Carbohydrate Polymers 5 (1985) 329–341

The Extrusion of Soya with Alginate Using a Twin-screw Cooking Extruder

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(Received: 2 November 1984)

SUMMARY

The twin-screw extrusion cooking of soya grits with the addition of sodium alginate is described. These studies showed that the extruder torque and die temperature were reduced with 1% additive, as observed in independent studies with a laboratory scale single-screw extruder. While the mechanical power consumption of the extruder was reduced, the consumption of thermal energy to the barrel heaters increased to maintain the set temperature profiles on adding the alginate. The total power consumption of the extruder is therefore only reduced to 94% of the value for soya alone. The die pressure has been shown to scale with the mechanical power consumption whereas the die temperature increases linearly with the combined mechanical and thermal power consumption. The results indicate the addition of alginate confers a temperature insensitivity on the aqueous dispersion rheology of soya.

1. INTRODUCTION

The production of textured foods from vegetable proteins provides one of the important applications of the extrusion cooking process. In particular, the extrusion of soya has received considerable attention

Carbohydrate Polymers 0144-8617/85/$03.30 – © Elsevier Applied Science Publishers Ltd, England, 1985. Printed in Great Britain

(e.g. Cumming *et al.*, 1973; Frazier *et al.*, 1980; Harper, 1981; Frazier & Crawshaw, 1984) although the process remains poorly understood. The differences between the behaviour of defatted soya flour and isolated soya protein in extrusion has led to an identification of the carbohydrate component as playing an active role (Smith *et al.*, 1982). The addition of polysaccharides to soya has been shown to have a pronounced effect on the extrusion behaviour. The addition of sodium alginate to soya grits has been observed to lower the dough viscosity, the die temperature and the extruder torque using a laboratory scale Brabender single-screw cooking extruder (Smith *et al.*, 1982; Berrington *et al.*, 1984). Independent studies of the effect of sodium alginate additions on the texture of soya extrudates have also been reported (Boison *et al.*, 1983).

The present experiments were carried out to investigate the effectiveness of added sodium alginate when extruding soya grits using a twin-screw pilot-scale extruder. The pressure and temperature profiles in the extruder barrel have been monitored for a number of extrusion conditions together with the motor torque, motor power and heater power. The product has been defined in terms of the diameter expansion ratio and bulk density. The viscosity of aqueous dispersions of the product has also been examined before and after post-extrusion heat treatment at 80°C. The extruder was also dead-stopped during soya/alginate extrusion and the barrel contents examined using scanning electron microscopy. The bulk density and aqueous dispersion viscosity were also measured for samples extracted from the extruder barrel.

The experimental procedure and the results of this study are described in Sections 2 and 3, respectively, of the paper followed by a discussion in Section 4.

2. EXPERIMENTAL APPROACH

2.1 Materials

Defatted soya grits (Prima Products Ltd, UK) were used in this study. The protein dispersibility index quoted by the suppliers was 68–76%. The moisture content as determined by oven drying at 105°C for 8 h was 9·5%.

The sodium alginate (supplied by Kelco/AIL International Ltd, UK) had a mannuronate/guluronate ratio of 1·4. Extrusion was carried out with soya alone and with added alginate. The alginate was added at the 1% level relative to the net weight of soya grits ((weight of alginate/ weight of soya grits and added water) = 0·01) and mixed in a Hobart mixer prior to extrusion.

2.2 Extrusion

A Baker Perkins MFP50 5OD intermeshing, co-rotating twin-screw extruder was used in this study. The barrel could be split longitudinally and the screws built up from screw and mixing paddle elements. The screw profile used for this study is shown in Fig. 1. The extruder comprises five temperature zones which are heated by electrical resistance heaters and cooled by a freon refrigeration system. The extruder was instrumented to measure the temperature and pressure along the barrel. The torque, screw speed, motor power and electrical heating power were also monitored. Water was added to the extruder separately from the solid feed. All data were continuously monitored and recorded at 10-s intervals using a microcomputer logging system.

