Carbohydrate Polymers 7 (1987) 395–402

Effect of Hydrocolloids on the Rheological Properties of Wheat Starch

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(Received 12 August 1985; revised version received and accepted 10 January 1987)

SUMMARY

The rheological properties of 5% starch alone and in the presence of 0·5% guar, locust bean or xanthan gums were studied using a Rheotest 2 viscometer at different temperatures. The 5% starch alone exhibited non-Newtonian behaviour at 30°C, but upon gelatinization it exhibited non-Newtonian shear thinning behaviour. In the presence of 0·5% guar, locust bean or xanthan gum at 30°C itself, the flow behaviour index 'n' of starch dispersions decreased and ranged between 0·83 and 0·90 indicating shear thinning or pseudoplastic behaviour of the starch-gum dispersions. After gelatinization, the effect of these gums was higher than at 30°C and the flow behaviour index 'n' decreased from 0·64 to 0·34, 0·45 and 0·25 in the presence of 0·5% guar, locust bean and xanthan gum respectively. None of the starch or starch-gum pastes studied exhibited the yield value in the range of shear rates studied.

INTRODUCTION

Wheat starch is a basic ingredient of various cooked and baked foods. Hydrocolloids such as guar gum, xanthan, locust bean gum etc., are used to improve the moisture retention, texture and overall product quality (Glicksman, 1974). The rheological behaviour of cooked wheat starch dispersions in water has been studied by Evans & Haisman (1979) and Bagley and Chistianson (1982, 1983); with a view to understanding the behaviour of starch under different conditions of cooking. Hydrocolloids have been known to affect the pasting properties and β-amylolysis (Christianson *et al.*, 1981). Addition of small amounts of hydrocolloids significantly increased the peak viscosity and decreased the degree of retrogradation, by interacting with the soluble amylose which leached out of the starch granules during the second stage of swelling. Hydrocolloids also reduced the blue value of starch, inhibited the syneresis of starch gels and improved the textural properties (Sajjan, 1986). Hence, it was of interest to study the effect of hydrocolloids on the rheological behaviour of wheat starch dispersions. Moreover, these studies may also provide the insight to understand the interactions that occur at molecular level. In the present paper, the rheological behaviour of wheat starch in the presence of guar, locust bean and xanthan gum is presented.

MATERIALS AND METHODS

Wheat starch

Wheat starch was isolated by the method of MacMasters & Hilbert (1944).

Gums

Guar gum: Guar seeds were dehusked by treating with boiling 2% sodium carbonate for 5 to 10 min. The dehusked seeds were neutralized with 0·05 N HCl, washed and dried. Seeds were ground to separate gum splits (endosperm) from germ, and the splits were then pulverized and passed through a 200 mesh sieve.

Xanthan and locust bean gums were purchased from Sigma Chemical Company.

Sample preparation and viscosity measurements

Starch dispersions in water or hydrocolloid solutions were prepared by mixing in a Virtis homogenizer, model-45 for 1 min. Viscosity was measured over a range of shear rates (72·9 to 1312 s^{-1}) at different temperatures in a Rheotest 2 (a concentric cylinder viscometer). To minimize the settling of the starch, the dispersions were prepared and transferred immediately to a viscometer cup, where the dispersion was stirred continuously at a shear rate of 72·9 s^{-1}. Viscosity was measured at each shear rate after subjecting the starch dispersion to shearing action for 30 s. The temperature of the sample was maintained within the range of ±0.1°C by circulating the water from a thermostatically controlled water bath in the jacket of the sample cup.

To determine the yield stress, starch pastes, either alone or in the presence of guar, locust bean or xanthan gum were prepared by heating at different temperatures for 15 min and transferred immediately to the viscometer cup maintained at the same temperature. The viscosity was determined over a shear rate range of 0·9 and 1312 s^{-1}.

