Shear Rate Corrections for Herschel-Bulkley Fluids in Couette Geometry

Vassilios C. Kelessidis[1] *, Roberto Maglione [2]

[1] Department of Mineral Resources Engineering, Technical University of Crete, Polytechnic City, 73100 Chania, Greece
[2] Consultant, Moncrivello, 13040 Vercelli, Italy

* Email: kelesidi@mred.tuc.gr
Fax: x30.28210.37874

Received: 31.10.2007, Final version: 5.1.2008

Abstract:
A methodology is presented to invert the flow equation of a Herschel-Bulkley fluid in Couette concentric cylinder geometry, thus enabling simultaneous computation of the true shear rates, $\dot{\gamma}_{HB}$, and of the three Herschel-Bulkley rheological parameters. The errors made when these rheological parameters are computed using Newtonian shear rates, $\dot{\gamma}_N$, as it is normal practice by research and industry personnel, can then be estimated. Quantification of these errors has been performed using narrow gap viscometer data from literature, with most of them taken with oil-field rheometers. The results indicate that significant differences exist between the yield stress and the flow behavior index computed using $\dot{\gamma}_{HB}$ versus the parameters obtained using $\dot{\gamma}_N$ and this is an outcome of the higher $\dot{\gamma}_{HB}$ values. Predicted true shear rates and rheological parameters are in very good agreement with results reported by other investigators, who have followed different approaches to invert the flow equation, both for yield-pseudoplastic and power-law fluids.

Zusammenfassung:
Eine Methode wird vorgestellt, um die Fließkurve einer Herschel-Bulkley Flüssigkeit zu berechnen und somit die simultane Berechnung der Scherraten, $\dot{\gamma}_{HB}$, und der drei Herschel-Bulkley Parameter zu ermöglichen. Die möglichen Fehler für die rheologischen Parameter können dann mittels einer newtonischen Scherrate, $\dot{\gamma}_N$, wie normalerweise üblich bei Forschungs- und Industriepersonal, abgeschätzt werden. Eine solche Fehlerabschätzung wurde mit Literaturdaten aus Couette-Viskometermessungen wie sie in der Ölfeldern eingesetzt werden, durchgeführt. Die Ergebnisse zeigen, dass bedeutende Unterschiede zwischen den Fließgrenzwerten und den Viskositätsindex bestehen, wenn die Werte mit $\dot{\gamma}_{HB}$ anstelle mit $\dot{\gamma}_N$ berechnet werden, welches auf die höheren Werte von $\dot{\gamma}_{HB}$ zurückzuführen ist. Korrekte Werte für die Scherraten und die rheologischen Parameter stimmen sehr gut mit den Ergebnissen überein, die von anderen Forschern berichtet werden, die verschiedene Methode verfolgt haben, um die Fließkurve, die Fließgrenze und die Potenzabhängigkeit zu rechnen.

Résumé:
Une méthodologie est présenté pour inverser l'équation d'écoulement d'un fluide de modèle de Herschel-Bulkley en géométrie concentrique de cylindre de Couette, de ce fait en permettant le calcul simultané des véritables taux de cisaillement $\dot{\gamma}_{HB}$, et des trois paramètres rhéologiques de Herschel-Bulkley. Les erreurs ont fait quand ces paramètres rhéologiques sont calculés en utilisant les taux de cisaillement Newtoniens, $\dot{\gamma}_N$, car c'est pratique normale par le personnel de recherches et d'industrie, peuvent alors être estimées. La quantification de ces erreurs a été exécutée en utilisant des données de la littérature de viscomètre d'espace étroit, avec la plupart d'entre elles prises avec des rhéomètres de gisement de pétrole. Les résultats indiquent qu'ils existent les différences significatives entre les matériaux à contrainte seuil et l' index de comportement d'écoulement calculé par employer $\dot{\gamma}_{HB}$ contre les paramètres obtenus employer $\dot{\gamma}_N$ et c'est des résultats du plus haut $\dot{\gamma}_{HB}$ valeurs. Les véritables taux de cisaillement et les paramètres rhéologiques prévus sont dans la concordance très bonne avec des résultats rapportés par d'autres investigateurs, qui ont suivi différentes approches pour inverser l'équation d'écoulement, pour le fluide seuil -pseudoplastique et de puissance-loi.

