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Proceedings of Symposium on Ultrasonic Electronics, Vol. 33 (2012) pp. 151-152
13-15 November, 2012

Accurate and rapid rheology measurement of complex fluids With EMS system
ディスク EMS システムによる複雑流体の高精度迅速粘性測定

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1. Introduction

A newly developed electromagnetically spinning (EMS) viscometer with floating disk would bring a breakthrough to the measurement of the viscoelastic properties of liquid materials, especially those of dilute aqueous solutions of biomaterials, such as proteins, surfactants, and nuclear acids, since the system enables the precise determination of shear viscosity with an accuracy of 1 %.[1-2] Up to now actually, the measurement of low viscosity, as low as 1 mPa·s, which roughly corresponds to that of pure water, has been available only by the capillary technique. The use of Zimm -type viscometers is another method applicable to low–viscosity materials; however, it has not been widely employed because of experimental difficulties. The disk-type EMS method has great advantages over the conventional methods in that the measurement is carried out in a noncontact manner and thus completely free from the problem of contamination. Disposable sample cells confine small amounts of samples (mL) and can be employed widely for the analysis of chemical, biological, and medical materials including human blood for example.

2. Determination of ultrasonic parameter from viscosity measurement

Measurement of viscosity is important also in the field of acoustics. The classical absorption of an elastic wave propagating in fluids is determined by shear and compressional viscosities. The accurate value of shear viscosity near zero frequency is necessary in the study of ultrasonic relaxation behavior, since it determines the high frequency limit of ultrasonic absorption above the relaxation region.

Although a variety of ultrasonic relaxation behaviors have been studied so far, many problems still remain even for low-weight molecules with simple structures. For example, we do not know the physical origin of the compressional viscosity of pure water, which contributes to two-thirds of ultrasonic absorption in water. Another common phenomenon is the excess damping of phonons in aqueous solutions of alcohols.

It is important to accurately determine the limit of energy dissipation due to shear viscosity for the investigation of ultrasonic relaxation. In this paper, we demonstrate the performance of our newly developed disk-type EMS viscometer as the measurement standard for the zero-frequency limit of shear viscosity. We measured the viscosities of liquid crystal near its phase transition point and compared them with the result of ultrasonic spectroscopy.

The details of the principle of the measurement and the experimental setup would be given elsewhere[1)], and here, we give a brief account. The measurement apparatus generates a rotating vertical magnetic field, in which a sample cell containing liquid sample is set. A thin metal disk floats owing to its buoyancy on the sample liquid and works as a rotor; the rotating magnetic field induces an eddy current in the metal disk and the Lorentz interaction between the current and the magnetic field drives the disk so that it rotates following the motion of the magnetic field. Figure 1 shows a schematic view of the internal experimental setup. The depth of the sample is about 0.5 mm and the rotational speed is 1 – 10 rad/s, giving a shear rate of 20 –200 s^{-1} for the disk with a diameter of 20 mm.

A remarkable difference from the Zimm-type viscometer, which also employs a floating rotor, is that the rotor of our viscometer is disk-shaped as opposed to the cylinder shape of the Zimm type. The Zimm type has a serious problem in stably holding the cylinder in the vertical direction during the rotation, while the thin disk is automatically held horizontal owing to its symmetry. The application of the disk becomes possible with the newly developed configuration of the rotating magnetic field.

The rotation of the disk is monitored using a video camera and analyzed using a computer. The torque applied to the disk can be changed by modulating the rotational speed of the magnetic field; therefore, we can obtain the shear rate dependence of viscosity. However, for the Newtonian fluids including liquid crystals, measurement at a fixed rotational velocity provides a satisfactorily accurate value of shear viscosity.

3. Accurate measurement of temperature dependence of liquid crystal viscosity around phase transition

The disk rotor is 30 mm in diameter and is made of thin aluminum foil with thickness of 0.1 mm, which has an edge to float on the sample liquid surface by the buoyancy. The sample cell is 44 mm in inner diameter and 15 mm in depth. The typical volume of the sample required is 3 mL, and the thickness is about 0.5 mm. The rotation of the magnetic field is controlled by a speed controllable motor and the motion of the disk is recorded by a video camera and the movies are analyzed to determine the rotational speed of the disk.

We then applied the disk-type EMS system for the observation of the slight change in the viscosity expected for liquid crystals around the phase transition temperature. The sample is 5CB （4-Cyano-4' –pentylbiphenyl） , which undergoes the nematic/isotropic phase transition at around 35 ℃. The sample was purchased from Tokyo Kasei and used without further purification.

For the precise measurement changing the temperature, we have to pay attention to the various contribution of the temperature to the torque driving the disk through the Lorentz interaction; One is the temperature dependent electric conductivity of the metal used for the disk. In the present experiment, the temperature coefficient of the conductivity of aluminium is 4.3×10^{-3}/ ℃ around the room temperature, which is not negligible compared to the change of the viscosity around the phase transition. The torque is proportional to the magnitude of the Lorentz current and is

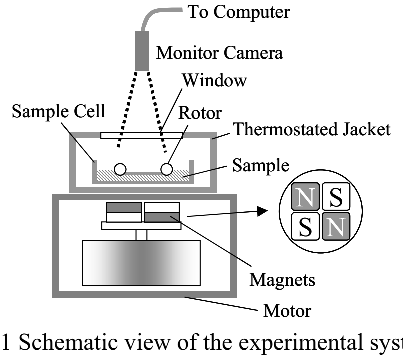

Fig.1 Schematic view of the experimental system.

compensated through the above coefficient.

On the other hand, the liquid crystal is known to show the discontinuous change in the density at the phase transition by about a few %, which might

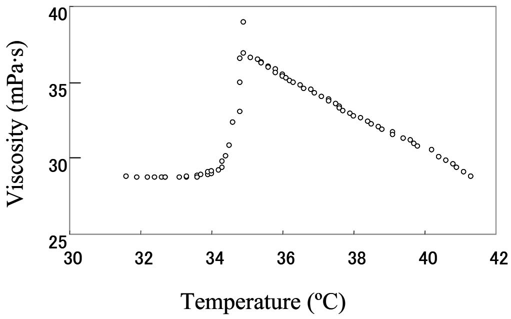

Fig.2 Temperature dependence of viscosity around the isotropic/nematic phase transition of the liquid crystal 4-Cyano-4'-pentylbiphenyl (5CB).

leads to the change in the height of the disk; the change in volume and buoyancy also contributes to the supported position of the disk. However, it does not matter in the present experiment, since, as we have already shown in the previous presentation, the disk height is adjusted to the insensitive region, where the effects of the decreasing torque and the decreasing viscous force compensate to each other.

The sample is contained in the thermostatic cell and the temperature is controlled within the accuracy of 0.1 ℃.

Figure 2 shows the temperature dependence of the shear viscosity of 5CB. We see that we can determine the viscosity with the accuracy better than 0.5 % from the scatter of the data. The phase transition temperature is about 35 ℃ and we found the gap in the viscosity. It has been well known from the result of the experiment using the capillary method that in the nematic phase in lower temperature region, the rod like molecules of liquid crystal are aligned so that they decrease the energy dissipation due to the viscous flow. It has also been believed that the change is simply discontinuous. However, in the present results, we can see gradual increase in the viscosity in the nematic phase, which might suggest some critical behavior with respect to the nematic/isotropic phase transition.

Although ffurther and detailed study would be required to examine this critical behavior, the disk-type EMS would be a powerful tool to investigate the physical properties and its dynamic behavior of the soft condensed matters through the accurate viscosity measurement.

References

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