Influence of the Ionic Strength in the Intrinsic Viscosity of Xanthan Gum. An Experimental Review

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Abstract This study involves the influence of ionic strength in intrinsic viscosity of xanthan gum. The best concentration of monovalent and bivalent cations chloride salts is evaluated. The salt concentration is 0.001 M for monovalent cations and 3×10^{-5} M for bivalent cations and the hydrodynamic radius is maximum for these concentrations. The minimal concentration is in the range of 0.01 to 0.1 M for different cations.

Keywords: *xanthan gum, ionic strength, intrinsic viscosity*

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1. Introduction

1.1. Xanthan Gum

Xanthan gum is a natural extracellular polysaccharide with high molecular weight, above one million g/mol. It is produced by *Xanthomonas campestris* through a pure cultural fermentation. The structure of this biopolymer is composed of pentasaccharide repeat units of mannose, glucuronic acid and mannose in the molar ratio of 2.0:1.0:2.0 [1,2]. A xanthan gum monomer is assigned $C_{32.34}H_{49.94}O_{28.34}Na_{1.38}$ average formula, with M_{w0} of 918.6 g/mol.

The structural rigidity of the Gum results in various functional properties such as high viscosity in a wide range of concentrations, and high pH stability from 1 to 11. Moreover, structural resistance against salt and temperature is notable.

Please mention the range of salt concentration and the range of temperature resistance. [1,3,4].

Xanthan gum is significantly able to control aqueous fluid rheology. Aqueous solutions of xanthan gum are extremely pseudo-plastic when a tangential force is applied. The viscosity decreases in direct upon the yield point; however at hoop stress, the loss of viscosity is reversible. This physical bahavior of the xanthan gum solution can be explained based on the helical structure [5].

The yield stress of xanthan gum is attributed to the amount of force required to cleave some of the "super-bonding zones". The decrease of the viscosity is the result of subsequent dissociation of the bonds due to the induction of continuous shear stress. However upon the end of the force, the bonds are formed again. This results in an increase of the viscosity [6,7].

The industrial application of the xanthan gum is based on two criteria:

1 - The ability to alter the flow properties of water.
2 - The ability to form gels as emulsifiers, adhesives, flocculants, film formers and lubricants.

In food industry, Xanthan gum in used in making ice cream, confectionery, fruit juices, beer, wine, mayonnaise, cheese, jams, dressings, meats, dietary products, etc. In each of these cases, the gum plays a distinctive role to improve the functional properties of the food system [8].

Xanthan gum, by itself, is not able to form a gel; however since it is rather resistant to the enzymes and high amounts of alcohol, it induces a satisfactory level of viscosity at even a low concentration [9].

One of the leading applications of Xanthan gum is its usage in dressings as a stabilizing agent. Moreover, the addition of the gum to these products helps to decrease the amount of oil in the recip. This results in not only a better microbiological stability but also leading to a healthier product [10].

The branches of the helical backbone stabilizes the whole structure, giving the gum a high level of stability to heat, acid, and alkali. This results in an increase of the viscosity in the food system due to the formation of aggregates with high molecular weight [11].

The previous studies on physical chemistry and rheological properties of Xanthan gum revealed the structural characteristics of the gum. They showed that the molecular weight of the polysaccharide determines the shape of the gum in a solution. Xanthan gum presents a rigid structure at low molecular weight; however a higher molecular weight results in a stiff coil. In both cases, the physical behavior of the gum is the result of a structural alteration from a disorder coil to an order helix due to an ionic strength, influenced by temperature [12].

The temperature increment favor the "disordered" transition, whereas high ionic strength favors the "ordered" transition. Moreover, it is known that in the absence of an electrolyte, xanthan gum tends to self-associate in order to reduce the interfacial tensions [13].

The viscosity should increase accordingly due to the formation of a better gel [14].

In principle, a solution of a polysaccharide tends a drop of viscosity as a function of temperature increase; however xanthan gum behaves differently. An increase of the viscosity in deionized water is observed after an initial decrease of the viscosity. A conformational change, due to the above mentioned factors, is the reason of this physical behavior. Optical rotation is a technique which can give a clue about this conformational change. This technique is employed in a salt free solution of xanthan gum. Based on this technique, decrease of the optical rotation is the result of viscosity increase. Please compose the sentence again; also divide it to two short sentences [15].

