Back Extrusion of Vocadlo-Type Fluids

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Abstract:
Back extrusion represents one of the cheapest experimental methods to determine rheological characteristics of studied fluids, and simultaneously minimise their disruption in comparison with conventional rotational rheometers. This method is based on plunging a circular rod into an axisymmetrically located circular cup containing the experimental sample. Formerly this method has, among other uses, been successfully applied to determinations of parameters appearing in power-law, Bingham and Herschel-Bulkley fluids. The aim of this contribution is to present a sufficiently simple user-friendly procedure for determining individual rheological parameters appearing in the Vocadlo model (sometimes called the Robertson-Stiff model) - yield stress, consistency parameter and flow behaviour index.

Zusammenfassung:
Rückextrusion stellt eine der günstigsten experimentellen Methoden zur Bestimmung rheologischer Eigenschaften von Fluiden dar und minimiert gleichzeitig ihre Störungseinflüsse im Vergleich zu konventionellen Rotationsrheometern. Diese Methode basiert auf dem Eintauchen eines zylindrischen Stabes in eine axialsymmetrisch befestigte runde Schale mit der Materialprobe. Diese Methode wurde schon – neben weiteren Anwendungen – zur Bestimmung der Parameter von Potenzgesetz-, Bingham- und Herschel-Bulkley-Fluiden angewandt. Das Ziel dieser Arbeit ist, ein ausreichend einfaches, anwenderfreundliches Verfahren zur Bestimmung individueller rheologischer Parameter des Vocadlo-Modells (das manchmal auch Robertson-Stiff-Modell genannt wird), d.h. Fließpannung, Konsistenzparameter und Fliessverhaltensindex vorzustellen.

Résumé:
L'extrusion inverse est l'une des méthodes expérimentales les moins chères utilisée pour déterminer les caractéristiques rhéologiques des fluides, et pour minimiser simultanément leur rupture par rapport aux rhéomètres rotationnels conventionnels. Cette méthode repose sur la pénétration d'une barre cylindrique dans un pot cylindrique placé symétriquement para rapport à l'axe de pénétration, et contenant l'échantillon à tester. Dans le passé, cette méthode, parmi d'autres, a été utilisée avec succès pour déterminer les paramètres des fluides en loi de puissance, de Bingham et de Herschel-Bulkley. Le but de cette contribution est de présenter une méthode versatile et facile à utiliser pour déterminer les paramètres rhéologiques individuels qui apparaissent dans le modèle de Vocadlo (parfois dénommé le modèle de Robertson-Stiff): la contrainte seuil, le paramètre de consistance et l'index d'écoulement.

Key words: viscosity, back extrusion, annular pumping, Vocadlo model, Robertson-Stiff model

1 INTRODUCTION

The present standard rheometers provide sufficiently precise measurements characterising the behavior of non-Newtonian materials. In practice, this degree of accuracy is not always necessary, and methods providing relatively cheap, fast and adequate measurements of rheological characteristics are fully acceptable. Moreover, usage of conventional rotational rheometers can result in sample disruption of foods due to the narrow gaps between the measuring plates. In this context it is possible to name consistometer rheometry (when the released volume of fluid starts to flow due to gravity either radially (Adams consistometer) or longitudinally (Bostwick consistometer)) for which the relations for power-law and yield stress fluids were derived by Piau [1, 2], and Piau and Debiane [3].The usage of the Adams and Bostwick consistometers is also analysed in Baudez et al. [4] and Perona [5], respectively. A

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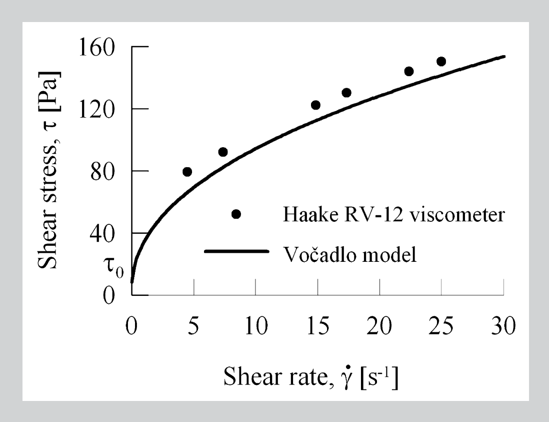

Figure 4: Comparison of the experimental data (measured by a Haake RV-12 viscometer, see Osorio and Steffe [30, Figure 9]) with the Vocadlo model (τ_o = 8.53, n = 0.446, K = 33.68).