Key words: Herschel-Bulkley fluid, Couette viscometry, shear rates

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

[3] Fordham EJ, Bittleston SH, Tehrani MA: Viscoplastic flow in centered annuli, pipes and slots. I & EC Research 29 (1991), 517-524.
[4] Hemphill T, Campos W, Tehrani MA: Yield power law model mode accurately predicts mud rheology. Oil and Gas J. 91 (1993) 45-50.
[5] Maglione R, Ferrario G: Equations determine flow states for yield-pseudoplastic drilling fluids. Oil and Gas J. 94 (1996) 63-66.
[6] Maglione R, Robotti G, Romagnoli R: In-situ Rheological Characterization of Drilling Mud. SPE J. 5 (2000) 377-386.
[7] Kelessidis VC, Mihalakis A, Tsamantaki C: Rheology and rheological parameter determination of bentonite-water and bentonite-lignite-water mixtures at low and high temperatures. Proceedings of the 7th World Congress of Chem. Engr., Glasgow (2005).
[8] Kelessidis VC, Tsamantaki C, Dalamarinis P: Effect of pH and electrolyte on the rheology of aqueous Wyoming bentonite dispersions, Applied Clay Science 38 (2007) 86-96.
[9] Mendes PRS, Dutra ESS: Viscosity function for yield-stress liquids, Appl. Rheol. 14 (2004) 296-302.
[10] Nguyen QD, Boger DV: Measuring the flow properties of yield stress liquids, Ann. Review Fluid Mech. 24 (1987) 47-88.
[11] Turian RM, Ma TW, Hsu FLG, Sung DJ: Characterization, settling and rheology of concentrated fine particulate mineral slurries. Powder Tech. 93 (1997) 219-233.
[12] Kelessidis VC, Maglione R, Tsamantaki C, Aspirtakis, Y: Optimal determination of rheological parameters for Herschel-Bulkley drilling fluids and impact on pressure drop, velocity profiles and penetration rates during drilling, J. Petr. Science & Engr. 53 (2006) 203-224.
[13] Maglione R, Guarneri A, Ferrari G: Rheologic and hydraulic parameter integration improves drilling operations. Oil and Gas J. 97 (1999) 44-48.
[14] Becker TE, Morgan RG, Chin WC, Griffith JE: Improved rheology model and hydraulic analysis for tomorrow's wellbore fluid applications. Paper SPE 84215 presented at the SPE Productions and Operations Symposium, Oklahoma City, OK (2003).
[15] Bailey WJ, Peden JM: A generalized and consistent pressure drop and flow regime transition model for drilling hydraulics, SPE Drill. & Completion 15 (2000) 44-56.
[16] Feys D, Verhoeven R, De Schutter G: Evaluation of time independent rheological models applicable to fresh Self-Compacting Concrete, Appl. Rheol. 17:5 (2007) 56244.
[17] OuldEleya MM, Gunasekaran S: Rheology of fluid foods for dysphagic patients, Appl. Rheol. 17 (2007) 33137.
[18] Malkin AY, Masalova I, Pavlovski D, Slatter P: Is the choice of flow curve fitting equation crucial for the estimation of pumping characteristics? Appl. Rheol. 14 (2004) 89-95.
[19] Yeow YL, Ko WC, Tang PPP: Solving the inverse problem of Couette viscometry by Tikhonov regularization. J. Rheol. 44 (2000) 1335-1351.
[20] Ancey C: Solving the Couette inverse problem using a wavelet-vaguelette decomposition, J. Rheol. 49 (2005) 441-460.
[21] Nguyen YT, Vu TD, Wong HK, Yeow YL: Solving the inverse problem of capillary viscometry by Tikhonov regularization, J. Non-Newtonian Fluid Mech. 87 (1999) 103-116.
[22] Krieger IM, Maron SH: Direct determination of flow curves of non-Newtonian fluids, J. Applied Physics 23 (1952) 147-149.
[23] Krieger IM, Elrod H: Direct determination of flow curves of non-Newtonian fluids, J. Applied Physics 24 (1953) 134-137.
[24] Krieger IM, Maron SH: Direct determination of the flow curves of non-Newtonian fluids. III. Standardized treatment of viscometric data, J. Applied Physics 25 (1954) 72-76.
[25] Krieger IM: Shear rate in the Couette viscometer. Trans. Soc. Rheology 12 (1968) 5-11.
[26] Yang TMT, Krieger IM: Comparison of methods for calculating shear rates in coaxial viscometers, J. Rheol. 22 (1978) 413-421.
[27] Hanks RW: Couette viscometry of Casson fluids, J. Rheol. 27 (1983) 1-6.
[28] Darby R: Couette viscometer data reduction for materials with a yield stress. J. Rheol. 29 (1985) 369-378.
[29] Toorman EA: An analytical solution for the velocity and shear rate distribution of non-ideal Bingham fluids in concentric cylinder viscometers, Rheol Acta 33 (1994) 193-202.
[30] Joye DD: Shear rate and viscosity corrections for a Casson fluid in cylindrical (Couette) geometries, J. of Colloidal and Interface Sci. 267 (2003) 204-210.
[31] De Hoog FR, Anderssen RS: Approximate solutions for the Couette viscometry equation, Bull. Austral. Math. Soc. 72 (2005) 461-470.
[32] De Hoog FR, Anderssen RS: Simple and accurate formulas for flow-curve recovery from Couette rheometer data, Appl. Rheol. 16 (2006) 321-328.
[33] Borgia A, Spera FJ: Error analysis for reducing noisy wide gap concentric cylinder rheometric data for nonlinear fluids: Theory and applications, J. Rheol. 34 (1990) 117-136.
[34] Kelessidis VC, Maglione R: Modeling rheological behavior of bentonite suspensions as Casson and Robertson-Stiff fluids using Newtonian and true shear rates in Couette viscometry, Powder Tech 168 (2006) 137-147.
[35] Maglione R, Romagnoli R: Idraulica dei Fluidi di Perforazione. Edizioni Cusl, Torino (1999).

