

Chapter 5

Determination of unperturbed dimension and interaction parameters of sodium alginate in binary solvent mixtures by viscosity measurements

5.1 Introduction

Alginate is a water-soluble linear polysaccharide and is the only polysaccharide which naturally contains carboxyl groups in each constituent residue, and possesses various abilities for functional materials [1,2]. Due to the presence of the carboxylic acid groups in the saccharides residue, alginic acid has an anionic nature, forming alginate salts with cationic metals, such as Ca^{2+} and Na^+ . Calcium alginate is insoluble and appears a swelling behaviour in water, whereas sodium alginate is soluble in water [3].

Furthermore, sodium alginate is a biodegradable polymer [4]. In the treatment of the properties of very dilute polymer solutions it is convenient to represent the molecule as a statistical distribution of chain elements, or segments, about the centre of gravity. The average distribution of segments for a polymer molecule is approximately gaussian; its breadth depends on the molecular chain length and thermodynamic interaction between polymer segments and solvent. According to hydrodynamics, the specific viscosity of a Newtonian liquid containing a small amount of dissolved material should depend in the first approximation only upon the volume concentration and the shapes of the suspended particles. Alginates are insoluble in water-miscible solvents such as alcohols and ketones. Aqueous solutions (1%) of most alginates would tolerate the addition of 10-20% of these solvents; propylene glycol alginate tolerates 20-40% while up to 65% ethanol can be added to triethanolamine alginate without causing precipitation. The presence of such solvents in water, before dissolving the alginate, will hinder hydration. An even more efficient method of diluting the alginate particles is to use liquid-mixture dispersion in which they are wetted with a non-solvent. This can be either a water-miscible non- aqueous liquid (such as ethanol or glycerol) or a water-immiscible liquid (such as a vegetable oil). The particles are dispersed and the rate of hydration, and solution, would depend on the time taken for the non-solvent liquid to diffuse from the surface of the particles. The behavior of dilute polymer solutions, expressed

by different parameters, the second virial coefficient, the mean dimensions, the intrinsic viscosity (η) and influenced by temperature, solvent quality, molecular weight domain, can be discussed through different excluded volume theories [5]. The theoretical approaches mutually differ in the mathematical methods approximations used, but all of them relate the excluded volume effects to measurable quantities, by considering different possible interactions. The unperturbed dimension (UD) of a given polymer in a solvent does not depend on the nature of the solvent, as long as the solvent has no influence on the rotation of the chain segments [6,7]. This is true in many cases, especially for nonpolar polymer-solvent pairs, but in the cases of polar polymer - polar solvents systems, the unperturbed dimension vary considerably with the nature of the solvent. Most of the polymeric materials are soluble only in a limited number of primary solvents, but they could be made soluble in all proportions in mixtures consisting of two or more solvents, which may be individually poor solvent for the polymers [8]. Several mixtures of nonsolvent are also known which produce good solvent systems or at least increase the solvency power of primary solvents [9-16]. The intrinsic viscosity $[\eta]$ is related to unperturbed dimension K_θ , molecular weight M , and the hydrodynamic expansion factor α_n by the relation [17,18]

$$[\eta] = \Phi (r_o^2/M)^{3/2} \alpha_n^3 = K_\theta M^{1/2} \alpha_n^3 \quad (1)$$

where Φ is universal parameter ($\Phi = 2.5 \times 10^{23} \text{ mol}^{-1}$) and r_o^2 is the unperturbed mean square end- to end distance. At theta temperature $\alpha = \alpha_n = 1$ and hence evaluation of K_θ is possible using this equation. On the other hand, for evaluation of K_θ from intrinsic viscosity at temperature other than theta temperature, a number of equations have been proposed [19-21].

The unperturbed dimension of polystyrene and poly (2- vinylpyridine) has been measured in solvent-precipitant mixtures of various compositions using the Stockmayer-Fixman representation by Dondos and Benoit [22]. Recently Savas and Zuhal have determined the unperturbed dimensions of anionically polymerized poly

(p-tert-butyl-styrene) at various temperatures and found the theta temperature of the polymer of the order of 31^o and 32.7^oC in nitropropane and 2-octanol respectively [23]. Several other workers reported the conformational transition of polymers in solution with change of temperature [24,25]. Coil dimension of poly(methyl methacrylate) in the cosolvent medium of carbontetrachloride CCl₄ and methanol have been investigated by Maitra and Nandi [26]. They observed that the intrinsic viscosity exhibited a maximum for all fractions of polymers at a composition, $\Phi_{\text{methanol}}=0.33$ and also Huggins constant showed a minimum at the same composition. The experimental data for the solution properties of poly(N,N-dimethyl acrylamide) and poly (n-isopropylacrylamide) show that the hydrodynamic and configurational characteristics of these two polymers in methanol and water are different, showing a peculiar behavior in water, which cannot be easily interpreted in terms of random coil molecules. Chintore and co-workers found that the behavior of poly(N-methylacrylamide) molecule in aqueous solution was quite abnormal, as indicated by the values of second virial coefficients, lowered than those measured in methanol solutions by the large difference of estimated unperturbed dimensions [27,28]. Therefore, the hypothesis was made that the solvation of N-substituted polyacrylamide by water would occur with large dipole interaction and/or hydrogen bonding with the structural units of the polymers in such a way as to give a large chain expansion with low chain flexibility, so that the polymer molecules could no more be treated as random coil in aqueous solutions. It has been pointed out that polyacrylamide, in which lack in N-substitutions increases the chances of intramolecular interactions, has the highest unperturbed dimensions [29]. It has been shown that, the unperturbed dimension of polyacrylamide could be determined by light scattering measurement in methanol-water system [30]. These authors concluded that the high value of the exponent (0.64) of the molecular weight dependence of radius of gyration was not related to a great expansion of macromolecular coil, and the determination of unperturbed dimension by extrapolation of viscosity measurements in good solvent at $M \rightarrow 0$ should be possible

and the work of Okada and Yamaguchi provides such determinations [31, 32]. The fundamental parameters of polyacrylamide obtained previously by viscometry in good solvent and in θ solvents have been analyzed by viscosity -molecular weight relationship procedures as suggested by several workers [15, 33]. High value of excluded volume exponent, as was observed in some cases, once thought to be the result of great expansion of polyacrylamide in aqueous solution as mentioned earlier. This arose doubts on the applicability of the method of extrapolation of the viscosity data in determining unperturbed dimension of the polymer in water. Further study, however, confirmed that high value of exponent of molecular weight dependence of the radius of gyration was not due to great expansion of the macromolecular coil in water and it is now believed that determination of unperturbed dimension by extrapolating viscosity data in good solvents is possible [30]. Saha and coworkers [34] have determined the unperturbed dimension of polyacrylamide (synthesized by them using a novel method to increase the chain length) in water-dimethylsulphoxide, water-1,4 dioxan, water-dimethyl formamide mixtures at 30-50⁰C by different methods of extrapolation and found minimum value of unperturbed dimension at different fractions of nonsolvent depending on the nature of the polymer and nonsolvent, and obviously the temperature.

From the above literature it appears that in some cases the estimated unperturbed dimensions of chains may depend on the method of measurement in some cases and in other instances these are consistent. The extrapolation procedures often yield much higher values for unperturbed dimensions as compared to the real one, due to the curvatures appearing in the linear dependences given by the experimental data for high values of the excluded volume [35-37].

An alginate molecule can be regarded as a block copolymer containing M, G, and MG blocks, the proportion of these blocks varying with the seaweed source. Viscosity measurements performed by Celine Sartori [38] on high-G and medium-G sodium alginate solutions gave values of 13,400 and 3,800 mPa.s respectively. This was indicative of a higher inflexibility of the G sequences in solution. The

observed low value of in dynamic viscosity and average molecular weight of alginate from *Laminaria digitata* during alkaline extraction [39] may be due to treatment of alkali because a significant decrease in alginate dynamic viscosity was observed after 2 h of alkaline treatment in a control experiment. Further, the intrinsic viscosity and average molecular weight of alginates from alkaline extractions (1–4 h) were determined, indicating depolymerization of alginates, average molecular weight decreased significantly during the extraction, falling by a factor of 5 between 1 and 4 h of extraction. These results suggest that reduction of extraction time could enable preserving the rheological properties of the extracted alginates.