The extrusion conditions used in this study are shown in Table 1. Extrusion of soya with and without alginate was carried out with 3 mm diameter dies. Under steady conditions of pressure, torque and temperature (after 20–30 min), samples of extrudate were collected. In one case (condition (e), Table 1) the extruder was dead-stopped and rapidly cooled.

2.3 Extruded material

The diameter and the bulk density of the extrudate were measured, the latter being calculated from the displacement of fine sand.

Rheological experiments on the extruded material were carried out after milling to within the size range 180–250 μm using a centrifuge mill. The milled material was added to distilled water to give a 9·1% by weight dispersion which was stirred continuously for 30 min using a laboratory vane stirrer. The dispersion was then sheared in a Couette type rheometer (Contraves Rheomat 115) at 25°C at a shear rate which was increased linearly to 148 s^{-1} in 431 s. The dispersion was then heated

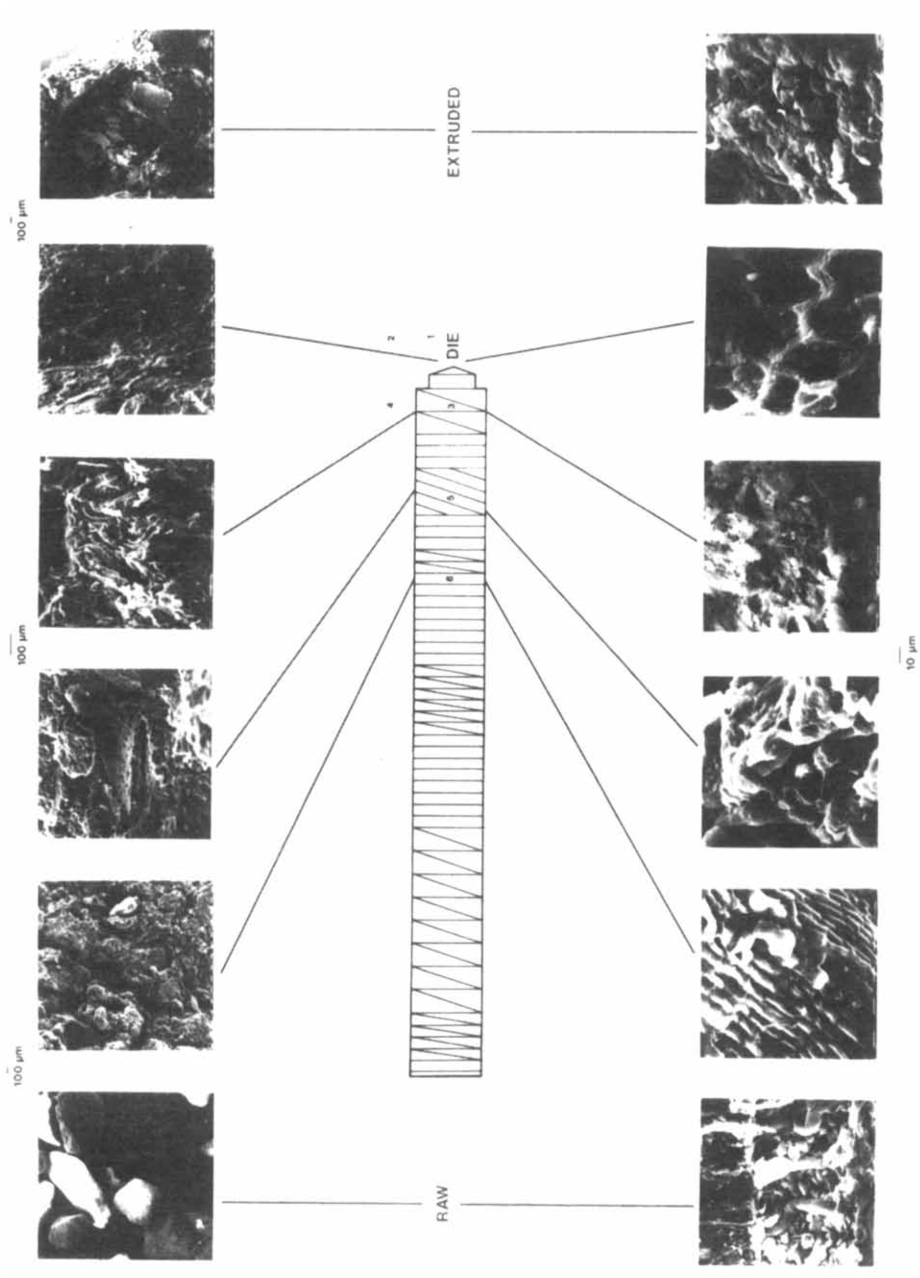

Fig. 1. The screw geometry used in these experiments: sequence of scanning electron micrographs corresponds to progress along the barrel for soya and alginate following the dead-stop procedure (condition (e), Table 1).

TABLE 1
Extrusion of Soya Grits

Condition	*Total water feed rate* ($kg\ h^{-1}$)	*Soya feed rate* ($kg\ h^{-1}$)	*Water feed rate* ($kg\ h^{-1}$)	*Extruder set temperatures* (°C) Feed ... Die	*Screw speed* (r.p.m.)	*Viscosity/density* ($Pa.m^3\ s\ kg^{-1}$)	*Torque* (% of extruder maximum)	*Motor power* (kW)	*Heater power* (kW)	*Mechanical and heater power* (kW)
Soya alone										
(a)	21·8	40	18	27-52- 93-120-120	200	6·0	29	1·82	3·10	4·92
(b)	21·8	40	18	27-60-120-170-170	200	8·7	43	2·56	4·47	7·03
Soya with 1% w/w sodium alginate										
(c)	21·8	40	18	27-52- 93-120-120	200	3·4	20	1·31	3·32	4·63
(d)	21·8	40	18	27-60-120-170-170	200	5·2	27	1·68	5·20	6·89
(e)	13·8	40	10	27-52- 93-120-120	200	13·8	46	2·79	2·37	5·16

