Rheology of Aqueous Dispersions of Hydrogenated Castor Oil

Dingzheng Yang, Andrew N. Hrymak*

Department of Chemical Engineering, McMaster University, Hamilton, Ontario L8S4L7, Canada
* Department of Chemical and Biochemical Engineering, University of Western Ontario, London, Ontario, N6A 5B9, Canada

*Corresponding author: ahrymak@uwo.ca
Fax: x1.519.850.2399

Received: 21.6.2012, Final version: 17.10.2012

Abstract:
Three major hydrogenated castor oil crystal morphologies have been observed: fiber, rosette and irregular crystal. Due to the difficulty in obtaining samples with a single crystal morphology, rheological studies of suspensions containing mixtures of the three morphologies in an aqueous solution have been undertaken. The viscometry of dilute suspensions has shown that the magnitude of intrinsic viscosity is dominated by the fraction of a crystal morphology type, i.e. fiber > rosette > irregular crystal. A modified Farris model was fitted to the rheology data for mixtures of crystal morphology with interacting particles. A yield stress exists for concentrated suspensions followed by a shear thinning behavior with the increase of shear rate. A power-law relation has been found between yield stress and total particle volume fraction, and a constant exponent of 1.5 has been obtained regardless of crystal morphology.

Zusammenfassung:
Drei große hydrogenierte Kastoröl-Kristallmorphologien wurden beobachtet: Faser, Rosette und irregulärer Kristall. Aufgrund der Schwierigkeit, Proben mit einer einzigen Kristallmorphologie zu erhalten, wurden rheologische Studien an Suspensionen aus Mischungen dieser drei Morphologien in wässrigen Lösungen durchgeführt. Die Viskosimetrie der verdünnten Suspensionen verdeutlichte, dass der Betrag der intrinsischen Viskosität von dem Anteil des kristallinen Morphologietypus bestimmt wird, nämlich Faser > Rosette > irregulärer Kristall. Ein modifiziertes Farris-Modell wurde an die rheologischen Daten für die Mischungen der Kristallmorphologie mit wechselwirkenden Partikeln angepasst. Bei den konzentrierten Suspensionen existiert eine Fließspannung, die von einem scherverdünnenden Verhalten mit zunehmender Schergeschwindigkeit begleitet wird. Es wurde ein Potenzgesetz zwischen der Fließspannung und dem Partikelgehalt gefunden. Der Exponent des Potenzgesetzes nahm unabhängig von der Kristallmorphologie den Wert 1,5 an.

Résumé:
Trois principales morphologies cristallines d'huile de castor hydrogénée ont été observées : fibre, rosette et cristal irrégulier. A cause de la difficulté d'obtenir des échantillons avec une morphologie cristalline unique, des études rhéologiques de suspensions contenant des mélanges des trois morphologies dans une solution aqueuse ont été entreprises. La viscosimétrie des suspensions diluées a montré que la magnitude de la viscosité intrinsèque est dominée par la fraction de morphologie cristalline type, c-à-d, fibre>rosette>cristal irrégulier. Un modèle de Farris modifié a été ajusté aux données rhéologiques des mélanges de morphologie cristalline et de particules inter agissantes. Une contrainte seuil existe pour les suspensions concentrées, qui est suivie par un comportement rhéo-amincissant aux vitesses de cisaillement plus élevées. Une relation de type loi de puissance a été trouvée entre la contrainte seuil et la fraction volumique totale en particule, avec un exposant constant de 1.5 obtenu quelle que soit la morphologie cristalline.

Key words: suspension rheology, morphology, hydrogenated castor oil, fiber, rosette

DOI: 10.3933/ApplRheol-23-23622

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

sions. Therefore, all the experiments were conducted in the hydrodynamic regime and Brownian motion was considered negligible. Also, due to the small Reynolds number particle inertia could be negligible too, while viscous forces dominated indicating particles and fluid motions were fully coupled.

Shear thinning behavior for non-Brownian particulate suspensions at high Peclet number is not fully understood. *Pe* is so large that no significant reduced viscosity will be observed caused by shear-induced alignment. Shear induced adhesions between particles [46] could be an explanation of such shear thinning. At low shear rate, flocs of particles form and break down with the increase of shear rate. Another explanation comes from Mueller et al. [40] who hypothesized that the shear thinning was caused by the decrease of the local viscosity between gaps of particles. During shear flow, the shear rate in the small gap between two particles is higher than the bulk shear rate. Mueller et al. [40] states that when the gap decreases, there will arise a point that the heat diffused out to the bulk is not enough, leading to a rise of local temperature in the gap. Thus, the viscosity in the gap will decrease resulting in the lubrication of one particle to another.

