ON-LINE OR PROCESS VISCOMETRY – A REVIEW

HOWARD A. BARNES

Unilever Research, Port Sunlight, CH63 3JW, UK
e-mail: howard.barnes@unilever.com
Fax: X44.151.6411829

Received: 16.4.99, Final version: 16.6.99

ABSTRACT

Process viscometry has many advantages in terms of saving time and gaining more immediate information about a process. However, it can also has disadvantages in terms of compromises that must be made in taking a stream of liquid and passing it through a viscosity-measuring element. The latter operation can be a strong function of flow rate through the instrument, making the measured value variable. The viscometer itself might has been chosen for simplicity of measurement, but which might actually represent a complicated flow pattern in the sense of being a mixture of shear and extensional flow, frequency and acceleration. The best practice in the area of on-line viscometry is reviewed, and the current commercial instruments are compared to this standard. It is concluded that the choice of instrument depends on the pressing need is either for quick information or for reliable information. The Nametre vibrating sphere and the Brookfield concentric-cylinder instruments are highlighted.

KURZFASSUNG

Die Prozessviskosimetrie besitzt viele Vorteile hinsichtlich Zeitersparnis und der Gewinnung direkter Informationen über den laufenden Verarbeitungsprozess. Sie hat aber auch Nachteile bezüglich der Kompromisse, die bei der Entnahme der Flüssigkeit im Seitenstrom, und bei der Zuführung dieser Flüssigkeit zu den Viskositäts-Meßelementen erforderlich sind. Der letztgenannte Schritt kann stark vom Durchsatz in dem Meßinstrument abhängen und daher den Meßwert selbst beeinflussen. Das Viskosimeter selbst muß eine einfache Messung ermöglichen, die Strömungsform ist jedoch kompliziert, da Scher- und Dehnströmung überlagert sind und zudem die Meßwerte von Frequenz und Beschleunigung des Geschwindigkeitsfeldes abhängig sind. Der Beitrag bewertet das beste praxisrelevante Verfahren aus dem Bereich der on-line Viskosimetrie und vergleicht die derzeit kommerziell erhältlichen Instrumente mit diesem Standard. Die Wahl des Meßinstruments hängt davon ab, ob schnelle oder zuverlässige Informationen benötigt werden. Sowohl die schwingende Kugel (Nametre) als auch das konzentrische Zylinder-Instrument (Brookfied) werden diskutiert.

RÉSUMÉ

La viscosimétrie de mise en oeuvre présente beaucoup d'avantages en terme d'économie de temps et de rapidité d'obtention d'informations sur un procédé. Cependant, elle peut aussi présenter des désavantages au regard des compromis qui doivent être concédés lorsqu'on fait passer un flot de liquide à travers un instrument qui mesure une viscosité. Cette mesure peut dépendre fortement de la vitesse d'écoulement dans l'instrument, rendant ainsi la valeur mesurée variable. Le viscosimètre peut lui-même avoir été choisi en raison de la simplicité de la mesure mais il peut en réalité résulter un écoulement compliqué, mélange de cisaillement et d'extension, de fréquence et d'accélération. La pratique la meilleure de la viscosimétrie en ligne est ici abordée et les instruments actuellement disponibles sur le marché sont comparés à ce standard. Il s'avère que le choix d'un instrument dépend des besoins: l'obtention rapide d'une information ou l'obtention d'une information sûre. Deux instruments sont présentés: la sphère de Nametre et les cylindres concentriques de Brookfield.

1 *INTRODUCTION*

The advantages – for both batch and continuous process operations –of being able to measure the viscosity of liquid products (or product precursors such as slurries) on-line, *during* their manufacture are obvious:

I Time and effort are saved in obtaining the current or batch-end viscosity, which is otherwise obtained by taking a sample to an off-line viscometer, which has to be carefully loaded and subsequently cleaned.

II A control function can be introduced – if means are available to alter the viscosity by process or chemical variables; and

III A continuous monitor of viscosity build-up – and hence structure – is available for batch-mixing operations.

While the term *'process viscometer'* is generic, the terms *in-line* and *on-line* need to be defined: here *'in-line'* is used to describe the situation where *all the liquid* whose viscosity is being measured passes through or around the process vis-

© Appl. Rheol. 9, 3, 102-107 (1999)

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

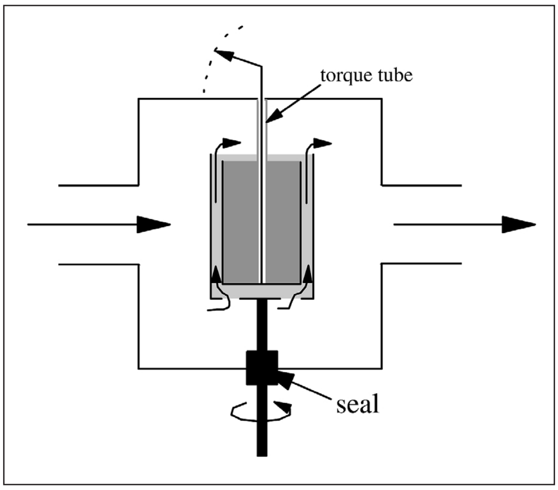

Figure 3. A schematic cross-section of the Brookfield TT100 in-line viscometer.

speed of fall is then related to the viscosity. The novelty here is that the action of the cylinder moving up and down which pumps fresh liquid in and out of the tube containing the piston. However, the one number so obtained can only yield the equivalent Newtonian viscosity.

