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Correlation of the Perceived Texture of Random Coil Polysaccharide Solutions with Objective Parameters

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SUMMARY

A wide range of concentrated random coil polysaccharide solutions have been assessed for textural attributes by a trained sensory panel. The only textural terms invoked to describe these model systems were 'thickness' and 'stickiness', which were shown to be highly correlated, and essentially identical numerically, using a ratio scaling technique. Viscosity (η) *measurements over a wide range of shear rates* ($\dot{\gamma}$) *for all these samples gave flow curves* ($\log \eta$ *versus* $\log \dot{\gamma}$) *of the same form. Differences in flow behaviour between samples could then be characterised completely by two parameters, the maximum viscosity at low shear rates* (η_0), *and the shear rate* ($\dot{\gamma}_{0\cdot1}$) *at which* $\eta = \eta_0/10$. *A simple linear relationship was demonstrated between these two parameters and perceived thickness* (T) *or stickiness* (S), *irrespective of polysaccharide type. For Newtonian liquids,* $\log T$ (*or* $\log S$) *varied linearly with* $\log \eta$. *Hence the effective 'in-mouth' thickness of random coil polysaccharide solutions, in normal viscosity units, may be predicted directly from* η_0 *and* $\dot{\gamma}_{0\cdot1}$ *by the simple relationship:* $\log \eta_N = 1{\cdot}13 \log \eta_0 + 0{\cdot}45 \log \dot{\gamma}_{0\cdot1} - 1{\cdot}72$ *where* η_N *is the viscosity of a Newtonian solution which would be perceived as identical in thickness (and stickiness) to the polysaccharide solution.*

INTRODUCTION

One of the principal industrial uses of carbohydrate polymers is in control of the viscosity of aqueous solutions (see for example Whistler,

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1973; Glicksman, 1970). This is of particular importance in the food industry, since palatability and consumer acceptance may be as much influenced by textural attributes as by, for example, flavour or nutritional value. Although the ultimate criterion of food texture must inevitably be subjective sensory evaluation, this is clearly a cumbersome and unsatisfactory method for regular use in, say, product development or process control. The development of objective measurements which correlate directly with perceived texture would therefore be of considerable value.

For fluid foodstuffs, such as soups, sauces, syrups, dressings and drinks, an obvious choice of objective parameter is solution viscosity. For a limited number of fluids, including simple oils or sugar syrups, viscosity is essentially independent of the flow regime under which it is measured; materials of this kind are known as 'Newtonian' liquids. In general, however, solution viscosity is not a simple, fixed parameter, but varies with the rate of flow, often by several orders of magnitude. For this reason a number of attempts have been made to determine the flow rates experienced in the mouth.

In an early investigation Szczesniak & Farkas (1962) observed that 'during eating the tongue moves about 30 times per minute' and then used viscosity measured at 30 r.p.m. on a Brookfield viscometer as an index of flow conditions in the mouth. Although this approach is still used (e.g. Pangborn *et al.*, 1978) it suffers from the fundamental problem that the measured viscosity of non-Newtonian liquids is dependent not upon the rate of *movement*, but upon the rate of *shear*. If we imagine a film of liquid sandwiched between two parallel plates, one of which is moving relative to the other, then shear rate ($\dot{\gamma}$) is defined as the distance moved in one second, divided by the separation of the plates. Since shear (γ) is a dimensionless ratio (distance moved/separation), $\dot{\gamma}$ has units of reciprocal time (s^{-1}). The viscosity (η) is then defined (eqn 1) as the stress (τ) generated by the liquid in resisting the movement, divided by the shear rate.

$$\eta = \tau/\dot{\gamma} \tag{1}$$

Since geometry in the mouth (e.g. the distance between the tongue and palate) is complex and is likely to change constantly during chewing and swallowing, direct determination of the shear rates involved seems an unrealistic target.

An elegant indirect approach to the problem was first developed by Wood (1968). For non-Newtonian liquids, viscosity may be expressed as a 'flow curve' of measured viscosity as a function of shear rate. By choosing materials whose flow curves cross and then asking panellists to say which seemed the more viscous, shear rate in the mouth was assessed as lying above or below the point of intersection. Using a number of such intersecting flow curves, Wood suggested that the shear rate operative in the mouth is $\sim 50\,s^{-1}$. In a subsequent, more extensive study by essentially the same method, Shama & Sherman (1973) concluded that the relevant shear rate varies with the viscosity of the material, from $\sim 10\,s^{-1}$ for highly viscous substances such as 'Golden Syrup', to $\sim 10\,000\,s^{-1}$ for water. Although this is an appealing model, since it seems not unreasonable that very viscous substances would be moved around in the mouth less rapidly than more fluid materials, a recent independent study (Christensen, 1979) found discrepancies between objective viscosity measurements at the appropriate shear rates and subjective assessments of the relative viscosities of the samples studied.