In the present section, the results of our investigation on unperturbed dimension, interaction parameter of sodium alginate in water-acetone and water-ethoxy ethanol have been described. The intrinsic viscosities of the polymer have been measured in different compositions (water-acetone and water-ethoxy ethanol) of the cosolvent mixture at different temperatures. From the relation between $[\eta]$ and M , the unperturbed dimension and molecular expansion factor have been measured. The Huggins constant value in each case was also determined in order to study the influence of co-solvent system [34, 40].

5.2 Experimental

In the present study, an Ubbelohde viscometer was used to measure the relative viscosities of polymer solutions. The related definitions are as follow:

$$\text{Specific viscosity, } \eta_{sp} = (t - t_0)/t_0 \quad (2)$$

$$\text{Reduced viscosity, } \eta_{red} = \eta_{sp}/C \quad (3)$$

$$\text{Intrinsic viscosity, } [\eta] = (\eta_{sp}/C)_{C \rightarrow 0} \quad (4)$$

and the Huggins equation is

$$\eta_{sp}/C = [\eta] + K_H [\eta]^2 C, \quad (5)$$

where K_H is the Huggins constant. In the above relations, the symbol η refers to the viscosity of solution, t is the efflux time of the solution, t_0 is the efflux time of solvent and C is the polymer concentration.

The viscosity average molecular weights of the sodium alginate (S.D Fine chemical India (High molecular weight), Loba, India (Medium molecular weight) and Fluka, Switzerland (Low molecular weight)) were determined using a suspended level Ubbelohde Viscometer placed in thermostated water bath at appropriate temperature (accuracy, $\pm 0.1^\circ\text{C}$). A digital stopwatch with accuracy ± 0.1 sec was used for measuring the flow time. Double distilled water was used throughout the experiment. Acetone (E Mark) and ethoxy ethanol (E Mark) were purified before used by fractional distillation following the usual procedure before use. A series of sodium alginate solutions of different concentrations in aqueous 0.1 M NaCl were prepared and the times of flow of the solutions were measured. Specific viscosity

$$[\eta] = \eta_{sp}/C, \text{ Lim } C \rightarrow 0 \quad (6)$$

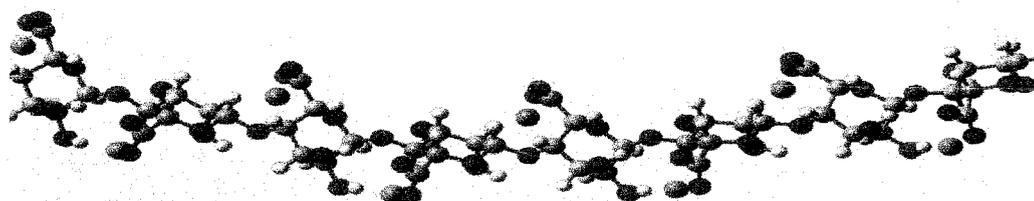
Where C stands for concentration of polymer solution. The molecular weight of the Sodium Alginate was finally calculated by using the model proposed by Mancini et al. [41].

$$[\eta] = 1.228 \times 10^{-4} M^{0.963} \text{ cm}^3/\text{g}. \quad (7)$$

The high, medium and low molecular weights of sodium alginates used in the study are listed in Table 1.

Table 1. Molecular weights of Sodium alginates

Sodium alginates types	$M_v \times 10^{-5}$
High Molecular weight (Type-A)	3.80
Medium Molecular weight (Type-B)	2.20
Low molecular weight (Type-C)	1.40



Scheme I: Molecular structure of sodium alginate (Grey; Carbon, Red: Oxygen; White: Hydrogen; Violate: Sodium)

5.2.1 Result and discussion

5.2.2 Intrinsic viscosity

Nature of the interaction between the liquids governs the solubility of a polymer in a binary liquid mixture. The changes in the molecular dimensions of the polymer in the varied molecular extension parameter (α_n) and the unperturbed dimensions due to the interaction with two component liquid have been studied [42]. In general for a flexible polymer in poor solvent, the intrinsic viscosity $[\eta]$ increases with rise in temperature, whereas in good solvent it decreases with temperature. In athermal solvent, however, it is independent of temperature [43]. The polymer chains are expanded most at the temperature at which $[\eta]$ is maximum. The variation of $[\eta]$ in the acetone of all three types of sodium alginates (Type-A, B and C) at different temperatures and solution compositions are shown in Figure 5.1-5.3. The result shows that with increasing the amount of non-solvent (acetone) up to certain limit, intrinsic viscosity also increases for the all types of sodium alginate (Type-A, B and C). This variation is, however, distinguishable from the variation observed in case of a pure solvent system [5]. Intrinsic viscosity reaches its maximum value near

$\Phi_{ACE} = 0.2$ (Φ being the relative volume composition in the mixture) for the all three types of sodium alginates (Figure 5.1-5.3). This indicates that energetically the most favorable solvent composition is same for all three types of different sodium alginates (Type-A, B and C). The decreases in $[\eta]$ after the maximum are explained by the decrease in unperturbed mean square end-to-end distance [5]. At a higher co-solvency condition, the energetic weighting factor favors the extended configuration of the sodium alginates molecules. For the sodium alginate of high molecular weight (Type-A), however, there is no such definite maxima in the plot of $[\eta]$ vs. Φ_{ACE} has been observed (Figure 5.1). The higher the molecular weight of the polymer, lower concentration of acetone is required for showing the co-solvency effect. The extended long chains are surrounded by the solvated hull and longer the chain lesser is the amount of acetone required for attaining the co-solvency condition. An increase in the temperature of a polymer solution generates two antagonistic effects [44,45]. This is apparent in case of higher molecular weight sodium alginate at higher concentration of acetone. Firstly, an increase in temperature generally leads to an increase in the solubility. This results in uncoiling of the polymer chain leading to an increase in intrinsic viscosity with temperature at 25⁰C. Further increase in temperature may lower the rotational barrier, thereby enhancing the degree of rotation about a skeletal bond, forcing the molecular chains to assume more compact coiled configuration. This leads to decrease in intrinsic viscosity with the increase in temperature at 30⁰C. On the other hand, in water-ethoxy ethanol mixture the variation of $[\eta]$ of all three types sodium alginates at different temperatures and solution compositions are shown in Figure 5.4-5.6. The result shows that with increasing the amount of non-solvent (ethoxy ethanol) up to a certain limit ($\Phi_{E.E.} \leq 0.2$), intrinsic viscosity decreases for all types of sodium alginates. With increasing ethoxy ethanol (poor solvent) concentration, the intrinsic viscosity decreases due to contraction of the dimensions of polymer coil as well as the degree of intermolecular agglomeration. This variation is, however, distinguishable from the variation observed in case of a pure solvent system.

Intrinsic viscosity reaches its maximum value near $\Phi_{E.E.} = 0.3$ for all type of sodium alginates. This indicates that energetically the most favorable solvent composition is same for all the types of sodium alginates. The decrease in $[\eta]$ after the maximum is explained by the decrease in unperturbed mean square end-to-end distance [5]. At a higher co-solvency condition, the energetic weighting factor favors the extended configuration of the sodium alginates molecules.

