Morphology Development During Microconfined Flow of Viscous Emulsions

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Abstract:
In this contribution, a brief review is given of the dynamics of emulsions in microconfined shear flow. The interest in confined flow is triggered by the increasing importance of microfluidic applications in the processing industries. In a first part, some important aspects of confinement on single droplet dynamics are highlighted. The validity of the conclusions drawn from this part are subsequently applied to more concentrated systems. It is shown that microconfined emulsions can exhibit rich dynamics, and can display some peculiar morphologies.

Zusammenfassung:
In diesem Beitrag wird ein kurzer Überblick über die Dynamik von Emulsionen in Scherströmungen mit einer begrenzten Mikrogeometrie gegeben. Das Interesse an Strömungen in einer begrenzten Geometrie wird durch die wachsende Bedeutung von Mikrofluidikanwendungen in der verarbeitenden Industrie verursacht. Zuerst werden einige wichtige Aspekte von begrenzten Geometrien auf die Dynamik von einzelnen Tropfen hervorgehoben. Die Gültigkeit der Schlussfolgerungen dieses Teils wird danach auf konzentriertere Systeme angewandt. Es wird gezeigt, dass Emulsionen in einer begrenzten Mikrogeomtrie eine vielseitige Dynamik aufweisen und einige besondere Morphologien bilden.

Résumé:
Dans cette contribution, une revue brève de la dynamique des émulsions dans un écoulement de cisaillement microconfiné est donnée. L'intérêt de l'´coulement confiné est conditionné par l'importance croissante des applications de procédés microfluidiques dans les industries de mise en ?uvre. Dans une première partie, des aspects importants de l'effet du confinement sur la dynamique d'une simple gouttelette sont soulignés. La validité des conclusions tirées de cette première partie est ensuite appliquée à des systèmes plus concentrés. Il est démontré que les émulsions microconfinées peuvent présenter une dynamique riche et exhiber des morphologies particulières.

Key words: morphology, blends, emulsions, microfluidics, confinement

1 INTRODUCTION

The study of blending two immiscible polymers has received a high degree of scientific attention in the last decades. Although many problems are still unresolved – for instance the precise role of component elasticity – important progress towards understanding the morphology development during flow has already been achieved (see [1 - 5] for recent reviews on the subject). In most of the investigations, flow was constrained to geometries with a characteristic size much larger than the typical size of the generated morphology. Recently however, flow in microdevices has received a lot of attention. This is related to the fact that methods have become available for fabricating flow configurations with length scales on the order of tens of microns or even smaller [6]. In addition, rapid developments in biotechnology, for which manipulations on the cellular length scale and the necessity to manipulate small volumes are essential, have accelerated the development of this microfluidic technology (see [7] for a recent review). Finally, the quest for high throughput experimentation has led to the development of small, portable devices that are able to perform relatively simple analytical, biological, or chemical tasks (see [7]). In the case of emulsions, such a trend towards miniaturization is also eminent. This is not surprising since liquid-liquid dispersions are quite common in macroscopic processes or in various consumer products such as food or cosmetics. The major part of the literature in this field deals with specific technologies to control droplet sizes and

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finement. Hence, the conclusions drawn by Vananroye et al. [40] do not necessarily hold whenever the degree of confinement becomes larger.

4 CONCLUSIONS

In this paper, a brief review of systematic experimental work on microconfined flow of emulsions is presented. Most of the experimental studies done so far are performed with the popular PIB/PDMS system, which has an extremely high viscosity compared to the systems used in most of the microfluidic applications discussed in literature [7]. Nevertheless, this system could be seen as a slowed down model for high throughput flows of lower viscosity emulsions, as long as Stokes flow prevails. Hence, the results discussed here are of direct interest to microfluidic technologies. The data on breakup of single confined droplets clearly demonstrate that wall effects drastically change the physics behind the structure development. The fact that - depending on the viscosity ratio of the emulsion - droplets are either stabilized or broken by confined flow, opens new potential dispersion applications in microfluidic devices. It also indicates that, whenever droplet sizes become roughly 40 % of the channel dimension (for instance, during a 'dead zone' in an extruder or during flow in dies during micromoulding of polymer blends), the deformation and breakup behaviour is altered completely with respect to the 'bulk' condition. Modeling such processes, based on the assumption of no wall interactions, can lead to erroneous results.

Next to a changing droplet dynamics, various interesting superstructures can be obtained in concentrated emulsions, going from pearl necklace structures, string-like towards sheet-like structures. Especially the latter two might seem useful from an application point of view. The long string-like morphology might for instance be used in self-reinforcing structures (in-situ composites during micromoulding) whereas ultra-thin sheets might find potential in biotechnological applications as scaffolds. However, in order to optimize such structures and to rationally design the necessary microfluidic devices needed to generate such beautiful morphologies, further systematical work in this area is without any doubt still necessary.

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