4 CONCLUSIONS

Rheology of three mixtures of HCO crystal morphologies has been studied to understand the relationship of rheology with crystal morphology. Rheological properties, intrinsic viscosity and yield stress, are functions of the volume fractions and crystal shape. The magnitudes of intrinsic viscosity and yield stress have the following decreasing sequence: fiber > rosette > irregular crystal. The Huggins coefficient is a decreasing function of morphology in the preceding sequence. A modified Farris model has been successfully applied on the mixture of morphology with particulate interactions. Concentrated suspensions show yield stress which is the power law function of total volume fraction.

ACKNOWLEDGEMENTS

The authors thank Dr. Shiping Zhu for facilitating this work through the use of the ATS rheometer. The authors also thank Dr. John Vlachopoulos for his insightful comments.

REFERENCES

[1] Moravkova T, Stern P: Rheological and textural properties of cosmetic emulsions, Appl. Rheol. 21 (2011) 35200.
[2] Magauran, *et al.*: Rheological additive comprising derivatives of castor oil, U.S. Patent, 5,340,390 (1994).
[3] Goddinger D, Nordende K, Schroeder T: Antidandruff Shampoo, US Patent 2009/0169644 A1 (2009).
[4] Yang D, Hrymak AN: Crystal morphology of hydrogenated castor oil in the crystallization of oil-in-water emulsions: Part 1. Effect of temperature, Ind. Eng. Chem. Res. 50 (2011) 11585 – 11593.
[5] Yang D, Hrymak AN, Kamal MR: Crystal morphology of hydrogenated castor oil in the crystallization of oil-in-water emulsions: Part 2. Effect of shear, Ind. Eng. Chem. Res. 50 (2011) 11594 – 11600.
[6] Mewis J, Wagner NJ: Current trends in suspension rheology, J. Non-Newtonian Fluid Mech. 157 (2009) 147 – 150.
[7] Merkus HG, Bellantone M, Scarlett B: Particle size measurements: fundamentals, practice, quality, Dordrecht, Springer (2009).
[8] Ouari N, Kaci A, Tahakourt A, Chaouche M: Rheological behaviour of fibre suspensions in non-Newtonian fluids, Appl. Rheol. 21 (2011) 54801.
[9] Brenner H: Rheology of a dilute suspension of axisymmetric Brownian particles, Int. J. Multiphase Flow 1 (1974) 195 – 341.
[10] Petrie CJS: The rheology of fibre suspensions, J. Non-Newtonian Fluid Mech. 87 (1999) 367 – 402.
[11] Petrich MP, Koch DL, Cohen C: An experimental determination of the stress-microstructure relationship in semi-concentrated fiber suspensions, J. Non-Newtonian Fluid Mech. 95 (2000) 101 – 133.
[12] Pabst W, Gregorova E, Berthold C: Particle shape and suspension rheology of short-fiber systems, J. Euro. Ceram Soc. 26 (2006) 149 – 160.
[13] Solomon MJ, Spicer PT: Microstructural regimes of colloidal rod suspensions, gels and glasses, Soft Matter 6 (2010) 1391 – 1400.
[14] Farris RJ: Prediction of the viscosity of multimodal suspensions from unimodal viscosity data, Trans. Soc. Rheol. 12 (1968) 281 – 301.
[15] Foudazi R, Masalova I, Malkin A: The rheology of binary mixtures of highly concentrated emulsions, Appl. Rheol. 21 (2011) 25326.
[16] Mor R, Gottlieb M, Graham A, Mondy L: Viscosity of concentrated suspensions of sphere/rod mixtures, Chem. Eng. Comm. 148 – 150 (1996) 421 – 430.
[17] Marti I, Höfler O, Fischer P, Windhab EJ: Rheology of concentrated suspensions containing mixtures of spheres and fibers, Rheol. Acta 44 (2005) 502 – 512.
[18] Krieger IM: Rheology of monodisperse lattices, Adv. Colloid Interface Sci. 3 (1972) 111 – 136.

