INNSPUB

International Journal of Biosciences | IJB |
ISSN: 2220-6655 (Print) 2222-5234 (Online)
http://www.innspub.net
Vol. 4, No. 1, p. 82-92, 2014

RESEARCH PAPER OPEN ACCESS

Effect of pH and salts on rheological properties of sodium alginate-hydroxypropyl cellulose mixture solutions

Fatemeh Mehmandoost[1*], Mohammad Hojjatoleslamy[1], Javad Keramat[2], Asma Behzadniya[1], Narges Shahbazpour[1], Zeinab Ghafari[1]

[1]*Department of Food Science and Technology, Islamic Azad University, Shahre Kord Branch, Shahre Kord, Iran*

[2]*Department of Food Science and Technology, Department, Isfahan University, of Technology, Isfahan, Iran*

Key words: sodium alginate, hydroxypropyl cellulose, synergistic effect, rheological properties.

doi: http://dx.doi.org/10.12692/ijb/4.1.82-92 Article published on January 01, 2014

Abstract

In this study, rheological properties of two gums, sodium alginate (Alg) and hydroxypropyl cellulose (HPC) in 5 concentration levels were studied. Total concentration of gums in solution was 0.1% (w/v) and different gums ratios (100% (Alg), 75% (Alg) and 25% HPC, 50% (Alg) and 50% (HPC), 25% (Alg) and 75% (HPC), and 100% (HPC)) were prepared. Measurements were carried out at 25°C. Consequently the synergistic effect of these gums in different pH values (3, 5 and 7) in 0.1 %(w/v) concentration was investigated. Obtained data indicated that dispersions which contain these polymers showed shear thickening behavior as mention in the text.

* **Corresponding Author:** Fatemeh Mehmandoost ✉ fateme.mehmandoost@yahoo.com

Introduction

Gums are hydrophilic biopolymers with high molecular weight and widely used in food industry to control functional properties of food products. The most important properties of a solution made from a gum are water binding and viscosity in terms of gelling and thickening. In addition to those functions, they are also used in food formulations for emulsion stabilization, prevention of ice recrystallization and sensory attributes. There are many types of gums available in the market which is of plants, seaweeds, microbial or synthetic base. They are also obtained by chemical or enzymatic treatment of starch or cellulose (Dikinson, 2003). Many factors including the concentration of gums, temperature, dissolution, electrical charge, previous thermal and mechanical treatments and presence of electrolytes may affect the rheology of containing gums food in liquid form (Marcotte *et al.*, 2001; Rao & Anatheswarn, 1982; Rao & Kenny, 1975). The use of two or more gums in the formulation of a single food is a common practice in the food industry for creating synergistic effect of the combined use. Product quality could be improved by synergism of gums and economic benefit may be gained from the use of mixed gums as they can impart better rheological properties to the product which may also result in cost reduction during manufacturing (Walkenström *et al.*, 2003).

Sodium alginate and sodium salts of alginic acid extracted from the cellular walls of brown algae (3). Sodium alginate form gel ionotropically at constant temperature upon addition of divalent cations, such as Ca^{2+}, Sr^{2+}, and Cu^{2+}(Wells & Shear down, 2007; Wang *et al.*, 1994; Liu *et al.*, 2003; Lu *et al.*, 2003; de krochove *et al.*, 2007; Skjåk-Bræk *et al.*, 1989).

Matsumoto and Mashiko investigated the influence of added salts on the viscoelastic properties of aqueous alginate and metal cations which did not work as the cross-linking points (Matsumoto & Mashiko, 1990). Recently there has been increased interest in self-associated polymer systems based on natural polymers, which are environmentally safe and biodegradable. It is known that a number of cellulose derivatives, in particular, methyl cellulose (MC), hydroxypropyl cellulose (HPC), hydroxypropyl methyl cellulose (HPMC), and methyl ethyl cellulose (MEC), form physical thermally reversible gels in aqueous solutions. These cellulose derivatives are widely used as gelling agents, thickeners, stabilizers, and emulsifiers in food industry, cosmetic products, and perfumery (Bochek *et al.*, 2001).

The aim of this research was to study the influence of different pH values, different amounts of salts and different ratios of these polymers on their rheological behavior.

