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Remote sensing of temperature dependence of viscosity below the freezing point by electromagnetically spinning system

EMS システムを用いた氷点下における液体粘度のモニタリング

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1. Introduction

Viscosity and elasticity are fundamental material properties in any liquid handling fields for achademic studies as well as industrial applications. They are the main factors for determing the mecanical response such as wave propagation and attenuation in ultrasonic field; demormation rate and flow velocity in rheology. Especially, the shear visocosity are well known for showing relaxation behaviors and/or resonance phenomena rather than constant values with respect to the time scale of dynamic response. Such variation in viscosity is a useful measure for assessing the degrees of freedom of molecular motion from microscopic view point.

Recently, the authors developed an innovative measuremet system for evaluating the viscosity and/or elasticity with remote driving and sensing techiniques. These techniques are based on an electromagnetically spinning (EMS) method1,2), which can achieve more accurate measurement compared with the other conventional viscometers and rheometers. In additon, a completely isolated sample-holding condition and a contamination-free operation are feasible easily.

In this study, we introduce new application of these advantages of the EMS system for sample liquids set into a Dewar vessel under the temperature condition below 0 degrees of Celcius. This simple procedure can be a powerful tool for continuously monitoring the material state through the chemical and physical reactions.

2. Experimental setup

In the conventional device for viscometry and rheometry, the mechanical parts for driving or detecting torque directly contact with the measured samples as well as the main body in the device. Then, the mechanical friction at the connecting area may be a main problem of the measurement accuracy. Additionally, a perfectly sealed condition can be hardly ready, and a cleaning operation should be needed every time when replacing samples.

On the other hand, the EMS method can provide us a solution for these difficulties with using remote controlling and sensing techniques3). The remote control of torque induction is due to an electromagnetic interaction between a time-varying magnetic field and eddy currents generated by it. The remote sensing in this setup can be obtained by an optical observation with a video imaging device.

Fig. 1 Photo images of the various parts for temperature retention mechanism (left) and the assembled experimental setup (right).

An auto-standing type rotor, which was recently developed by the authors4,5), was used in all measurements. In this type of setups, the sample volume must not be too much or too little, and then the appropriate volume was fixed to be 0.5 ml. Generally speaking, viscosity measurements below the freezing point are hardly conducted from the view point of dew condensation prevention. The EMS method, however, secured a free space around the sample container. In this study, we brought a commercially available Dewar vessel, and the sample container and dry ice were set together into it. Figure 1 shows the photo images of this setup before and after assembled. The sample temperature was monitored by a resistance temperature sensor insensitive to magnetic field variation, which was pasted on the side of the sample container.

3. Results and discussions

First, for testing accuracy in measurement of viscosity and temperature in our experimental setup,

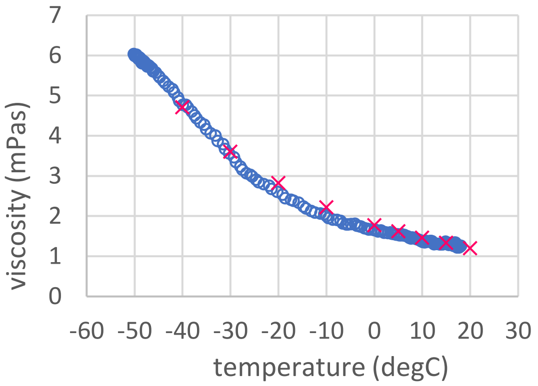

Fig. 2 Viscosity data depending on temperature for ethanol obtained from this experimental setup (○) and referred in a previous literature (×).

we measured the temperature dependence of viscosity for ethanol, which keeps liquid state down to minus 70 degrees of Celsius. The data comparing the literature values with the experimentally obtained values are shown in Fig. 2. The results were in good agreement, so that the measurement accuracy was ensured also in the below-freezing temperature range.

Next, we tried to monitor the viscosity of water in the supercooled state. For such advantage in the EMS method as applying quite low torque, it is supposed that the viscosity measurement can be conducted while suppressing water freezing. The obtained data from two similar trials are shown in Fig. 3. Each data could be measured from room temperature to minus five degrees of Celsius. The results show no discontinuous change at 0 degrees, which means no anomalous increase or decrease of viscosity exists in the supercooled state of water.

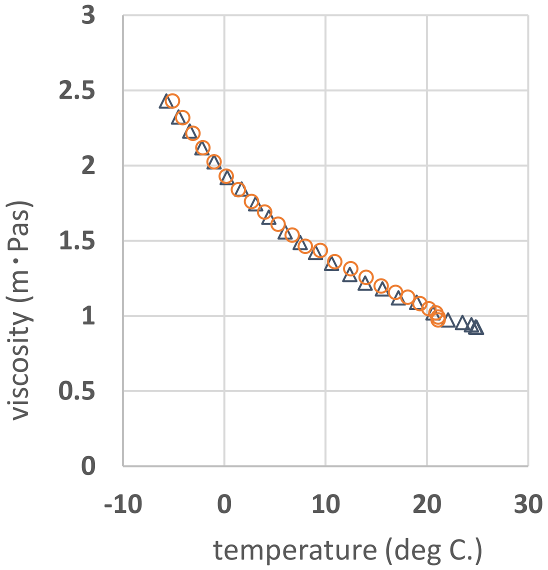

Fig. 3 Temperature dependence of viscosity for water from the normal liquid state to the supercooled state.

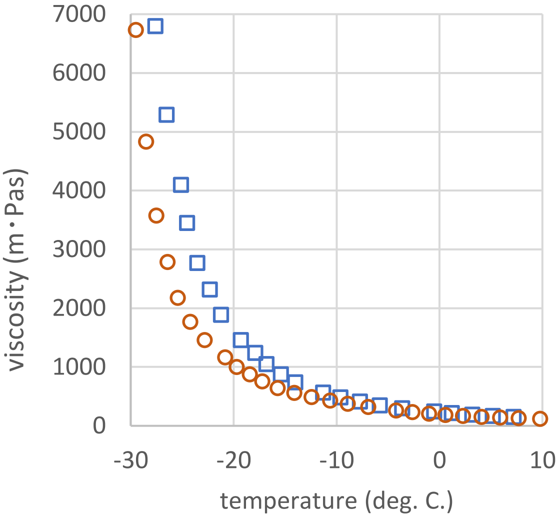

Fig. 4 Temperature dependence of viscosity for two kinds of engine oils: 5W-30 (□) and 0W-30 (○) having specifications intended for cold areas.

Finally, we investigated the viscosity of engine oils as for a typical example, where the sub-zero viscosity variation can be an important factor. The used samples were the Mobil 1$^{\mathrm{TM}}$ synthetic oils 0W-30 and 5W-30. They have same viscosity at high temperature and show different characteristics in low temperature range. Figure 4 shows the comparison data of temperature dependence of viscosity with the two kinds of engine oils. The results show clear difference in lower temperature region. The oil 0W-30 has tendency keeping lower viscosity than the oil 5W-30. This tendency roughly agrees with the manufacturer's claim.

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