COMPARISON OF SHEAR AND EXTENSIONAL VISCOSITY CHARACTERISTICS OF STARCH PASTES.

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ABSTRACT

The extensional and shear viscosity characteristics of potato starch pastes were studied as a function of concentration and shear rate. Extensional viscosities were found to be higher than shear viscosities in all cases. The Trouton ratios demonstrate a relatively independent response to strain rate, taken to indicate the particle dispersion like character of starch pastes. These observations demonstrate the potential dominance of extensional viscosity measurements in rheological characterisation of potato starches.

INTRODUCTION

Shear viscosity measurements of starch pastes have been reported[1,2] outlining the typical flow curves for polymeric materials of non-Newtonian nature as suggested by Cross[3] and Carreau[4]. Extensional viscosity measurements on potato starch pastes have not been reported, however it is becoming increasingly apparent from work carried out by others[5,6,7] on different materials that extensional viscosity values differ significantly from those seen for shear flow. Aqueous non-Newtonian solutions have been found to display extensional viscosities considerably greater than those seen under shear flow conditions[8]. The differences between the extensional and shear flow viscosity values serves to highlight the dominant role extensional flows exert on the polymer. Extensional forces are present in a number of processes, pumping, pouring[9] and extrusion[10]. Therefore this leads to the conclusion that an understanding of extensional flow properties is necessary before a total rheological characterisation of a polymer can be achieved.

The aim of this study, therefore, is to demonstrate the differences between shear and extensional viscosities for potato starch pastes at different concentrations, comparing the results and their impacts on the rheological properties.

Direct comparison of extensional and shear viscosities is achieved by means of the Trouton ratio, T_R, which can be defined as:

$$T_R = \frac{\eta_E(\dot{\varepsilon})}{\eta(\dot{\gamma})} \qquad (1)$$

where η_E is the extensional viscosity of the system at a strain rate of $\dot{\varepsilon}$ and η is the shear viscosity at a corresponding shear rate of $\dot{\gamma}$. For Newtonian fluids the extensional viscosity of the system is three times that of the shear viscosity as required by Trouton's rule. Hence, the Trouton ratio, by definition, is 3 over all strain rates. Calculation of the Trouton ratio depends of the choice of a suitable conversion relating strain rates of extensional flows to shear rates in shear flows. Jones et al[11] proposed that the appropriate shear rate to calculate T_R is given by:

$$\dot{\gamma} = \sqrt{(3)}\,\dot{\varepsilon} \qquad (2)$$

MATERIALS AND METHODS

Starch

The starch used in this study is an example of a commercially available potato starch. Starch pastes were prepared by addition of starch to distilled water which was simultaneously stirred and heated to 90°C. This ensured all the starch graules had swollen. The sample was then cooled before the measurements were made at 20°C.

Stress Tech Rheometer

All shear viscosity measurements were performed using a Stress Tech, a controlled stress rheometer from Reologica Instruments AB of Lund Sweden.

The measurement system used was a single concentric cylinder where the shear rate range covered was 3 to 400s⁻¹.

The Rheometrics RFX Fluids Analyser

The Rheometrics RFX Fluids Analyser is an example of a stagnation point device which uses the opposing jets principle[12] to create an area of intense extensional flow. The RFX is capable of measuring the extensional viscosity of low viscosity fluid materials over approximately four decades of extensional strain rates (ca. 10^{-1} to 10^{3} s⁻¹). The sensitivity of the torque rebalance transducer allows average apparent extensional viscosities of between 10^{-2} and 10^{3} Pa s to be measured. The RFX, Figure 1, achieves the desired strain rate by controlled withdrawal of fluid from a beaker into two syringes through the twin jets. This is continued until the torque rebalance transducer records a steady reading. Calculation of the extensional viscosity is achieved from a knowlede of the force, jet separation, jet diameter and volumetric flow rate.

Extensional stress;

$$\sigma_e = \frac{F_j}{A} \qquad (3)$$

where F_j is the measured force at the jet and A is the cross sectional area of the jet.
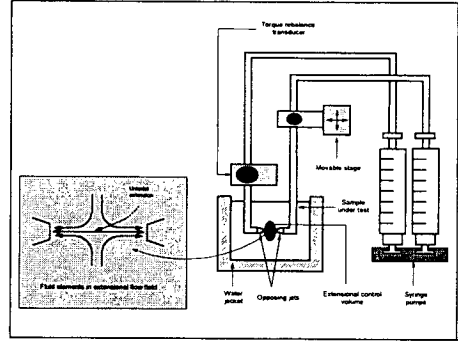

Figure 1. Schematic drawing of the RFX Fluids Analyser.