An underlying assumption in the method adopted by Wood (1968) and by Shama & Sherman (1973) is that, for a particular material, viscosity in the mouth is assessed at a single shear rate, although it is far from obvious that this should be the case. Indeed Christensen (1979) has suggested that a range of shear rate is involved, although a number of other interpretations of the results on which this conclusion is based seem equally likely. A more fundamental assumption of almost all work in this field is that viscosity under constant shear is the appropriate objective measurement for correlation with perceived solution texture. Again it is not obvious that this assumption is valid, since other types of deformation, such as extensional flow, or rapidly changing rates of shear, seem at least as likely.

While some investigations (e.g. Shama & Sherman, 1973) have involved relatively complex food systems, simple polysaccharide solutions have been more widely studied (e.g. Szczesniak & Farkas, 1962; Moskowitz, 1972; Pangborn *et al.*, 1978; Christensen, 1979), both as model systems and also for their direct relevance to the practical application of polysaccharides as thickeners. Recently Morris *et al.* (1981) demonstrated that the flow behaviour of polysaccharide solutions is far more general and predictable than previously believed. In particular it was shown that the flow curves (variations of η with $\dot{\gamma}$) for concentrated solutions of random coil polysaccharides have a general form. Hence the viscosity at all shear rates of practical importance may be defined completely by two parameters, η_0, the maximum viscosity of the solution at low rates of shear ('zero-shear' viscosity) and $\dot{\gamma}_{0\cdot1}$, the shear rate at which the measured viscosity is reduced to one tenth of this maximum value (see Fig. 1).

An alternative parametric approach which has been widely applied to textural studies (e.g. Moskowitz, 1972; Wood, 1974; Christensen, 1979) is the use of a 'power law' relationship (eqn 2) to characterise the flow curve.

$$\tau = \mathrm{k}\dot{\gamma}^{n} \qquad (2)$$

Hence:

$$\eta = \mathrm{k}\dot{\gamma}^{(n-1)} \qquad (3)$$

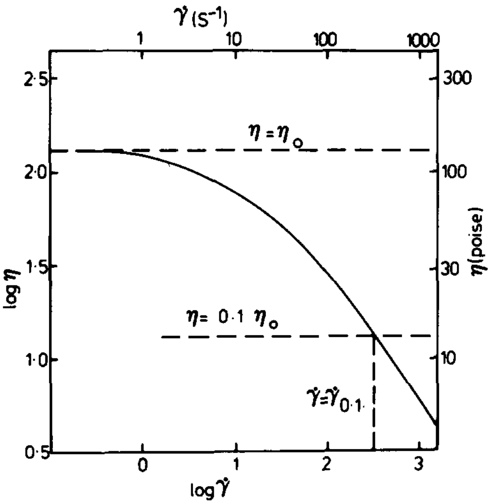

Fig. 1. Characterisation of the shear-thinning behaviour of concentrated random coil polysaccharide solutions by the two parameters η_0 ('zero-shear' viscosity) and $\dot{\gamma}_{0\cdot1}$ (shear rate required to reduce viscosity to one tenth of η_0). The flow curve shown is for a solution of sodium alginate (4·5% w/v) in the presence of sucrose (10% w/v).

or equivalently:

$$\log \eta = \log k + (n - 1) \log \dot{\gamma} \qquad (4)$$

Thus the power law method treats flow curves such as those in Figs 1 and 2 as straight lines of gradient $(n - 1)$. While viscosity measurements over a narrow range of shear rates commonly studied may approximate to linearity, it is clear that depending upon the region of the flow curve sampled, almost any value of $(n - 1)$ between zero and the terminal slope of about $-0{\cdot}73$ may be obtained for random coil polysaccharide solutions. We do not therefore regard this approach as reliable or valid for systems of this type.

In the present work we have attempted to correlate the objective values η_0 and $\dot{\gamma}_{0{\cdot}1}$ for a range of polysaccharide solutions of different concentration and chemical type, with subjective assessments of solu-