RESULTS

Figure 1(a) shows the apparent viscosity–shear rate curves of 5% wheat starch at different temperatures in water. At 30°C the viscosity remained constant (0·00055 Nsm^{-2}) at all the shear rates but, when heated to 60°C, showed a slight decrease in viscosity with increasing shear rate. As the temperature increased, the dependence of viscosity on shear rate also increased while the cooled paste exhibited a similar shear rate-dependent viscosity. Fig. 1(b) illustrates the results for 5% starch in a 0·5% guar gum medium minus the viscosity contributed by the 0·5% guar gum alone at the respective shear rate and temperature. At 30 and 60°C

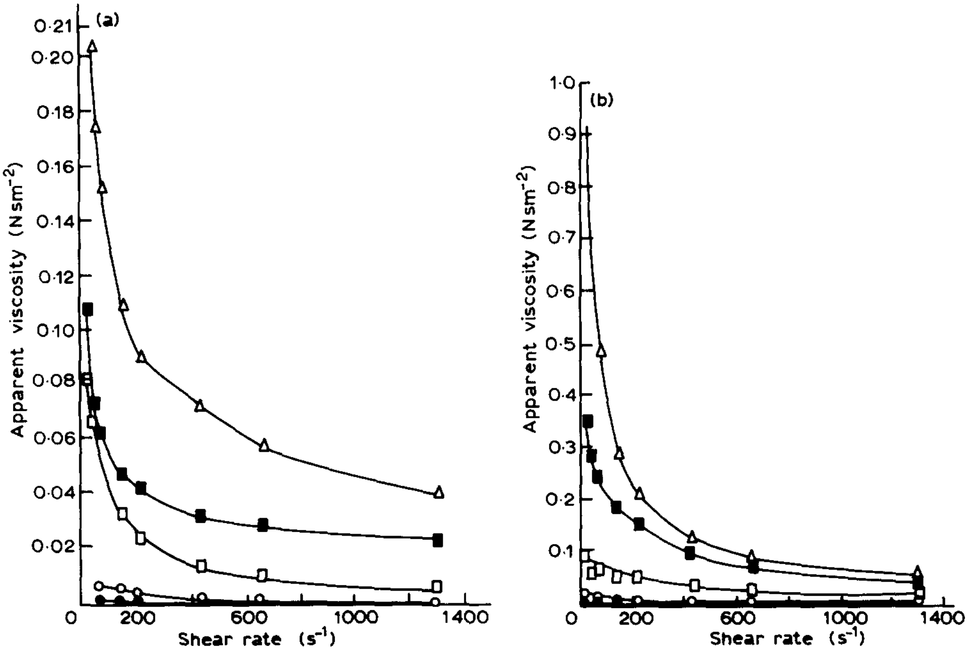

Fig. 1. Apparent viscosity–shear rate curves of (a) 5% wheat starch and (b) 5% wheat starch in a 0·5% guar gum medium at different temperatures in water. ●, 30°C; ○, 60°C; □, 70°C; ■, 90°C; △, after cooling to 30°C.

the viscosities showed very little dependence on the shear rate, and are nearly comparable to the control at 30 and 60°C (Fig. 1(a)). But at higher temperatures, although the dispersion showed similar shear-thinning behaviour, the effect of shear rate on the viscosity was high and the apparent viscosities were also high. The same pattern of curves was observed in the presence of 0·5% locust bean gum but with a comparatively lower viscosity dependency of the shear rates than in the presence of 0·5% guar gum. Whereas in the presence of 0·5% xanthan gum a slightly higher degree of viscosity dependency on the shear rate than in presence of 0·5% guar gum was observed. Figures 2(a) and 2(b) show the log–log plot of shear rate versus shear stress of 5% starch heated in water and in a 0.5% guar gum medium at different temperatures. Similar types of curves were observed in the presence of 0.5% locust bean gum but with a comparatively lower viscosity dependency of the shear rates than in the presence of 0·5% guar gum. Whereas in the presence of 0·5% xanthan gum a slightly higher degree of viscosity dependency on the shear rate than in presence of 0·5% locust bean and xanthan gum also (not shown). These curves indicated that at all the temperatures studied, starch and starch-gum pastes behaved, to a very good approximation, as power law liquids over the range of shear rates tested, and it can be described by a simple power law model with the yield stress:

