Velocity Profiles and Shear-Induced Structuring in Wormlike Micellar Solutions Flowing in a Microcapillary

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ABSTRACT

In the present work we have highlighted the correspondence between flow induced structures and discontinuity point of the velocity profile in a flowing wormlike micellar solution, using a microfluidic device coupled with optical microscopy and μPIV technique.

INTRODUCTION

Thanks to their ability to ensure the rheological control of surfactant-based systems, wormlike micellar solutions are widely used in a number of applications, one of the most important of which is the formulation of cleaning agents and personal care products, in which they provide high viscosity, elasticity and stability[1, 2].
Besides the huge industrial interest, basic research is devoting a growing attention in wormlike micelles. In fact, in addition to their unique morphology and rheological behaviour, wormlike micellar systems are characterized by peculiar phenomena, such as flow instabilities, sometimes widely reported in literature (for instance, the shear banding[3]), but not completely elucidated.

MICROFLUIDICS APPROACH

Microfluidics is an emerging technology, in which a very small amount of fluid – microliters or even picoliters – is fed to a micrometric controlled geometry, thus ensuring a minimum chemical consumption. Other advantages of using microfluidics are low cost, low space-occupation, portability, low response-time and the possibility of designing the flow geometry. Furthermore, two specific features make microfluidics an ideal tool to study wormlike micellar solutions: the high confinement which characterizes a microfluidic device[4], enhances the surface forces-driven effects, thus facilitating the onset of flow instabilities; then, it's possible to couple the device with other techniques, as optical microscopy – thus ensuring the direct visualization of the flow induced structures – or tracking techniques – from which it's possible to analyse the flow pattern of the solution.

PRESENT STUDY

In this study, we have coupled a microfluidic device with optical microscopy in order to analyse the flowing solution texture, and with μPIV technique, thanks to which we have evaluated its velocity profiles.

Hence, during the formulation, a widely used wormlike micellar solution has been seeded with monodisperse polystyrene microbeads; the system has then been fed into a microcapillary, and the flow has been visualized using an inverted microscope equipped with a high-speed camera – which allows one to perform the particle tracking analysis.

By increasing the fixed pressure drop, we have thus studied the flow behaviour of the solution as a function of the flow rate.

At very low flow rates, there is no evidence of flow structuring in the solution, nor is there any kind of discontinuity in the velocity profile.

As the flow rate increases, the solution shows the presence of shear-induced structures, and from the μPIV analysis, a relationship has been highlighted between the structures location in the geometry, and a discontinuity-point in the velocity profile.

When even higher flow rates have been reached, the velocity profile became even more complex, showing several points of discontinuity.

Finally, the velocity profile seems never to meet the no-slip condition. Understanding if there is a real slip velocity component, or if the velocity abruptly falls to zero in a very thin layer by the wall, goes beyond the scope of this study, as it's not possible to resolve the velocity profile on a length-scale smaller than the microbeads' diameter.

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