Comparison of Measurement Techniques for Evaluating the Pressure Dependence of the Viscosity

Alain Goubert [1], Jan Vermant [1], Paula Moldenaers [1],
Axel Göttfert [2], and Benoît Ernst [3]

[1] Department of Chemical Engineering, K.U. Leuven, de Croylaan 46, B-3001 Leuven, BELGIUM
[2] Göttfert Werkstoff-Prüfmaschinen GmbH, D-74711 Buchen, GERMANY
[3] CERDATO, Elf Atochem F-27140 Serquigny, FRANCE

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Abstract:
The different methods that can be used for measuring the effect of a hydrostatic pressure on the viscosity of polymer melts are evaluated. A linear low-density polyethylene is chosen as test material, as it can be expected to have a small pressure dependency. Special attention is given to methods employing capillary rheometry, as these methods yield a range of shear rates and pressures that are typically encountered under polymer processing conditions. The accuracy of the different techniques is evaluated considering also the complexity of the experimental devices. First it is investigated to which extent standard capillary rheometry can be used to extract information about the pressure dependency of the viscosity. Secondly, it is shown how the accuracy can be greatly increased by the simple addition of a pressure chamber below the exit of the capillary, with a needle valve to regulate the back pressure. The results from this device are compared with those from a more robust method using a pressurized double piston rheometer and with literature data. The experimental values for the pressure coefficient of the viscosity will also be compared with those predicted from PVT data using Utracki's method.

Zusammenfassung:
Es werden unterschiedliche Methoden ausgewertet, die für das Messen des Effektes eines hydrostatischen Drucks auf die Viskosität von Polymerschmelzen verwendet werden können. Als Testmaterial wurde low-density Polyäthylen gewählt, da es sich aufgrund seiner geringen Druckabhängigkeit der Viskosität besonders eignet. Besondere Aufmerksamkeit wird denjenigen Methoden gewidmet, die Kapillar-Rheometrie einsetzen, da sie eine weite Spanne – typisch für die Polymerverarbeitung – von Scherraten und Drücken realisieren lassen. Die Genauigkeit der unterschiedlichen Techniken wird ausgewertet, wobei auf die Komplexität der experimentellen Anlagen ebenfalls eingegangen wird. Zunächst wird untersucht, in welchem Masse die Standard-Kapillar-Rheometrie herhalten kann, um Information über die Druckabhängigkeit der Viskosität bereitzustellen. Anschliessend wird gezeigt, wie die Genauigkeit verbessert werden kann durch Hinzufügen eines einfachen Druckraums, mit Nadelventil zur Regulierung des Rückstaus, unter dem Ausgang der Kapillare. Die Ergebnisse, die mit diesem Instrument erhalten wurden, werden mit denjenigen einer robusteren Methode, einem unter Druck gesetzten doppelten Kolbenrheometer, sowie mit Literaturdaten verglichen. Zusätzlich werden die Daten mit denen verglichen, die sich aus PVT-Daten nach Utracki's Methode ergeben.

Résumé:
Les différentes méthodes qui peuvent être employées pour mesurer l'effet de la pression hydrostatique sur la viscosité des fondus de polymères, sont évaluées. Un polyéthylène lineaire basse densité est choisi comme matériau test, puisque l'on peut s'attendre à trouver une faible dépendance à la pression. Une attention particulière est donnée aux méthodes qui emploient les rhéomètres capillaires, car elles impliquent des grandeurs de vitesses de cisaillement et de pression qui sont typiquement rencontrées lors de la mise en œuvre d'un polymère. La précision des différentes techniques est évaluée, tout en considérant également la complexité des appareils instrumentaux. Premièrement, nous avons cherché à savoir jusqu'à quel point un rhéometre capillaire peut être employé afin d'extraire des informations sur la dépendance en pression de la viscosité. Deuxièmement, il est montré comment la précision peut être grandement accrue par la simple addition d'une chambre de pression en-dessous de la sortie du capillaire, avec une "valve aiguille" afin de réguler la pression de retour. Les résultats obtenus avec cet appareil sont comparés à ceux obtenus avec une méthode plus robuste, qui utilise un rhéometre pressurisé à deux pistons, et avec les données de la littérature. Les valeurs expérimentales pour le coefficient de pression de la viscosité seront également comparées avec celles prédites à partir des données PVT et en utilisant la méthode d'Utracki.

Key words: rheometry, pressure dependency, polymer melts

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6 CONCLUSIONS

Different methods for determining the dependence of the viscosity on pressure have been reviewed and evaluated. The use of non-linear pressure profiles obtained with standard capillary rheometry is not a viable method for many materials. The propagation of experimental and fitting errors causes the analysis of the non-linear behaviour to be an unreliable method. It is also difficult to separate temperature, pressure and slip effects with this technique. A relatively simple modification that provides accurate results is the enhanced exit pressure technique. Such a device which can be mounted on a standard capillary rheometer is described. With this set-up the pressure dependency coefficient β is obtained from a linear regression and the resulting error on β is only about 10 %. In addition β can be determined under industrially relevant kinematic conditions. The measured values agree fairly well with data obtained using more robust methods. Estimating the pressure dependency from PVT data seems to provide an alternative route to evaluate the pressure dependency of the zero shear viscosity. However, at this point, this method lacks some robustness, especially with respect to the choice of the relation between free volume and the zero-shear viscosity.

It can be concluded that reliable experimental tools are now available to investigate the effects of pressure and temperature on the viscosity of polymers. Further work should address important issues such as determining the separability of temperature and pressure effects, the uniqueness of the relation between zero shear viscosity and free volume and the pressure effect on the elongational viscosity.

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