Rheological Behavior of Suspensions Dispersed in non-Newtonian Matrix

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Received: 23.11.2012, Final version: 17.3.2013

Abstract:

Suspensions composed with silica particles or cellulose fibers dispersed in glycerin and/or xanthan aqueous solutions were formulated with solids volume fraction varying up to 15 and 10 % for silica and cellulose dispersions, respectively. In addition, xanthan was added to the aqueous solutions (water or 82 % glycerin + water) at concentrations of 0.005, 0.1, and 0.2 % to impart non-Newtonian character to matrices, and results were compared to the Newtonian systems, without xanthan addition. Even though developed for suspensions in Newtonian fluids, Krieger-Dougherty and Eilers models described properly the influence of solids content on the flow behavior of suspensions in non-Newtonian fluids. Generally, increasing cellulose particles concentration led to an increase on the suspension pseudoplasticity, while for silica particles such increase was more discrete. Low deformation rheological measurements showed that glycerin-containing matrices were more independent on frequency as compared to suspensions of aqueous xanthan solutions. Results showed that, besides particles characteristics, the rheological properties of the suspending matrix are crucial for determining the arragements and flow properties of suspensions.

Zusammenfassung:

Suspensionen, die aus in Glyzerin und/oder in wässrigen Xanthan-L ösungen dispergierten Silika-Partikeln oder Zellulose-Fasern bestehen, wurden mit Feststoffanteilen bis zu 15 bzw. 10 Vol.-% für Silika- und Zellulose-Dispersionen hergestellt. Darüber hinaus wurde zu den wässrigen Lösungen (Wasser oder 82 % Glyzerin und Wasser) Xanthan in Konzentrationen von 0.005, 0.1 und 0.2 % gegeben, um einen nicht-Newtonschen Charakter zu erhalten. Die Resultate wurden mit denen der Newtonschen Systeme ohne Xanthan verglichen. Obgleich das Krieger-Dougherty- und das Eilers-Modell für Suspensionen in Newtonschen Fluiden entwickelt wurden, beschreiben diese Modelle den Einfluss des Feststoffgehalts auf das Fließverhalten der Suspensionen in nicht-Newtonschen Systemen gut. Generell führt eine Erhöhung der Konzentration der Zellulosepartikel zu einem ausgeprägteren strukturviskosen Verhalten der Suspension. Dabei war diese Erhöhung des strukturviskosen Verhaltens für die Silikapartikel diskreter. Rheologische Messungen bei kleinen Deformationen zeigten, dass die auf Glyzerin basierten Matrizes weniger frequenzabhängig waren im Vergleich zu den Suspensionen, die auf den wässrigen Xanthan-Lösungen basierten. Diese Resultate zeigten, dass neben den Partikeleigenschaften die rheologischen Eigenschaften der Matrix für die Bestimmung der Fließeigenschaften der Suspension wesentlich sind.

Résumé:

Les suspensions composées de particules de silice ou de fibres de cellulose dispersées dans de la glycérine et/ou des solutions aqueuses de xanthane, ont été formulées avec des fractions volumiques solides variant jusqu'à 15 et 10 % pour les dispersions de silice et de cellulose, respectivement. De plus, la xanthane a été ajoutée à des solutions aqueuses (eau ou 82 % de glycérine dans de l'eau) à des concentrations de 0.005, 0.1 et 0.2 % afin d'allouer un caractère non Newtonien aux matrices, et les résultats ont été comparés avec des systèmes Newtoniens sans addition de xanthane. Malgré le fait que les modèles de Krieger-Dougherty et Eilers aient été développés pour des suspensions dans des fluides Newtoniens, ces modèles décrivent correctement l'influence de la fraction solide sur le comportement d'écoulement de suspensions dans des fluides non Newtoniens. En général, l'augmentation de la concentration de particules de cellulose conduit à une augmentation de la pseudoplasticité de la suspension, tandis que pour les particules de silice l'augmentation est moins remarquable. Les mesures rhéologiques à basse déformation montrent que les matrices contenant de la glycérine dépendent moins de la fréquence que les suspensions en solution aqueuse de xanthane. Les résultats montrent que, en dépit des caractéristiques des particules, les propriétés rhéologiques des matrices sont cruciales pour déterminer les arrangements et les propriétés d'écoulement des suspensions.

Key words: suspension, rheology, non-Newtonian matrix, reduced shear rate

 DOI: 10.3933/ApplRheol-23-45397

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G82X005, G82X01) were more independent on frequency, reflecting a better structuring of such suspensions. For the highly viscous G82X02 matrix, distinct behavior was observed, mainly for cellulose suspensions. In this case, the increase on solids concentration promoted lower variation on G^* and η_r when compared to other matrices. The reduced mobility of particles due to the high viscosity of the dispersing matrix would reduce particles interaction and thus, their influence on the rheological behavior of the suspension. Such effect was more discrete for silica suspensions, once interaction between silica particles is small for all the dispersing matrix. Other characteristic behavior was observed for pure xanthan solutions, particularly when silica particles were added. In this case, a slight loss of structure complexity was observed with increasing solids addition, which was reflected by the higher dependency of G^* on frequency and by the reduction of pseudoplasticity (higher n) with increasing solids content. The deviation from the "reduced shear rate concept" also observed in this case could be and indication that other interaction than solely the predictable fluid dynamic forces should be occurring. When suspended in shear thinning viscoelastic fluids, spherical particles such as silica form strings in both steady state and oscillatory measurements [20]. Such strings would be oriented in the flow direction, which corresponds to a quantitative reduction in the measured shear stress [4, 20]. However, beyond the organization of the spherical particles into strings it is believed that the biopolymer should also influence the flow of the suspensions of silica on xanthan solutions on an additional manner. In this case, the xanthan solutions would in fact behave as a xanthan dispersion. Thus the biopolymer molecules should stretch, aligning themselves so that biopolymer-particle strings layers would be formed (Figure 13). Such organization would avoid the hydrocolloid molecules to entangle at the same time as it would form paths that would facilitate particles movement. Even though cellulose could also form layers when dispersed into biopolymer solutions, rod-like particles would still rotate when subjected to flow in viscoelastic matrices albeit slower than in Newtonian solutions [21]. Such rotation would interfere in the organized structure so that the effects observed for the silica suspensions would be more pronounced than the observed for the cellulose ones.