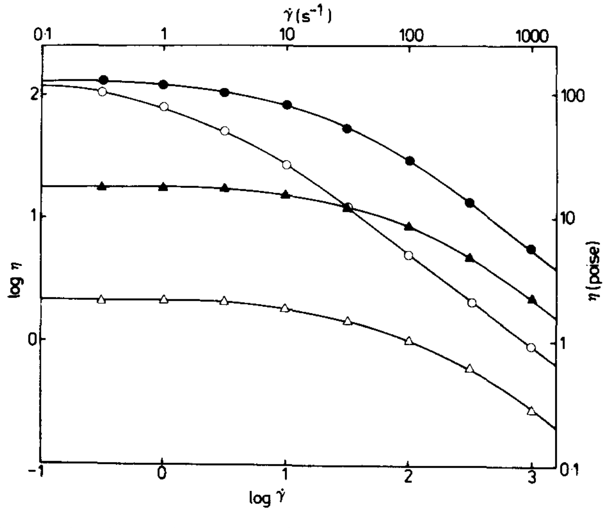

Fig. 2. Variation in shear thinning behaviour of random coil polysaccharide solutions used in this work, with changes in η_0 and $\dot{\gamma}_{0{\cdot}1}$. 1·10% w/v Guar (○) and 4·5% w/v alginate (●) have the same zero shear viscosity ($\log \eta_0 = 2{\cdot}11$) but show the onset of shear thinning at different rates of shear ($\log \dot{\gamma}_{0{\cdot}1} = 1{\cdot}47$ and $2{\cdot}53$ respectively) while 0·15% w/v locust bean gum (△) and 2·18% w/v pectin (▲) have virtually identical values of $\dot{\gamma}_{0{\cdot}1}$ ($\log \dot{\gamma}_{0{\cdot}1} \approx 3{\cdot}18$) but different zero shear viscosities ($\log \eta_0 = 0{\cdot}33$ and $1{\cdot}25$ respectively). All solutions contain 10% w/v sucrose.

tion texture by a trained sensory panel. Since these two parameters are sufficient to define the entire flow curve, this approach involves no assumptions about the flow conditions in the mouth. The viscosity measurements, however, relate solely to constant rates of shear, and thus the success or failure of their correlation with perceived texture should give an indication of the relevance of such measurements to the in-mouth situation. A preliminary account (Morris & Taylor, 1982) of some aspects of this work was presented at the conference on Gums and Stabilisers for the Food Industry, Wrexham, July 1981.

EXPERIMENTAL

Polysaccharide solutions

The following commercial polysaccharides were used: lambda carrageenan (Marine Colloids, Rex 5400); high methoxy pectin (Bulmers, Firmagel HM); guar gum (Kobenhavns Pektinfabrik, purified grade); locust bean gum (Marine Colloids, Rex 5924), and 'high guluronate' alginate (Protan, LF 20/60). The polysaccharides were dispersed in distilled water at ambient temperature using an overhead stirrer, and solid sucrose (10% w/v) was then added. Final solubilisation was obtained using a Silversun high shear mixer. Banana flavouring (P.F.W. Ltd, 510581E; 0·2% w/v) was incorporated for palatability.

Objective measurements

Viscosity (25°C) was measured at intervals of half a decade from 0·1 to 1000 s^{-1} on a Rheometrics Mechanical Spectrometer (Model RMS 605), using a 50 mm cone and plate with cone angle 0·04 rad, or 25 mm cone and plate with cone angle 0·10 rad, as appropriate. Shear rate ($\dot{\gamma}$) was calculated (eqn 5) from angular velocity, Ω (rad s^{-1}) and cone angle, θ (rad).

$$\dot{\gamma} = \Omega/\theta \tag{5}$$

η_0 and $\dot{\gamma}_{0\cdot1}$ values were derived by fitting the observed flow curves to the generalised shear thinning profile previously reported (Morris *et al.*, 1981) for concentrated solutions of random coil polysaccharide, by an iterative least squares computer method. Observed and fitted viscosities agreed to within experimental error in all cases.

Sensory evaluation

Textural assessments were made on the same solutions which were characterised objectively. The samples were served at room temperature (25°C) in small plastic beakers containing 30 ml of solution, and transferred to the mouth with a teaspoon. When not in use the solutions were stored in a refrigerator. A randomised incomplete block design was used and the samples were tasted at 15 sessions over a five day period. Twelve panellists from a pool of 15 attended each session at which 12 samples were tasted (11 from the total of 22 plus a 'blind' control). Each panellist first tasted a pre-scored standard solution, followed by a further four samples. Textural attributes were assessed relative to those of the standard by ratio scaling (Stevens, 1975). Panellists were instructed to cleanse their palates after tasting each sample; water and dry biscuits were available for this purpose. The panel results were subjected to an analysis of variance which adjusted the scores for differences between panellists and between sessions.

RESULTS AND DISCUSSION

Random coil polysaccharides, in common with other disordered polymer chains, display two very different types of solution behaviour depending on concentration. In dilute solution, where the chains are widely separated, viscosity shows only limited shear-rate dependence. With increasing concentration, a stage is reached at which the polymer coils are forced to interpenetrate and this produces an abrupt change in flow behaviour. Figure 1 illustrates the shear rate dependence of viscosity for a typical concentrated polysaccharide solution. At low rates of shear the viscosity remains constant, but then decreases sharply with increasing shear rate (shear thinning). The molecular origin of this behaviour has been discussed previously (Morris *et al.*, 1981). For a fuller treatment see Graessley (1974); Ferry (1970). The transition from 'dilute' to 'concentrated' solution behaviour occurs when the constant 'zero shear' or 'Newtonian' viscosity η_0 exceeds about 10 cP.