Whether or not one can live with the compromise associated with any instrument depends on the nature of the liquids being measured. Thixotropic, shear-thinning liquids are very difficult to measure even in the best off-line viscometer under ideal laboratory circumstances. To measure such liquids on-line is *extremely* difficult. While most instruments are calibrated to give an *equivalent Newtonian viscosity*, this is not always very useful for difficult materials. If on the other hand the liquids of interest are easy to measure, being virtually time independent and only slightly non-Newtonian, than almost any method will suffice, since a reliable correlation can be established between on-and off-line measurements.

7 DETAILED ANALYSIS OF A PARTICULAR INSTRUMENT

The *Brookfield* TT100 is a typical on-line instrument that fulfils the criteria set out above, in that it follows the 3Rs, *i.e.*, representative sampling, relatability, reliability and robustness of operation. It is manufactured by the Brookfield Engineering Company of the USA, who are the longest-standing manufacturers of commercial rotational viscometers in the world. It is a concentric-cylinder instrument that can operate in- or on-line, and has an open-ended variant that can be mounted into the wall of a vessel – the TT200.

The TT100 is mounted in a chamber through which the liquid of interest flows – the general arrangement is shown in schematic cross-section in figure 3. The speed of the motor driving the outer cylinder can be varied or fixed and the torque produced on the inner cylinder causes a small twist of the sealed torque-tube supporting it. This small twist is transmitted through the wall without friction and is measured on a rotation transducer mounted outside the chamber.

Some of the flow finds its way down through the gap between the cylinders either by natural means because the flow resistance is asymmetric or as directed using a flow-deflector that drives most the flow downwards, so enhancing enhances the flow between the cylinders. The limits of the viscosity that can be measured by this instrument are set by the onset of instabilities when the viscosity is too low and the torque-tube being twisted too far when the viscosity is too high. The shear rate can be set to any value between about 1 and 1000 s^{-1}, being a combination of the effect of the motor speed and the gap between the cylinders. The latter value is quite small for most pourable liquids and therefore the shear rate is virtually constant throughout the gap. The response time depends on the complete replacement of all the liquid in the measuring volume.

The TT100 has a very effective CIP set-up. Inlet ports for hot water are positioned to wash the cylinders and keep the all-important gap clean. A special APV hygienic housing is now available that ensures easy cleaning by washing through with cleaning fluids.

8 CONCLUSIONS

On-line viscometers should be carefully chosen – the amount of care depending on the complexity of the liquid. The viscosity of Newtonian liquids can be measured by any kind of viscometer. If the non-Newtonian liquid of interest is simple, then we will be able to correlate any in- or on-line viscosity with its carefully measured off-line equivalent. If however there is no simple correlation, we need to do our best to measure on-line in the same way as we are measuring off-line. For instance a number of suitable concentric-cylinder type instruments are now available. Even then, care has to be taken to ensure there is no interference from the flow; either by choice of viscometer or care in regulating the flow through. In the latter situation, single speed or multiple speed models are available. Computer control of course allows us any degree of complexity in measuring.

In terms of response time, we have a compromise situation: fast response times usually come from devices such as vibrating elements (*e.g.* the Nametre) placed directly in the flow line, however these might be difficult to relate to off-line measurement, and are certainly very sensitive to the local flow rate. On the other hand, the best devices that virtually duplicate off-line measurements are usually much slower in response because of the relatively long time taken to replace the liquid being measured (*e.g.* the Brookfield TT100). Thus the actual choice of device must be made very carefully.

REFERENCES

[1] Dealy, J M, Rheol Acta, 29, 519 (1990)

[2] Cheng D C-H; Hunt, J A and Madhvi, P, Status Report on Process Viscometers: Current Applications and Future Needs, Warren Spring Laboratory, Rep. No. W85034, 1985, ISBN 0 85624 363 9. (Now available from AEA Technology, Harwell, UK).

[3] Barnes, H A, Journal of Non-Newtonian Fluid Mechanics, 56, 221 - 251 (1995).

BIOGRAPHY

Howard Barnes graduated in Physics at the University of Wales, Aberystwyth and joined Dr. Ken Walters' (now Prof. K. Walters FRS) research group in the Applied Mathematics department. Having completed a Ph.D. and postdoctoral work there, he moved to Unilever Research Port Sunlight, UK in 1970. He is now a senior scientist there, where he occupies the position of science area advisor in Rheology and fluid Mechanics. He has published over 50 papers, holds two patents and is a co-author of the best-selling book in the area of Rheology - *An Introduction to Rheology*. He was awarded a D.Sc. by the University of Wales in 1994, and in 1997 was appointed an Officer of the Order of the British Empire (OBE) for his work in Science and Technology.

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