The co-solvency and the intermolecular interaction of polymers are also manifested in the Huggins constant values when the composition of the solvent is varied (equation-5). K_H values are used to predict the degree of interaction between polymer and the solvent. The sign of K_H is also often taken as a measure of the type of interaction in the polymer chain. The general positive nature of the K_H values and their increment indicate enhanced inter unit attractive interactions. Values of Huggins constant are presented in Table 5.1 and 5.2 for water-acetone and water-ethoxy ethanol mixture respectively. The K_H values are calculated from the least square slopes of equation 5. It is observed that K_H values are maximum at the solvent composition, $\Phi_{ACE} = 0.3$ for water-acetone mixture and $\Phi_{E.E.} = 0.1$ for water-ethoxy ethanol mixture respectively in all of the types of the polymers (Type-A, B and C) and the value decreases with decreasing molecular weight of the polymer, indicating lowering of the tendency of intermolecular aggregation with lower molecular weight fractions of the polymers (Type-A→Type-C). K_H has the smallest value at $\Phi_{ACE} = 0.4$ for water-acetone mixture and $\Phi_{E.E.} = 0.4$ for water-ethoxy ethanol mixture respectively. Under this condition, both type of solvent pulls the distance between polymer molecules closer to make polymer side chains twisted around each other. This action makes polymer main chain wind around polymer side chain and agglomerates.

5.2.3 Unperturbed dimension (UD)

The UD of a polymer chain is the dimension where volume exclusion due to long range segmental interaction is nullified by its interaction with a definite solvent

(theta solvent) [46]. UD is the end-to-end distance of the polymer chain under theta condition and can be determined from intrinsic viscosity measurement at this condition using the following equation (47,48).

$$[\eta]_{\theta} = \Phi_0(r_0^2/M)^{3/2}M^{1/2}\alpha_n^3 = K_{\theta}M^{1/2}\alpha_n^3 \quad (8)$$

But, under non-theta conditions various equations are employed to derive K_{θ} of sodium alginates in different water-acetone and water-ethoxy ethanol mixtures.

The required equations for the evaluation of K_{θ} are as follows [19-21, 49]

$$([\eta]/M)^{1/2} = K_{\theta} + 0.51\Phi BM^{1/2} \text{ [Burchard-Stockmayer and Fixman (BSF)]} \quad (9)$$

$$\{([\eta]/M)^{1/2}\}^{1/2} = K_{\theta}^{1/2} + 0.42K_{\theta}^{3/2}B(r_0^2/M)^{3/2}(M/[\eta]) \quad \text{[(Berry)] (10)}$$

$$[\eta]^{4/5}/M^{2/5} = 0.786K_{\theta}^{4/5} + 0.454 K_{\theta}^{2/5}B^{2/3}\Phi^{2/3}M^{1/3} \text{ [Inagaki-Suzuki-Kurat (ISK)] (11)}$$

The value of K_{θ} obtained from three different methods of measurements viz., BSF, Berry ISK and agree well with each other except in a few compositions of the solvents. The results are summarized in Table 5.3 and 5.4 for water-acetone and water-ethoxy ethanol mixture respectively. The representative BSF plots for sodium alginate fractions for various cosolvent compositions at 20⁰C, 25⁰C and 30⁰C temperature are shown in Figures 5.7 and 5.9 for water-acetone and in Figures 5.10-5.12 for water-ethoxy ethanol mixture respectively. In the case of water-acetone mixture it is apparent that at $\Phi_{ACE}=0.4$, the sodium alginate has the lowest unperturbed dimension and this result is in general true for all the adopted methods for K_{θ} calculation (BSF, Berry and ISK). Above the Φ_{ACE} -value of 0.4 the co-solvency of the system is lost and the sodium alginate is precipitated out from the solution. The effect of temperature is interesting for BSF Plot of sodium alginate in both the acetone and ethoxy ethanol fraction at various co-solvent compositions (Figure 5.7-5.11). At $\Phi_{ACE} = 0.1$ the sodium alginate shows highest K_{θ} value for all the methods which are used (.BSF, Berry and ISK). With an increase in temperature K_{θ} decreases due to greater freedom of rotation around the skeletal

bonds [85]. However, such a temperature dependence of K_θ can be attributed not only to the change in flexibility of macromolecular chain but also to the specific polymer solvent interaction [86]. The effect may also be correlated to the cohesive energy density of the polymer and the solvent. In case of ethoxy ethanol, the sodium alginate has the lowest unperturbed dimension value at $\Phi_{E.E.} = 0.2$ (true for all the methods for K_θ calculation). Strong attraction of two solvents (water and ethoxy ethanol), causes the sodium alginate to have the lowest value of unperturbed chain at above relative volume composition in the mixture where as at $\Phi_{E.E.} = 0.4$ the sodium alginate has the highest unperturbed dimension and this result is in general true for all the methods which are adopted for K_θ measurement. Above $\Phi_{E.E.} = 0.4$, the co-solvency effect is the same as that found at the $\Phi_{ACE} = 0.1$ in the water-acetone mixture.

5.2.4 Molecular extension factor (α_n)

The molecular expansion factor (α_n), which represents the effect of long-range interaction, can be described as an osmotic swelling of the chain by the solvent-polymer interaction. It has been calculated from the relation [26],

$$\alpha_n^3 = [\eta] / K_\theta M_v^{1/2} \quad (12)$$

Where K_θ has been taken from the BSF plot. The actual end-to-end distance, $\alpha_n K_\theta$, of the polymer molecule is also computed, which is shown in Table 5.5 for water-acetone and Table 5.6 for water-ethoxy ethanol mixtures respectively. It is observed that $\alpha_n K_\theta$ attains its highest value at $\Phi_{ACE} = 0.1$ for all the fractions of the sodium alginate in water-acetone mixture and at $\Phi_{E.E.} = 0.4$ for all the fractions in water-ethoxy ethanol mixture respectively. As the number of segmental interaction of the polymer molecules increases with molecular weight, the value of α_n also increases. This trend is observed at all the temperatures under the study.