at 80°C whilst being stirred for a further 30 min followed by a repetition of the above shear history at 25°C. The shear viscosity at 148 s^{-1} before and after heat treatment at 80°C was calculated.

The bulk density and dispersion viscosities were measured for material removed from the extruder following the dead-stop procedure. Samples from the extruder barrel were also mounted with silver paint and coated with gold before examination by scanning electron microscopy (Philips 501B, 30 kV).

3. Results

The torque, heater power and motor power consumptions are given in Table 1.

The material viscosity, η, has been defined as $(\Delta P/Q)\ d^3$ where d is the die diameter, Q is the volume flow rate and P is the die pressure. The viscosity normalised by the density (ρ); $\eta/\rho = \Delta P.d^3/M$ has been tabulated in Table 1, where M is the mass flow rate (soya and water). The viscosity defined in this fashion is not a true shear viscosity as it includes die end effects and assumes Newtonian behaviour. It serves as a means of comparing the material rheologies using the existing die. The viscosity, torque, heat and drive powers increased with increasing extrusion temperature, both with and without alginate. An increase in the moisture of the soya with alginate led to lower viscosity, torque and motor power, although the heat power consumption increased.

The data in Fig. 2 show the pressure and temperature profiles in the extruder under equilibrium operation. The pressure in the extruder barrel only rose sharply near the die under all conditions with the present screw configuration. The temperature profiles show the principal effect of the two barrel temperature settings used. The addition of alginate to the soya resulted in a decreased die temperature, although the extrusion moisture also affected its value.

The results of Table 2 characterise the extrudate according to expansion, bulk density and dispersion viscosity. A cohesive cylindrical extrudate was not formed with soya alone using 3 mm diameter dies. The effect of added alginate was to increase the extrudate bulk density. An increase in the extrusion temperature raised the bulk density.