Materials and method

Samples of Alginic acid-sodium salt (medium viscosity, lot x092N76322) and hydroxylpropyl cellulose (331T8860, CAS Number: 9004-64-2) were purchased from Sigma (Sigma-Aldrich, St. Louis, MO, USA). The stock solutions (0.1% m/w) were prepared by mixing 0.1 g of dry sample with deionized distilled water while continuously stirring at ambient temperature. The gum solutions were continuously stirred with a magnetic stirrer for 2 h at ambient temperature. The solutions were refrigerated overnight (16 h) to completely hydrate the gums. To study rheological properties of gums amalgamation, the following treatments were considered: sodium alginate 100%, sodium alginate 75%-HPC 25%, alginate sodium 50%-HPC 50%, alginate sodium 25%-HPC 75%, HPC 100%. Stock solutions were stirred at room temperature. Prepared sodium alginate and HPC solutions were mixed at 25˚C, and were measured at neutral and acidic (5 and 3) pH values. To adjust pH, pH meter (Metrohm, France) and 0.1 N HCl solutions were applied for adjusting pH values. To study the effect of salt on the polysaccharide solutions, the appropriate amounts of calcium chloride and magnesium chloride were added to the prepared solutions and were completely dissolved to obtain final concentrations of 10 and 5 mM $CaCl_2$ and $MgCl_2$. For rheological properties determination Brookfield rheometer (Brookfield engineering, INC, MiddleBoro, MA02346 USA. (LV DV III)) Equipped by ULA (ULA_EY UL Adaptor) and rheocalc (Rheocalc V3.2 Build 47_1) software was used. All rheological measurements were carried out at 25˚C by using a temperature-controlled circulating water bath (Brookfield engineering, TC 502). All the solutions were allowed to stand for 2 h at room temperature before rheological data were obtained.

Results and discussion

Several models have been used to characterize the flow behavior of gum solutions and among them Power law model has been frequently used for the determination of rheological properties of the food in liquid form (Eq. (1)). In addition, Casson equation (Eq. (2)) and Herschel–Bulkley model (Eq. (3)) have been also used for the characterization of some gum solutions (7, 11, and 12).

$$\sigma = K(\dot{\gamma})^n \quad (1)$$

$$\sigma^{0/5} = K_1(\dot{\gamma})^{0/5} + \sigma_\circ^{0/5} \quad (2)$$

$$\sigma = K(\dot{\gamma})^n + \sigma_\circ \quad (3)$$

Where σ (d/cm2) is shear stress, K (cP) is the consistency coefficient, $\dot{\gamma}$ (s^{-1}) is the shear rate and n (dimensionless) is the flow behavior index, $\sigma_\circ$ is the yield stress and K_1 is plastic viscosity. Several authors have employed the power law model (Eq. (1)) to describe the viscosity of gum solutions (3, 4 and 8). Other authors have used the Casson model (Eq. (2)) for rheological description of some gum solutions and in other studies Herschel–Bulkley model has been used (3 and 8).

Table 1. Consistency index for sodium alginate solution in various pH values and salt concentrations.

Salt concentration					pH
5mM $CaCl_2$	10mM $MgCl_2$	5mM $CaCl_2$	10mM $CaCl_2$	Without salt	
2.00 Aab	4.00 Ab	4.68 Ab	4.11 Ab	0.01 A***a**	3
3.55 Ab	3.54 Ab	3.68 Ab	3.72 Ab	0.91 ABa	5
2.87 Aa	2.34 Aa	3.05 Aa	3.36 Aa	1.17 Ba	7

* Values obtained by mean of 3 times repetitions.

** Different lower case letter in each row indicate significant differences among various samples with equal pH values (p<0.05).

*** Different upper case letter in each row indicate significant differences among various samples with equal salt concentration (p<0.05).

It is shown that these three models are the best models for description of rheological properties of gum solutions. In this study these three models was investigated to select the best model to predict accurately the behavior of xanthan-CMC solutions. Rheological parameters under steady shear were measured. All of curves were adjusted to the three models and rheological parameters of the Casson (C), Power-law (PL) and Herschel–Bulkley (HB) models were investigated for description of rheological behavior of sodium alginate -methyl cellulose mixtures in all ratios at pH 7, 5 and 3 before and after adding calcium salt (10,5 mM). The results were summarized in Table 1-5. All of samples showed high conformity with the three models, and in all treatments the regression coefficient, r^2; was not lower than 0.94, But curves were adjusted to the Herschel Bulkley model (Eq. (2)) by the best-fit regression.

Table 2. Flow index for sodium alginate solution in various pH values and salt concentrations.

Salt concentration					pH
5mM $CaCl_2$	10mM $MgCl_2$	5mM $CaCl_2$	10mM $CaCl_2$	Without salt	
0.95 Aa	0.97 Aa	0.97 Aa	0.93 Aa	1.78 Bb	3
0.99 Aa	0.99 Aa	0.91 Aa	0.96 Aa	0.96 Aa	5
1.00 Aa	0.96 Aa	0.87 Aa	0.92 Aa	0.96 Aa	7

Analysis of Results for Sodium Alginate Gum Samples

In general, contained sodium alginate gum solutions show shear thinning behavior with increase in shear rate, which is consistent with previous studies (Fig 1). Study of consistency index confirms the issue strongly, and indicates adding magnesium salts results in consistency index decrease in contrast to calcium salts. Adding 10 mM of Ca^{2+} compare to 5 mM shows higher consistency index decrease. In other word, it cause more shear thinning effect in solutions.