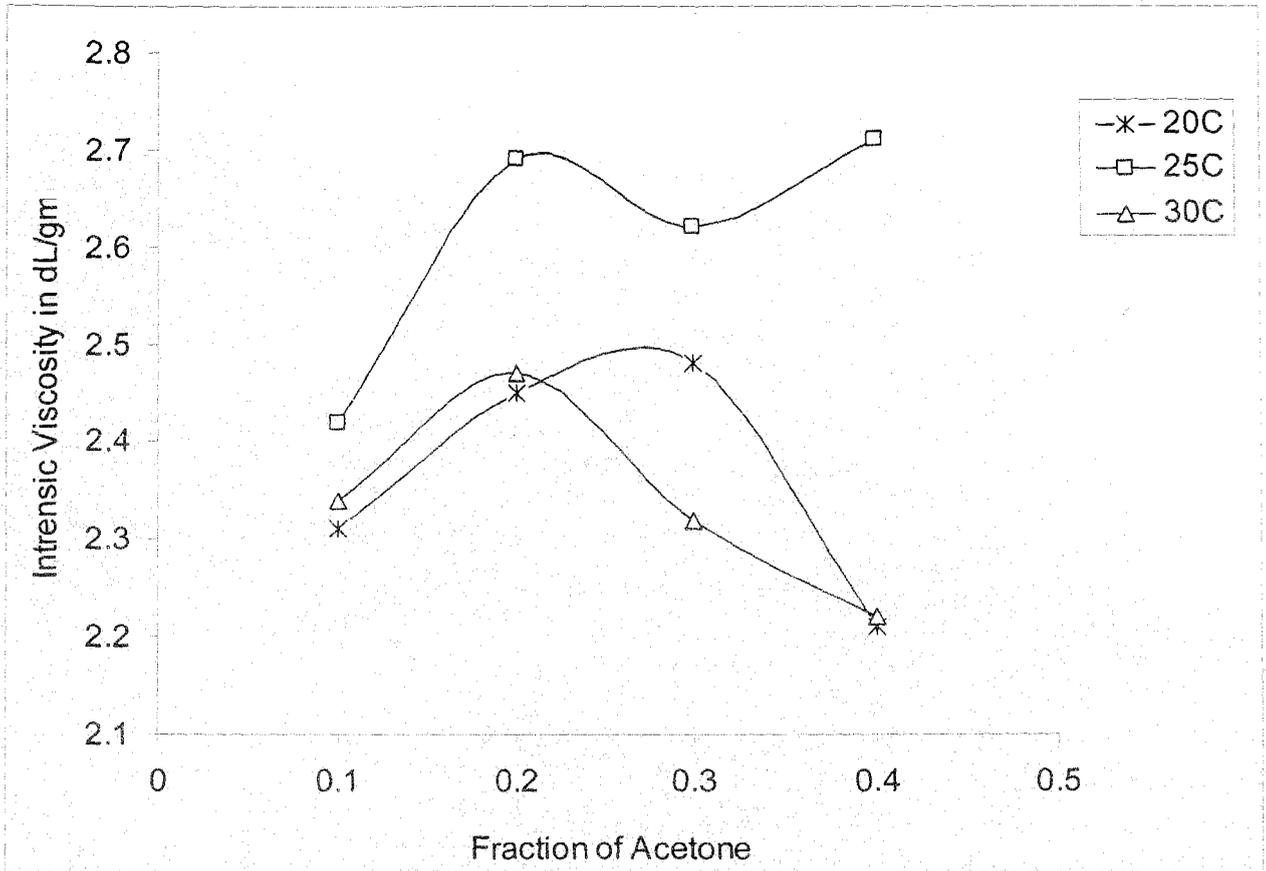


Figure 5.1: Change in intrinsic viscosity with fraction of acetone for sodium alginate of (type-A)

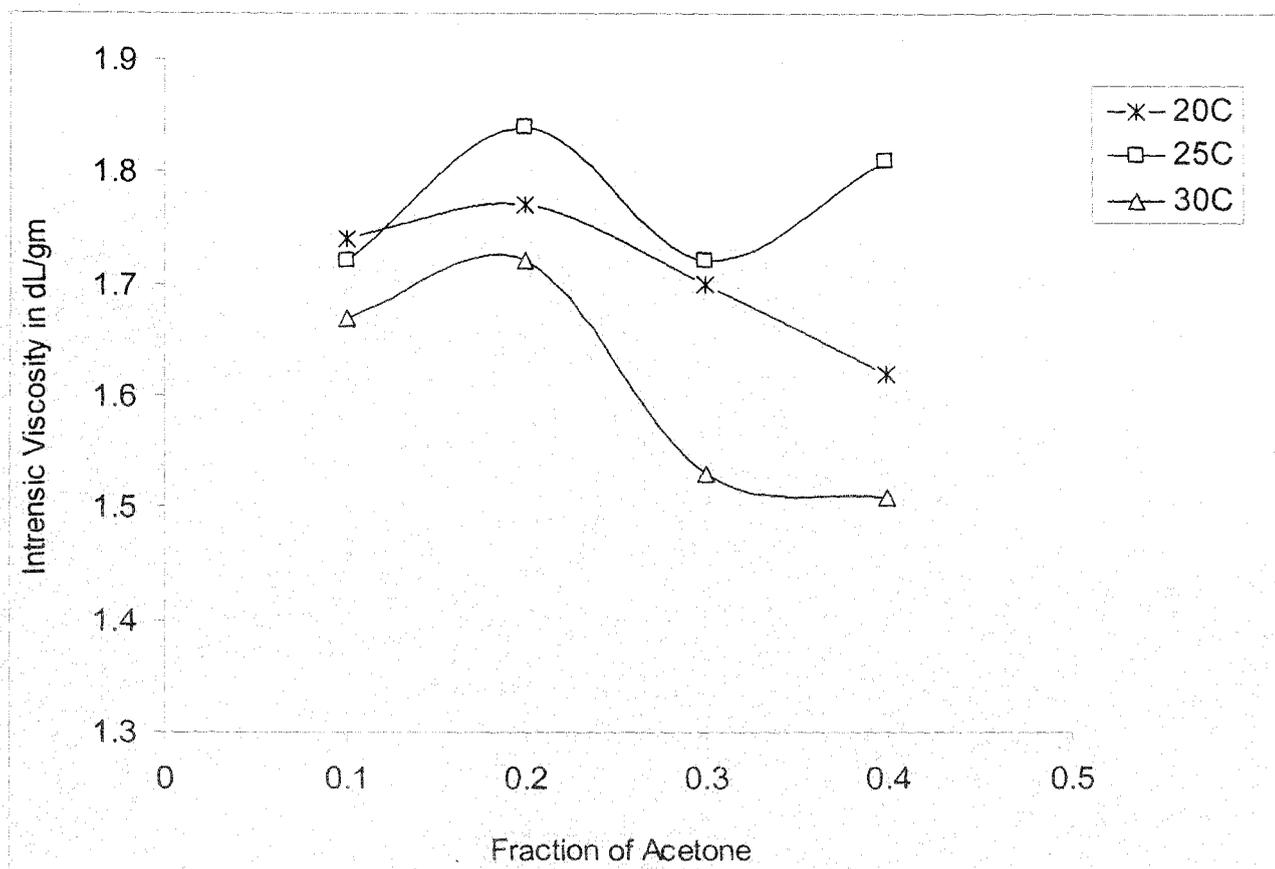


Figure 5.2: Change in intrinsic viscosity with fraction of acetone for sodium alginate of (Type-B)

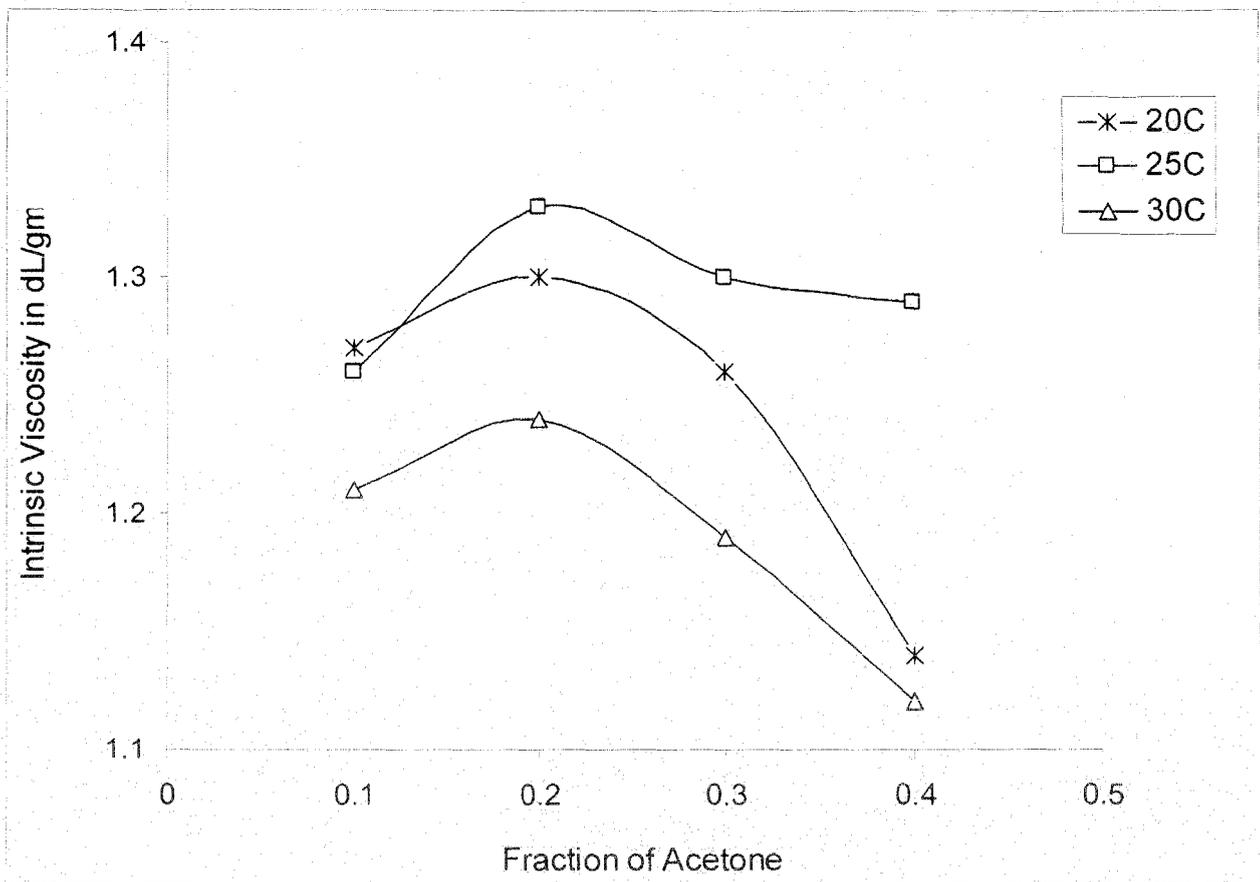


Figure 5.3: Change in intrinsic viscosity with fraction of acetone for sodium alginate of (Type-C)

