Calibration of a Commercial Kneader for Rheological Applications

Tim Kealy*, Carlos Tiu

Cooperative Research Centre for Clean Power from Lignite, 8/677 Springvale Road, Mulgrave, Victoria 3170, Australia
Department of Chemical Engineering, Monash University, Clayton Campus, Victoria 3800, Australia

*Email: timkealy@rheologysolutions.com
Fax: x61.3.53687439

Received: 26.3.2002, Final version: 19.7.2002

Abstract:
In the case of some highly viscous fluids, or thick pastes (such as those exhibiting high yield stress and/or high plastic viscosity), neither rotational nor tube type viscometers are suitable for rheological characterisation. Due to their capacity for generating and maintaining high torque or high rates of rotation, kneaders and mixers can often engender shear rates in excess of those of conventional rotational viscometers. Often these devices are instrumented, to measure and record the rate of rotation of the mixing blades and the related torque on the shaft turning the blades. The major problem facing users of these mixers lies in data interpretation, specifically in relating rate of rotation and torque data to shear rate and shear stress respectively. If it were possible to obtain such relationships, useful rheological data could be generated with instrumented mixers.
This work outlines the experimental and analytical techniques required to convert pertinent data from the Ika Visc MKD 0.6-H60 instrumented kneader into useful rheological quantities. The kneader is calibrated using a Newtonian fluid and the calibration successfully tested with other Newtonian fluids, as well as on shear thinning solutions. The possibility of using a constant factor, α, which accounts for both the geometric complexity of the mixing chamber, and non-ideal fluid flow properties, is examined. It is shown that α is not constant, but depends on the non-Newtonian flow indices. At moderate and high rates of kneading blade rotation, calibration was not reliable and results are based on rates of rotation from 0 - 8rpm for the slower of the two mixing blades (0-16rpm for the quickly rotating blade). A number of assumptions and empirical relationships are utilised for this technique. The approximate nature of the technique necessitated by their use is more than offset by providing us with a potentially important outcome in that the capacity for collecting rheological data available to the interested scientist or engineer has been enhanced. A robust calibration technique has been developed, which is not, in principle limited to the specific equipment utilised for our analysis.

Zusammenfassung:
Für sehr zähflüssige Fluide und starke Pasten (wie die, die eine grosse Fliesgrenze und/oder eine hohe plastische Viskosität aufweisen) eignen sich weder Rotations- noch röhrenförmige Messinstrumente zur rheologischen Charakterisierung. Wegen ihrer Kapazität zum Erzeugen und Beibehalten hoher Drehkräfte und hoher Umlaufzahlen, können Kneter und Mischer häufig Scherraten erzielen, die diejenigen in herkömmlichen Rotationsdichte-Messern übertreffen. Häufig sind diese Instrumente so ausgestattet, dass sie sowohl die Umlaufrate als auch die Drehkraft vom Blatt auf die Welle messen. Die Schwierigkeit liegt in der Deutung der Daten. Wenn es möglich wäre, Rotation und Drehmoment zu Schergeschwindikeit und Scherspannung in Verbindung zu setzen, können nützliche rheologische Daten mit Mischern erzeugt werden. Diese Arbeit umreisst die experimentellen und analytischen Techniken, um Daten des Ika Visc MKD 0.6-H60 Kneters in rheologische Quantitäten umzuwandeln. Der Kneter wird mit einer newtonischem Flüssigkeit kalibriert, und die Kalibrierung mit anderen newtonischen Flüssigkeiten sowie scherverdünnenden Lösungen geprüft. Es zeigt sich, dass der auftretende Umrechnungsfaktor nicht konstant, sondern vom nicht-Newtonschen Fliessindex abhängt. Diese Untersuchungen ergeben sich aus der Aufnahme eines besonders umfangreichen, und daher aussagekräftigen, Datensatzes. Die vorgestellte Kalibrierung ist nicht prinzipiell auf die Analyse des verwendeten Instruments beschränkt, und lässt sich für ähnliche Instrumente analog durchführen.

Résumé:
Dans le cas des fluides très visqueux, ou de pâtes épaisses (telles que celles qui présentent de grandes contraintes seuils et/ou une forte viscosité plastique), ni les viscosimètres rotationels ni les viscosimètres en tube ne sont adéquates pour une caractérisation rhéologique. A cause de leur capacité à générer et maintenir de grands couples ou de grandes vitesses de rotation, les mélangeurs et les pétrisseurs peuvent souvent engendrer des vitesses de cisaillement supérieures à celles des viscosimètres rotationels conventionels. Souvent ces appareils sont faits pour mesurer et enregistrer la vitesse de rotation des lames du mélangeur et le couple résultant sur l'arbre qui tourne les lames. Le problème principal qui se pose aux utilisateurs de ces mélangeurs réside dans l'interprétation des données, particulièrement pour relier la vitesse de rotation et le couple à une vitesse de cisaillement et

© Appl. Rheol. 12 (2002) 241-251
This is an extract of the complete reprint-pdf, available at the Applied Rheology website
http://www.appliedrheology.org

This is an extract of the complete reprint-pdf, available at the Applied Rheology website
http://www.appliedrheology.org

Visc unit, the appropriate guiding curve, with $A = 2.5$, $b = 2$ is shown in Fig. 10) α can be estimated and Eqs. 8 - 11 used as before.

