xanthan gum solution decreases. One thing that is common to both fig. 6(a) and 6(b) is that as salinity increases from 0% to 20%, viscosity decreases. This however is also the case when nanoparticle is added but reduction in viscosity is less pronounced in the present of Nano. It is worth mentioning that salinity and temperature effects are less pronounced at high polymer concentration i.e. 2000ppm

Polymer and Nanoparticle Concentration Effect on viscosity

Increase in the concentration of polymer solution results in corresponding increase in the solution viscosity. Increasing concentration from 1500ppm (i.e. fig. 6a and fig. 6b) to 2000ppm (i.e. fig. 7a and fig. 7b), it is evidently clear that there is an increase in viscosity by 10% order of magnitude. This is also the case when Nanoparticle concentration is increased i.e. (0.1-wt% to 0.15-wt%).

Density dependence of Polymer solution on Concentration, Salinity, Nanoparticle and temperature.

Density of polymer solution generally is influenced by a lot of factors among which include temperature, salinity, polymer concentration and the presence of Nanoparticle. As the temperature increases from 25 through 100^oC (i.e. No Nanoparticle case), there is reduction in density and the same effect is observed in the presence of Nanoparticle. Adding nanoparticle itself causes a slight increase in density. Salinity on the other hand also causes increase in density. Tables [1] through [2] shows these effects.

Conclusions

1. Xanthan gum polymer was chosen for this research work. Samples of these polymers were prepared at different NaCl brines concentrations (0% to 20% NaCl). Two temperatures were used (25 ^oC and 60 ^oC).

2. Samples of Xanthan gum was prepared in standardized tap water, all fluids strongly obey (Power Law) model as they demonstrated shear-thinning behavior at all conditions.

3. Consistency index (K) decreases with increasing temperature and salinity. (K) Starts to increase as the concentration of Xanthan gum increases and also as the concentration of Nanoparticle increased i.e. (0.1-wt% to 0.15-wt%).

4. Viscosity of Xanthan polymer solution decreases with increasing temperature from 25 to 60 ^oC. Sharp decrease in viscosity in the case of 1500ppm whereas slight decrease in viscosity in the case of 2000ppm.

5. Addition of Sodium Magnesium Silicate Nano caused the viscosity of xanthan to increased and making it even more thermal resistant, still maintaining shear-thinning property.

6. Solution density increase with salinity, polymer concentration and addition of nanoparticle while it decreases with temperature.

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Effects of Salinity, Polymer Conc. , Nanoparticle and Temperature on solution density.

(Sodium Magnesium silicate Nano)

Table 1. Effect of Salinity, Polymer Conc., Temperature on solution density at 1500ppm and 0, 0.1 and 0.15-wt% Nano.

	1500ppm Xanthan + 0% Nano			
	Temperature			
	25	60	80	100
Salinity	Density (g/cc)			
0	0.976	0.916	0.896	0.876
3.5	0.997	0.936	0.917	0.896
10	1.018	0.956	0.936	0.918
15	1.110	1.050	1.030	1.010
20	1.220	1.160	1.140	1.120

	1500ppm Xanthan + 0.15-wt% Nanoparticle		
	Temperature		
	25	60	90
Salinity	Density (g/cc)		
0	1.103	1.054	1.004
15	1.248	1.207	1.145
20	1.389	1.302	1.260

	1500ppm Xanthan + 0.1-wt% Nanoparticle		
	Temperature		
	25	60	90
Salinity	Density (g/cc)		
0	0.983	0.934	0.884
15	1.128	1.087	1.028
20	1.269	1.182	1.135

Table 2. Effect of Salinity, Polymer Conc., Temperature on solution density at 2000ppm and 0, 0.1 and 0.15-wt% Nano.

	2000ppm Xanthan + 0% Nano			
	Temperature			
	25	60	80	100
Salinity	Density (g/cc)			
0	0.996	0.936	0.916	0.896
3.5	1.016	0.956	0.936	0.916
10	1.046	0.986	0.966	0.946
15	1.135	1.075	1.055	1.035
20	1.301	1.241	1.221	1.201

	2000ppm Xanthan + 0.1-wt% Nanoparticle		
	Temperature		
	25	60	90
Salinity	Density (g/cc)		
0	1.186	1.126	1.096
15	1.325	1.265	1.235
20	1.491	1.431	1.401

	20000ppm Xanthan + 0.15-wt% Nanoparticle		
	Temperature		
	25	60	90
Salinity	Density (g/cc)		
0	1.306	1.246	1.216
15	1.445	1.385	1.355
20	1.611	1.551	1.521

Const. \ NaCl	0%	15%	20%
K	23.358	14.839	13.769
n	0.2183	0.2726	0.2771
R^2	0.97164	0.95648	0.96045

Power Law parameters for shear stress vs. shear rate plots.

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Table 3. 1500ppm Xanthan and 25 oC (a) 0% nano and (b) 0.1% nano

NaCl / Const.	0%	3.5%	10%	15%	20%
K	21.077	18.124	15.488	13.226	11.64
n	0.2268	0.244	0.2624	0.2816	0.2976
R	0.96502	0.96235	0.95935	0.95611	0.95331

(a)

(b)

Table 4. 1500ppm Xanthan and 60 oC (a) 0% nano and (b) 0.1% nano

NaCl / Const.	0%	3.5%	10%	15%	20%
K	15.488	12.758	10.36	8.3421	6.9565
n	0.2624	0.2861	0.3125	0.3409	0.3656
R^2	0.95935	0.95533	0.95036	0.9453	0.94048

(a)

NaCl / Const.	0%	15%	20%
K	19.665	11.063	8.5196
n	0.227	0.3012	0.3384
R^2	0.96233	0.94706	0.92252

(b)

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Table 5. 1500ppm Xanthan + 0.15-wt% Nano (a) 25 oC and (b) 60 oC

NaCl / Const.	0%	15%	20%
K	9.5053	5.2048	3.2948
n	0.3745	0.4604	0.5038
R^2	0.94737	0.95708	0.96168

(a)

NaCl / Const.	0%	15%	20%
K	22.292	14.257	11.102
n	0.2119	0.2669	0.3014
R^2	0.96465	0.95758	0.93217

(b)

Table 6. 2000ppm Xanthan at (a) 25 oC and (b) 60 oC

NaCl / Const.	0%	3.5%	10%	15%	20%
K	6.3652	3.9298	2.2837	1.6095	0.8834
n	0.4593	0.5167	0.5621	0.6085	0.6869
R^2	0.99774	0.99542	0.9721	0.96955	0.96105

(a)

NaCl / Const.	0%	3.5%	10%	15%	20%
K	3.9496	2.636	1.2243	0.7485	0.2347
n	0.529	0.570	0.6501	0.7061	0.8749
R^2	0.99014	0.98977	0.98779	0.99806	0.99366

(b)