The rheology of the extrudate dispersions is characterised in Table 2 according to the effect of heat treatment at 80°C. Prior to heat treat-

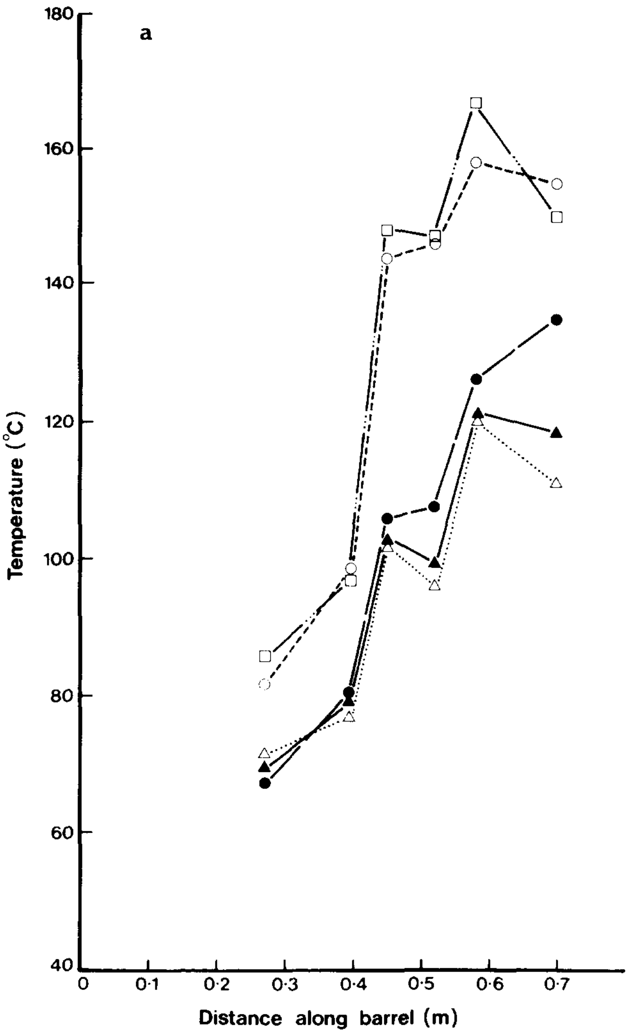

Fig. 2(a) The temperature profiles in the extruder barrel for the extrusion of soya with and without alginate using 3 mm dies. Extrusion conditions are given in Table 1. Barrel distance measured from centre of feed port. Die probe at 0·7 m. Extrusion conditions given in Table 1: (a), ▲; (b), ○; (c), △; (d), □; (e), ●.

ment the viscosity was low for raw and extruded soya without alginate. Heat treatment increased the viscosity of extruded soya whereas the raw material rheology was little changed. Addition of alginate raised the dispersion viscosity of raw and extruded soya.