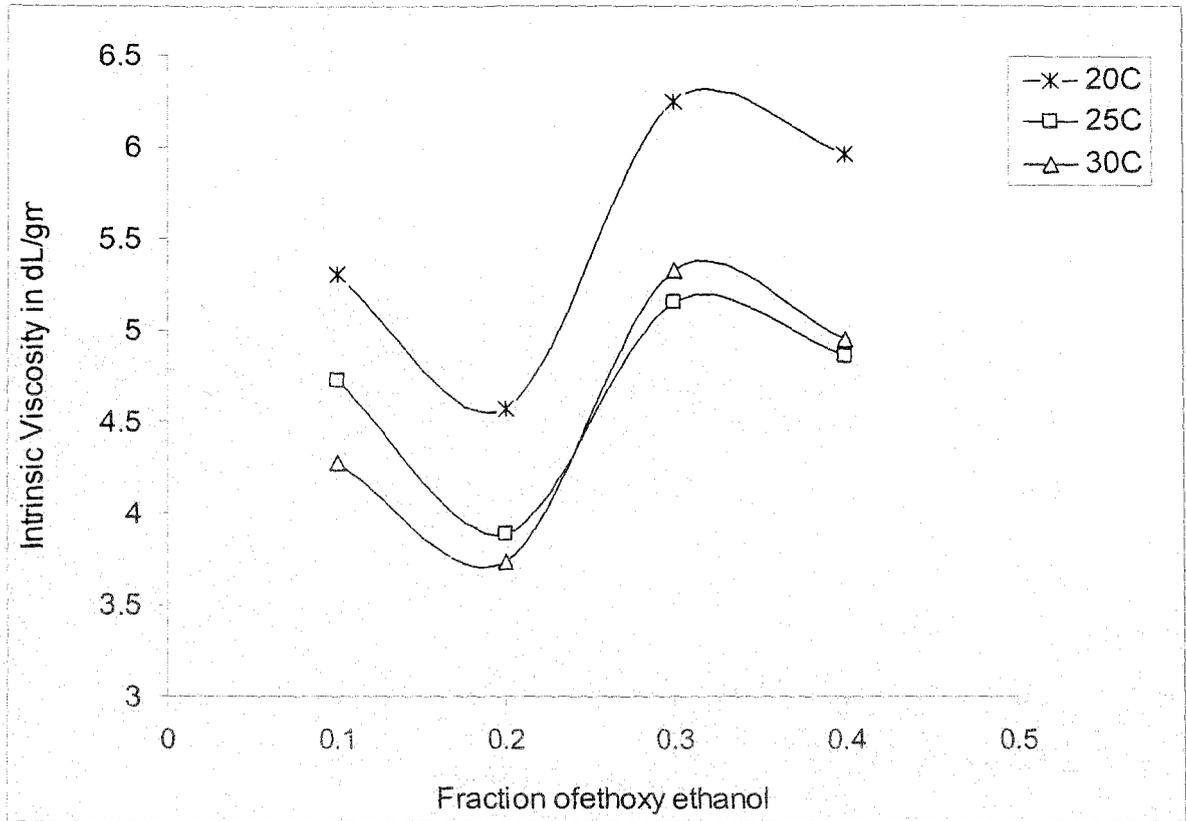


Figure 5.4: Change in intrinsic viscosity with fraction of ethoxy ethanol for sodium alginate of (type-A)

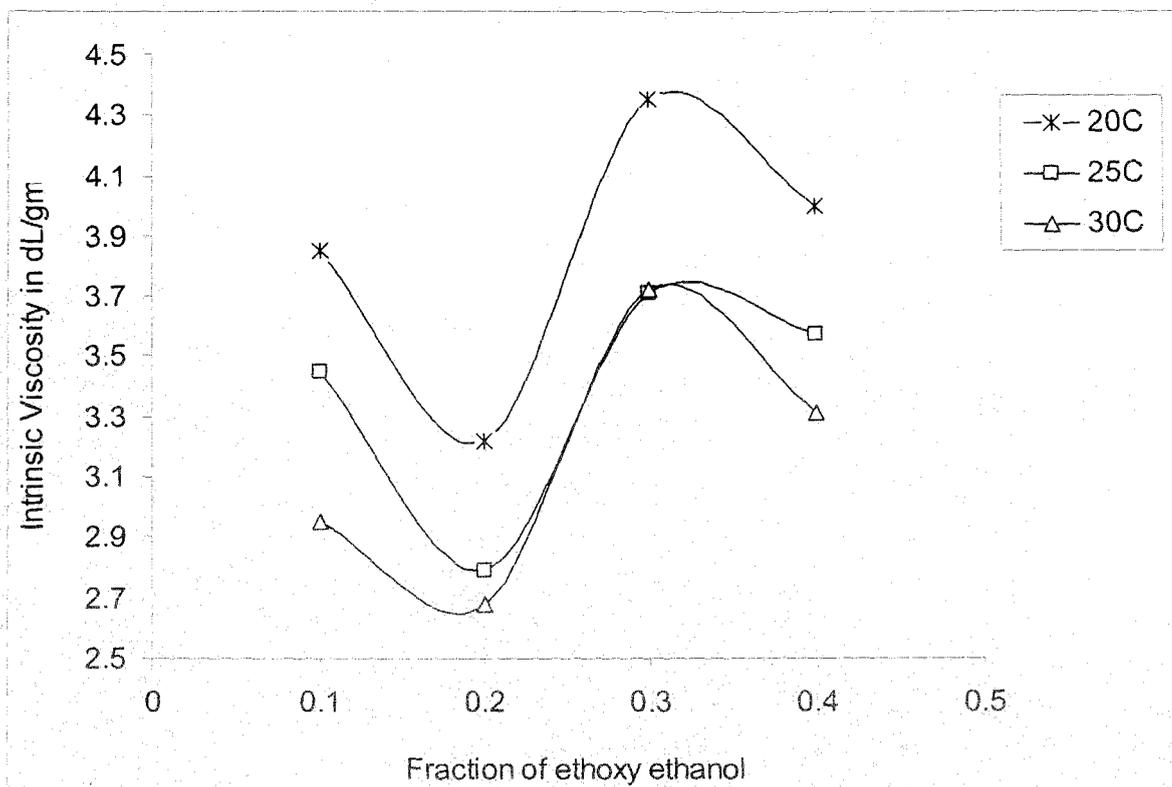


Figure 5.5: Change in intrinsic viscosity with fraction of ethoxy ethanol for sodium alginate of (type-B)

