Proceedings of Symposium on Ultrasonic Electronics, Vol. 30 (2009) pp. 451-452
18-20 November, 2009

Rheology Measurement of protein solution by EMS system

電磁スピニングシステムによるタンパク質水溶液の粘弾性測定

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1. Introduction

Ultrasonic spectroscopy is quite an effective tool to investigate the mechanical properties of materials and their physical origin at the molecular level. Roughly describing, the sound velocity and absorption give the information on the elastic and viscous behavior of the material, respectively.

From the viewpoint of the relaxation behavior, it is important to rigorously determine the limiting value of the propagation constants of the ultrasound at higher of lower frequencies; the relaxation strength is given by the sound velocity as the difference from its high frequency limit, while it is also determined just by the viscosity at zero-frequency, for the sound absorption. Though accurate determination of the shear viscosity is strongly required, there has not been a simple and easy method to measure the viscosity particularly in the low viscosity region below 10 mPa· s.

Recently, we developed a new apparatus of viscosity measurement based on the principle of electro-magnetically driving of the probe in a non-contact manner. The system has an advantage that its is completely free from the contamination to both of the sample and the measurement apparatus. It is also a feature that the viscosity depending on the shear rate can be obtained within very short time.

The present system can be applied to the lowly viscous sample below 10 mP· s in the shear rate region of 5 – 500 s^{-1}, where protein solutions often show characteristic relaxation behaviors. In this study, we introduce the experimental result of the rapid measurement of the relaxation behavior of protein solutions during the gelation process.

2. EMS viscometer system

Here, we give a brief account of the newly developed electro-magnetically spinning (EMS) sphere viscometer system. The viscometer has two magnets attached to the rotor, which applies a rotating magnetic field. The sample cell is a commercially available small glass tube with a smooth concave bottom. An aluminum sphere with a diameter of 2 mm is placed in the tube, and the tube is set such that the sphere is located at the center of the magnets.

The rotating magnetic field produces eddy currents in the sphere; then, the resulting Lorentz interaction between the magnetic field and these eddy currents produces torque that rotates the sphere. This is the same principle as that of the Zimm-type viscometer; however, in the present method, a metal sphere is set as the rotor at the bottom of the cell. A remarkable advantage of employing a sphere as the probe is that we can easily calculate the applied torque with a known magnitude of the magnetic field.[9] Another advantage is that the incline of the rotational axis during the rotation does not matter at all due to the perfect geometrical symmetry of a sphere.

Figure 1 shows a schematic view of the measurement principle and the photograph of the experimental system. The rotating magnetic field is generated by two permanent magnets turning

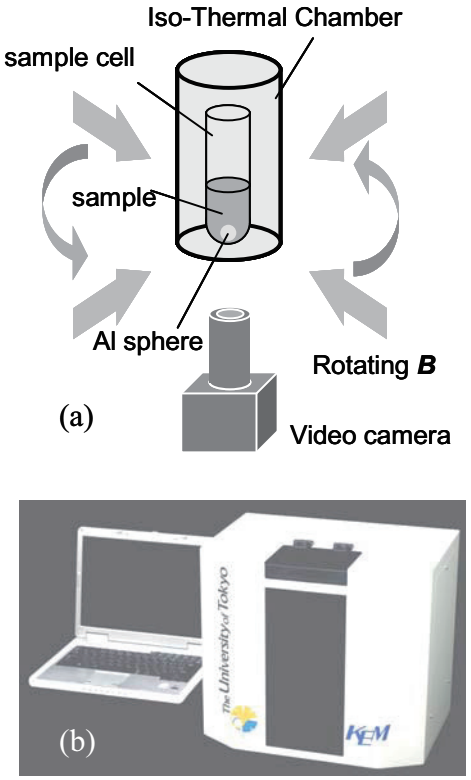

Fig.1 schematic view of the measurement principle (a) and the photograph of the experimental system (b).

around the sample cell. The sample is contained in a commercially available glass tube with an inner diameter of 6 mm and a smooth concave bottom, where an aluminum sphere with a diameter of 2 mm is initially placed.

The metal sphere rotates following the magnetic field; its speed of revolution in the steady state is determined by the rotational velocity, the magnitude of the magnetic field, and the viscosity of the sample around the sphere. The motion of the sphere is monitored by a microscope and a video camera set below the sample cell. The sphere can be observed even if opaque samples are measured, since the sample layer between the cell bottom and the sphere is quite thin. The video images are sent from the camera to a computer, which analyzes the rotational motion of the sphere as a function of the revolution of the magnetic field. The viscosity depending on the shear rate is thus obtained from the rotational speed of the probe sphere at different revolution of the magnetic field.

3. Rheology measurement of protein solutions

We carried out the measurement of shear viscosity of aqueous solutions of typical proteins. The sample is albumin from chicken egg purchased from Sigma and is used without further purification. The buffer is the phosphate pH standard equimoral solution (pH 6.86) and solutions with different concentrations are prepared.

The shear rate dependence of the viscosity is measured changing the revolution of the rotating magnetic field in the temperature range of 40 – 75ºC. Figure 2 shows the viscosity plotted against the shear rate obtained for the concentration of 5%. At high shear rates above γ>100 s^{-1}, the viscosity is independent of γ while it shows rapid increase below 100 s^{-1} towards the zero-shear rate.

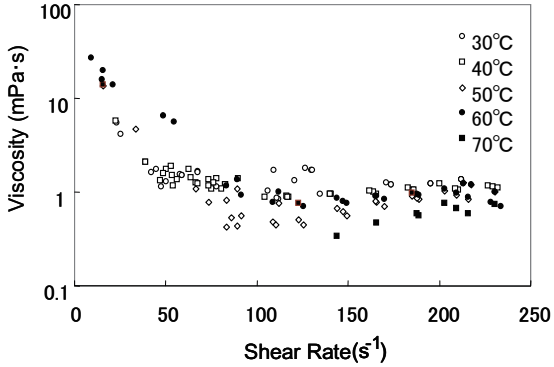

Fig.2 viscosity plotted against the shear rate.

It is known that the protein solutions show characteristic shear rate dependence due to the aggregation of the molecules[1,2] and the relaxation is also observed in the present experiment.

As seen in Fig.2, the viscosity also shows the temperature dependence. At high shear rates, the viscosity show gradual decrease with the temperature, which is the typical tendency of the viscosity described as the rate theory of the molecular translation. In the low shear region below 50 s^{-1}, on the other hand, the viscosity increases as the temperature exceeds about 60ºC. The present sample undergoes the gelation at around 70ºC, above which the sample becomes opaque as shown in Fig.3. The behavior of the viscosity is now analyzed in detail along the percolation theory of chemical gelation.

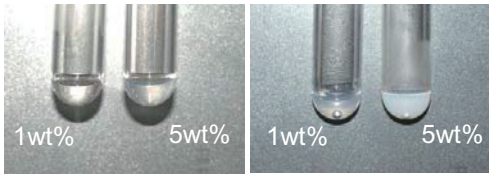

Fig. 3 The aspect of the protein solution samples, before (left) and after (right) the heating.

4. Conclusion

The experiments with the EMS viscometer is quite easy; we only have to pour sample fluid into a sample tube and set it in the viscometer, and no adjustment or cleaning process is required. Properties and structures of complex fluids such as protein solution sensitively depend on the environment and there are quite many control parameters for them. The EMS system would be a powerful tool to establish the database of rheological properties of those soft condensed materials.

References

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