The study of flow index for sodium alginate solutions shows that for pH values of 3 and 5, adding salt results in decreasing flow index and the rate of this decrease is higher for adding Ca^{2+} compare to use of Mg^{2+} (table. 1 and 2). Data analysis shows that in sodium alginate gum solutions higher ionic radius of calcium cause higher decrease in flow index, because distance of like charges increases and repulsion force between like charges in chains decrease, which results in stronger attraction between chains and gum hydrodynamic radius will decrease, which this shrinkage and reducing of chains results in higher flow index decrease.

Table 3. Consistency index for hydroxypropyl cellulose solution in various pH values and salt concentrations.

Salt concentration					pH
5mM $MgCl_2$	10mM $MgCl_2$	5mM $CaCl_2$	10mM $CaCl_2$	Without salt	
0.03 Aa	0.02 Aa	0.02 Aa	0.01 Aa	0.03 Aa	3
0.02 Aab	0.00 Aa	0.05 Ab	0.03 Aab	0.01 Aab	5
0.03 Ab	0.01 Aab	0.02 Aab	0.01 Aab	0.00 Aa	7

Table 4. Flow index for hydroxypropyl cellulose solution in various pH values and salt concentrations.

Salt concentration					pH
5mM $CaCl_2$	10mM $MgCl_2$	5mM $CaCl_2$	10mM $CaCl_2$	Without salt	
1.35 Aa	1.85 Aa	1.50 Aa	1.39 Aa	1.01 Aa	3
1.52 Aa	1.97 Aa	1.53 Aa	1.45 Aa	1.54 Aa	5
1.62 Aa	1.72 Aa	1.27 Aa	1.32 Aa	1.93 Aa	7

Table 5. Consistency index for 75-25 mixture of sodium alginate and hydroxypropylcellulose in various pH values and salt concentrations.

Salt concentration					pH
5mM $CaCl_2$	10mM $MgCl_2$	5mM $CaCl_2$	10mM $CaCl_2$	Without salt	
0.07 Aa	0.02 Aa	1.97 Ab	0.00 Aa	0.36 Aa	3
0.13 Aa	0.04 Aa	0.85 Ab	0.00 Aa	1.74 Bc	5
0.17 Aa	0.03 Aa	1.41 Ab	0.00 Aa	1.37 Bb	7

Analysis of Results for HPC Gum Samples

Flow index for these solutions were greater than one which is evidence for shear thickening behavior with increasing shear rate, which means, the fluid is a dilatant fluid. In overall, adding salt to HPC solutions causes flow index increase in contrast to control group (no salt added solution) for all pH values, and adding 10mM salt had higher effect (Table 3 and 4).

Table 6. Flow index for 75-25 mixture of sodium alginate and hydroxypropylcellulose in various pH values and salt concentrations.

Salt concentration					pH
5mM $CaCl_2$	10mM $MgCl_2$	5mM $CaCl_2$	10mM $CaCl_2$	Without salt	
1.27 Aab	1.67 Ac	1.06 Aa	1.46 Abc	1.02 Aa	3
1.25 Ab	1.63 Ac	0.97 Aa	1.53 Ac	1.14 Ab	5
1.34 Aab	1.48 Ab	1.03 Aa	1.45 Ab	1.09 Aab	7

Therefore it can be concluded in HPC gum solutions, the effective concentration of salts is 10mM. The reason can be the higher hydrophobic interaction for gum solutions, and also, high molecular weight of this polymer in solution results in declining interactions rate. Hence, there are more factors for altering these types of solutions. One of these factors may be higher salt concentration in solution. In other words, as ionic forces increase, possibility to change the primary structure of polysaccharide gum or possibility to generate interaction between gums polysaccharide chains increases. Therefore adding more salt seems to have higher effect.

Table 7. Consistency index for 50-50 mixture of sodium alginate and hydroxypropylcellulose in various pH values and salt concentrations.

Salt concentration					pH
5mM $CaCl_2$	10mM $MgCl_2$	5mM $CaCl_2$	10mM $CaCl_2$	Without salt	
0.01 Aa	0.04 Aa	1.79 Aa	0.00 Aa	0.24 Aa	3
0.17 Aab	0.03 Aa	0.26 Aab	0.00 Aa	0.35 Ab	5
0.09 Aba	0.03 Aa	0.73 Ab	0.00 Aa	0.40 Aab	7

Table 8. Flow index for 50-50 mixture of sodium alginate and hydroxypropylcellulose in various pH values and salt concentrations.

Salt concentration					pH
5mM $CaCl_2$	10mM $MgCl_2$	5mM $CaCl_2$	10mM $CaCl_2$	Without salt	
1.51 Aa	1.40 Aa	1.36 Aa	1.81 Aa	1.29 Aa	3
1.30 Aa	1.43 Aab	1.36 Aa	1.72 Ab	1.11 Aa	5
1.42 Aa	1.40 Aa	1.10 Aa	1.33 Aa	0.97 Aa	7

Table 9. Consistency index for 25-75 mixture of sodium alginate and hydroxypropylcellulose in various pH values and salt concentrations.

