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FLOW AND CONSISTENCY INDEX DEPENDENCE OF PSEUDOPLASTIC GUAR GUM SOLUTIONS

By

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ABSTRACT

The flow and consistency index values for aqueous solutions of guar gum have been shown. The effects of particle size, ionic strength and pH variations on rheological parameters were investigated. The rheograms generated in this study were fitted to the power law with a correlation coefficient greater than 0.99 in all cases. From a practical point of view, the flow index of gum solutions is a useful parameter in designing a gum system for a given formulation. This study used guar gum as a model to point out the utility of flow and consistency index in formulation work.

INTRODUCTION

Guar gum is a naturally occurring hydrocolloid used as a thickener in the food and pharmaceutical industries. It is derived from seeds of cyamopsis tetragonolobus. It consists of linear chains of (1→4)-beta-manopyranosyl units with alpha-D-galactopyranosyl units attached by (1→6) linkages (1). Because of its non-ionic nature, it shows compatibility with electrolytes and a wide range of pH values. It hydrates in cold water. It was also noted that there is an increase in the flow rate with an increase in temperature (2).

The pseudoplastic behavior of guar gum solutions are often represented by the power law (3, 4, 5). Other relationships have also been used to represent guar gum solutions (6, 7), to predict Newtonian behavior at a sufficiently lower shear rate. Patton (8) suggested that guar gum solutions show Newtonian behavior, both at low and high shear rates.

Flow properties of a gum system are very important when designing liquid products such as suspensions, emulsions and solutions. Most gum solutions at functional concentrations are pseudoplastic, that is the viscosity appears thinner when shaken in a bottle. Further, Catacalos and Wood (9) developed relationship between pourability and suspendability for some non-Newtonian gum systems.

EXPERIMENTAL

The viscosity of liquids, in general, is measured with a synchro-lectric viscometer. This instrument subjected the sample to a known shear rate (sec^{-1}) and then measures the shear stress ($dynes/cm^2$). The power law is defined as:

$$\eta = K \gamma^{(N-1)} \qquad \text{(Eq. 1)}$$

Where η is viscosity (poise), K is consistency index (poise) at 1 sec^{-1}, N is flow index (dimensionless) and γ is shear rate, sec^{-1}.

Gum solutions at low concentrations are expected to show Newtonian flow. It is assumed that the diluted guar gum solutions have a yield value of zero.

Materials:
Three different grades of guar gum[1], graded according to their particle size distribution were used in this study. Reagents[2] used to adjust pH or ionic strength were of analytical grade materials. Glass distilled, deionized water was used to hydrate the gums. All materials were directly obtained from vendors.

1. Dycol, National Starch and Chemical Corp., Bridgewater, NK 08807
2. Mallinckkrodt Chemical Inc., St. Louis, MO 63147

Methods:

Solutions of guar gum were made in deionized water, containing 3% ethanol. The gum was initially wetted with alcohol, then water was added and the system gently mixed with a magnetic stirrer. The following concentrations, 0.4, 0.6, 0.8 and 1.0% solutions were prepared for the study. The rheograms were generated by subjecting these solutions to Brookfield, Synchro-Lectric Viscometer[3], model RVT, at 5, 10, 20, 50 and 100 RPM, and at room temperature (25° ± 0.2°C). In all cases, the volume was adjusted to 300 ml in a 400 ml beaker and used all this volume in determining apparent viscosities.

Effect of Particle Size:

In one set of experiments, coarse grade (Dycol 4500n FCC), medium grade (Dycol 3600 FC) and fine grade (Dycol 4500F) materials were compared by developing rheograms and fitting this data to power law equation.

Effect of pH:

Solutions of 0.6% guar gum were made in 0.2 M phosphate (pH 6 and 8) and/or glycerine (pH 2 and 10) buffer, containing 3% ethanol. The gum was initially wetted with alcohol, then buffer added and pH was adjusted carefully by adding hydrochloric acid or sodium hydroxide. In all cases, the final volume was adjusted to 300 ml. Viscosity measurements were made on the solution in a 400 ml beaker.