(For ease of comparison with previous texture studies we will express viscosity in units of poise; as a simple conversion to S.I. units, 1 cP = 1 mPa s, which is approximately the viscosity of water at 20°C.)

As illustrated in Fig. 2, concentrated solutions of random coil polysaccharides all show the same form of shear thinning; i.e. the *shape* of flow curves of η as a function of $\dot{\gamma}$ (or more conveniently $\log \eta$ versus $\log \dot{\gamma}$) is essentially constant (Morris *et al.*, 1981), but the curves may be offset from each other along either axis. Thus to characterise differences in the flow behaviour of different concentrated polysaccharide solutions, only two parameters are required to position the flow curves on the vertical (viscosity) and horizontal (shear rate) axes. As described previously (Morris *et al.*, 1981) we have chosen the 'zero shear' viscosity (η_0), and the shear rate ($\dot{\gamma}_{0\cdot1}$) at which $\eta = \eta_0/10$ (see Fig. 1). Thus as shown in Fig. 2, solutions with the same value of η_0 but different values of $\dot{\gamma}_{0\cdot1}$ will have identical viscosities at low rates of shear, but the onset of shear thinning will occur at different shear rates for each. Conversely solutions with the same value of $\dot{\gamma}_{0\cdot1}$ but different values of η_0 will each experience the same degree of shear thinning throughout; thus the ratio of their observed viscosities will remain constant at all shear rates.

By expressing measured viscosities as a fraction of η_0 and actual shear rates as a fraction of $\dot{\gamma}_{0\cdot1}$, the relative displacements of the flow curves for different solutions may be eliminated. Figure 3 shows a plot of $\log(\eta/\eta_0)$ versus $\log(\dot{\gamma}/\dot{\gamma}_{0\cdot1})$ for the solutions used in this work. The results superpose closely and are in good agreement with the generalised form of shear thinning previously reported (Morris *et al.*, 1981).

The polysaccharides used were sodium alginate, high methoxy pectin, lambda carrageenan, guar galactomannan and locust bean gum. It is now well established (see for example Rees, 1977; Rees & Welsh, 1977; Morris *et al.*, 1977) that certain polysaccharides can exist in solution in regular, ordered conformations, such as the double helix structure of iota and kappa carrageenan and rigid rod-like structure of xanthan, which show flow properties very different from those of random coils (e.g. Morris, 1977). The polysaccharides used in this work were chosen because previous spectroscopic studies (e.g. Bryce *et al.*, 1974; Morris *et al.*, 1978), had shown them to be conformationally mobile in aqueous solution. Reduction in water activity by small hydro-

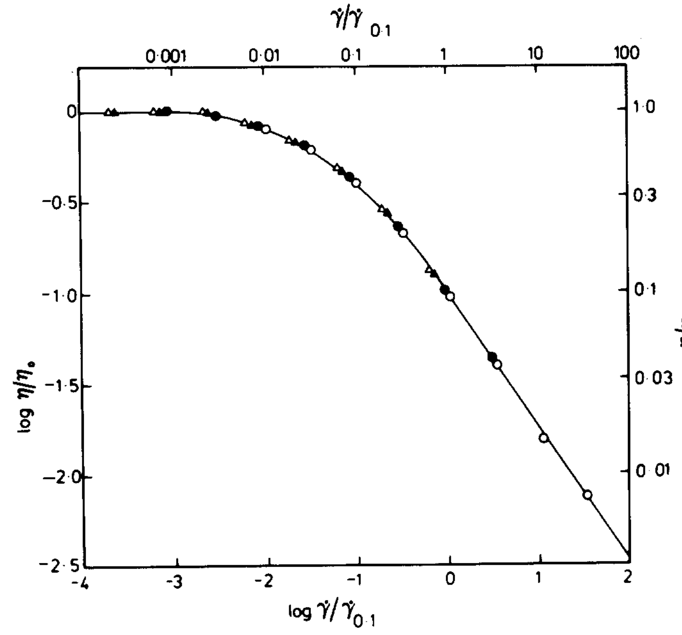

Fig. 3. Comparison of the shear-rate dependence of viscosity for the solutions used in this work, with the generalised shear thinning behaviour (——) previously reported (Morris *et al.*, 1981) for concentrated solutions of disordered polysaccharides. The results shown are for the guar gum (o), alginate (●), locust bean gum (△) and pectin (▲) flow curves from Fig. 2. A comparable quality of fit was obtained for all other samples used.

philic molecules, however, can induce ordered interchain association of polysaccharides (Dea *et al.*, 1977). The close agreement observed (Fig. 3) between the shear thinning behaviour of our samples and previous results for other random coil polysaccharide solutions confirms that no such complications have been introduced by the addition of sucrose and flavouring to make the solutions palatable.