Salt concentration					pH
5mM $CaCl_2$	10mM $MgCl_2$	5mM $CaCl_2$	10mM $CaCl_2$	Without salt	
0.03 Aab	0.04 Ab	0.03 Aab	0.00 Aa	0.03 Aab	3
0.08 Aa	0.02 Aa	0.01 Aa	0.00 Aa	0.20 Ab	5
0.02 Aa	0.02 Aa	0.02 Aa	0.00 Aa	0.24 Ab	7

Table 10. Flow index for 25-75 mixture of sodium alginate and hydroxypropylcellulose in various pH values and salt concentrations.

Salt concentration					pH
5mM $CaCl_2$	10mM $MgCl_2$	5mM $CaCl_2$	10mM $CaCl_2$	Without salt	
1.59 Aa	1.65 Aa	1.40 Aa	1.33 Aa	1.40 Aa	3
1.57 Aa	1.41 Aa	0.89 Aa	1.60 Aa	1.37 Aa	5
1.38 Aa	1.18 Aa	1.31 Aa	1.52 Aa	1.40 Aa	7

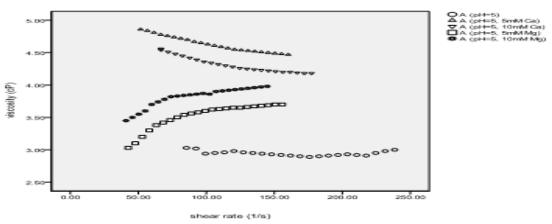

Fig. 1. Viscosity as a function of shear rate of methylcellulose solution at A(pH 3), B(5) and C(pH=7) without or with salts.

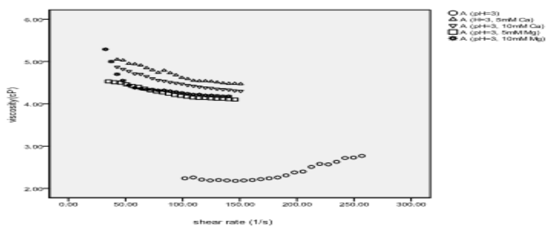

Fig. 2. Viscosity as a function of shear rate of methylcellulose solution at A(pH 3), B(5) and C(pH=7) without or with salts.

In pH values of 5 and 7, adding magnesium salt results in flow index increase, while in pH=3 the issue is true for adding calcium salts. The reason may be explained as pH increases, ionization rate for ionic group's increases and therefore presence of salts with lower ionic radius can be supportive in creating attraction force between opposite charges. Since, HPC polymer is a high molecular weight polymer and contain hydroxypropyl groups , it binds better to smaller radius ions and ionic bonds formation rate for Mg2+ is higher than Ca2+, therefore, gum molecule has a regular structure with ionic and hydrophobic interactions in higher pH values, but in lower pH values (pH=3) because of lack of ionization for ionic groups, ionic interaction is lower, therefore, present of a salt with high ionic radius in solution results in increasing hydrophobic interactions in solution and also electrostatic repulsion between gums chains and calcium ions results on stability of primary structure of gum and only grounds for regular arrangement and positioning them far from each other, which in its turn increases solution flow index and viscosity , compare to no salt added condition. (Fig. 2).

Analysis of Results for Samples of Sodium Alginate-HPC mixtures

Data statistical analysis shows that with increasing HPC ratio in sodium alginate and HPC aqueous mixture, flow behavior of solutions becomes close to100% Hydroxypropyl cellulose solution. In other words, flow index amount of solutions increase as HPC ratio increases. As a result, highest flow index amounts will achieve for 100% HPC solutions. Flow index for mixtures compare to use of only sodium alginate in solution was higher (Table 5 to 10). This issue indicates adding HPC polymer to sodium alginate solution was able to increase flow index and consequently increases shear thickening behavior. In overall, for all mixtures, the flow index was more than 1, which shows dilatant behavior of all these solutions.

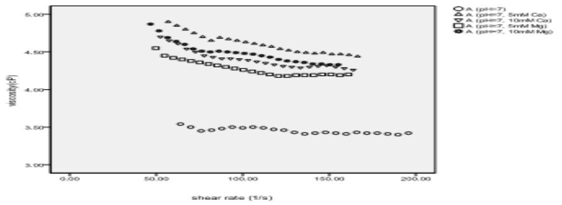

Fig. 3. Viscosity as a function of shear rate of methylcellulose solution at A(pH 3), B(5) and C(pH=7) without or with salts.