5 CONCLUSIONS

As particle concentration increased the rheological behavior of suspensions diverged from the suspending matrices, which was not observed for systems with small amounts of solids. Generally, the influence of cellulose was higher than silica, which was reflected by the higher values of complex moduli, viscosity, and pseudoplasticity of suspensions. By evaluating the dispersing matrices effects it was observed that the high viscosity matrix (G82X02) reduced particles interaction, while suspensions dispersed in other glycerin-xanthan matrices were more structured. Aqueous xanthan matrices, which showed higher pseudoplasticity behaved differently from others specially for silica suspensions. Results showed that such behavior was associated to arrangements between rigid and spherical particles-xanthan molecules. Thus, besides particles characteristics the rheological properties of the suspending matrix may be crucial for determining the re-arragements of particles and flow properties of suspensions.

ACKNOWLEDGEMENTS

Authors would like to thank CNPq (proc. # 140463/2005-4 and 301869/2006-5) and FAPESP (proc. # 2007/58017-5) for financial support.

REFERENCES

[1] Larson RG. Particulate Suspension. In: The structure and rheology of complex fluids, Oxford University Press, Oxford (1999).

[2] Iso Y, Koch DL, Cohen C: Orientation in simple shear flow of semi-dilute fiber suspensions 1. Weakly elastic fluids, J. Non-Newton Fluid Mech. 62 (1996) 115–134.

[3] Mewis J, Wagner NJ: Current trends in suspension rheology, J. Non-Newton Fluid Mech. 157 (2009) 147–150.

[4] Scirocco R, Vermant J, Mewis J: Effect of the viscoelasticity of the suspending fluid on structure formation in suspensions, J. Non-Newton Fluid Mech. 117 (2004) 183–192.

[5] Eberle APR, Baird DG, Wapperom P: Rheology of non-Newtonian fluids containing glass fibers: A review of experimental literature, Ind. Eng. Chem. Res. 47 (2008) 3470–3488.

[6] Ferrini F, Ercolani D, Cindio BD, Nicodemo L, Nicolais L, Ranaudo S: Shear viscosity of settling suspensions, Rheol. Acta 18 (1979) 289–296.

[7] Zirnsak MA, Boger DV, Tirtaatmadja V: Steady shear and dynamic rheological properties of xan-

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than gum solutions in viscous solvents, J. Rheol. 43 (1999) 627–650.
[8] Sepehr M, Carreau PJ, Moan M, Ausias G: Rheological properties of short fiber model suspensions, J. Rheol. 48 (2004) 1023–1048.
[9] James DF: Boger Fluids, Ann. Rev. Fluid Mech. 41 (2009) 129–142.
[10] Chernov V, Natan B: A Simplified Model for the Evaluation of the Rheological Properties of a Suspension of Solids in a Power-Law Fluid, Appl. Rheol. 22 (2012) 15163.
[11] Ohl N, Gleissle W: The characterization of the steadystate shear and normal stress functions of highly concentrated suspensions formulated with viscoelastic liquids, J. Rheol. 37 (1993) 381–406.
[12] Chang C, Powell RL: Hydrodynamic transport properties of concentrated suspensions, AIChE J. 48 (2002) 2475–2480.
[13] Ouari N, Kaci A, Tahakourt A, Chaouche M: Rheological behaviour of fibre suspensions in non-Newtonian fluids, Appl. Rheol. 21 (2011) 54801.
[14] Ferguson J, Kemblowski Z: Applied fluid rheology. Elsevier Applied Science, New York (1991).
[15] Pawlik M, Laskowski JS, Melo F: Effect of coal surface wettability on aggregation of fine coal particles, Coal Prep. 24 (2004) 233–248.
[16] Pasquino R, Grizzuti N, Maffettone PL, Greco F: Rheology of dilute and semidilute noncolloidal hard sphere suspensions, J. Rheol. 52 (2008) 1369–1384.
[17] Marti I, Höfler O, Fischer P, Windhab EJ: Rheology of concentrated suspensions containing mixtures of spheres and fibres, Rheol. Acta 44 (2005) 502–512.
[18] Lindström SB, Uesaka T: Simulation of semidilute suspensions of non-Brownian fibers in shear flow, J. Chem. Phys. 128 (2008) 024901.
[19] Meng Q, Higdon JJL: Large scale dynamic simulation of plate-like particle suspensions. Part I: Non-Brownian simulation, J. Rheol. 52 (2008) 1–36.
[20] Lyon MK, Mead DW, Elliott RE, Leal LG: Structure formation in moderately concentrated viscoelastic suspensions in simple shear flow, J. Rheol. 45 (2001) 881–890.
[21] Gunes DZ, Scirocco R, Mewis J, Vermant J: Flow-induced orientation of non-spherical particles: Effect of aspect ratio and medium rheology, J. Non-Newton Fluid Mech. 155 (2008) 39–50.

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