For units differing in geometry and gearing ratio to the Ika Visc, it is important to assess the validity of constant α. This is done using plots similar to those in Figs. 4 and 5, and assessing the impact of α on final estimates for shear rate and shear stress. In addition, $\alpha = 0.84$ is unlikely to be a suitable value when $b = 1$ in a different system than that described here, initial testing should be carried out to determine an equivalent value.

It is important to note that this technique should be similarly effective for other fluids such as Bingham plastics, yield pseudoplastics, or shear thickening fluids as it has been for the fluids detailed here. However, in the case of yield pseudoplastics and shear thickening fluids at low shear rates, where the Ika kneader is not sensitive, precise values of yield stresses and/or shear stresses can not be determined. Also, in every case at rates of kneader arm rotation above 8 rpm data should be treated with caution.

6 CONCLUSIONS

An instrumented measuring kneader has been used to predict both Newtonian and non-Newtonian behaviour for extremely viscous fluids, which would not normally be readily measurable at the shear rates and shear stresses generated by the instrument. An empirical methodology for the prediction of the relevant fluid properties, with reasonable accuracy has been obtained, using the technique of Marquez et al [5], adjusted for the new equipment, but allowing the geometric constant, $\alpha = 0.84$ for all fluids. This easily allows construction of a flow curve at these elevated shear rates and shear stresses. Newtonian fluid flow behaviour is quite accurately predicted in this way, but it provides only a rough estimate for non-Newtonian, power-law fluids. Allowing α to vary increases the precision of prediction for these fluids. α is related to the consistency index, n, and, less strongly, to the flow behaviour index, K.

The ability of the instrument to predict the general shape of a flow curve is excellent in both Newtonian and non-Newtonian (power-law) cases. It is also worthy of note that the approach of Marquez et al. [5] has been successfully applied to a substantially different geometric configuration, and to an instrument designed for substantially different applications. It seems likely that the technique will apply equally to other configurations, etc.

Further refinement of the empirical predictions should be possible using a broader spectrum of K and n values for pseudoplastic fluids, as well as testing other types of non-Newtonians. It is in this direction that we intend to progress. High yield suspensions are being trialed in the unit.

NOMENCLATURE

C	Constant of proportionality
K, n	Non-Newtonian consistency and flow index
R	Radius [mm]
S	Rate of rotation [rpm or s^{-1}]
T	Torque [Nm]
$\dot{\gamma}$	Shear rate [s^{-1}]
η	Apparent non-Newtonian Viscosity [Pas]
μ	Newtonian Viscosity [Pas]
τ	Shear stress[Pa]
s, f	low, high rpm blade quantity
i, o	inner, outer concentric cylinder quantity

ACKNOWLEDGMENT

The authors gratefully acknowledge the financial support for this research from the Cooperative Research Centre (CRC) for Clean Power from Lignite, which is established by the Australian Government Cooperative Research Centre program. The assistance of Rheology Solutions Pty. Ltd. is acknowledged for the use of their facilities.

REFERENCES

[1] Kealy T, Tiu C, "An examination of the rheological properties of Victorian Brown Coal." XIII International Congress on Rheology, Cambridge, UK (2000).

[2] Goodrich JE, Porter RS: A rheological interpretation of torque-rheometer data. Polymer Engineering and Science 7 (1967) 45-51.

[3] Blyler LL, Daane JH, "An analysis of Brabender torque rheometer data. Polymer Engineering and Science 7 (1967) 178-181.

[4] Lee GLN, Purdon JR: Brabender viscometry: 1. Conversion of Brabender curves to Instron flow curves, Polymer Engineering and Science, 9(5) (1969), 360-367.

This is an extract of the complete reprint-pdf, available at the Applied Rheology website
http://www.appliedrheology.org

This is an extract of the complete reprint-pdf, available at the Applied Rheology website
http://www.appliedrheology.org

[5] Marquez A, Quijano J, Gaulin M: A calibration technique to evaluate the power-law parameters of polymer melts using a torque-rheometer. Polymer Engineering and Science 36 (1996) 2256-2563.
[6] Bousmina M, Ait-Kadi A, Faisant JB: Determination of Shear rate and viscosity from batch mixer data. Journal of Rheology, 43 (1999) 415-433
[7] Darby R: Viscoelastic fluids, an introduction to their properties and behaviour, Marcel Dekker Inc., New York (1976).
[8] Tam KC, Tiu, C: Steady and dynamic shear properties of aqueous polymer solutions. Journal of Rheology, 33 (1989) 257.
[9] Carriere S, Pinder KL: Kneader-type pulpers: Lab test. Pulp and Paper Canada 98 (1997) 76-79.
[10] Kawaguchi Y, Kaminoyama M, Kazuhiko N, Kamiwano M: Analysis of mixing process for wet particle system in a double blade batch kneader mixer. Chemical Engineering of Japan 30 (1997) 550-556.

This is an extract of the complete reprint-pdf, available at the Applied Rheology website
http://www.appliedrheology.org

This is an extract of the complete reprint-pdf, available at the Applied Rheology website
http://www.appliedrheology.org