Vane Rheometry with a Large, Finite Gap

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Received:16.10.2001, Final version: 28.2.2002

Abstract:
The vane geometry with a large gap is used to determine the Newtonian, non-Newtonian and viscoelastic properties of complex fluids. We show that when this geometry is carefully characterized, it can be used for precise rheometry. A novel effective cylinder approximation is used to obtain the shear rate and shear stress factors. The effective radius is found to be close to the height of the triangle formed by joining the tips of adjacent blades. This result differs significantly from that of previous work. Flow visualization has been used to confirm that the stream lines bend towards the centre between the blades. These factors can be used to determine the flow curves of non-Newtonian liquids, using Krieger's power law expansion. The standard procedure for using the vane to determine the yield stress is also carefully investigated and alternative procedures are suggested.

Zusammenfassung:
Wegen einer ganzen Anzahl praktischer Schwierigkeiten werden sowohl in- als auch online Messungen der rheologischen Eigenschaften komplexer Systeme während der Extrusion normalerweise am Ende des Extruders unter sehr spezifischen experimentellen Bedingungen vorgenommen. Dieses Vorgehen macht Instrumente solcher Art mehr für die Qualitätskontrolle als für die Prozessoptimierung nützlich, zumal Information über den Einfluss der Geometrie und/oder Prozessbedingungen auf die Entwicklung der Materialcharakteristika innerhalb des Extruders nicht leicht zu erfassen ist. Kürzlich haben die Autoren ein on-line Kapillarrheometersystem entwickelt, welches die meisten der existierenden Probleme überwindet und es erlaubt, kleine Probenmengen in nahezu Echtzeitbedingungen entlang des Extruders zu testen. Die vorliegende Arbeit zielt darauf ab, die Nützlichkeit dieses Konzeptes für die Untersuchung des physikalischen Verbundprozesses an einigen reagierenden Systemen zu illustrieren. Zwei sehr verschiedene Systeme werden zu diesem Zweck verwendet: ein reaktiver Extrusionsprozess (die Peroxid-induzierte thermische Zersetzung von Polypropylen) und das dispersive Mischen, welches in der Herstellung von Thermoplast-Karbonfasern Kompositen auftritt.

Résumé:
La géométrie vane en entrefer large est utilisée pour déterminer les propriétés newtonienne, non-newtonienne et viscoélastique des fluides complexes. Nous montrons que lorsque cette géométrie est correctement caractérisée, elle peut être utilisée pour des mesures rhéométriques précises. Une nouvelle approximation considérant le système vane comme une géométrie cylindrique effective est utilisée pour obtenir les facteurs géométriques. Le rayon effectif est trouvé proche de la hauteur du triangle obtenu en joignant le sommet de pales adjacentes. Ce résultat diffère sensiblement de travaux précédents. La visualisation des lignes d'écoulement permet de valider notre approche. Ces facteurs géométriques peuvent ensuite servir à la détermination les courbes d'écoulement pour des fluides non-newtoniens en utilisant le développement en loi de puissance proposé par Krieger. La procédure standard d'utilisation du système vane pour déterminer la contrainte seuil est également étudiée et des protocoles alternatifs sont proposés.

Key Words: Vane rheometry, non-newtonian fluids, viscoelastic materials, yield stress determination

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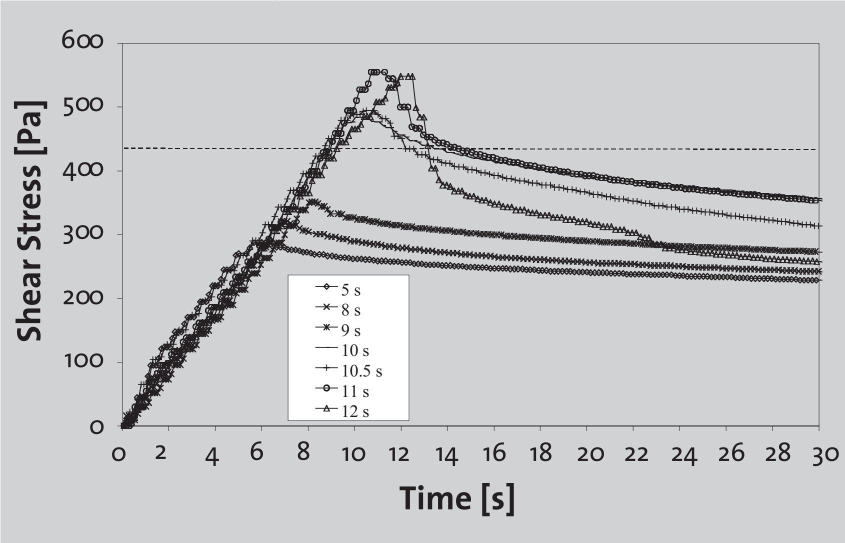