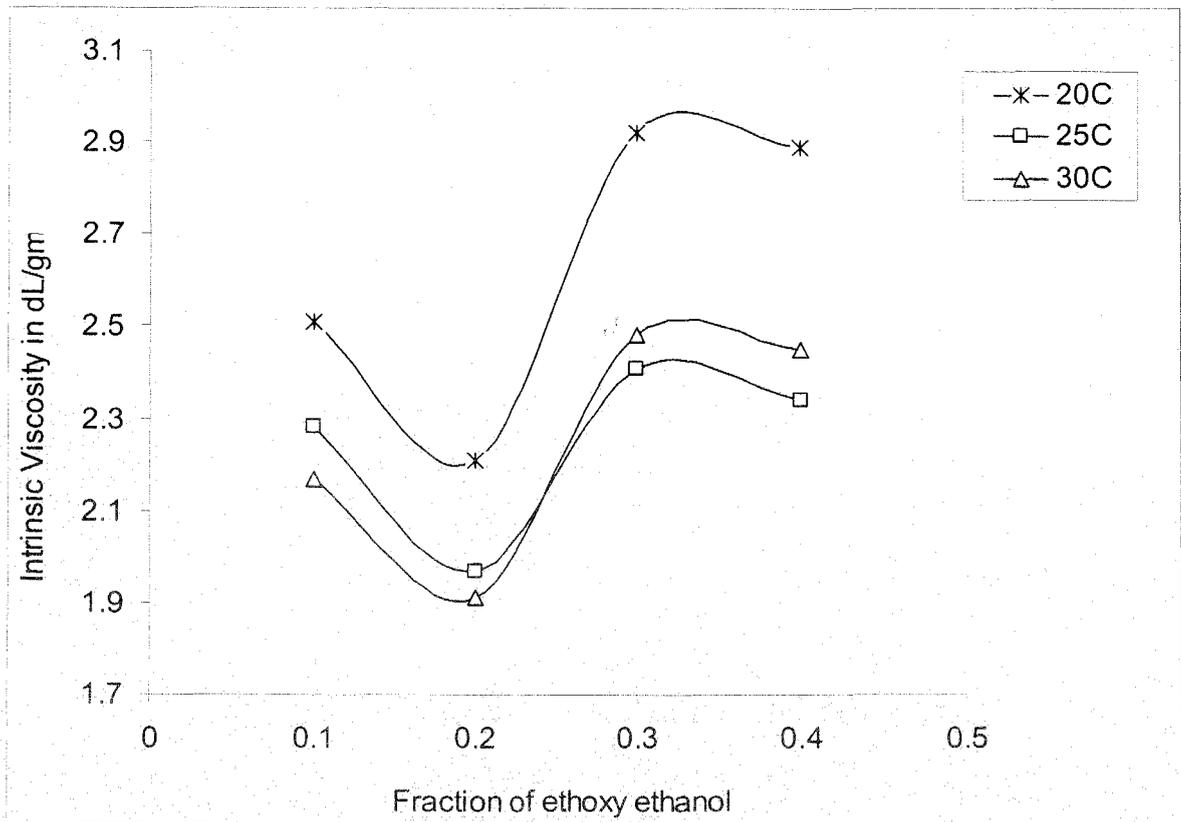


Figure 5.6: Change in intrinsic viscosity with fraction of ethoxy ethanol for sodium alginate of (type-C)

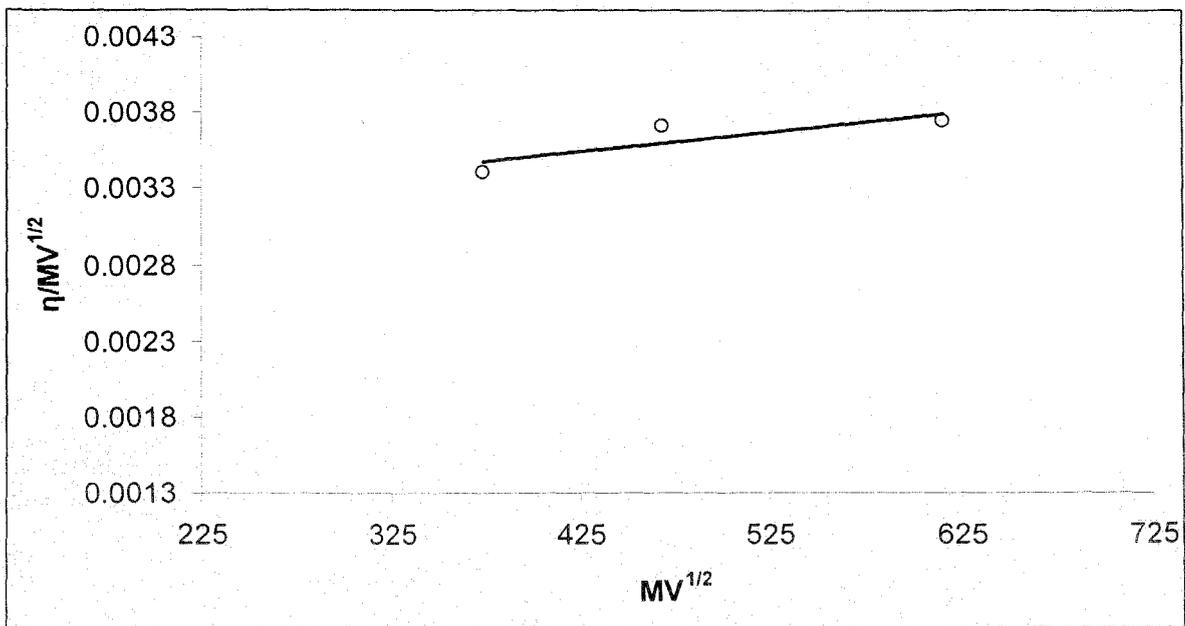


Figure 5.7: BSF plot at 20°C: $\Phi_{ACE}=0.1$ for sodium alginate.