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

[19] Zaman AA, Moudgil BM: Rheology of bidisperse aqueous silica suspensions: a new scaling method for the bidisperse viscosity, J. Rheol. 42 (1998) 21–39.
[20] Spicer PT, Hartel RW: Crystal comets: dewetting during emulsion droplet crystallization, Aust. J. Chem. 58 (2005) 655–659.
[21] Chong JS, Christiansen EB, Baer AD: Rheology of concentrated suspensions, J. Appl. Polym. Sci. 15 (1971) 2007–2021.
[22] Kuwahara T, Nagase H, Endo T, Ueda H, Nakagaki M: Crystal structure of DL-12-Hydroxystearic acid, Chem. Lett. 6 (1996) 435–436.
[23] Rogers MA, Wright AJ, Marangoni AG: Engineering the oil binding capacity and crystallinity of self-assembled fibrillar networks of 12- hydroxystearic acid in edible oils, Soft Matter 4 (2008) 1483–1490.
[24] Russel WB, Saville DA, Schowalter WR: Colloidal Dispersions, Cambridge University Press, Cambridge (1989).
[25] Genovese DB, Lozano JE, Rao MA: The rheology of colloidal and noncolloidal food dispersions, J. Food Sci. 72 (2007) R11–R20.
[26] Brenner H: Coupling between the translational and rotational Brownian motions of rigid particles of arbitrary shape, J. Colloid Int. Sci. 23 (1967) 407–436.
[27] Macosko CW: Rheology: Principle, Measurements, and Applications, VCH Publishers Inc., New York (1994).
[28] Leal LG, Hinch EJ: Theoretical studies of a suspension of rigid particles affected by Brownian couples, Rheol. Acta 12 (1973) 127–132.
[29] Berry DH, Russel WB: The rheology of dilute dispersions of slender rods in weak flow, J. Fluid Mech. 180 (1987) 475–494.
[30] Hinch EJ, Leal LG: The effect of Brownian motion on the rheological properties of a suspension of non-spherical particles, J. Fluid Mech. 52 (1972) 683–712.
[31] Wierenga AM, Philipse AP: Low-shear viscosities of dilute dispersions of colloidal rodlike silica particles in cyclohexane, J. Colloid Int. Sci. 180 (1996) 360–370.
[32] Solomon MJ, Boger DV: The rheology of aqueous dispersions of spindle-type colloidal hematite rods, J. Rheol. 42 (1998) 929–949.
[33] Horn FM, Richtering W: Viscosity of bimodal charge-stabilized polymer dispersions, J. Rheol. 44 (2000) 1279–1292.
[34] Barnes HA, Walters K: The yield stress myth, Rheol. Acta 24 (1985) 323–326.
[35] Hartnett JP, Hu RYZ: Technical not: the yield stress – An engineering reality, J. Rheol. 33 (1989) 671–679.
[36] Astarita G: Letter to the editor: the engineering reality of the yield stress, J. Rheol. 34 (1990) 275–277.
[37] Reeve P: Yield Stress: a predictive tool for determining suspending properties? Appl. Rheol. 20 (2010) 33009.
[38] Larson RG: The structure and rheology of complex fluids, Oxford University Press Inc., New York (1999).
[39] Zhou Z, Solomon MJ, Scales PJ, Boger DV: The yield stress of concentrated flocculated suspensions of size distributed particles, J. Rheol. 43 (1999) 651–671.
[40] Mueller S, Llewellin EW, Mader HM: The rheology of suspensions of solid particles, Proc. R. Soc. A 466 (2010) 1201–1228.
[41] Johnson SB, Franks GV, Scales PJ, Healy TW: The binding of monovalent electrolyte ions on α–Alumina. 2. The shear yield stress of concentrated suspensions, Langmuir 15 (1999) 2844–2853.
[42] Leong YK, Scales PJ, Healy TW, Boger DV: Effect of particle size on colloidal zirconia rheology at the isoelectric point, J. Am. Ceram Soc. 78 (1995) 2209–2212.
[43] Marangoni AG, Roger MA: Structural basis for the yield stress in plastic disperse systems, Appl. Phys. Lett. 82 (2003) 3239–3241.
[44] Marangoni AG, Narine SS: Identifying key structural indicators of mechanical strength in networks of fat crystals, Food Res. Int. 35 (2002) 957–969.
[45] Stickel JJ, Powell RL: Fluid mechanics and rheology of dense dispersions, Annu. Rev. Fluid Mech. 37 (2005) 129–149.
[46] Chaouche M, Koch DL: Rheology of non-Brownian rigid fiber suspensions with adhesive contacts, J. Rheol. 45 (2001) 369–382.

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