Table 1: The parameters n and K determined from the combination of individual experimental runs in Osorio and Steffe [30].

Run	#2	#3	#4
#1	n = 0.565 K = 30.82	n = 0.447 K = 32.64	n = 0.449 K = 32.5
#2		n = 0.355 K = 37.88	n = 0.41 K = 35.91
#3			n = 0.452 K = 32.33

5 DISCUSSION

The application of the procedure presented above is significantly subject to the assumption of an axisymmetrical position of the plunger with respect to the cylindrical container. Deviation from this assumption can cause non-negligible errors in the prediction of the parameters τ_o, K and n. As the power-law and Bingham models are sub-cases of the Vocadlo model for $\tau_o = 0$ and $n = 1$, respectively, it is also possible to apply the procedure presented above to these two models with the corresponding pre-setting of the individual parameters. As far as the authors are aware, no explicit relation between volumetric flow rate and pressure gradient (analogous to Equation 23) is known for the case of the Herschel-Bulkley model. This implies it is not possible to apply the procedure derived above to fluids obeying this model.

6 CONCLUSION

Determination of all three parameters in the Vocadlo model with the use of a back extrusion technique (supposing no-slip boundary conditions) represents a cheap experimental method requiring only a compression testing machine and common commercial software enabling the calculation of these parameters. The accuracy of these parameters does not attain those when sophisticated rheometers are used. Nevertheless, from the practical point of view, it is for many applications fully satisfactory and, moreover, sample disruption is substantially lower compared with application of measuring plates or cylinders with a narrow gap.

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REFERENCES

[1] Piau J-M: Consistometry slump and spreading tests: Practical comments, J. Non-Newtonian Fluid Mech. 135 (2006) 177 – 178.

[2] Piau J-M: Axisymmetric slump and spreading of cohesive plastic soft materials: a yield stress measurement by consisto-rheometry, J. Rheol. 49 (2005) 1253 – 1276.

[3] Piau J-M, Debiane K: Consistometers rheometry of power-law viscous fluids, J. Non-Newtonian Fluid Mech. 127 (2005) 213 – 224.

[4] Baudez JC, Chabot F, Coussot P: Rheological interpretation of the slump test, Appl. Rheol. 12 (2002) 133 – 141.

[5] Perona P: Bostwick degree and rheological properties: An up-to-date viewpoint, Appl. Rheol. 15 (2005) 218 – 229.

[6] Sun A, Gunasekaran S: Yield stress in foods: Measurements and applications, Int. J. Food Prop. 12 (2009) 70 – 101.

[7] Estellé P, Lanos C: High torque vane rheometer for concrete: Principle and validation from rheological measurements, Appl. Rheol. 22 (2012) 12881.

[8] Perrot A, Rangeard D, Mélinge Y, Estellé P, Lanos Ch: Extrusion criterion for firm cement-based materials, Appl. Rheol. 19 (2009) 53042.

[9] Lanos Ch, Estellé P: Vers une réelle rhéométrie adaptée aux bétons frais, Europ. J. Envir. Civ. Eng. 13 (2009) 457 – 471.

[10] Boujlel J, Coussot P: Measuring yield stress: a new, practical, and precise technique derived from detailed penetrometry analysis, Rheol. Acta 51 (2012) 867 – 882.

[11] Zacahua-Tlacuatl G, Pérez-Gonzáles J, Javier Castro-Arellano J, Balmori-Ramírez H: Rheological characterization and extrusion of suspensions of natural zeolites, Appl. Rheol. 20 (2010) 34037.

[12] Steffe JF, Osorio FA: Back extrusion of non-Newtonian fluids, Food Technol. 41 (1987) 72 – 77.

[13] Perrot A, Mélinge Y, Estellé P, Rangeard D, Lanos C: The back extrusion test as a technique for determining the rheological and tribological behaviour of yield stress fluids at low shear rates, Appl. Rheol. 21 (2011) 35642.

[14] Koke J, Modigell M: Flow behaviour of semi-solid metal alloys, J. Non-Newtonian Fluid Mech. 112 (2003) 141 – 160.

[15] Modigell M, Pape L, Hufschmidt M: The rheological behaviour of metallic suspensions, Steel Res. Int. 75 (2004) 506 – 512.