Extensional strain rate;

$$\dot{\varepsilon} = \frac{8Q}{\pi G (D_j)^2} \qquad (4)$$

where Q is the volumetric flow rate, G is the gap between the jets and D_j is the diameter of the jets.

Extensional viscosity;

$$\eta_E = \frac{\sigma_e}{\dot{\varepsilon}} \qquad (5)$$

RESULTS AND DISCUSSION.

The extensional and shear viscosities of the potato starch pastes have been measured at comparable strain and shear rates and are shown in Figure 2.

All measurements were made at 20°C and it is clear that the extensional viscosity (filled symbols) of the starch pastes in all cases have higher values than their shear viscosity counterparts. The greater values of the extensional viscosities can be attributed directly to the nature of extensional flows. Under extensional flow the molecules are forcibly aligned and stretched or 'unwound'[13], a process which increases the 'internal friction' between the molecules. Thus by a combination of alignment and stretching the extensional viscosity recorded is higher than that seen in the purely disruptive effects of shear.
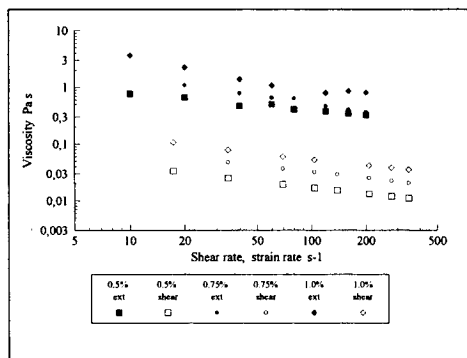
Figure 2. Comparison of extensional and shear viscosities of potato starch pastes at various concentrations.

Figure 3. Trouton ratios for the various potato starch pastes.

It should be noted that in true solutions the difference between extensional viscosity and shear viscosity increases with increasing shear rates[9,14,15]. However, in Figure 2, as shear or strain rate increases the difference between the two viscosity values remains relatively constant. This would seem to indicate a different behaviour being exhibited by the starch than that of a true solution. This can best be explained by describing a starch paste as a particulate dispersion[16] of material as opposed to a true solution

The established means of comparing extensional and shear flow viscosities is the Trouton ratio, which has the low strain Newtonian value of 3. From this start point a true solution will show increasing Trouton ratios with strain rates. The Trouton ratio plots for the starches are shown in Figure 3.

With the exception of the 0.5% starch paste, the Trouton ratio graphs show an essentially independent profile with respect to increasing strain rate. This is in contrast with the generally accepted trend of increasing Trouton ratios with strain rate seen for true solutions seen by a number of authors[6,8,9]. Again the reason for the difference in behaviour stems from the properties of the starch paste itself; that it can be thought of as a particulate dispersion.
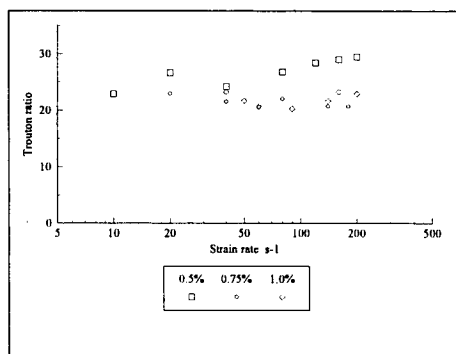
Thus, as seen from Figure 2, the difference between the extensional and shear viscosties was relatively constant, indicating that the Trouton ratios calcualted tend to show independence of increasing strain rate. Similar observations have been seen for latex paints[17]. As with these latex paints it can be envisaged that at sufficiently low strain rates with starch pastes the Trouton ratio will attain a value close to the Newtonian value of 3.

CONCLUSIONS

We have shown that the extensional viscosity values for potato starch pastes at a number of varying concentrations differ significantly from the corresponding shear flow viscosity. This highlights not only the difference between the two flow regimes but also the potential dominance of extensional viscosity with respect to characterising starches. We have also demonstrated that starch pastes do not behave as true solutions under extensional flows and attribute this to their particulate dispersion type character. It is envisaged that this technique offers the ability to not only better characterise different starches but also to increase the understanding of starch functionality as a whole.

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