Regard to higher flow index for 100% HPC solution compare to 100% sodium alginate solution, we can concluded that adding HPC gum to alginate solutions results in increasing flow index, therefore, HPC can increase hydrophobic interactions, and give a regular structure to solutions. Also, adding salts to solutions in any ratio and for all samples causes flow index increase in contrast to control group (no added salt solution). It is predicted that with notice to HPC non-ionic structure, and sodium alginate ionic structure, in addition to high sodium alginate tendency to react with ions, sodium alginate is accountable for cation-polymer bonds formation in mixtures. Hence, with formation of polymer-cation-polymer (which sodium alginate percent has a role on it), shrinkage in sodium alginate chains will appear, and with ions increase, hydrodynamic volume of these molecules decrease. Therefore, as sodium alginate ratio in solutions with HPC increases, the flow index decreases and shear thinning behavior of solution increases. Hence we can conclude that, HPC hydrocolloid has fundamental role in flow index increase or thickening behavior of aqueous mixtures, because with increasing HPC ratio, hydrophobic interaction increases and HPC gum hydrodynamic volume, which is considerably huge, maintain in solutions, which results in thickening of aqueous mixtures.

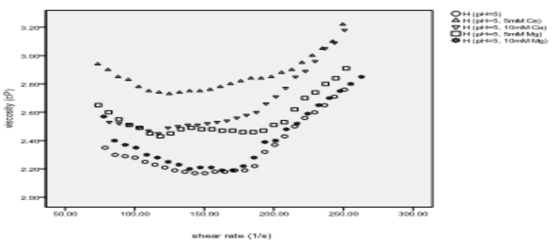

Fig. 4. Viscosity as a function of shear rate of methylcellulose solution at A(pH 3), B(5) and C(pH=7) without or with salts.

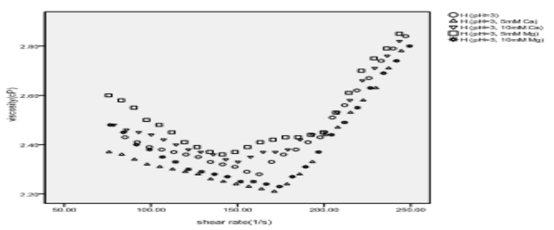

Fig. 5. Viscosity as a function of shear rate of methylcellulose solution at A(pH 3), B(5) and C(pH=7) without or with salts.

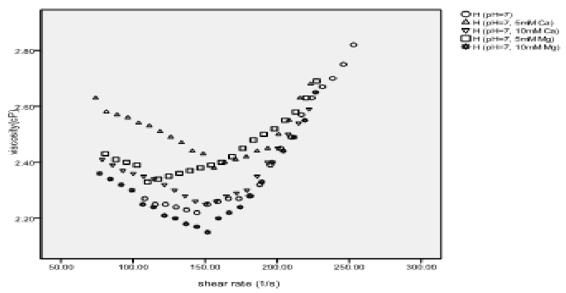

Fig. 6. Viscosity as a function of shear rate of methylcellulose solution at A(pH 3), B(5) and C(pH=7) without or with salts.

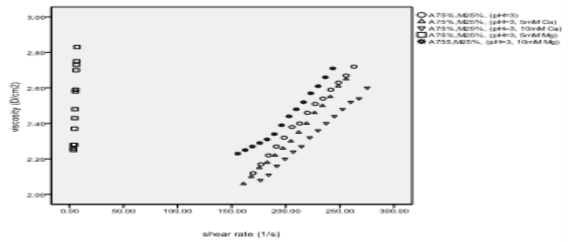

Fig. 7. Viscosity as a function of shear rate of methylcellulose solution at A(pH 3), B(5) and C(pH=7) without or with salts.

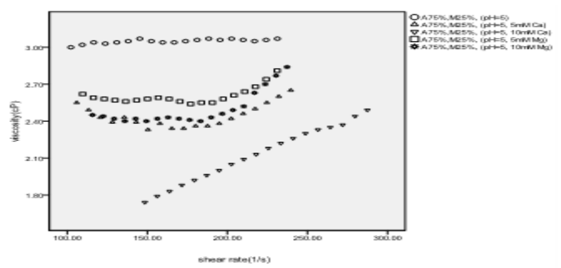

Fig. 8. Viscosity as a function of shear rate of methylcellulose solution at A(pH 3), B(5) and C(pH=7) without or with salts.

Change in thickening of aqueous mixtures with different pH values provides evidence for a nonhomogeneous pattern for these solutions with different ratio for each of two polymers. As a result, in sodium alginate-HPC aqueous mixtures with 75-25 ratios respectively, increase of pH value from 3 to 7 results in flow index and thickening behavior increase. Which can be explained as pH increases, ionization rate of polysaccharide anionic groups increases, and adding cations enhances binding to them. Because adding magnesium salts are more effective than calcium salts, it can be concluded that since ionic radius of magnesium is less than calcium, therefore, ions distances decrease and attraction between cations and anions increases. Hence in 10mM concentration, shear thickenin behavior is more appearance, it can be concluded as the result of smaller ionic radius, excess Mg^{2+} ions also show higher tendency to repel like charges in contrast to Ca^{2+}. Therefore, ionic bonds formation, even in present of these electrostatic repulsion forces, stabilized and hydrophobic interaction between polysaccharides in solution increases and with increase of pH value, shear thickening of solution will increase. In 50:50 aqueous mixtures, the opposite of the issue has been observed, that is; with adding salts to aqueous mixtures, flow rate increases or with pH value decrease, shear thickening behavior increases (Fig. 4).

