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Continuous in-line measurement of viscosity by self-balancing EMS technique

EMS システムによるインライン連続粘性測定

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1. Introduction

The ultrasonic spectroscopy investigates the mechanical physical properties of materials from the viewpoint at the molecular level. It reveals the dynamics of molecules and molecular associations through the frequency spectra of the ultrasonic velocity and absorption, which are directly dominated by the elasticity and viscosity of the media, respectively. The determination of the shear viscosity of materials is quite important to assign various kinds of degrees of freedom, which contribute to the frequency spectra of the spatial and temporal decay of the ultrasonic wave. Actually, for the ultrasonic decay of α/f^2=25x10^{-17} [s^2/m], one thirds of that can be attributed to the shear viscosity of pure water, while the rest remains. The excess ultrasonic decay should be attributed to the bulk viscosity, however, the physical image of the energy dissipation through the isotropic compression in water is still remained to be solved.

The shear viscosity is, of course, important also for the industrial field other than academic approach to the ultrasonic propagation. Recently, ultrasonic imaging technique is applied for the investigation of the rheological properties of soft human organs. The authors are carrying out experimental study of both the ultrasonics and rheology and have tried to integrate their experimental techniques treating hardness and viscous properties in both slow and fast phenomena. In this study, we would introduce an application of our new techniques for monitoring visco-elasticity in isolated pipelines or tube. This technique can be applied for the continuous monitoring of the material condition through the chemical and physical reactions.

2. Design of in-line EMS system

First before explaining the newly developed apparatus for the in-line rheology measurement, we very briefly introduce the principle of the remote detection of the viscosity. A rotational viscosity probe is made of conductive but not ferromagnetic metal, which is in touch with the sample liquid. A rotational magnetic field is applied to the probe by a couple of magnets set outside the sample cell, which induces Lorentz current in a probe. The interaction between the current and the magnetic field drives the probe to rotate following the rotation of the magnetic field. The torque is proportional to the difference in the rotational speed of the magnetic field and the probe, while the shear deformation rate is linearly related to that of the probe, therefore, the viscosity can be determined as their ratio.

The early type of the EMS viscometer employed a small sphere as the probe. The system is easy to operate, since the accurate setting of the probe is possible only by putting a small metal ball into the concave bottom of the sample tube. A fatal fault is that the accuracy in determining low viscosity is not satisfactory and typically worse than 10% for the measurement of pure water, of which viscosity is about 1 mPa·s. It is also a problem that the compatibility to other conventional ration type viscometer is poor.

In the second generation of EMS viscometer, we employed a thin metal disk as a probe. The accuracy of the measurement was then remarkably improved and the range of the shear deformation rate is expanded especially towards the lower region. However for the use of the in-line

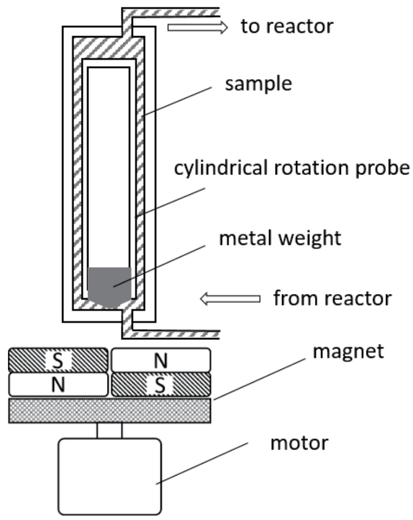

Fig.1 Schematic view of in-line EMS measurement.

measurement, the configuration around the sample composed of a disk, flat substrate and thin sample layer sandwiched by them is not suitable; smooth replacement of thin sample is difficult and gas bubbles might be trapped between the gap.

In the in-line measurement system, we adopted the co-axial double cylinder configuration, which is also popularly employed in commercially available viscosity measurement apparatus. Figure 1 shows the schematic view of the in-line measurement system. The sample tube is 12 mm and 80 mm in its inner diameter and height, respectively, and stand vertically. The probe rotor has a diameter of 10 mm and height of 70 mm and it include metal weight at the bottom. It works as the remote detector of torque. The shape is a kind of auto-balancing probe characterized by a feature that it automatically stands vertically by controlling the positions of the centers of mass and the buoyancy. In addition, when it rotates, the horizontal position of the probe is automatically adjusted to the center axis of the inner diameter of the cylindrical sample tube by the effect of the rotational shear flow.

The sample fluid is introduced from the bottom and discharged from the top. The amount of the sample required is about 2 mL, which is a standard quantity of the other in-line measurement system of, for example, density, pH, electric conductivity and so on.

3. Experiment

To examine the accuracy of the viscosity measurement, we prepared standard viscosity liquids having several different viscosities. The sample is purchased from Nippon Grease Co., LTD. and has the viscosities, 1.8, 3.6, and 7.3 mPa·s at temperature of 25 °C. The measurements were carried out at temperature of 25 °C. Figure 2 shows the relation between the difference in the rotational speeds of the magnetic field Ω_M and the probe disk Ω_D, which is proportional to the applied torque, and that of the disk, which is linearly related to the shear deformation rate. The ratio in between them gives the viscosity. As clearly seen, the gradient of the experimentally obtained curves are different owing to their viscosity. We can examine that the measurement system has ability to distinguish viscosities even in the region lower than 10 mPa·s. Figure 3 shows the literature values of the sample viscosities and the gradient of curves in Fig.2. As seen, the viscosities and the gradient show good linear relation.

In conclusion, we designed a new type of a rotational probe applicable to the in-line viscosity measurement with EMS principle. The system is quite accurate to detect low viscosity with the error less than 1%. The time resolution of the measurement is determined by the time required for the replacement of the sample, that is about 10 s at present. Analogous in-line measurements of other liquid properties are already established for the measurements of, for example, density, optical reflectivity, electric conductivity and so on. These apparatuses are normalized in its shape of the joint and can be connected as needed; Sequential measurements are thus possible. Our system is now being designed so as to be aligned among the actually working in-line measurement apparatus.

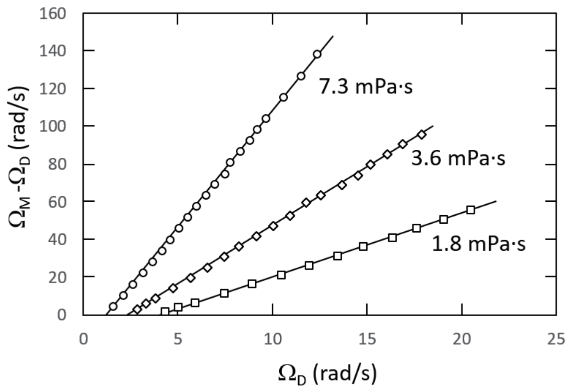

Fig.2 Relation between Ω_D and (Ω_M - Ω_D), which are proportional to shear deformation rate and applied torque, respectively.

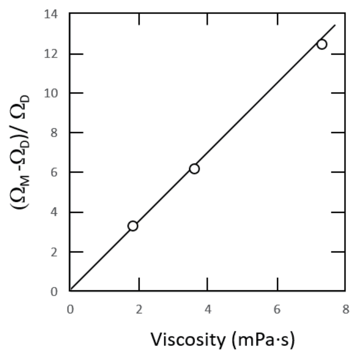

Fig.3 Relation between sample viscosities and gradient of curves in Fig.2.

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