As mentioned before, a solution of xanthan gum shows a good resistance to temperature variations, pH and salt; however precipitation occurs in the presence of multivalent cations. Previous studies showed the conformational change of xanthan gum in a solution due to the self-aggregation. These studies indicate that the molecule has a rod-like conformation but that it still has some degree of flexibility [8]. At sufficient ionic strength, xanthan undergoes a disorder-order conformational transition from a random coil to a single or double helix. With increased concentration and ionic strength, an intermolecular ordering or self-aggregation through hydrogen bonding and entanglement effects becomes increasingly significant. This aggregation phenomenon has been the subject of a great deal of research in the field due to its important influence on the rheological properties of the solution.

Addition of salt to xanthan gum enhances the intermolecular interactions between the chains and results in an increase of aggregation. The xanthan molecules should be in the sodium form and the side chain substitution should be Na^+, but excess ions in solution should be minimal with dialysis [16].

Xanthan gum in distilled water tends to a disordered conformation; however it is also highly dependent on the concentration of the gum. Addition of salt in concentrations sufficient to acquire the xanthan gum helical conformation and undergo a disorder-order transition, and therefore assumes a rod-like shape. Furthermore, the non-addition salt is required for sufficient attractions occurs to cause the formation of aggregates [17].

The ordered conformational structure is helical; however it is not known that if it is a single coil or a double helix. Upon an increase of the gum concentration as well as ionic strength, the hydrogen bonds present at the intermolecular structure promote self-aggregation and increase of the viscosity accordingly [18].

This polysaccharide adopts a local ordered conformation in given conditions (low temperature, presence of external salt). Evidence of this ordered local conformation is obtained from measurements of optical rotation when the conformational transition is induced by changes in temperature, pH or by addition of salt. Nevertheless, the chromophores involved in such studies are the carbonyls on the lateral chains; the modification of their adjacent molecules does not significantly alter the characteristic of the backbone [19,20].

Xanthan gum is a polysaccharide with a high molecular weight which works in food industry as a viscosity giving agent. Aqueous xanthan solutions are shear-thinning the viscosity of a 1 mg/ml solution changes from 700 cP to less than 10 cP as the shear stress increases from 0.01 to 20 dyne cm^{-2} [21].

Shear thinning behavior of dilute polymer solutions can be qualitatively explained by two distinct models: 1- the molecule may be a non-deformable, highly elongated prolate ellipsoid, which becomes oriented at high shear stresses [21]; 2- the molecule may be a stiff but wormlike chain [22], which becomes oriented and deformed under high shear stresses. The first model has been explored for xanthan and show that an undeformable ellipsoid of length 1.5 µm and midpoint diameter 19 Å can fit data they observed for the variation of intrinsic viscosity with shear stress in distilled water [23].

This work studies the effect of six inorganic salts (LiCl, NaCl, KCl, $MgCl_2$, $CaCl_2$, $SrCl_2$) in dilute aqueous xanthan solutions to obtain information about the extension of the xanthan molecule in an effectively uncharged state. The degree of extension is mainly determined by the intrinsic stiffness of the biopolymer and also by electrostatic expansion caused by monovalent and bivalent cations.

1.2. Intrinsic Viscosity

The drainage time measured of liquid volume through a capillary viscometer. The flow through the capillary is governed by the law of Hagen-Poiseuille. Where the viscosity is determinate by the following equation

$$\eta = A\rho t \qquad (1)$$

where η is viscosity (poise = g/cm s), ρ is density (g/cm^3), t is fluid drainage time (s), A is instrumental viscometer constant (cm^2/s^2) which is generally obtained by calibration of the viscometer with a reference liquid of known viscosity.

Empirically relate viscosity to molecular weight of the polymer or biopolymer, insofar simplicity and utility of the molecular weight viscosity-correlation is so good that the viscosity measurements is an extremely valuable tool for the characterization of macromolecules [24].

One of the properties, which characterize a polymer, is increase of the viscosity which is influenced by the purity of the solvent, even at very low polymer concentrations, and size and shape of the polymer molecules in solution and polymer-solvent interactions [25].

In the dilute system, the ratio of the viscosities of a polymer solution η (for low concentrations) to the pure solvent η_0, is called relative viscosity η_r.

$$\eta_r = \frac{\eta}{\eta_o} = \frac{t\rho}{t_0\rho_0} \qquad (2)$$

The specific viscosity (η_{sp}), is related to the increase in viscosity due to polymer molecules.

$$\eta_{sp} = \frac{\eta - \eta_o}{\eta_o} = \eta_r - 1 \qquad (3)$$

The reduced viscosity (η_{red}), is a measure of the ability of a polymer to increase the viscosity of a solvent, polymer concentration unit.

$$\eta_{red} = \frac{\eta_{sp}}{c} \qquad (4)$$

The intrinsic viscosity [η] determines the hydrodynamic volume due to the presence of macromolecules in solution and the ability of a polymer molecule to increase the viscosity of a solvent, where [η] depends on the concentration of polymer in solution [26,27].