Effect of Metal Ions:

Solutions of guar gum with metal ions were made and the final volumes were adjusted to 300 ml in these experiments. Sodium chloride, potassium chloride, magnesium chloride or calcium chloride were added at 0.1, 0.2, 0.4 and 0.6 M levels. Viscosity measurements were made on these solutions.

Particle Size Determination:

Particle size of gum powders were determined by sieve analysis. A sample of 100 g was charged on a nest of six U.S. standard sieves. This nest was placed on Ro-Tap[4] for 10 minutes in all cases. The average particle diameter was calculated by using the data collected in this experiment.

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3. Brookfield Engineering Laboratories, Inc., Stoughton, MA 02072

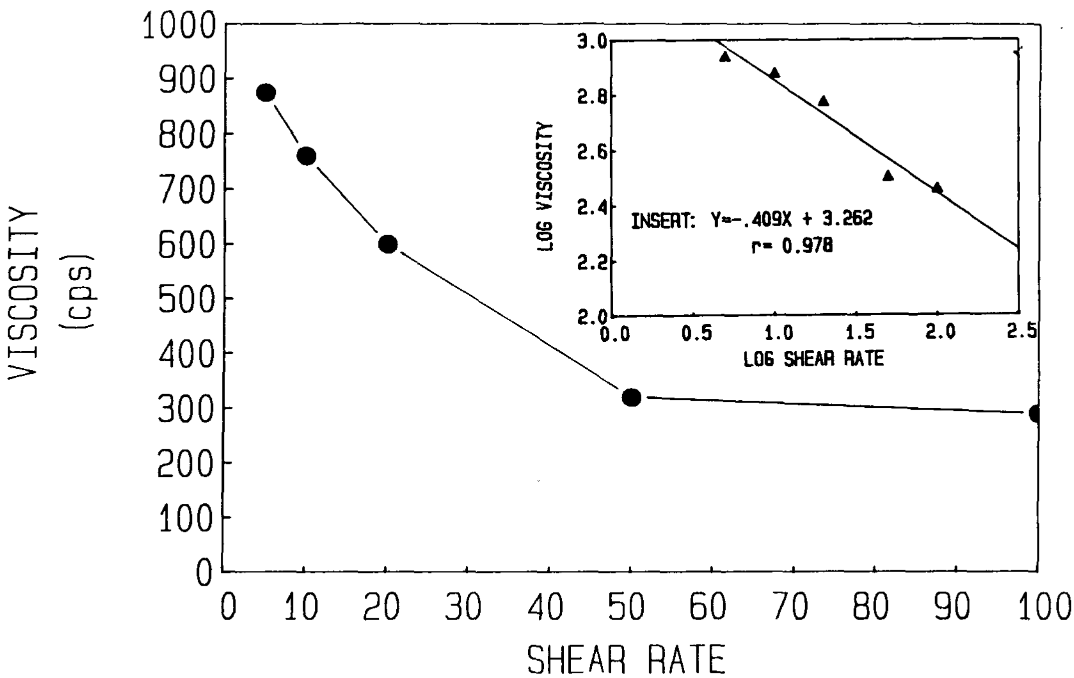

FIGURE 1

A rheogram of a 0.6% solution of guar gum made in water containing 3% ethanol. The insert is a linearized log-log plot. Viscosity was determined at room temperature with the Brookfield Viscometer, Model RVT, Spindle #4.

All experiments in this study were repeated at least three times. The data presented in the tables is representative of the mean values of these experiments.

RESULTS AND DISCUSSION

The studied concentration levels of guar gum showed non-Newtonian behavior. The dependence of shear rate on shear stress for pseudoplastic liquids can be described by the power law, as given in equation 1. All rheograms generated show pseudoplastic phenomena as shown in Figure 1. Equation 1 was rearranged by taking logarithms on both sides. Then this equation transforms into:

$$\text{Log } \eta = (N-1) \text{ Log } \dot{\gamma} + \text{Log } K \qquad \text{(Eq. 2)}$$

Viscosity data collected at various shear stress values is fitted to this linear equation with the help of a commercially available "Statistics" software and an IBM Personal Computer. In all cases, the data regressed with high confidence ($r = 0.99$) to linear form of power law. The value of N is derived from slope of the equation while K is antilog of Y-intercept.

