Particle Image Velocimetry in Concentrated Suspensions: Application to Local Rheometry

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Abstract:
This paper presents an experimental facility that allows simultaneous viscosimetric and Particle Image Velocimetry measurements on concentrated suspensions in a wide-gap Couette rheometer. The experimental procedure is detailed: the optical characteristics of the index-matched suspension are carefully studied, the bottom end effect on both the viscosimetric measurements and the recorded velocity profiles are analysed. First the experimental procedure is tested on a Newtonian fluid whose viscosity is known. The spatial and time resolutions of our device are shown to be 200 μm and 100 ms. The precision of the local viscosity measurement is evaluated to better than 4 %. Then we show that the device can be used to characterize the rheological behaviour of a 47 %-concentrated suspension of 30 μm spheres. According to the particles large size, the Brownian motion can be neglected. However, colloidal interaction are still noticeable.

Zusammenfassung:
In dieser Arbeit wird ein experimenteller Aufbau vorgestellt, mit dem gleichzeitig viskosimetrische und sogenannte Particle-Image-Velocimetry (PIV)-Messungen an konzentrierten Suspensionen in einem Couette-Rheometer mit einem großen Spaltabstand durchgeführt werden können. Das experimentelle Verfahren wird im Detail beschrieben: Die optischen Eigenschaften der Suspension mit dem angepassten Brechungsindex werden genau gemessen, und die Randeffekte werden sowohl bei den viskosimetrischen Messungen und den aufgenommenen Geschwindigkeitsprofilen analysiert. Zuerst wird das experimentelle Verfahren anhand eines Newtonschen Fluids getestet, dessen Viskosität bekannt ist. Die räumliche und zeitliche Auflösung unserer Apparatur betragen 200 μm bzw. 100 ms. Es wurde festegestellt, dass die Genauigkeit der lokalen Viskositätsmessungen größer als 4% ist. Darüber hinaus zeigen wir, dass die Apparatur benutzt werden kann, um das rheologische Verhalten einer Suspension mit einer Kugel-Konzentration von 47% Kugeldurchmesser 30 μm) bestimmt werden kann. Aufgrund des großen Partikeldurchmessers kann die Brownsche Bewegung vernachlässigt werden. Jedoch sind kolloidale Wechselwirkungen erkennbar.

Résumé:
Nous présentons ici un dispositif expérimental permettant de coupler des mesures rhéologiques macroscopiques à des mesures de champ de vitesse par PIV, dans des suspensions concentrées cisaillées dans une cellule de Couette cylindrique large entrefer. Nous présentons la méthode d'analyse d'images que nous avons choisie et la procédure expérimentale que nous avons suivie en insistant sur la façon dont l'adaptation d'indice entre les particules et le fluide est réalisée et sur l'influence du fond de la cellule de Couette sur les profils de vitesse et le couple visqueux exercé sur le rotor. La méthode proposée est d'abord validée sur un liquide simple, newtonien, dont la viscosité est connue. Sur ce liquide, il est montré que la résolution spatiale est de l'ordre de 200 μm, la résolution temporelle, de 10 ms et que l'incertitude de mesure sur la viscosité est inférieure à 4 %. Ensuite, le dispositif expérimental est utilisé pour caractériser la réponse visqueuse d'une suspension concentrée (ϕ = 47 %) de sphères non-browniennes.

Key words: particle image velocimetry, concentrated suspension, viscosity, local rheometry

1 INTRODUCTION

The knowledge of the rheological behaviour of concentrated suspensions of solid particles is an important issue since suspensions are involved in many domains like industrial processes or geophysical phenomena. A theoretical understanding of the mechanical behaviour of concentrated suspensions is difficult because of the particle interactions and its experimental characterization is complicated by numerous disturbing effects such as shear induced particle migration or wall slip. During these last decades, a significant effort has been made to develop non-invasive techniques that ensure that the measured properties are actually the bulk properties of the suspensions. Among these techniques, we may cite the Ultrasound

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packing volume fraction is still an open problem, we plan to perform some more measurements in this concentration range.

Finally, one difficult but interesting and open problem that arises in such measurements of suspension properties in a wide-gap Couette cell is the shear-induced migration (for a recent review, see [27]). Thanks to the good time resolution of our apparatus, we have been able to check that the migration was sufficiently slow in our case to induce only weak variations of the velocity profiles at the time scale of one experiment. However, we clearly understand that the main drawback of our experimental device is the lack of a quantitative concentration profile measurement, that will be necessary in order to deal with the open question of the shear-induced migration models [28–32]. At this time, we were not able to measure concentration profiles due to the large uncertainties linked with the small concentration of tracers, but some experiments are in progress, with particles larger than the laser sheet thickness, where we try to slightly tag the host liquid in place of some tracer particles.

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