Effect of Interdroplet Interaction on Elasticity of Highly Concentrated Emulsions

R. Foudazi, I. Masalova*, A. Ya. Malkin

Institute of Material Science and Technology, Cape Peninsula University of Technology, Cape Town, South Africa

* Email: masalovai@cput.ac.za
Fax: x27.21.4603990

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Abstract:
We present a model for osmotic pressure and shear modulus of highly concentrated emulsions by including the interdroplet interaction in terms of disjoining pressure. The results show that even a small addition in interdroplet interaction can lead to significant deviations from the classical Princen-Lacasse-Mason models that take into account only the surface energy as the sole source of elasticity. The newly proposed model predicts new effects, in particular the possibility of nonlinear dependency of elastic modulus on the droplet size, and can be used to discuss the elasticity sources of highly concentrated emulsions. In the second part of this article, the unusual elasticity of highly concentrated explosive emulsions is discussed by using the proposed model.

Zusammenfassung:
Wir stellen ein Modell für den osmotischen Druck und Schubmodul von hochkonzentrierten Emulsionen, durch Einbeziehen der Tröpfchenwechselwirkung im Hinblick auf den Abstoßungsdruck, vor. Die Ergebnisse zeigen, dass bereits eine geringe Erhöhung der Tröpfchenwechselwirkung zu erheblichen Abweichungen von den klassischen Princen-Lacasse-Mason-Modellen führen kann, die lediglich die Oberflächenenergie als einzige Elastizitätsquelle berücksichtigen. Das neu vorgestellte Modell ermöglicht die Vorhersage neuer Effekte, insbesondere die Möglichkeit einer nichtlinearen Abhängigkeit des Elastizitätsmoduls auf die Tröpfchengröße, und kann zur Diskussion der Elastizitätsquellen von hochkonzentrierten Emulsionen verwendet werden. Im zweiten Teil dieses Artikels wird die ungewöhnliche Elastizität hochkonzentrierter explosiver Emulsionen mithilfe des vorgestellten Modells diskutiert.

Résumé:
Nous présentons un modèle de pression osmotique et un module de rigidité d'émulsions à forte concentration en incluant l'interaction entre gouttelettes en termes de pression de disjonction. Les résultats montrent que même un ajout minime d'interaction entre gouttelettes peut mener à des déviations importantes des modèles classiques Princen-Lacasse-Mason qui ne prennent en considération que l'énergie de surface comme source unique d'élasticité. Le nouveau modèle proposé prévoit de nouveaux effets, en particulier la possibilité de dépendance non linéaire du module d'élasticité de la taille de la goutte, et peut être utilisé pour discuter de la source d'élasticité des émulsions à forte concentration. Dans la deuxième partie de cet article on discute de l'élasticité insolite des émulsions explosives à forte concentration, en utilisant le modèle proposé.

Key words: shear modulus, osmotic pressure, highly concentrated emulsion, Laplace pressure

1 INTRODUCTION

An emulsion is a mixture of two immiscible fluids, one of which is dispersed in the continuous phase of the other, typically formed by rupturing droplets down to colloidal sizes through mixing. To inhibit recombination or coalescence, a surfactant that concentrates at the interfaces must be added to create short-ranged interfacial repulsion between droplets [1]. The increase of the dispersed phase concentration beyond close packing of spheres has significant technological applications in the food and cosmetics industries, as well as "liquid explosives" [2].

Emulsions consisting of highly concentrated droplets, despite comprising fluids only, can possess a striking shear elasticity that is usually characteristic of a solid. Princen [3, 4] attributed this elasticity to the interfacial energy of deformed droplets that is due to the increment of droplet surface area. Lacasse et al. [5, 6] and Mason et al. [7] also predicted the osmotic pressure Π and the static shear modulus G – by using

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surfactant head-group in the surface layer of droplets. Hence, it is reasonable to claim the presence of electrostatic repulsion; its theoretical formulation, however, needs further fundamental studies.

It is known that the diffuse electric double layer (Debye length) of electrostatic forces is decreased by increasing the concentration of electrolytes in the continuous aqueous phase [25]. Therefore it is expected that, increasing the reversed micelle concentration in the studied explosive emulsions will decrease the electrostatic repulsion. This implies that a higher surfactant concentration will result in lower interdroplet interaction and hence, lower shear modulus. The same trend was seen in the shear modulus of the studied explosive emulsions.

5 CONCLUSION

A basic model for the elasticity of highly concentrated emulsion has been proposed. This model takes into account the effect of interdroplet interaction as additional to the classical understanding of the elasticity of compressed emulsions. The model includes two components: a usual term reflecting the role of interfacial tension due to the increase of droplet area and a term considering the disjoining pressure which can be introduced by the presented optimisation method. It was shown that the disjoining pressure gives a physically meaningful contribution which results in the deviation of shear modulus to scale with the Laplace pressure. This model predicts the possibility of a nonlinear dependency of elastic modulus on the droplet size. The model was used to discuss the unusual high elasticity of explosive emulsions which is not contributed by Van der Waals, steric and micellar forces, but by electrostatic repulsion enhanced by reversed micelles.

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