4. Ro-Tap, Model B, W.S. Taylor Inc., Mentor, OH

Table I shows the dependency of N (flow index) and K (consistency) values on guar gum concentration in solution. Figure 2 shows the influence of particle size of gum on the N values. The coarse (0.2318 mm) and medium (0.1229 mm) grade materials showed similar N values, whereas the fine (0.0832 mm) particle grade material showed smaller N values.

The value of N indicates flow characteristics. When N is less than 1, the flow would be pseudoplastic. The smaller the value of N is, the more pseudoplastic the gum system is. For example, the viscosity of guar gum is dependent on shear rate while the value of N is a dimensionless number independent of shear rate. Lower values of N indicate less viscous and easy to flow characteristics upon shaking a bottle, but show high viscosity at rest. The phenomena of lower N values of guar gum are desirable in formulating a suspension or emulsion product. Thus, the fine grade material which showed smaller N values compared to the others is more desirable with respect to holding the suspension together as well as the pourability characteristics of a pharmaceutical suspension or emulsions such as salad dressings.

Since guar gum is non-ionic material, it was expected to have no pH dependency. However, in all experiments, the value of N was influenced by pH. Table I shows the effect of pH on N values. Higher N values were observed in alkaline pH (=10) compared to the other pH's studied. These larger values of N may be attributed to the denaturization of manopyranosyl units and/or galactopyranosyl units of guar gum. In this paper, the author do not wish to dwell on possible reasons for variations on N, but merely present the observed effect.

Figure 3 shows the semilogarithemic relationship between K (consistency) and concentration of guar gum solutions.

TABLE I

This table shows the effect of particle size, pH and concentration of gum in solution on rheological parameters. 0.6% gum solutions were used to study the effect of pH. Rheograms were generated using a rotary viscometer and data fitted to the equation 2. In all cases, data regressed well with a correlation coefficient greater than 0.99.

Guar gum Grade	Gum Conc.	pH	Apparent Viscosity (cps)*	Flow Index N	Consistency K
Coarse	0.6	2	254	0.629	639
		5.6	208	0.672	479
		8	196	0.648	486
		10	166	0.711	342
	0.8		465	565	1380
	1.0		852	453	1416
Medium	0.4		78	0.75	134
	0.6	2	248	0.651	596
		6	228	0.681	526
		8	234	0.686	526
		10	220	0.684	483
	0.8		512	0.575	1483
	1.0		920	0.46	3444
Fine	0.4				
	0.6	2	304	0.638	756
		5.7	292	0.635	493
		8	298	0.638	748
		10	292	0.672	679
	0.8		618	0.52	2017
	1.0		1098	0.42	4477

*Brookfield viscometer, model RVT, @25°C ± 0.2° spindle #4, and RPM100.

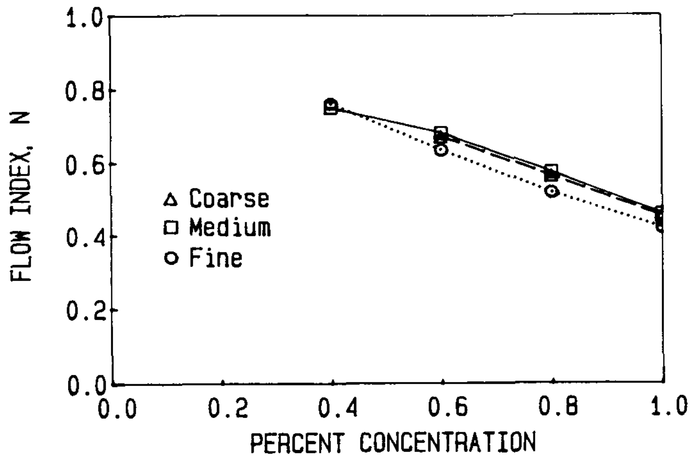

FIGURE 2

Effect of Average Particle Diameter of Dry Gum on the Flow Index is Shown.