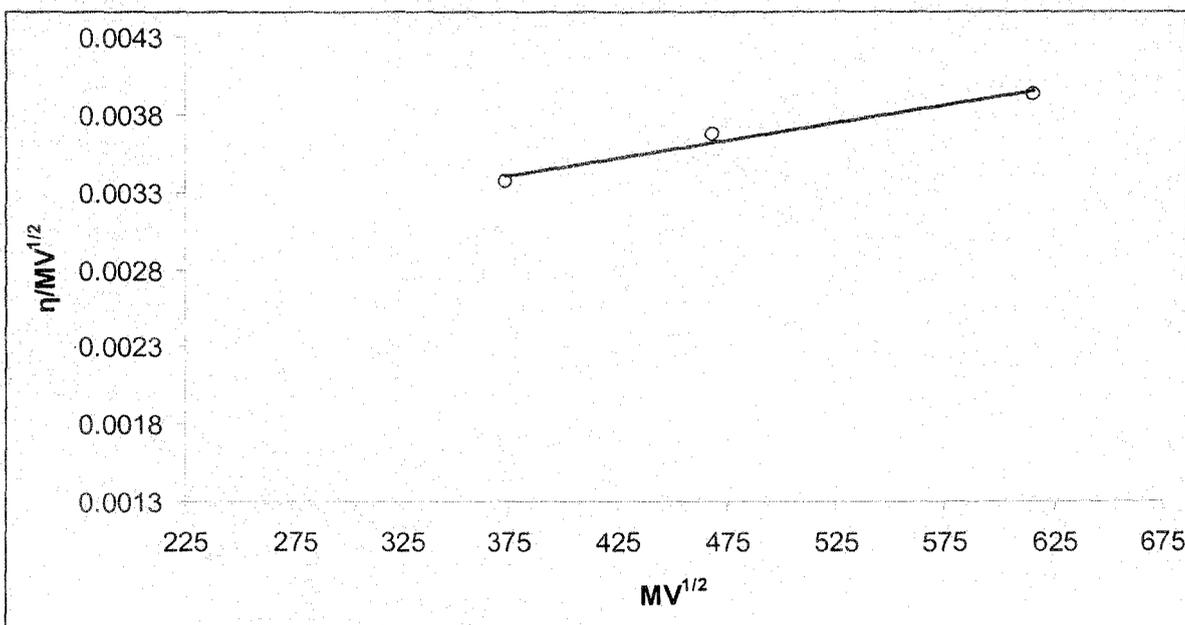


Figure 5.8: BSF plot at 25°C: $\Phi_{ACE}=0.1$ for Sodium Alginate

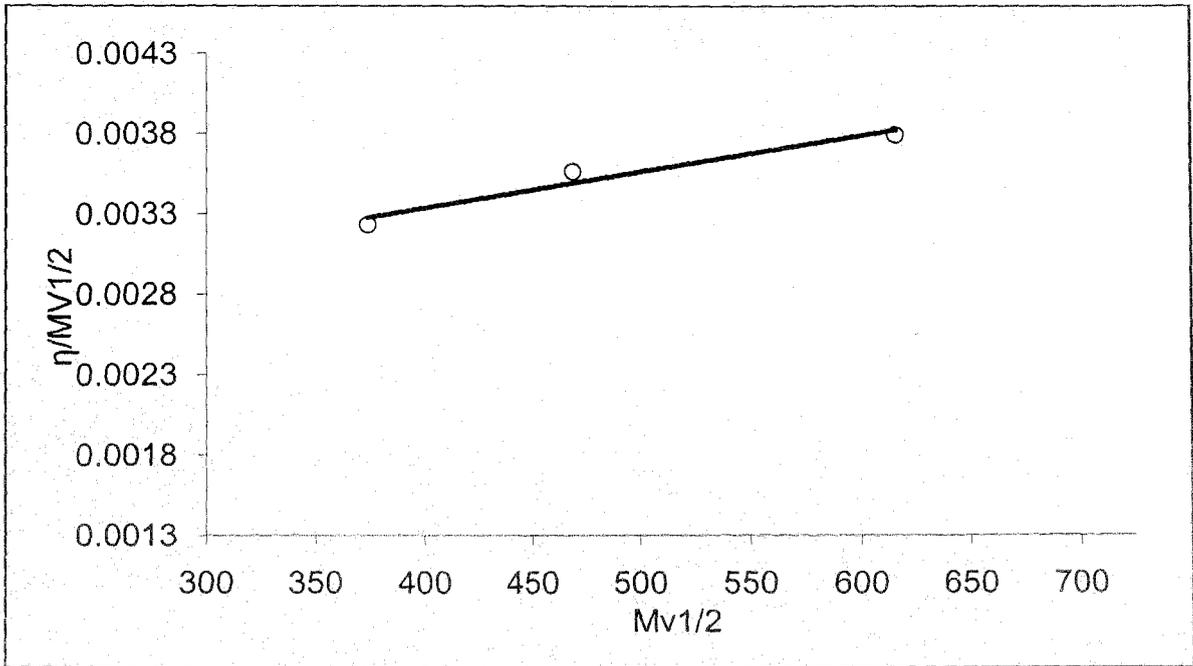


Figure 5.9: BSF plot at 30°C: $\Phi_{ACE}=0.1$ for Sodium Alginate

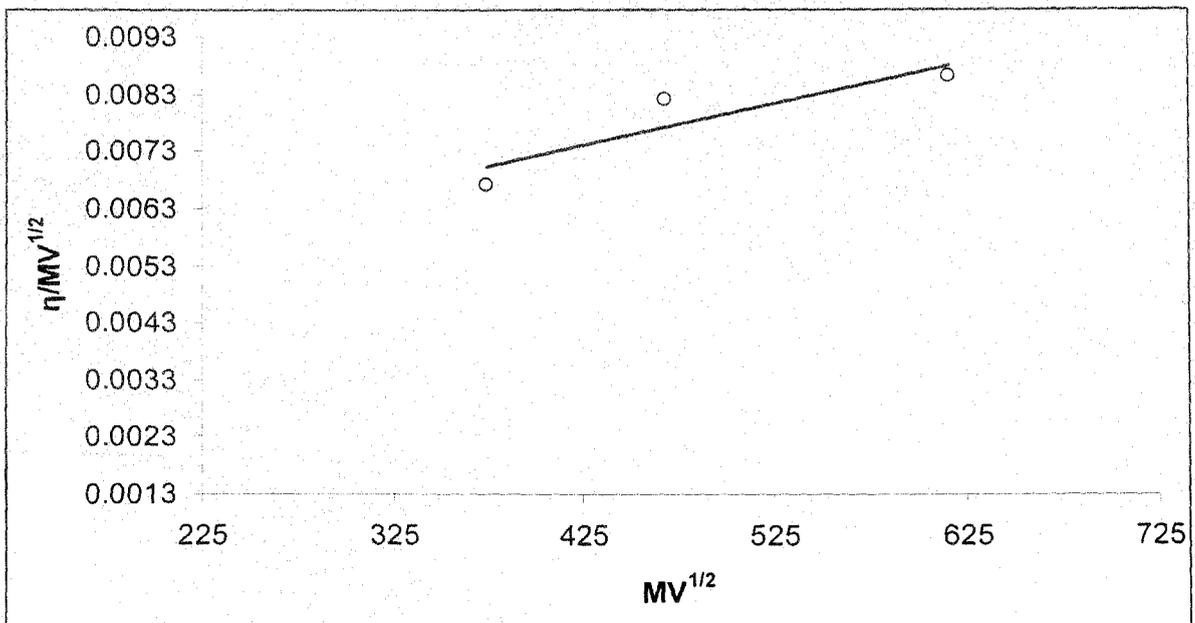


Figure 5.10: BSF plot at 20°C: $\Phi_{E.E..}=0.1$ for sodium alginate

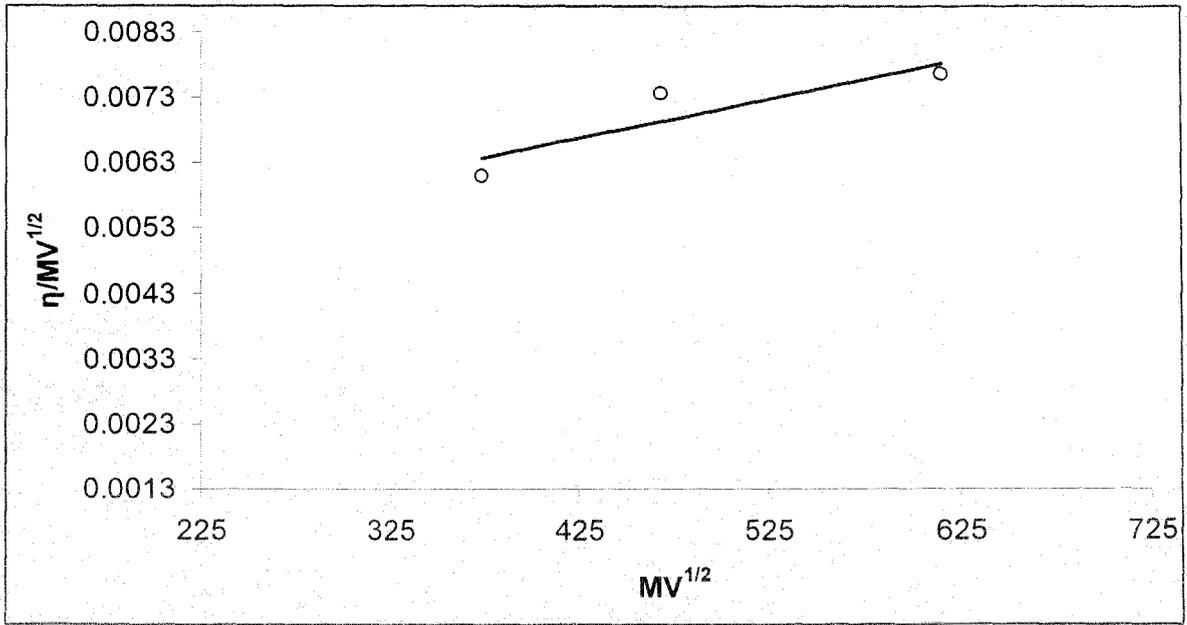


Figure 5.11: BSF plot at 25°C: $\Phi_{E.E.}=0.1$ for sodium alginate

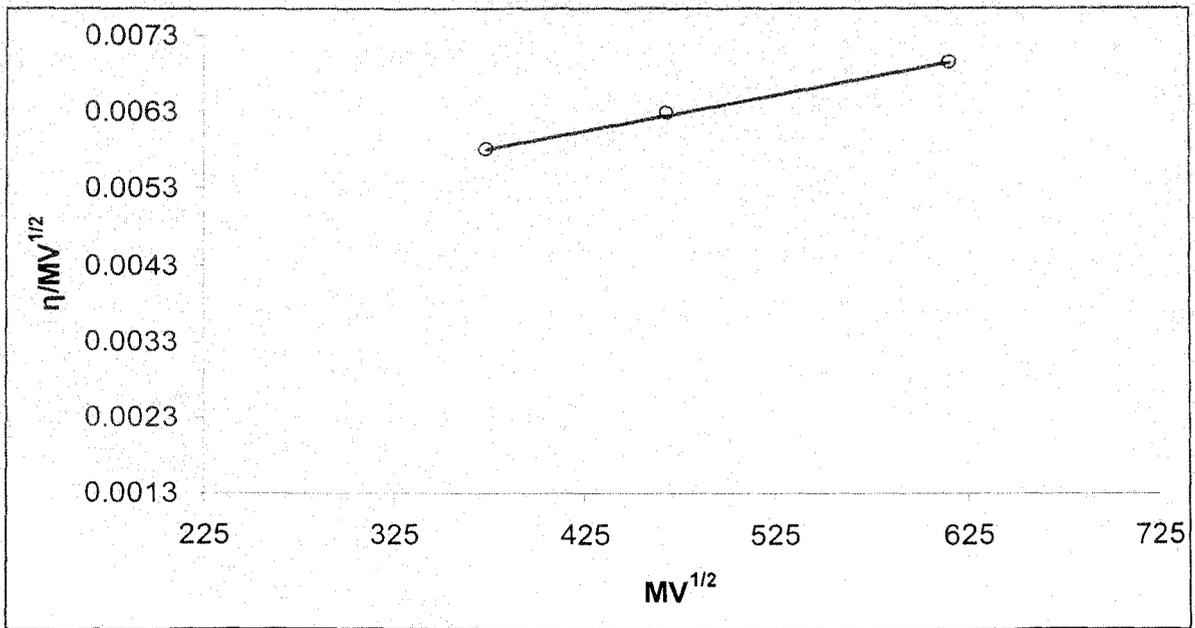


Figure 5.12: BSF plot at 30°C: $\Phi_{E.E.}=0.1$ for sodium alginate

Table 5.1

Huggins constant of different fractions of sodium alginate at different temperature and various solvent compositions (water-acetone).

Temp. in °C	Φ_{ACE}	Sodium alginate		
		Type-A K_H	Type-B K_H	Type-C K_H
20	0.1	1.242	1.131	0.968
	0.2	1.513	1.317	1.072
	0.3	1.628	1.431	1.163
	0.4	0.752	0.533	0.279
25	0.1	0.973	0.857	0.629
	0.2	1.171	0.972	0.752
	0.3	1.214	1.102	0.925
	0.4	0.472	0.386	0.296
30	0.1	1.163	1.118	0.861
	0.2	1.214	1.127	1.154
	0.3	1.246	1.238	1.179
	0.4	0.641	0.527	0.438

Table 5.2

Huggins constant of different fractions of Sodium alginate at different temperature and various solvent compositions (water-etoxy ethanol)

Temp. in °C	$\Phi_{E,E}$	Sodium alginate		
		Type-A . K_H	Type-B . K_H	Type-C. K_H
20	0.1	2.107	1.628	1.197
	0.2	1.734	1.218	1.041
	0.3	1.518	1.108	0.975
	0.4	1.445	0.873	0.448
25	0.1	1.749	1.292	1.021
	0.2	1.441	1.172	0.964
	0.3	1.138	1.008	0.825
	0.4	0.942	0.852	0.727
30	0.1	1.772	1.318	1.263
	0.2	1.460	1.284	1.154
	0.3	1.397	1.225	1.109
	0.4	1.274	0.937	0.878

Table 5.3

Unperturbed Dimension of Sodium alginate in water- acetone mixtures at different temperatures determined by different methods.

Temp. in °C	Φ_{ACE}	$K_0 \times 10^4 (\text{mol}^{1/2} \text{g}^{-3/2} \cdot \text{dL})$		
		BSF	BERRY	ISK
20	0.1	29.60	29.11	35.69
	0.2	27.70	25.54	31.52
	0.3	23.60	19.08	24.60
	0.4	23.40	21.42	25.46
25	0.1	25.60	22.59	28.14
	0.2	23.40	16.93	22.98
	0.3	22.10	16.53	21.62
	0.4	20.10	10.86	17.69
30	0.1	24.30	21.35	26.48
	0.2	22.90	18.11	23.46
	0.3	21.90	19.04	23.08
	0.4	20.50	16.14	21.02

Table 5.4

Unperturbed Dimension of Sodium alginate in water- ethoxy ethanol mixtures at different temperatures determined by different methods.