Figure 4 shows the range of η_0 and $\dot{\gamma}_{0\cdot1}$ values used. As discussed previously (Morris *et al.*, 1981) the two parameters are not independent; for a given polysaccharide sample, as η_0 increases with increasing concentration, $\dot{\gamma}_{0\cdot1}$ moves to progressively lower values (i.e. the onset of shear thinning occurs at lower shear rates). Thus combinations of very high or very low values of both η_0 and $\dot{\gamma}_{0\cdot1}$ are not experimentally

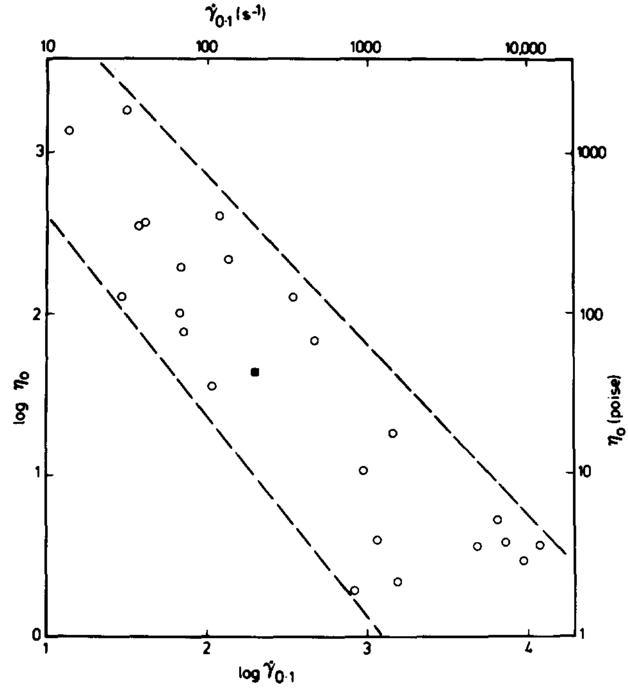

Fig. 4. Range of η_0 and $\dot{\gamma}_{0\cdot1}$ values spanned by the polysaccharide solutions used in this work (o). For each polysaccharide $\dot{\gamma}_{0\cdot1}$ decreases as η_0 increases, and thus accessible combinations are restricted to the band indicated (— — —). The solution (2·77% w/v pectin) chosen as standard (■) is close to the centre of the range for both parameters.

accessible with normal polysaccharides. We have, however, managed to achieve about a 30-fold variation in each parameter for any given value of the other and the overall range spanned is approximately 1000-fold for both η_0 and $\dot{\gamma}_{0\cdot1}$.

Preliminary studies with the sensory panel showed that the only textural attributes which were necessary to describe the perceived properties of these solutions were 'thickness' and 'stickiness', the latter being alternatively described as 'cloyiness', or difficulty in clearing the sample from the mouth. No other textural terms, such as creaminess or sliminess (e.g. Wood, 1974), were regarded by the panellists as appropriate for these model systems. A similar reduction in attribute vocabulary has recently been reported by Kokini *et al.* (1977). In subsequent

TABLE 1

Objective and Subjective Textural Parameters for Random Coil Polysaccharide Solutions

Polysaccharide	*c (% w/v)*	$\log \eta_0$	$\log \dot{\gamma}_{0\cdot1}$	*log thickness*		*log stickiness*	
				observed	*fitted*	*observed*	*fitted*
Carrageenan	0·58	0·29	2·91	1·71	1·67	1·69	1·67
Locust bean gum	0·51	0·33	3·19	1·71	1·71	1·73	1·72
Carrageenan	0·72	0·59	3·05	1·73	1·76	1·72	1·76
Alginate	1·26	0·47	3·97	1·74	1·82	1·76	1·84
Locust bean gum	0·75	1·02	2·97	1·84	1·86	1·85	1·86
Carrageenan	1·45	1·55	2·04	1·85	1·90	1·86	1·88
Pectin	1·96	0·55	3·68	1·85	1·82	1·87	1·83
Alginate	1·68	0·56	4·07	1·87	1·86	1·89	1·88
Pectin	1·86	0·71	3·81	1·93	1·87	1·94	1·88
Pectin	2·18	1·25	3·16	1·96	1·94	1·96	1·94
Locust bean gum	1·04	1·89	1·85	1·96	1·97	1·95	1·94
Pectin (standard) – blind control	2·77	1·64	2·30	2·00	1·95	2·01	1·94
Guar gum	1·10	2·11	1·47	2·02	1·98	1·99	1·95
Locust bean gum	1·34	2·29	1·84	2·04	2·07	2·03	2·04
Pectin	3·16	1·84	2·68	2·05	2·04	2·05	2·03
Carrageenan	2·07	2·00	1·82	2·05	1·99	2·01	1·97
Alginate	4·50	2·11	2·53	2·11	2·09	2·13	2·08
Guar gum	1·91	2·57	1·61	2·12	2·11	2·06	2·09
Carrageenan	2·97	2·55	1·57	2·14	2·10	2·06	2·08
Pectin	4·28	2·34	2·13	2·17	2·11	2·17	2·09
Alginate	10·0	3·28	1·50	2·21	2·28	2·22	2·25
Pectin	5·97	3·15	1·14	2·22	2·21	2·24	2·17
Alginate	6·68	2·62	2·07	2·23	2·17	2·23	2·15