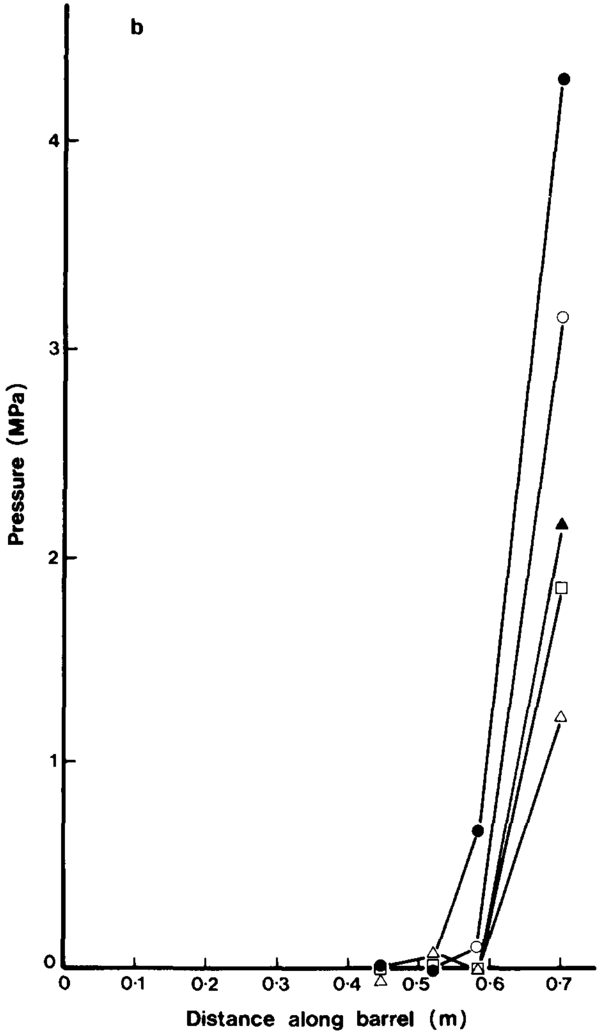

Fig. 2(b) The pressure profiles in the extruder, as for Fig. 2(a).

The variation of the bulk density and the dispersion rheology with progression in the extruder is shown in Figs 3 and 4 following a typical dead-stop procedure. The bulk density increased towards the die corresponding to the increase in both pressure and temperature in the barrel (Fig. 2). The aqueous dispersion viscosity decreased monotonically down the barrel. Heat treatment caused an increase in the viscosity.

TABLE 2
Extruded Soya Properties

Condition	*Expansion ratio*[a], *(diametric)*	*Aqueous dispersion viscosity (m Pa s) at 148 s⁻¹, 25°C*		*Bulk density (kg m⁻³)*
		As made	*After heating at 80°C*	
Soya alone				
(a)	–	39·7	86·5	390
(b)	–	39·7	65·1	890
Raw		33·5	33·3	630
With 1% w/w sodium alginate				
(c)	0·98	92·4	86·8	820
(d)	1·19	42·8		1270
(e)	1·22	46·4	105·7	940
Raw		178·8	166·3	620

[a] Cohesive cylindrical extrudate not formed with soya alone.

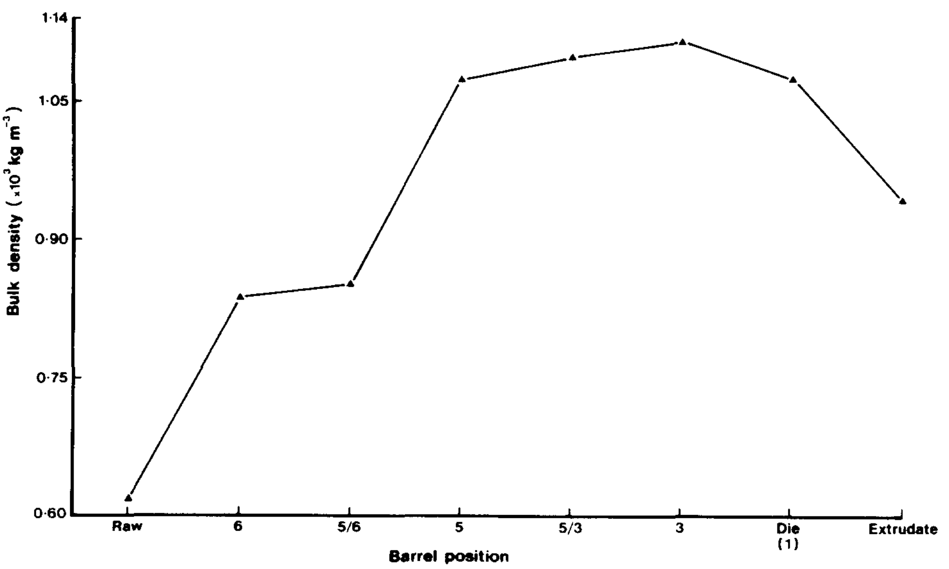

Fig. 3. The bulk density of samples removed from the extruder barrel following a dead-stop procedure for soya and alginate (extrusion condition (e), Table 1).