The intrinsic viscosity is calculated by determining the relative viscosity for different concentrations of a polymer. The value of [η] is obtained by extrapolating η_{red} when the concentration of polymer in solution tends to zero.

$$[\eta] = \lim_{c \to 0} \frac{\eta_r - 1}{c} \qquad (5)$$

The calculation of the intrinsic viscosity can be accomplished by Schulz-Blashke equation

$$\frac{\eta_r - 1}{c} = [\eta] + k_{SB}[\eta]\eta_{sp}. \qquad (6)$$

Schulz-Blashke equation relates first Huggins equation with increase of the relative viscosity, wherein (η_{sp}/c) has a linear relationship based on the concentration, the intercept is the intrinsic viscosity, which is expressed in cm^3/g [28].

The empirical equation of Mark-Houwink-Sakurada established the relationship between the intrinsic viscosity of a solution of a polymer and its molecular weight at constant temperature.

$$[\eta] = KM^a \qquad (7)$$

Where "K" and "a" are two constant parameters depending on the nature of the solvent, the polymer and the temperature are independent of the concentration and molecular weight of the polymer [29]. The "*a*" parameter show the conformation of the polymer in a solvent, 0-0.5 is spherical, from 0.5-0.8 is ellipsoidal (random-coil), and from 0.8 to 2 is rod-like [30].

1.3. Ionic Strength and Electro-kinetic Effect

The intrinsic viscosity it is depends of ionic strength and defined function of molecular structure and protein folding. It is well known that the conformational and rheological properties of charged biopolymer solutions are dependent not only upon electrostatic interactions between macromolecules but also upon interactions between biopolymer chains and mobile ions. Due electrostatic interactions, the specific viscosity of extremely dilute solutions seems to increase infinitely with decreasing ionic concentration [31].

It was found earlier that the viscosity intrinsic of polyelectrolyte solutions is nearly linear as a function of the reciprocal square root of the ionic strength over a certain range, such as

$$[\eta] = [\eta]_\infty + \varepsilon I^{-1/2} \qquad (8)$$

where ε is extension coefficient. The $I^{-1/2}$ dependence viewed in terms of an increased Debye length can be explained as the electrostatic excluded volume contribution [32].

The increase the valence of the ion of opposite sign is greater effect to reduce the potential electrokinetic of surface (colloid or polymer). Increasing the concentration of electrolyte on a surface of negative charge, cations tend to accumulate on the fixed layer, reducing the thickness of the double layer and consequently charge density and zeta potential. To study the stability of colloids trace amounts of electrolytes, with causes aggregation of particles and precipitate formation is necessary. The phenomenon of precipitation, flocculation, coagulation, and conservation depends. The rate of precipitation is depending on the salt concentration and the concentration of the polysaccharide as well. The ions are effective for the coagulation are the opposite to that of the colloidal particle, and that the clot can grow considerably increases the valence of the ion (Schulze-Hardy rule) [33].

The stability of a colloid such as gelatin in water is determined by the electric charge and hydration. The addition of large amounts of electrolytes to a colloid (biopolymers). High salt concentration dehydrates the biopolymer and reduce the zeta potential. The salification effect depends on the nature of the ion. The ions can be arranged according to decreasing ability to remove the lyophilic substances on colloidal solution, these series have been called Hofmeister or lyotropic series [34].

The electrolyte concentration implies a decrease in the thickness, 1/κ, of the electrical double layer,

$$\frac{1}{\kappa} = \sqrt{\frac{\varepsilon_r \varepsilon_0 k_s T}{4\pi e^2 \sum_i c_i z_i^2}} \qquad (9)$$

where ε_r is the dielectric constant of the liquid medium, ε_0 is the vacuum permittivity, e is the proton charge, $k_B T$ is the Boltzmann energy, and c_i and z_i are the concentrations and the valences, respectively, of the various ionic species in the solution, far away from any particle [35].