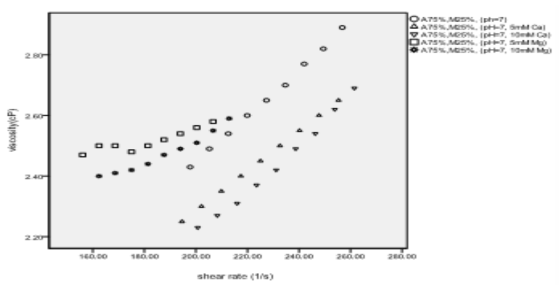

Fig. 9. Viscosity as a function of shear rate of sodium alginate - HPC (75/25) solution at A(pH 3), B(5) and C(pH=7) without or with salts.

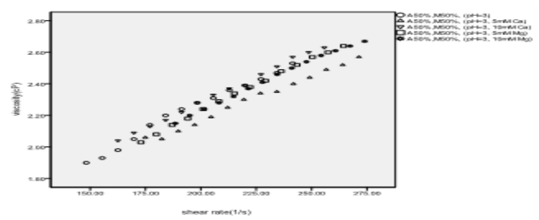

Fig. 10. Viscosity as a function of shear rate of

sodium alginate - HPC (75/25) solution at A(pH 3), B(5) and C(pH=7) without or with salts.

It is obvious in this type of solutions adding salts results in thickening versus to control group (no-salt added) were observed (Figs. 4, 5, 6). Regard to shear-thinning behavior of solution, we can tell in lower PH values, polymer ionization rate in mixtures will decrease. Therefore hydrophobic interaction in solution play more important role compare to ionic attraction forces, hence, possibility of interaction between different polysaccharides resulted by ionization will decrease, and structure stabilizing forces in aqueous mixtures will decrease. While, will pH increase, ionization rate of gum chains increases and various hydrophobic interactions and ionic bonds between agent groups with a solution regular structure result in viscosification and increase thickness. It seems we can concluded that considering type of salt and its concentration effect on flow index, 10mM salt concentration has highest effect on flow rate index, and magnesium ions has stronger effect versus Ca^{2+} , which the reason has been explained previously.

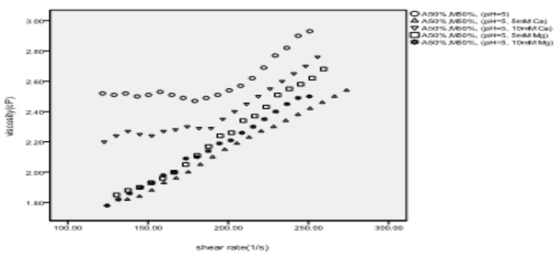

Fig. 11. Viscosity as a function of shear rate of sodium alginate - HPC (75/25) solution at A(pH 3), B(5) and C(pH=7) without or with salts.

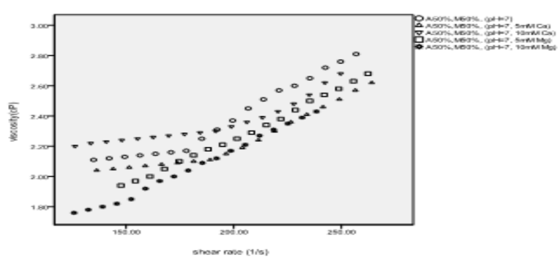

Fig. 12. Viscosity as a function of shear rate of sodium alginate - HPC (75/25) solution at A(pH 3), B(5) and C(pH=7) without or with salts.

In sodium alginate-HPC aqueous mixtures , with 25:75 mixing ratio, added salts cause increase on thickening compare to control group (not salt added)solutions (Fig. 5). The results show that with pH increase, flow index and consequently, shear thickening behavior decreases that the reason may be lower portion of sodium alginate in aqueous mixtures. Specially, with adding salts, hence, sodium alginate ionic composite are low in mixture, binding rate to sodium alginate decrease, therefore the ionic bonds decrease in solution, but in overall, shear thickening behavior of solution will increase with increase of HPC amount. It seems hydrophobic interaction will increase because of HPC amount increase. These types of interactions play fundamental role in mixture apparent viscosity increase. In 25-75 mixing, the effect of type of salt and its concentration on flow behavior index for different pH values is varied. As an example in pH=3, the magnesium salt in flow index increase play more significant role compare to Ca^{2+}. The reason is lack of ionization for gum anionic groups in this specific pH value.

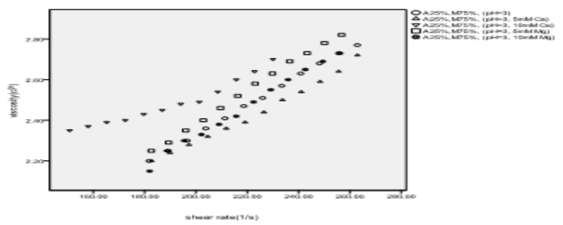

Fig. 13. Viscosity as a function of shear rate of sodium alginate - HPC (75/25) solution at A(pH 3), B(5) and C(pH=7) without or with salts.