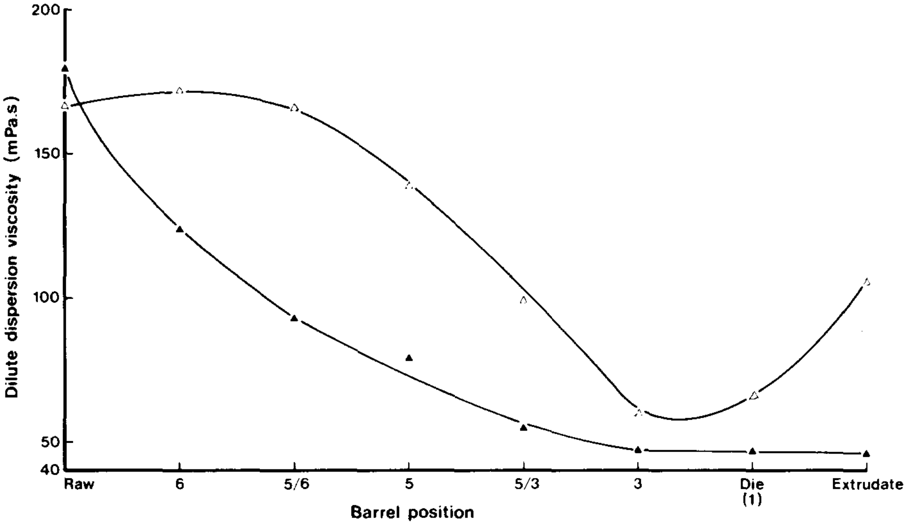

Fig. 4. The aqueous dispersion viscosity at 148 s^{-1} before (▲) and after (△) heat treatment at 80°C as a function of barrel location for samples removed from the extruder barrel following a dead-stop procedure for soya and alginate (extrusion condition (e), Table 1).

The sequence of scanning electron micrographs for material extracted from the barrel showed the texturing effect of the extrusion process (Fig. 1), which is similar to that observed for soya (Frazier *et al.*, 1980).

4. DISCUSSION

The trends in the die pressure in the present experiments may be related to the apparent dough viscosity. The dough viscosity of soya with alginate increased with decreasing moisture in agreement with the observation of Frazier & Crawshaw (1984) who used a die of 8 mm diameter in single-screw extrusion of soya. Harper *et al.*, (1971) embodied an exponential moisture dependence of viscosity in their empirical equation for extrusion doughs, which is in accord with these observations.

Extrusion of soya through 3 mm dies showed a viscosity increase with increasing temperature. This level of moisture may promote denaturation or other reactions which will increase the viscosity.

The dough viscosity (as indicated by the die pressure) decreased on addition of alginate to soya. Without alginate the viscosity was 1·76 times greater at a barrel temperature of 120°C and 1·67 times greater at a barrel temperature of 170°C. Smith *et al.* (1982) observed that the soya dough viscosity was 1·35 times greater without alginate for an extrusion temperature of 170°C and a screw speed of 250 r.p.m., although data were not available at the same flow rate. These authors also showed that without alginate the torque was 1·65 times greater compared with present values of 1·45 and 1·59 at 120 and 170°C, respectively.

The die pressure increased linearly with the mechanical power dissipation as did the product of torque and screw speed.

The decrease in the die temperature caused by adding alginate was 7 and 5°C for set barrel temperatures of 120 and 170°C, respectively. Smith *et al.*, (1982) observed a decrease of 7°C for extrusion on adding alginate at a barrel temperature of 170°C although their extrusion parameters were different from the present studies. The specific heater energy consumption is plotted against the die temperature in Fig. 5.