Proteins and polysaccharides are charged biopolymers in due to dissociation of their ionizable groups in an aqueous solution and have been widely used in paints, cosmetics, and film industries. In contrast to the neutral polymers, polyelectrolytes have a comparatively extended conformation, owing to the repulsive intrachain electrostatic interaction screened by the surrounding small ions in the solution. As a result, their rheological properties in a dilute solution due to an applied flow will change accordingly [36].

Plot of intrinsic viscosity in function of ionic strength can be observed the increasing dilution of flexible polyelectrolytes at low ionic strength, the reduced viscosity may increases first; reach a maximum and then decreases. Since a similar behavior can also be observed even for solutions of polyelectrolyte lattices at low salt concentration.

Studies on electrokinetic phenomena of proteins or other macromolecules in solution are very scarce in the literature; therefore, this fact limit us to the basic concepts of electrokinetic changes observed as conformational changes, due to the presence of salts and the zeta potential change in pH [37,38].

For polyelectrolyte solutions with added salt, previous experimental studies indicated that the intrinsic viscosity decreases with increasing salt concentration. As more salts are added, the intrachain electrostatic repulsion is weakened by the stronger screening effect of small ions. As a result, the polyelectrolytes are more compact and flexible, leading to a smaller resistance to fluid flow and thus a lower viscosity. For a wormlike-chain model, by incorporating the tertiary effect on the chain conformation

would not predict the intrinsic viscosity behaviour. The effect of the intrachain electrostatic repulsion on the chain conformation is based on the equilibrium interaction which depends on the Debye screening length [39].

When the salt concentration added salt is very low, Debye length needs to be modified by including the charge contribution of the dissociating counterions from the polyelectrolytes. Due the equilibrium interaction is used, their theory predicts that the intrinsic viscosity is independent of ion species at constant ionic strength. At very high ionic strength, the intrachain electrostatic interaction is nearly screened out, and the chains behave as neutral polymers. Aside from the tertiary effect, the intrinsic viscosity will indeed be affected by the ionic cloud distortion and thus cannot be accurately predicted by their theory [40].

2. Experimental

Xanthan gum was obtained by Parafarm, Nº 509, 2013, Argentina with viscosity of 1400 to 1600 Pa.s and pH of 6-8 in 0.1% solution, moisture of 7-12%.

Xanthan gum was prepared in 0.135, 0.1 and 0.075% wt. into the bidistilled-deionized water of the solutions of LiCl, NaCl, KCl, $MgCl_2$, $CaCl_2$ and $SrCl_2$ from $5x10^{-6}$ to 0.1M.

The solutions were stored in a thermal bath Ultraterm S-383 (Selecta), equipped with a double-walled vessel. Water was circulated through the double-wall keeping for 30 minutes and at 25°C of temperature. Temperature was measured by a digital Checktemp thermometer. The density was measured with an Anton Paar DMA 35N.

The calibration was released by 10 runoff-time measurements (t_0, s) in water at 25°C were performed with an Ubbelohde 1B viscometer. The average, and the density (ρ_0) and viscosity (η_0) values tabulated for water under the same conditions were employed for constant (A) determination. The drainage time (t) measurements and density (ρ) of solutions were performed by triplicate.

3. Results and Discussion

The molecular weight of xanthan gum in NaCL 0.01M solution is 1675000 g/mol [41].

This difference led to consolidated discussions about of size, shape and molecular weight of the structure, which were relevant to the characterization process [42].

In salt free systems for polyelectrolytes is studied for different works evaluated of molecular weight and intrinsic viscosity properties [43].

Xanthan gum presents different physical behaviors which are significant for industrial purposes. Solutions have a high viscosity and have been reported to exhibit shear and extension thinning as the deformation rate increases (recovering rapidly on the removal of the shearing force). At xanthan gum concentrations of commercial importance, the solution viscosity is high and relatively independent of salt concentration over a large range. This behavior is atypical of normal polyelectrolytes, which have a highly expanded conformation at low ionic strength and collapse to a more compact coil as the salt concentration is increased (due to charge screening). This change in the

hydrodynamic dimensions of the molecule would cause a significant drop of the solution viscosity. At moderate ionic strengths, there is little reduction in viscosity as function of temperature, whereas most polymer solutions show a marked decrease.