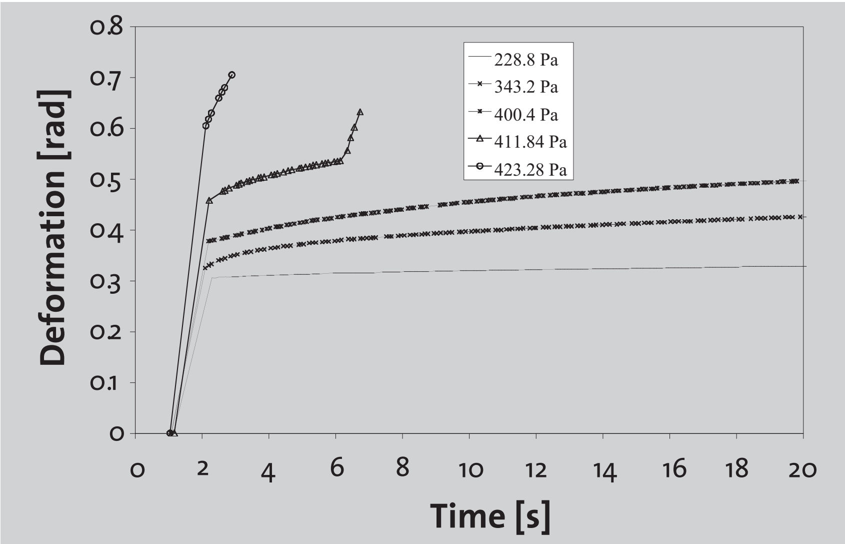

Figure 6 (above): Yield stress determination of a 2.5 g/kg Kappa-carrageenan gel using maximum stress for different rotation times. Each curve was obtained using a fresh sample (VT 550 Haake rheometer).

Figure 7 (below): Yield stress determination of a 2.5g/kg Kappa-carrageenan gel using creep measurements. Each curve was obtained using a fresh sample (RS 150 Haake rheometer).

strongly non-linear when approaching and passing the yield stress. This procedure gives a lower value for the yield stress (470 ± 30 Pa) than the usual procedure. In our opinion, the maximum stress just represents an upper bound on the yield stress.

Our second alternative procedure is to use a series of creep curves. Fig. 7 shows that creep curves measured with a controlled stress rheometer, also give a good estimate of the yield stress through a clear change in shape of the curve. This method gave a value for the yield stress of 412 ± 15 Pa.

These three different methods are in rather good agreement. The choice of the appropriate procedure will be essentially dependant on the rheometer available (controlled stress or controlled rate) and its performance. However, determining the velocity range over which the maximum torque is independent of the rotation speed is non-trivial and time consuming. Application of different rotation times avoids the need to determine this velocity range and so saves time.

6 CONCLUSIONS

We have shown that it is legitimate to use an equivalent coaxial cylindrical geometry for the vane geometry. A simple protocol using Newtonian fluids with partial immersion of the vane can be used to determine the dimensions of the effective cylinder. Once this effective geometry has been determined, standard methods can be used to convert torque, rotation rate and angular displacement to shear stress, shear rate and deformation, respectively. The vane geometry can then be used as an efficient rheometric measurement system for determining the viscosities of Newtonian and non-Newtonian fluids and viscoelastic characterisation, even at large deformations. Validation has been performed by comparing results from the cone and plate geometry fitted to both controlled torque and controlled speed rheometers. Determination of the yield stress using the vane has also been investigated. Alternative procedures are described, which are simpler than the usual method, which uses the maximum torque.

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