The samples are arranged in order of increasing perceived thickness. All solutions contained 10% (w/v) sucrose. Fitted values for thickness (T) and stickiness (S) were calculated from eqns 7 and 8 respectively. The significant difference ($p = 0{\cdot}05$) of panel scores was 0·06 for $\log T$ and 0·07 for $\log S$.

sessions, panellists were asked to assess the perceived thickness (T) and stickiness (S) of each solution, relative to a standard solution, using the 'ratio-scaling' method of Stevens (1975).

The solution chosen as standard (2·77% w/v pectin) was close to the centre of the range of both η_0 and $\dot{\gamma}_{0\cdot1}$ (see Fig. 4), and was assigned a value of 100 for both attributes. Thus a sample judged to be four times as 'thick' as the standard would be given a thickness 'score' of $T = 400$ by the panellist, whilst one that was perceived to be half as thick would be rated at $T = 50$, and so on, with the same procedure being adopted for 'stickiness'. The mean scores for each textural attribute are shown in Table 1, together with the values of $\log \eta_0$ and $\log \dot{\gamma}_{0\cdot1}$ for the solutions. The standard solution was also included as a 'blind' control in each panel session. In no case did the mean thickness or stickiness score for the 'blind' control differ significantly ($p = 0{\cdot}05$) from 100. As shown in Fig. 5, the mean scores for thickness and stickiness for all solutions are highly correlated ($r = 0{\cdot}99$) and essentially identical numerically. Thus although these two textural attributes were perceived

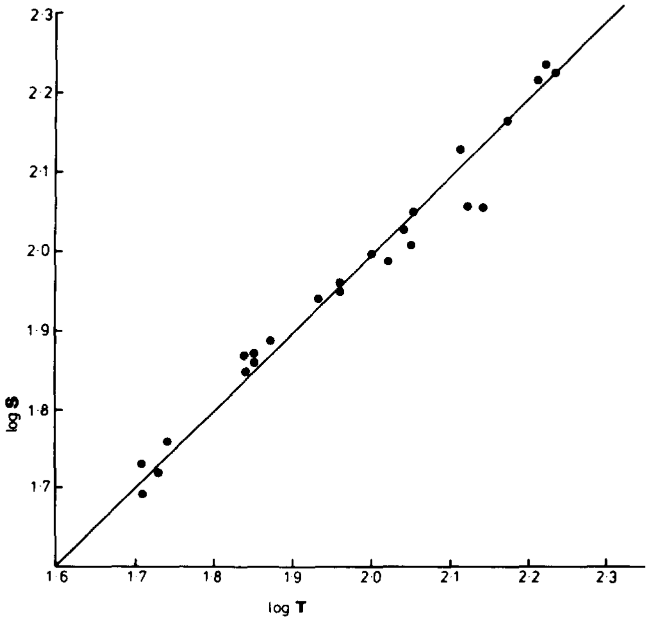

Fig. 5. Correlation of perceived thickness (T) and stickiness (S).

initially by the panel as separate and distinct, quantitative analysis by ratio scaling strongly suggests that they have a common physical origin.