$$T - T^0 = KD^n$$

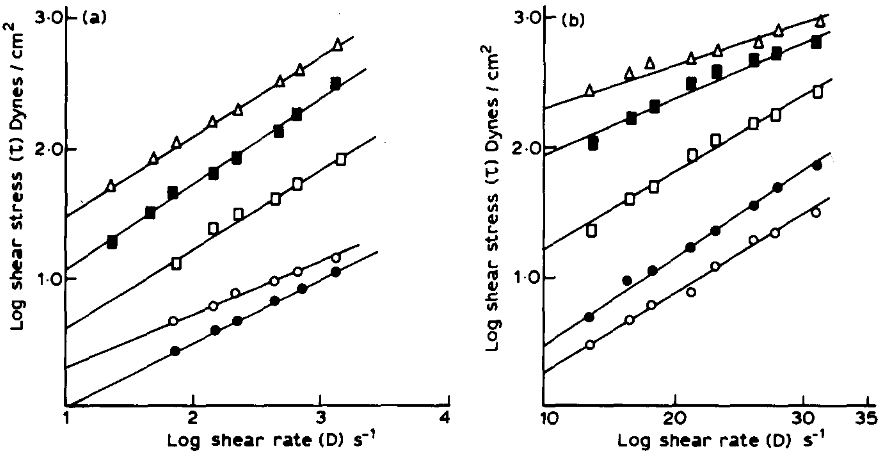

Fig. 2. Log–log plots of shear rate versus shear stress of 5% starch heated in water (a) and in a 0·5% guar gum medium (b) at different temperatures. ●, 30°C; ○, 60°C; □, 70°C; ■, 90°C; △, after cooling to 30°C.

where T = shear stress, N m^{-2} (dynes cm^{-2}); D = shear rate, s^{-1}; K = consistency index, N m^{-2}, n = the pseudoplasticity index (which is unity for Newtonian liquids, less than 1 for pseudoplastic and greater than 1 for dilatant liquids) and T^0 = yield stress, N m^{-2} (dynes cm^{-2}). The power law constants k and n were calculated by the linear regression analysis method substituting $C = 0$ as none of the starch or starch-gum pastes exhibited yield stress under these experimental conditions and the correlation coefficients varied between 0·996 and 0·999 or better. Table 1 gives the power law constants of 5% starch heated in water medium (control) and other gum media, at different temperatures. At 30°C, 5% starch in water showed a very low value of K 0·00002 N m^{-2} while n was almost unity, indicating that the system was Newtonian. As the temperature increased to 90°C, the system exhibited a typical non-Newtonian shear thinning behaviour (flow behaviour index = 0.61). In the presence of 0·5% gum (guar, locust bean or xanthan), even at 30°C, the system exhibited a tendency towards the non-Newtonian behaviour with n values ranging between 0·83 and 0·90. With increasing temperature, the degree of pseudoplasticity also increased and the n values ranged from 0·25 to 0·45, with the lowest value being for 0·5% starch–xanthan gum pastes.

TABLE 1
Power Law Constants of 5% Wheat Starch at Different Temperature Without Gum (Control) and with Guar, Locust Bean and Xanthan Gum

Concentration and type of gum	*Power law constants*[a]	*Temperature (°C)*					
		30	*60*	*70*	*80*	*90*	*After cooling to 30*
5% starch	$K\times10^{-3}$	0·02	0·93	1·35	1·50	1·74	7·39
	n	0·99	0·72	0·64	0·66	0·67	0·64
5% starch + 0·5% guar gum	$K\times10^{-3}$	1·21	2·04	10·65	15·83	30·20	75·82
	n	0·83	0·70	0·61	0·60	0·44	0·34
5% starch + 0·5% locust bean gum	$K\times10^{-3}$	0·23	9·11	15·46	20·43	45·39	102·3
	n	0·96	0·73	0·65	0·59	0·59	0·45
5% starch + 0·5% xanthan gum	$K\times10^{-3}$	4·60	22·93	22·78	23·45	36·27	74·23
	n	0·80	0·78	0·33	0·31	0·30	0·25

[a] K is the consistency index, N m^{-2}; n is the Pseudoplasticity index, dimensionless.

