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Low viscosity measurement by electro-magnetically revolving method

EMR 法による希薄溶液の高精度粘性測定

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1. Introduction

The elector-magnetically spinning (EMS) viscometer, recently developed by us, measures the sample viscosity in a non-contact manner; the rotating magnetic field applied to the probe metal sphere generates the induced current and the Lorentz interaction between the current and the magnetic field drives the sphere to spin following the rotation of the magnetic field. The method has other advantages that the sample required is only 0.3 mL and the sample can be kept in a closed circumstance.

On the other hand for the low viscosity measurement as applied to the pure water, the accuracy of the measurement is restricted to about 5 % due to the mechanical friction between the probe sphere and the bottom of the sample tube. We propose in the presentation, a new method of low viscosity measurement, which is based on the principle of EMS, but the motion of the sphere is the revolution along a circular guide.

2. Low viscosity measurement by EMR method

We refer to the method as electro-magnetically revolving (EMR) method, in which the magnetic field is applied so that the sphere probe rolls on a horizontal substrate. The falling ball viscometer is a conventional method of rheology measurement, and its modification, the rolling ball method is also used especially for the low viscosity measurement. In the method, a probe sphere rolls downward due to the gravity and the speed of the sphere is measured and related to the viscosity of the surrounding medium. In the EMR method, on the other hand, the probe sphere continues to revolve around the circular orbital, therefore, the continuous and stable observation of the viscosity is possible.

Figure 1 shows the schematic image to explain the principle of the EMR method, in which the series of the couples of N and S poles of the permanent magnets are aligned in line and move to right-hand. The magnetic field above the magnets are rotating anti-clockwise and the sphere set here feels the torque to drive it leftward by rolling. In the actual system, the magnets are aligned to form the circle and the sphere revolves along the circular orbital formed on the bottom of the sample cell. The sphere surrounded by the viscous fluid feels the resistant force due to the viscosity, therefore, we can determine the viscosity from the speed of revolution under a constant driving force. The EMR is completely different from the conventional rolling ball viscometer, in a point that the sphere stably and infinitely translates along the circular orbital, and therefore, the accuracy of the viscosity measurement can be improved by taking the log measurement time.

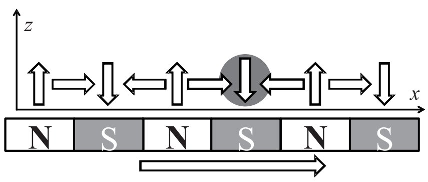

Fig.1 Schematic view of the principle of EMR viscometer.

We show here the results of the low viscosity measurement. The sample cell is a petri-dish and the circular orbital is formed with polymer. The samples are the standard liquids of viscosity purchased from Shin-etsu Silicone. The probe sphere is an aluminum ball with a diameter of 2 mm, which is also employed as the probe sphere in the EMS viscometer. The radius of the orbital is 10 – 20 mm and the sample quantity required is about 0.5 mL. The revolving motion of the sphere is monitored by a video camera set above the sample cell, and the time required for a turn is obtained by the analysis of the movie.

Figure 2 shows the relation between the revolutional speed of the sphere and the torque applied, measured for the low viscosity samples with 1.0, 2.0 and 5.0 mPa·s. Here, by considering the relative motion of the sphere and the magnetic field, the applied torque is given as

$$T \propto n\Omega_M + (1 - R/r)\Omega_S,$$

where Ω_S and Ω_M are the angular velocity of the revolution and the magnetic field, respectively, r is the radius of the sphere and R is the radius of the circular orbital. As shown in the figure, the EMR method has high resolution for the viscosity lower

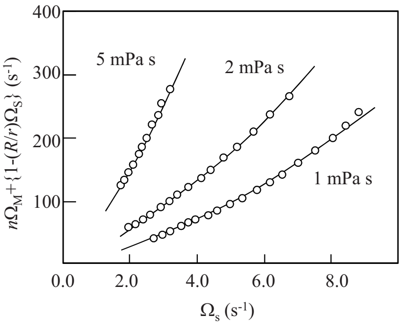

Fig.2 Relation between the revolving angular velocity of the prove sphere and the applied torque obtained for several standard sample of viscosity.

than 10 mPa·s. Especially for the lowly viscous samples, we can see the relation deviates from the linear function, that is due to the effect of the inertia described by the non-linear terms of the Navie-Stokes equation.

3. Monitoring of the solid-liquid interface

The rolling friction should be satisfactorily small for the accurate measurement of the viscosity in EMR method, on the other hand, the rolling friction is expected to sensitively depend on the state of the solid-liquid interface. In the EMR method, the contribution of the rolling friction as the resistant force is several times smaller than that of the viscosity, when the probe sphere revolves one turn during 1 s in pure water. Therefore, we can expect to detect the change of the state of the interface through the modulation of the rolling friction.

To examine the ability, we measured the process that small sphere colloid particles are gradually fall down on to the solid substrate; the initial sample is pure water and we added a small amount of latex solution including polystyrene spheres with 20 μm diameter. The latex sinks due to the gravity and lies on the substrate modulating the rolling friction. Figure 3 shows the apparent viscosity derived from the decrease in the revolving velocity, plotted against the volume fraction of the latex in the solution. We can see that the change in the volume fraction as small as 10^{-4} can be detected by observing the revolution.

According to the Einstein's equation for the viscosity, the expected relative change of the viscosity is in the order of 2.5ϕ for the dilute solution with the volume fraction of ϕ, which is quite small in the present case and we conclude that the change observed is due to the colloid spheres scattered on the solid substrate. As shown, the EMR method is found to be effective to monitor the state of the solid-liquid interface.

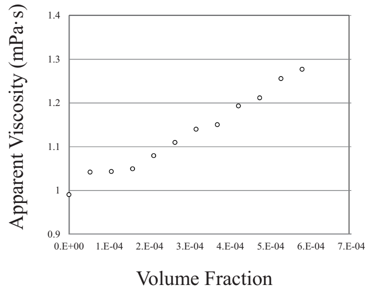

Fig.3 Apparent viscosity of the colloidal solution measured by EMR system.

4. Several topics on the rolling ball viscometer

The feature of the rolling ball viscometer is that the accurate measurement of the low viscosity is possible with simple experimental apparatus. Here, we introduce several points to be considered for the further application of the rolling ball viscometers. First, we should take into account the time required for the sphere to reach the steady state of rolling. The characteristic time calculated from the equation of motion is $\tau = 2R^2\rho/9\eta$, where ρ is the density of the sphere. The time and the length required for the measurement of the pure water viscosity is 2 s and 2 m, respectively, therefore, the size of the rolling ball viscometer with a straight path should be larger than at least 5 m. The EMR method, however, has the path of the revolution in a circle and does not suffer from the above problem.

We have also to pay attention to the motion of the sphere, whether it rolls or slips on the tilted path; it severely depends on the friction coefficient and the gradient of the path. If we expect the probe sphere rolls on the substrate without slipping, the friction coefficient μ and the tilting angle θ should satisfy the relation of $\mu > \tan\theta$, however, the equation does not necessarily hold at θ=15° for various combinations of the materials.

In conclusion, we developed a new method of low viscosity measurement. We are now applying it for the observation of the phase transition of the liquid crystals and the surfactant solutions.

References

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