Previous studies (e.g. Szczesniak *et al.*, 1963) have suggested that an important factor in determining the perceived texture of polysaccharide solutions is the chemical nature of the gum with, for example, pectin, alginate and locust bean gum being grouped in one category of behaviour, guar and carrageenan in another. To explore this interpretation, we have included among our samples pairs of solutions which are different chemically (i.e. made with different gums) but essentially identical in their flow behaviour. The approach adopted to prepare such 'matched pairs' is outlined in Fig. 6. For a particular polysaccharide sample, η_0 increases steeply with increasing concentration while $\dot{\gamma}_{0\cdot1}$

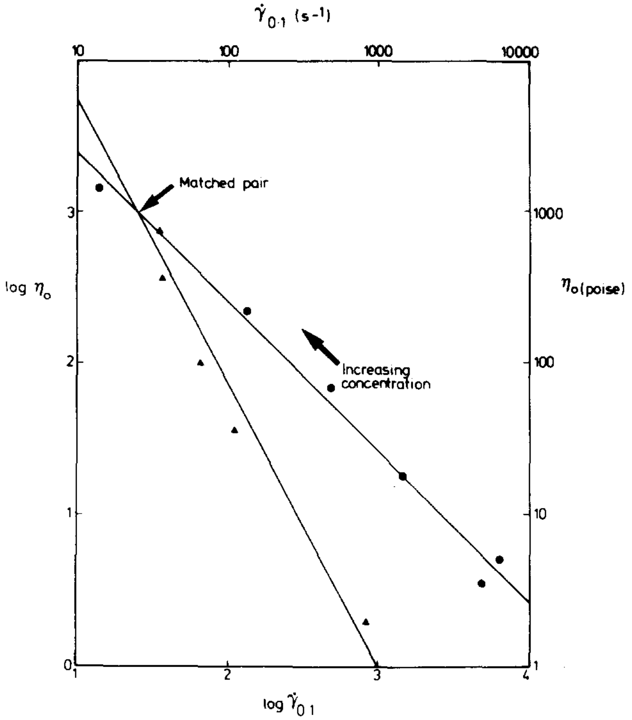

Fig. 6. Illustration of the method adopted to obtain 'matched pairs' of solutions with identical values of both η_0 and $\dot{\gamma}_{0\cdot1}$, and hence identical flow curves, but prepared from different polysaccharides. The results shown are for pectin (●) and lambda carrageenan (▲).

shows a corresponding decrease, as discussed above, and plots of $\log \eta_0$ versus $\log \dot{\gamma}_{0\cdot 1}$ are approximately linear. For some of the polysaccharides used in this work, these plots cross (e.g. Fig. 6) and thus solutions of each, made up to the concentrations corresponding to the point of intersection, should have identical values of both η_0 and $\dot{\gamma}_{0\cdot 1}$ and thus identical flow curves.

Two such matched pairs were included in our samples, one with a high value of η_0 and low value of $\dot{\gamma}_{0\cdot 1}$ (1·91% w/v guar; 2·97% w/v carrageenan) and the other with low η_0 and high $\dot{\gamma}_{0\cdot 1}$ (0·72% w/v carrageenan; 1·26% w/v alginate). As shown in Fig. 7, the measured viscosities for each pair are in close agreement at all shear rates. Panel assessments of perceived thickness and stickiness did not differ significantly (p =

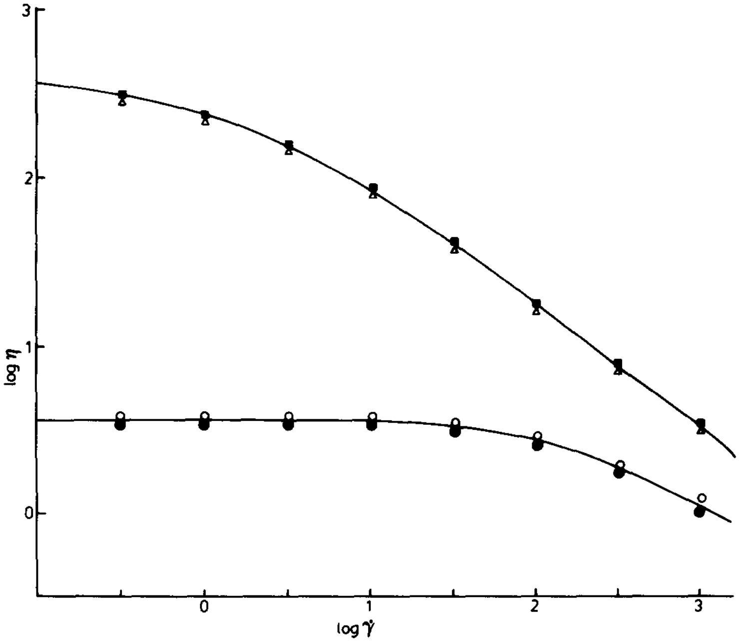

Fig. 7. Observed flow curves for 'matched pairs'. 1·91% Guar (■) and 2·97% carrageenan (△) were assigned thickness (T) and stickiness (S) scores of $\log T = 2{\cdot}12$ and 2·14 and $\log S = 2{\cdot}06$ and 2·06 respectively. For 0·72% carrageenan (○) and 1·26% alginate (●) the panel scores were $\log T = 1{\cdot}73$ and 1·74 and $\log S = 1{\cdot}72$ and 1·76 respectively. The significant difference ($p = 0{\cdot}05$) was 0·06 for thickness and 0·07 for stickiness.