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http://www.appliedrheology.org

[16] Vieira EA, Kliauga AM, Ferrante M: Microstructural evolution and rheological behaviour of aluminium alloys A356, and A356 + 0.5 % Sn designed for thixocasting, J. Mat. Proc. Technol. 155–156 (2004) 1623–1628.
[17] Chukwu GA: A practical approach for predicting casing running speed from Couette flow of non-Newtonian power-law fluids, Soc. Petr. Eng. Paper No.29638, Western Regional Meeting in Bakersfield, CA, USA, 8–10 March 1995.
[18] Alviar MSB, Reid DS: Determination of rheological behavior of tomato concentrates using back extrusion, J. Food Sci. 55 (1990) 554–555.
[19] Brusewitz GH, Yu H: Back extrusion method for determining properties of mustard slurry, J. Food Eng. 27 (1996) 259–265.
[20] Gujral HS, Sodhi NS: Back extrusion properties of wheat porridge. J. Food Eng. 52 (2002) 53–56.
[21] Singh N, Singh J, Sodhi NS: Morphological, thermal, rheological and noodle-making properties of potato and corn starch, J. Sci. Food Agriculture 82 (2002) 1376–1383.
[22] Castro E, Silva C, Osorio F, Miranda M: Characterization of caramel jam using back extrusion technique, Latin Amer. Appl. Res. 30 (2000) 227–232.
[23] Sodhi NS, Singh N, Arora M, Singh J: Changes in physico-chemical, thermal, cooking and textural properties of rice during aging, J. Food Proc. Preserv. 27 (2003) 387–400.
[24] Sousa MB, Canet W, Alvarez MD, Tortosa ME: The effect of the pre-treatments and the long and short-term froyen storage on the quality of raspberry (cv. Heritage), Europ. Food Res. Technol. 221 (2005) 132–144.
[25] Sousa MB, Canet W, Alvarez MD, Tortosa ME: Effect of processing on the texture and structure of raspberry (cv. Heritage) and blackberry (cv. Thornfree), Europ. Food Res. Technol. 223 (2006) 517–532.
[26] Sousa MB, Canet W, Alvarez MD, Fernandéz C: Effect of processing on the texture and sensory attributes of raspberry (cv. Heritage) and blackberry (cv. Thornfree), J. Food Eng. 78 (2007) 9–21.
[27] Piazza L, Gigli J, Rojas C, Ballabio D, Todeschini R, Tripaldi P: Dairy cream response in instrumental texture evaluation processed by multivariate analysis, Chemometr. Intell. Lab. 96 (2009) 258–263.
[28] Osorio FA, Steffe JF: Back extrusion of power law fluids, J. Text. Stud. 18 (1987) 43–63.
[29] Hanks RW, Larsen KM: The flow of power-law non-Newtonian fluids in concentric annuli, Ind. Eng. Chem. Fundam. 18 (1979) 33–35.
[30] Osorio FA, Steffe JF: Evaluating Herschel-Bulkley fluids with the back extrusion (annular pumping) technique, Rheol. Acta 30 (1991) 549–558.
[31] Barnes HA, Walters K: The yield stress myth, Rheol. Acta 24 (1985) 323–326.
[32] H.A.Barnes, The yield stress – a review or ‘παντα ρει‘ – everything flows?, J. Non-Newtonian Fluid Mech. 81 (1999) 133–178.
[33] Corradini MG, Peleg M: Consistency of dispersed food systems and its evaluation by squeezing flow viscometry, J. Text. Stud. 36 (2005) 605–629.
[34] Parzonka W, Vočadlo J: Modèle à trois paramètres pour les corps viscoplastique. Solution pour le viscosimètre rotatif type Couette, C. R. Acad. Sc. Paris Série A 264 (1967) 745–748.
[35] Robertson RE, Stiff HA: An improved mathematical model for relating shear stress to shear rate in drilling fluids and cement slurries, Soc. Pet. Engnrs J., Feb. (1976) 31–36.
[36] Filip P, David J: Axial Couette-Poiseuille flow of power-law viscoplastic fluids in concentric annuli, J. Pet. Sci. Eng. 40 (2003) 111–119.
[37] Osorio FA, Marte NJ, Steffe JF: Back extrusion of power law fluids. Influence of end effects (in Spain), Rev. Esp. Ciencia Tecn. Alim. 32 (1992) 207–212.
[38] Picart D, Manceau R, Fauré JP: A penetroviscosimeter for Newtonian and visco-plastic fluids, Instr. Sci. Technol. 29 (2001) 169–184.
[39] Malik R, Shenoy UV: Generalized annular Couette flow of a power-law fluid. Ind. Eng. Chem. Res. 30 (1991) 1950–1954.
[40] Brent RP: Algorithms for minimisation without derivatives. Courier Dover Publ. (2002).

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