DISCUSSION

Since at 30°C, the starch granules do not hydrate and hence behave as rigid particles which are not subject to shear effects, they exhibit Newtonian behaviour. In contrast, Bagley & Christianson (1982) observed dilatancy but this discrepancy may be due to the higher concentration of starch that was used in their studies. The shear-thickening or dilatancy occurs, only in closely packed assemblies of solid particles, for which the system volume must increase to accommodate particle flow under shear. For spheres this 'volumetric dilation occurred only when particle concentration was greater than that required for simple cubic packing i.e. 52·3% by volume' (Morghan, 1968). As the temperature increases the starch granules swell, soften and become deformable in the shear field and the dispersions exhibit a non-Newtonian shear-thinning behaviour without yield stress which remains even after cooling. On the other hand, Doublier (1981) and Lang & Rha (1981) observed a yield value for cooled starch pastes. Bagley & Christianson (1983) reported similar behaviour of starches at high temperatures as found in our studies; that is shear-thinning behaviour without a yield value even with more concentrated starch pastes (11, 12, 13 and 14%) but they observed a yield value above 10% starch after cooling the starch pastes to 23°C. Thus the yield value depends on the concentration of the starch, the cooking temperature and time (Doublier, 1981), intermolecular hydrogen bonds and molecular entanglement (Glicksman, 1969; Hodge & Osman, 1976; Heckman, 1977) and also on the method used to determine the yield value (Lang & Rha, 1981). Hence the concentration of starch used in these experiments may be very low to exhibit yield stress at the temperatures studied. The high *K* value after cooling compared to the *K* value at 30°C is a result of the increased consistency due to the swelling of the starch granules.

Starch, when heated in a gum medium also exhibited similar non-Newtonian shear-thinning behaviour but with low '*n*' values and high *K* values. These results indicated that these gums do not affect the overall flow behaviour of starch pastes although they change the degree of pseudoplasticity. In the presence of 0·5% guar gum, the flow behaviour index '*n*' decreased to 0·34 in cooled pastes whereas in the presence of 0·5% xanthan and 0·5% locust bean gum it decreased to 0·25 and 0·45 respectively. It is well known that the degree of pseudoplasticity depends on the number of molecules, their chain length and their conformation (Szezesniak, 1977). An increase in the degree of pseudoplasticity of starch-guar gum pastes may be explained on the basis of its structure. Guar gum is a non-ionic hydrocolloid and is essentially a galactomannan with a β-(1 → 4) linked mannan backbone to which single galactose stubs are linked through a (1 → 6) linkage on every alternate mannose residues (Baker & Whistler, 1973). These alternate galactose branches inhibit the formation of intramolecular hydrogen bondings thus keeping the molecule in an extended form, which can readily interact with the amylose molecules which are present in the system through non-covalent hydrogen bondings resulting in the more extended conformation which, in turn, increases the degree of pseudoplasticity. In contrast, locust bean gum, is also a galactomannan, but with a different galactose to mannose ratio (1:4), and with a mannan backbone irregularly substituted with galactose residues at their sixth position (Baker & Whistler, 1975). Owing to this irregular branching, it tends to coil with the formation of intramolecular hydrogen bondings and hence interacts less with the linear amylose molecules, as the number of hydroxyl groups available to form intermolecular hydrogen bondings with amylose molecules decreases, thus the observed low pseudoplasticity compared to guar gum. The much higher degree of pseudoplasticity that was observed for the starch–0·5% xanthan gum, compared either to guar or locust bean gum-starch pastes is due to its ionic nature and also to its highly branched structure (Kovacs & Kang, 1977). The ionic groups (principally carboxylic in nature) that are distributed throughout the molecule repel each other due to their like charges and tend to keep the molecule in a highly extended conformation which readily interacts with the non-ionic amylose molecules that are present in the medium resulting in much more extended conformation, thus the observed pseudoplasticity. Although these gums enhanced the degree of pseudoplasticity of starch dispersions, none of them seemed to induce a yield value at the concentration used in our studies.

ACKNOWLEDGEMENTS

We are thankful to Dr K. R. Bhattacharya for his helpful discussion. One of us (S.U.S.) is grateful to the Council of Scientific and Industrial Research, India, for awarding the research fellowship while carrying out this work.

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