0·05) within each pair, suggesting that for concentrated solutions of disordered polysaccharides perceived texture is dependent solely upon the objective flow properties and not upon the type of polysaccharide used.

Since, as discussed above, the differences in flow behaviour of our solutions can be characterised completely by η_0 and $\dot{\gamma}_{0\cdot1}$, we have attempted to correlate these with subjective assessments of perceived thickness (T) and stickiness (S). The first model tested was a simple linear relationship of the type shown in eqn 6, where a, b and c are adjustable parameters.

$$\log T = a \log \eta_0 + b \log \dot{\gamma}_{0\cdot1} + c \tag{6}$$

The parameters were estimated by the method of least squares. The best-fitting values are shown in eqn 7.

$$\log T = 0\cdot25 \log \eta_0 + 0\cdot10 \log \dot{\gamma}_{0\cdot1} + 1\cdot31 \tag{7}$$

As illustrated in Fig. 8, the agreement between observed and calculated values is excellent ($r = 0\cdot97$). A comparable quality of fit ($r = 0\cdot97$),

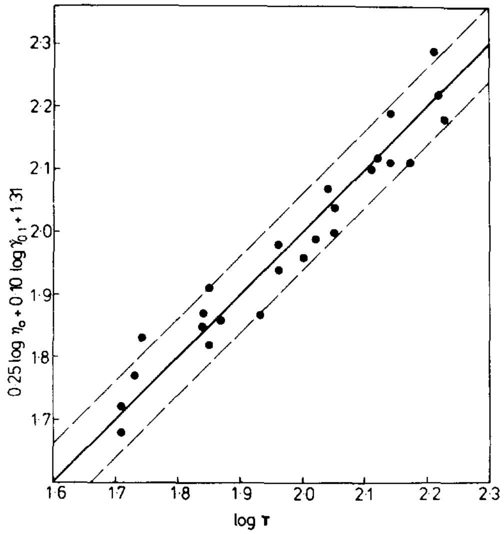

Fig. 8. Correlation of perceived thickness (T) with values calculated from η_0 and $\dot{\gamma}_{0\cdot1}$ by eqn 7. The dashed lines indicate the significant difference ($p = 0\cdot05$) of the panel scores.

with closely similar numerical parameters, was obtained (eqn 8) using the subjective assessments of 'stickiness' (S).

$$\log S = 0{\cdot}25 \log \eta_0 + 0{\cdot}12 \log \dot{\gamma}_{0{\cdot}1} + 1{\cdot}25 \qquad (8)$$

No improvement could be achieved in the statistical significance of these correlations using higher-order polynomial equations, or a 'bicubic spline' technique.

The sensory panel scores, however, all relate to an arbitrary standard (2·77% w/v pectin solution). To overcome this problem, panellists were also asked to assess the thickness of a range of 'Newtonian' samples (mainly sugar syrups) against the same standard solution (Cutler *et al.*, 1983). A good linear correlation ($r = 0{\cdot}99$) was observed between Newtonian viscosity (η_N) and perceived thickness (T) (eqn 9), with again a closely similar result for 'stickiness'.

$$\log T = 0{\cdot}221 \log \eta_N + 1{\cdot}691 \qquad (9)$$

The possible significance of the unusually low 'power law' exponent of 0·221 (cf. Stevens, 1975) is discussed elsewhere (Cutler *et al.*, 1983). By combining eqns 7 and 9 it is possible to calculate (eqn 10) the vicosity (η_N) of a Newtonian liquid which would be perceived as having an identical thickness (and stickiness) to any given polysaccharide solution of known η_0 and $\dot{\gamma}_{0{\cdot}1}$.

$$\log \eta_N = 1{\cdot}13 \log \eta_0 + 0{\cdot}45 \log \dot{\gamma}_{0{\cdot}1} - 1{\cdot}72 \qquad (10)$$

In summary we therefore conclude that disordered, 'random coil' polysaccharides in concentrated solution (i.e. $\eta_0 > 10$ cP) show only one independent textural variable, although subjectively this may be described both as 'thickness' and as 'stickiness'. The objective parameters η_0 and $\dot{\gamma}_{0{\cdot}1}$ correlate well ($r = 0{\cdot}97$) with perceived texture. Since these parameters are sufficient to characterise flow behaviour at all shear rates, this method neither assumes nor tests any particular model for oral perception. The standard of agreement between subjective and objective parameters, however, indicates that viscosity measurements under conditions of steady shear are a valid index of the perceived 'in-mouth' texture of fluid foods thickened by normal 'random coil' polysaccharides of the type studied in this work.

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