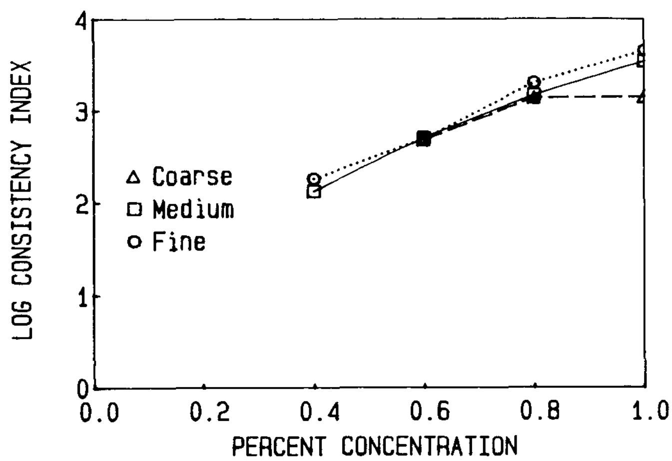

FIGURE 3

Semilogarithemic Relationship Between Guar Gum Concentration in Solution and Consistency Index is Shown.

TABLE II

Solutions of 0.6% guar gum in water containing 3% ethanol. Rheograms were generated using rotary viscometer, and fitted data to the equation 2. In all cases, data regressed with a correlation coefficient greater than 0.99. This table shows ionic strength effects on fine particle grade (4500F) guar gum solutions.

Ion Concen.	Nature of ions	pH	*Apparent viscosity	Flow Index N	Consistency K
Control	None	5.56	280	0.649	675
0.1M	Na+	5.57	268	0.713	631
0.2M	from	5.53	272	0.678	621
0.4M	NaCl	5.5	275	0.68	621
0.6M		5.51	248	0.688	553
Control	None	5.48	298	0.651	724
0.1M	K+	5.61	274	0.637	678
0.2M	from	5.61	288	0.658	679
0.4M	KCl	5.63	274	0.595	656
0.6M		5.61	270	0.655	642
Control	None	5.82	332	0.67	775
0.1M	Mg++	4.86	258	0.668	560
0.2M	from	4.79	250	0.672	577
0.4M	MgCl	4.7	246	0.675	569
0.6M		4.68	236	0.683	527
Control	None	5.41	280	0.648	685
0.1M	Ca++	5.78	285	0.622	706
0.2M	from	6.8	372	0.61	959
0.4M	CaCl2	7.75	366	0.592	1028
0.6M		8.25	380	0.551	1202

*Brookfield viscometer, model RVT, @25°C ± 0.2°, spindle #4 and 100RPM

Table II shows the effects of sodium, potassium, magnesium and calcium ions at various concentration levels on guar gum solutions. Concentration of calcium ions has an effect on the apparent viscosity of guar gum at 100 RPM. However, this effect was not profound for the other metal ions. Sodium ions at 0.1 M concentration showed larger N values compared to the higher concentrations of sodium. On the other hand, calcium ions showed a clear increase in consistency (K) values as the ionic concentration increased. Further, the pH of solutions increased as the ionic concentration of calcium increased. Thus, the change in values of N and K is a combination effect if ion concentration as well as the pH shift.

The Power law was used to calculate flow index and consistency values for guar gum solutions at different pH values, for various particle grades and for various ionic concentrations of four different metallic ions. Flow index was influenced by particle size, the smaller the particles, the better suspension characters it would have. Calcium ions tend to increase the consistency index of guar gum. This means formulations containing calcium ions and guar gum become more viscous than the formulations without calcium ions in them. Variations in pH has a slight effect on flow index of guar gum dispersions, but it does seem to have an effect in the presence of calcium ions.

CONCLUSION

Pharmaceutical scientists can custom-design a gum system by studying the flow index and consistency index. In a stability study, the physical parameters such as N and K may be used for characterizing the stability of suspensions and emulsions. The N and K values may be adjusted to desired levels by combining two or more gums in designing a stabilizer system in pharmaceutical as well as in food development laboratories.

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