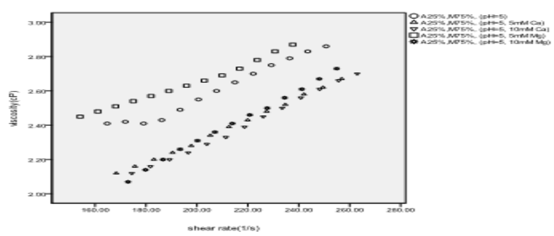

Fig. 14. Viscosity as a function of shear rate of sodium alginate - HPC (75/25) solution at A(pH 3), B(5) and C(pH=7) without or with salts.

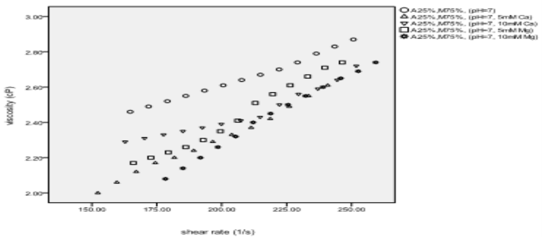

Fig. 15. Viscosity as a function of shear rate of sodium alginate-HPC (25/75) solution at A(pH 3), B(5) and C(pH=7) without or with salts.

Therefore, lower ionic radius has more effect on drawing polysaccharides chains close to each other and consequently creating weak hydrogen bonds. Other reason that contributes to the issue is polysaccharide sodium alginate tendency for polymer-cation-polymer bond forming for magnesium ions is lower compare to Ca^{2+}. Therefore electrostatic repulsion which causes by magnesium ion results in more stable molecular structure, and causes repulsion forces reach maximum amount result to smaller ionic radius and as a result apparent viscosity and thickening behavior of solution increase. Since in higher pH levels (5, 7), the tendency of sodium alginate polymer-cation-polymer bond formation with calcium ions as a result to increase in gum ionization rate increases and eggs box model in this pH takes shape, as the result of these ionic bonds formation, some of hydrophobic interaction decreases and results in lower repulsion forces. Hence, hydrophobic interactions play a major role in apparent viscosity and increasing shear thickening behavior rate, therefore in these higher pH values, lightness and decrease in viscosity were observed.

Conclusion

The results show that most suitable model for flow behavior explanation in tested samples was Herschel–Bulkley model, and change pattern for flow parameters in various conditions were studied by this rheological model (though, power law model also explains the flow behavior of solution considerably well). The analysis of results for tested data show cations with taking into consideration gum structure, cause change in gum rheological behavior and mixture. As it has been observed, all solutions exclusively with one gum give rise to higher viscosity with adding cations. The reason for this effect in sodium alginate solution is formation of gelling network and formation of egg box structure between polymer molecules and cations. For other polymer, hydrophobic interactions and electrostatic repulsion of like charges in solution cause a regular and affix structure for polymeric solutions.

In sodium alginate solutions, adding calcium salts contribute more to apparent viscosity increase, and most effective salt concentration was found to be 5mM. For HPC gum solutions, adding 10mM salts had higher effect on solution flow index increase. In pH level of 5 and 7, adding Mg salt and in pH=3 adding calcium salt had higher effect in viscosity increase of solution.

For sodium alginate-HPC aqueous mixtures, for all samples and pH values, adding salt results in higher viscosity versus control group (not salt added). In general, magnesium salt has highest effect on increasing flow index compare to calcium salt. However, for 25-75 sodium alginate-HPC for pH level of 5 and 7, the effect of Ca^{2+} was more than Mg^{2+}. For apperceive effect of pH on aqueous mixtures of these polymers, we should indicate in 75-25 ratio of sodium alginate-HPC mixture , with increasing pH form 3 to 7, flow index and thickening behavior increase. For 50-50 mixing, the mixture shows increase in flow rate for pH decreases and adding salts. For 25-75 ratios also this behavior is apparent. Therefore, as it has been mentioned, change in pH level has an obvious effect in viscosity and rheological parameters alteration.

For sodium alginate -HPC mixture, also we can tell that viscosity of aqueous mixtures were higher compare to sodium alginate solution only, and as HPC ratio in mixture increases, thickening increases, whereas highest flow rate will be belong to 100% HPC solution.

In overall, we can conclude that gums mixing, are a profitable way and provide better viscosity compare to sodium alginate solution alone. In other words, adding HPC to sodium alginate gum results in synergistic effect.

Therefore, in food applications, gum structure, food pH and different minerals in food, all play fundamental role in final product rheological properties.