Temp. in °C	$\Phi_{E.E.}$	$K_B \times 10^4 (\text{mol}^{1/2} \text{g}^{-3/2} \cdot \text{dL})$		
		BSF	BERRY	ISK
20	0.1	42.30	35.41	37.76
	0.2	38.10	27.64	35.79
	0.3	45.70	27.76	38.91
	0.4	47.50	30.09	44.17
25	0.1	40.80	35.74	38.76
	0.2	38.20	32.63	40.02
	0.3	39.30	16.53	34.00
	0.4	41.80	37.66	39.44
30	0.1	40.60	21.35	42.24
	0.2	37.90	33.09	40.60
	0.3	38.30	19.04	31.97
	0.4	42.10	30.41	41.29

Table 5.5

Molecular extension factor and coil dimensions of sodium alginate at different temperature in various solvent composition (water-acetone).

Temp. in °C	Φ_{ACE}	Sodium alginate					
		Type-A		Type-B		Type-C	
		α_n	$\alpha_n \times K_{\theta} \times 10^4$	α_n	$\alpha_n \times K_{\theta} \times 10^4$	α_n	$\alpha_n \times K_{\theta} \times 10^4$
20	0.1	1.082	32.021	1.078	31.913	1.047	30.982
	0.2	1.128	31.242	1.109	30.707	1.078	29.873
	0.3	1.195	28.192	1.154	27.228	1.126	26.569
	0.4	1.153	26.976	1.139	26.643	1.092	25.252
25	0.1	1.153	29.521	1.127	28.858	1.096	28.050
	0.2	1.231	28.803	1.188	27.798	1.150	26.899
	0.3	1.244	27.483	1.184	26.164	1.163	25.697
	0.4	1.298	26.091	1.243	24.982	1.197	24.001
30	0.1	1.160	28.195	1.136	27.600	1.100	26.729
	0.2	1.205	27.595	1.170	26.791	1.131	25.903
	0.3	1.198	26.232	1.142	25.011	1.132	24.800
	0.4	1.207	24.736	1.162	23.828	1.134	23.257

Table 5.6

Molecular extension factor and coil dimensions of sodium alginate at different temperature in various solvent composition (water-ethoxy ethanol).

Temp. in°C	$\Phi_{E.E.}$	Sodium alginate					
		Type-A		Type-B		Type-C	
		α_n	$\alpha_n \times K_{\theta} \times 10^4$	α_n	$\alpha_n \times K_{\theta} \times 10^4$	α_n	$\alpha_n \times K_{\theta} \times 10^4$
20	0.1	1.267	53.594	1.247	52.761	1.166	49.328
	0.2	1.248	47.549	1.217	46.362	1.157	44.095
	0.3	1.303	59.547	1.266	57.859	1.195	54.624
	0.4	1.267	60.183	1.215	57.731	1.175	55.856
25	0.1	1.233	50.326	1.217	49.656	1.143	46.637
	0.2	1.182	45.157	1.159	44.276	1.113	42.512
	0.3	1.285	50.532	1.263	49.619	1.179	46.335
	0.4	1.236	51.645	1.221	51.043	1.144	47.808
30	0.1	1.196	48.551	1.157	46.977	1.126	45.725
	0.2	1.169	44.296	1.147	43.458	1.104	41.855
	0.3	1.312	50.243	1.275	48.818	1.201	45.983
	0.4	1.240	52.211	1.188	50.010	1.159	48.778

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