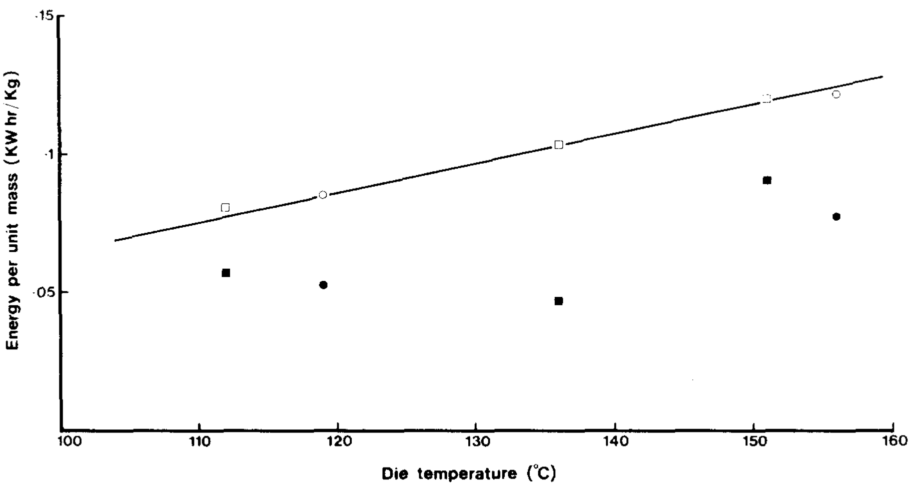

Fig. 5. The thermal power per unit flow rate and the sum of thermal and mechanical power per unit flow rate as a function of die temperature for the experiments with and without added alginate (Table 1). Thermal power: ●, conditions (a) and (b) (soya, 3 mm die); ■, conditions (c)–(e) (soya/alginate, 3 mm die). Total power: ○, conditions (a) and (b) (soya, 3 mm die); □, conditions (c)–(e) (soya/alginate, 3 mm die).

The sum of the motor and heater specific energies is also plotted against the die temperature. These data imply that the temperature rise in the material in the extruder is due to viscous and mechanical energy dissipation in addition to direct heating. The addition of alginate to soya reduced the mechanical energy consumption but this was compensated for by increased direct heating energy to maintain the fixed barrel temperature set points. On adding alginate the sum of the thermal and mechanical energies was reduced to 94 and 98% of the alginate-free experiments for 120 and 170°C set barrel temperatures, respectively. This was reflected in the reduced die temperatures for added alginate, according to Fig. 3.

The addition of alginate to soya results in a more aggregated structure before and after extrusion (Smith *et al.*, 1982). This was shown by the higher viscosity of the soya–alginate dispersions of both raw and extruded material. The effect of heat treatment of the dispersions was greatest for extruded soya and least for the raw material with or without alginate. The proposed inhibition of the denaturation process in soya by the alginate (Smith *et al.*, 1982) may be such that the extruded soya/alginate system bears some similarity to the unextruded material.

5. CONCLUSIONS

The 'scaling up' of soya grits extrusion to a pilot-scale twin-screw extruder shows that the addition of sodium alginate produces many of the desirable extrusion characteristics that typified the use of a laboratory-scale single-screw extruder. The extruder torque, die temperature and mechanical power input are all reduced on addition of 1% by weight of sodium alginate. A cautionary side effect is that the consumption of thermal power increases to maintain the set extrusion temperatures since less viscous heating occurs on reducing the mechanical power. A consideration of the thermal and mechanical power input nonetheless shows that the addition of alginate reduces the consumption to 94% although the die temperature is also reduced.

The die pressure in the extruder has been shown to scale with the mechanical power dissipation for the experiments of this study. In addition, the die temperature increases with the sum of the thermal and mechanical energy input.

The measurement of the aqueous dispersion viscosity shows that the addition of alginate confers a temperature stability on the extrudate that is typical of raw soya whereas extruded soya in water increases in viscosity by a factor of over 3 on heating to 80°C. These observations are consistent with the proposed hindering of the soya denaturation/aggregation processes by the alginate.

A further study involving a greater variation of temperature, moisture and screw geometry would indicate the range of product properties and efficiencies that are possible with a pilot-scale cooking extruder.

ACKNOWLEDGEMENTS

The experimental assistance of Misses S. I. Fletcher and A. L. Hayter, and T. J. McMaster and R. J. Turner are gratefully acknowledged.

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