The intrinsic viscosity increases as a function of salt concentration, in dilute zone and decreases in concentrated zone. For cations monovalent salinites above 10^{-3} M, the dependence of [η] on c_s is the same as for uncharged polymers and can be described by a Huggins equation in the polymer concentration range (c < 10^{-2} g/ml). The polymer concentration depends on the chains length. Under these conditions, an estimation of the hydrodynamic equivalent rod length. As expected for a single stranded sample, the variations of intrinsic viscosity with salinity are reversible. Moreover, the intrinsic viscosity decreases only slightly with increasing salinity above 10^{-3} M for monovalent cations due to the relatively rigid conformation of xanthan.

Since no change was observed in the molecular weight, the variations of intrinsic viscosity with salinity must be interpreted by an intramolecular process. The structural conformation of xanthan gum is due to steric hindrances of both backbone and the side chains, however mainly due to intramolecular interactions such as hydrogen bonds in the ordered state. The second part arises from the electrostatic repulsions between neighbouring charged groups along the chain.

At low salinity in monovalent cation below 10^{-3} M an extended disordered conformation prevails, and both the intrinsic viscosity assume high values due to electrostatic repulsions between charged groups [44].

Table 1. Molecular weight and intrinsic viscosity depending on the ionic strength of xanthan gum

I (M)	[η] (cm³/g)	M_v (g/mol)	Reference
0.78 NaCl	270	380000	Holzwarth 1978
0.04 Na₂HPO₃	1100	1080000	[45]
30ºC	1900	1830000	
	3900	3670000	
	12300	12200000	
	35000	52000000	
0.25 NaCl	2240	7600000	Whitcomb & Macosko 1978 [21,46]
0.5 NaCl	3000	2000000	Holzwarth 1981
	8000	10000000	[23]
0.1 NaCl	9000	7400000	Sato et al. 1984
	5110	3940000	[47]
	3580	2560000	
	1800	1420000	
	1010	994000	
	575	603000	
	320	362000	
	181	240000	
	152	209000	
	106	164000	
	60.8	112000	
	35	74000	
0.1 NaCl	800	2000000	Cuvelier & Launay 1986 [48]
0.00001 NaCl	15000	1800000	Muller et al. 1986
30ºC	15000		[44]
0.0001	7000		
0.0005	4600		
0.001	4500		
0.01	4300		
0.1	3900		
0.3	3200		
0.9			
0.1 NaCl	4300	587000	Chauveteau 1982

	3900	700000	[49], Berry & Russell 1987 [50]
0.01 0.03 0.1 0.3	1862 1543 1415 1170	1400000	Tinland & Rinaudo 1989 [51]
0.01 NaCl	10300 Natured 13200 Renatured	5250000	Milas et al. 1990 [52]
0.01 NaCl Natured Renatured	5600 11400	≈9000000	Milas et al. 1996 [53]
-	-	900000 2000000	Ross-Murphy et al. 1996 [54]
0.01 0.1	7400 7150	5200000 5300000	Capron et al. 1997 [55]
0.2% wt. NaCl 2% 20%	8600 4050 3680	-	Lounay et al. 1997 [56]
0.13M KCl	6500	-	Schorsch et al. 1997 [57]
Culture Conditions 1.114 g/l NH$_4$NO$_4$ 28ºC 100rpm 300rpm 500rpm 800rpm		3600000 4300000 4200000 3100000	Casas et al. 2000 [58]
0 0.04 0 0.04	Native 7520 1690 Deacetilated 4330 -	1143000 1025000	Wang et al. 2002 [59]
Aqueous	11230	-	Achayuthakan et al. 2006 [60]
Aqueous	15570 Native	2650000	Khouryieh et al. 2006 [61]
Aqueous 0.002 0.04 0.2 0.4	Deacetilated 16300 9060 5670 Native 9290 7320	2360000 2650000	Khouryieh et al. 2007 [62]
Aqueous 0.005 NaCl 0.050 0.005 KCl 0.050 0.005 CaCl$_2$ 0.050	21421 7544 6872 7793 7382 6308 5977	2650000	Higiro et al. 2006 and 2007 [12,13]
0.01 NaCl	11230	3470000	Achayuthakan et al. 2008 [63]
-	2294	7741000	Heinzmann & Tartsch 2009 [64]
0.1 NaCl	1590 1340 1170		Choppe et al. 2010 [65]
0.01 NaCl	1936 1906	-	Desplanques et al. 2012 [66]
0.01 NaCl	2665	≈2470000	Laneuville et al. 2013 [67]
0.01 NaCl 25ºC	2420	1675000	Masuelli 2014 [41]
0.01 NaCl	2130 1220 820	1680000 1040000 730000	Gunasekar et al. 2014 [68]

Table 1 present the values of differents authors that worked with xanthan gum in salt presence.

