DEVELOPMENT OF A MICROFLUIDIC RHEOMETER FOR COMPLEX FLUIDS*

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INTRODUCTION

A recent advance in the burgeoning field of microfluidics that is of particular interest to chemists, and particularly polymer scientists, is the ability to carry out chemical reactions (e.g., polymerizations[1]) inside microfluidic channels. A natural question to ask is whether one can characterize the rheology (flow properties) of these and other complex fluids as they flow through microfluidic devices, especially in either a combinatorial or high-throughput fashion.

As a first step towards answering this question, our group[2] has recently developed a combinatorial viscometer for complex fluids. Two orthogonal magnetic fields, one steady and the other oscillating sinusoidally, drove that viscometer. The physics underlying the rheometer was that of a damped harmonic oscillator and it employed hydrodynamic similarity[3] to calibrate an oscillating body viscometer of arbitrary geometry. That rheometer required ≈ 4 mL of fluid per sample for combinatorial measurements. The present work aims at microfluidic samples, through appropriate modifications to the oscillator. Both rheometers use Helmholtz coils to drive the harmonic oscillator with magnetic fields.

EXPERIMENTAL

MAGNETIC FIELDS AND MAGNETIC MATERIALS. The Helmholtz coils are described in detail in ref 2. We use one pair of these coils to generate a horizontal sinusoidal magnetic field, and we use a Neodymium-Iron-Boron (Nd-Fe-B) bar magnet (of dimensions 3.2 cm × 1.68 cm × 0.99 cm) to generate a vertical steady field. The harmonic oscillator is a domino-shaped Nd-Fe-B magnet; the first prototype was 10 mm × 5.0 mm × 1.25 mm. The oscillator magnet was placed in standard fluids of known viscosity (described next) and the amplitude and phase of its oscillation in the presence of the two magnetic fields were measured. After the prototype was successfully demonstrated, the size of the oscillator magnet was further scaled down to 2.2 mm × 5.0 *mm* × 1.25 *mm*. The goal of further size reductions is to encapsulate in microfluidic devices an oscillator magnet with dimensions on the order of 500 μm × 300 μm × 500 μm.

TEST FLUIDS. The test fluids of known viscosity (η) used in this work are water (η =1.0 mPa-s), silicone oils (η = 9.8 mPa-s, η = 0.0954 Pa-s and η = 0.96 Pa-s) and glycerol (η = 1.5 Pa-s).

PROCEDURE AND DISCUSSION

A sketch of the general experimental setup is shown in Fig. 1. The test (oscillator) magnet rests in a petri dish. When the prototype is scaled down, the test magnet will be imbedded into a microfluidic device during device fabrication. The petri dish is placed between the Helmholtz coils, which produce a sinusoidal field $B_1 = B_{1,max}\sin(\omega t)$. Here ω denotes frequency, t denotes time and $B_{1,max}$ is the amplitude. The amplified output of the function generator is monitored on an oscilloscope. The Nd-Fe-B magnet used to produce the vertical steady field (B_o) is placed below the petri dish. This magnet is a simpler way of producing a steady field, compared to Helmholtz coils used in the previous generation of the instrument[2]. With the current to the Helmholtz coils turned off, B_o vertically aligns the test magnet. When the current to the Helmholtz coils is turned on, the test magnet pivots back and forth about its rest position (see dotted arrows in Fig. 1, which shows a side view of the setup). The amplitude and phase of this back-and-forth rocking motion of the oscillator are a function of the viscosity of the surrounding fluid.

Current work is focused on modeling this system as a damped harmonic oscillator with a view to (a) maximizing the viscosity resolution and (b) relating the amplitude and phase information of the oscillator to the complex viscosity[4] $\eta^*(\omega)$ and, hence, the complex modulus[4] $G^*(\omega)$ of the fluid. Finally, with a view to operating the microfluidic rheometer in a high-throughput mode and to work with opaque fluids, we are currently testing magnetic field gradient sensors as alternatives to optical detection of oscillator motion, currently done by a CCD camera[2].

CONCLUSIONS

We have developed a prototype rheometer at the bench top scale. Its response agrees with our qualitative expectations, and supports scaling down its dimensions for microfluidics.

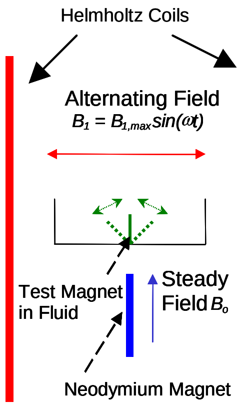

Figure 1. Sketch of Prototype of Magnetic Rheometer (side view)

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