In the case of using, a combination of sodium alginate and HPC, it was concluded that with HPC ratio increases, viscosity of aqueous mixtures also increases, since the highest viscosity were for HPC solution alone. As it has been indicated by previous studies, HPC solutions in lower pH levels (acidic pH values) give rise to higher viscosity. Present research found that with HPC ratio increases in sodium alginate-HPC mixture (25:75, 50:50 respectively)with pH decrease from 7 to 3, an increase in thickening behavior were observed. As HPC ratio decreases (such as 75:25 ratio of alginate to HPC), pH decrease results in lower thickening, and shear-thinning increases. In overall, in these aqueous mixtures adding calcium and magnesium salts to samples results on higher viscosity versus control group (no salt samples). Adding 10mM magnesium salts were more effective compare to calcium salt. Since flow index was more than 1 for all mixtures, therefore a thickening behavior was observed for all solutions compare to sodium alginate solution by itself. With mixing HPC a better synergistic effect compare to sodium alginate by itself were observed.

Therefore , for pH=3 such as in fruit juices, nectars, and acidic beverages, use of sodium alginate - HPC gum mixture, specifically, for higher sodium alginate to HPC ratio (50:50, 75:25) can enhance stability of these food group and causing formation of homogenous product . Sodium alginate-HPC mixture with 25:75 ratios in higher pH values (5 and 7) can be used for low acidity food such as milk, cereals, vegetables cans with high Mg in order to stabilize them. This specification enhances changes in taste and improves product line.

References

Bochek AM, Zabivalova NM, Lavrent›ev VK, Lebedeva MF, Sukhanova TE, Petropavlovskii GA. 2001. Formation of Physical Thermally Reversible Gells in Solutions of Methyl Cellulose in Water and Dimethylacetamide and Properties of Films Thereof. Macromolecular Chemistry and polymeric materials **(74),** 10-16. http://dx.doi.org/10.1023/A:1013774800778

De Kerchove AJ, Elimelech M. 2007. Formation of polysaccharide gel layers in the presence of Ca^{2+} and K^{+} ions: measurements and mechanisms. Biomacromolecules **8(1),** 113-21.

García –Ochoa F, Santos VE, Casas JA, Gomez E. 2000. Xanthan gum: production, recovery, and properties. Biotechnology Advances **18,** 549-579. http://dx.doi.org/S0734975000000501

Liu L. 2003. Sol-gel transition in aqueous alginate solutions induced by cupric cations observed with viscoelasticity. Polymer Journal **35(10),** 804-809. http://dx.doi.org/10.1016/S0032-3861(02)00771-1

Liu XX. 2003. Rheology characterization of Sol-gel transition in aqueos alginate solution s induced by cupric cations observed with viscoelasticity. Polymer Journal **35(10),** 804-809. http://dx.doi.org/10.1016/S0032-3861(02)00771-1

Macosko CW. (1994). Rheology, principles, measurements, and applications. Wiley-VCH, Inc. New York-USA.

Marcotte M, Taherian AT, Trigui M, Ramaswamy HS. 2001. Evaluation of rheological properties of selected salt enriched food hydrocolloids. Food Engineering **48,** 157-167. http://dx.doi.org/10.1016/S0260-8774(00)00153-9

Martínez-Padilla LP, López-Araiza F, Tecante A. (2004). Steady and oscillatory shear behavior of fluid gels formed by binary mixtures of xanthan and gellan. Food hydrocolloids **18,** 471-481.

http://dx.doi.org/10.1016/j.foodhyd.2003.07.002

Matsumoto T, Mashiko K. 1990. Viscoelastic properties of alginate aqueous solutions in the presence of salts Biopolymers **29,** 411-421.
http://dx.doi.org/10.1002/bip.360291404

Rao MA, Anantheswaran RC. 1982. Rheology of fluid in food processing. Food Technology **36,** 116-126.

Rao MA, Kenny JF. 1975. Flow properties of selected food gums. Canadian Institue of Food science and Technology **8,** 142-148.
http://dx.doi.org/10.1016/S0315-5463(75)73766-5

Rosenthal AJ. 1999. Food texture, Measurement and Perception. Aspen Publishers, Inc.

Skjåk-Bræk G, Grasdalen H, SmidsrØd O. 1989. Inhomogeneous polysaccharide ionic gels. Carbohydrate Polymer **10,** 31-47.
http://dx.doi.org/10.1016/0144-8617(89)90030-1

Walkenström P, Kidman S, Hermansson A, Resmusen PB, Hoegh L. 2003. Microstructure and rheological behavior of xanthan/pectin mixed gels. Food Hydrocolloids **17,** 593-603.
http://dx.doi.org/10.1016/j.jfoodeng.2003.12.005

Wang ZY. 1994. Sol-Gel transitions of alginate solution by the addition of various divalent-cations- a rheological study. Biopolymers **34(6),** 737-46.
10.1002/bip.360340606

Wells LA, Sheardoe\wn H. 2007. Extended release of high pI proteins from alginate microspheres via a novel encapsulation technique. European Journal of Pharmaceutics and Biopharmaceutics **65,** 329-35.
http://dx.doi.org/10.1016/j.ejpb.2006.10.018