The ε are provided by short-range electrostatic intrachain interactions and are comparable with the Debye screening length. At extremely high NaCl concentration polyelectrolyte chains became discriminated by their degree of hydrophobicity. Chains of hydrophobic nature are compacted up to pre-rod state, whereas the chains of the hydrophilic nature stay in the conformation of swelling coils at the highest concentration of NaCl [69].

The intrinsic viscosity is indispensable information abaout the conformation of single polymers chain. In salt-free and low added-salt concentration cases, the intrinsic viscosity of polyelectrolyte solutions exhibits a drastic increase with dilution and intense maximum appears in a very dilute concentration range of 10^{-4} - 10^{-2} M for monovalent cations; and for bivalent cations in range of 10^{-5} - 10^{-3} M (see Figure 1 and Figure 2).
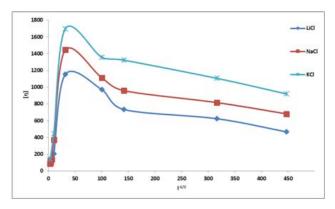

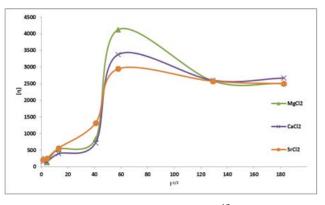**Figure 1.** Intrinsic viscosity as a function of $I^{-1/2}$ of monovalent cations solution

Figure 2. Intrinsic viscosity as a function of $I^{-1/2}$ of divalent cations solution

Figure 1 shows the plot of intrinsic viscosity and $I^{-1/2}$ for monovalent cations as Li^+, Na^+, and K^+ at different concentrations. Here the characteristic behabior of the intrinsic viscosity is observed; the intrinsic viscosity increases greatly with decreasing of salt concentration, attaining a maximum at very low concentration c=c$_{max}$, and the it goes down. A concentration sufficiently lower tha c$_{max}$, however, the intrinsic viscosity tends of plateau, as is clearly seen in the plots for concentration salt in 10^{-4} at 10^{-2} M. This fact suggests that the contribution from polyion conformation itself will remain when the solution is diluted to a electrolitic concentration where the intermolecular interactions can be neglected, but significantly influence the macromolecule. In order to estimate [η] of a polyelectrolyte solution by the conventional linear extrapolation, measurements must be conducted to such a very dilute concentration where the [η] indicates plateau [70,71,72,73].

This study indicates that the molecule has a rod-like conformation but it still has some degrees of flexibility. In addition, xanthan gum rheological properties vary with acetate and pyruvate content as has been shown by recent studies. At sufficient ionic strength, xanthan undergoes a

disorder-order conformational transition from a random coil to a single or double helix. An increased ionic strength, an intermolecular ordering or self-aggregation through hydrogen bonding and entanglement effects becomes increasingly significant. This aggregation phenomenon has been the subject of a great deal of research in the field due to its important influence on the rheological properties of the solution [18].

Studies on the behavior of xanthan gum in distilled water indicate that it has a highly disordered conformation. Although aggregation may occur through entanglements at high concentrations, intermolecular attractions through ionic effects are minimized. It is not until salt is added at sufficient concentrations that xanthan gum acquires rod-like conformation. Furthermore, the addition of salt is necessary for sufficient attractions to occur aggregation [18].

The rheological consequences of dilute aqueous xanthan solutions (NaCl 0.1M) in terms of the formation of additional junction zones between xanthan chains based on the duplex motif of the native xanthan double strand [74].

In the case of bivalent ions when $\Gamma^{-1/2} = 60$ is the maximum intrinsic viscosity of 2945 to Sr^{2+}, Ca^{2+} and 3377 to 4123 for Mg^{2+} (see Figure 2). This phenomenon is due to the great degree of hydration possessing these bivalent cations at which cause insolubilization of the xanthan gum.

By increasing the temperature, the viscosity increases significantly with increasing concentration, however it decreases strongly with increasing temperature [65].

4. Conclusions

The results show that dilute xanthan solutions are non-interacting entangled polymer solutions. The strength of the transient gel is only weakly dependent on the xanthan concentration and the ionic strength, but the lifetime of the bonds is strongly depending on these parameters. The coil to helix transition decreases the gel strength but, more importantly, it increases the bond lifetime, especially at higher xanthan concentrations [65-76].

Acknowledgement

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