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

[36] Maglione R, Robotti G: Field rheological parameters improve stand pipe pressure prediction while drilling, Paper SPE 36099 presented in Fourth Latin American and Caribbean Petroleum Engineering Conference, Port of Spain (Trinidad), April 23-26 (1996a).
[37] Maglione R, Robotti G: A Numerical procedure for solving a N non-linear equation system for determining the three rheological parameters of a drilling mud from experimental data, Paper presented in Fourth International Conference on Integral Methods in Science and Engineering, Oulu (Finland), June 17-20 (1996b).
[38] Merlo A, Maglione R, Piatti C: An innovative model for drilling fluid hydraulics. Paper SPE 29259 presented at the Asia-Pacific Oil & Gas Conf., Kuala-Lumpur, Malaysia (1995).
[39] Middleman S: The flow of high polymers, Wiley-Interscience, New York (1968).
[40] Yoshimura A, Prud'homme RK: Wall slip corrections for Couette and parallel disk viscometers, J. Rheol., 32(1) (1988) 53-67.
[41] Barnes HA: A review of the slip (wall depletion) of polymer solutions, emulsions and particle suspensions in viscometers: its cause, character and cure, J. Non-Newtonian Fluid Mech. 56 (1995) 221-251.
[42] Kiljanski T: A method for correction of the wall-slip effect in a Couette rheometer, Rheol Acta, 28 (1989) 61-64.
[43] Wein O, Tovchigrechko VV: Rotational viscometry under presence of apparent wall slip, J. Rheol. 36 (1992) 821-844.
[44] Manneville S, Becu L, Grondin P, Colin A: High-frequency ultrasonic imaging: A spatio-temporal approach of rheology. Colloids Surf. A 270-271 (2005) 195-204.
[45] Goudoulas TB, Kastrinakis EG, Nychas SG: Rheological aspects of dense lignite-water suspensions; structure development on consecutive flow loops. Rheol Acta 46 (2007) 357-367.
[46] Møller PCF, Mewis J, Bonn D: Yield stress and thixotropy: on the difficulty of measuring yield stresses in practice, Soft Matter 2 (2006) 274-283.
[47] Blick EF: Non-Newtonian Fluid Mechanics Notes, Engineering Library, Univ. of Oklahoma, Norman, OK (1992).
[48] Myslyuk MA: Determining rheological parameters for a dispersion system by rotational viscometry, J Eng Phys Thermophysics 54 (1988) 655-658.
[49] Steffe JF: Rheological methods in food process engineering. Freeman Press, East Lansing MI (1996).
[50] MacSporran WC: Direct numerical evaluation of shear rates in concentric cylinder viscometry. J Rheol 30 (1986) 125-132
[51] Fisher DT, Boger DV, Scales PJ: Measurement errors in yield stress rheometry that arise from torque auto zero, Appl. Rheol. 16 (2006) 206-209.
[52] Tanner RI, Williams G: Iterative numerical methods for some integral equations arising in rheology. Trans Soc Rheol 14 (1970) 19-38.

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