Development of RheoSpec Viscometer Based on EMS Method

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ABSTRACT

The RheoSpec viscometer, which we have newly developed, has many advantages in liquid viscosity measurements, such as wide range of shear rate, ease of use, and so on. Especially, our device has quite high performance for the measurement of low viscous liquids such as water or human blood. In addition, this device is designed under the stress-control concept and has an ability to measure the yield stress. In this work, we demonstrated that this device can measure the high viscosity and the yield stress of pastes such as toothpastes.

INTRODUCTION

A family of the Electro Magnetically Spinning (EMS) viscometers has many advantages in liquid viscosity measurements, such as a wide range of shear rate, easy handling, low cost, contamination-free for sample and environment, and so on. These viscometers are based on the EMS method, in which a nonmagnetic metal probe in/on the sample liquid is driven by the remote torque generated by rotating magnetic field, and the rotational speed of the probe gives shear stress, shear rate and viscosity. We have already developed two types of EMS viscometer with different probe shapes, a sphere submerged in the liquid and a floating disk on the liquid surface. With the former type, we can set a sample liquid and probe quite easily without care to the direction of the rotational axis of the probe. The latter has an ability to measure the surface viscosity of aqueous solution with surfactants adsorbed on the surface.

Now we developed the third generation of EMS viscometer named RheoSpec with a spinning top, just like a Japanese KOMA, in the liquid as a probe. One of the key features is a wider measurable range of the viscosity. Especially, it shows quite high performance in measuring low viscous liquids such as aqueous solutions or human blood. In addition, this device is designed under the stress-control concept. In this work, we demonstrated that we can measure the high viscosity and the yield stress of pastes as well as the low viscous liquids with RheoSpec viscometer.

RHEOSPEC VISCOMETER

Figure 1 shows the schematic view of the sample cell and the magnet in our RheoSpec.

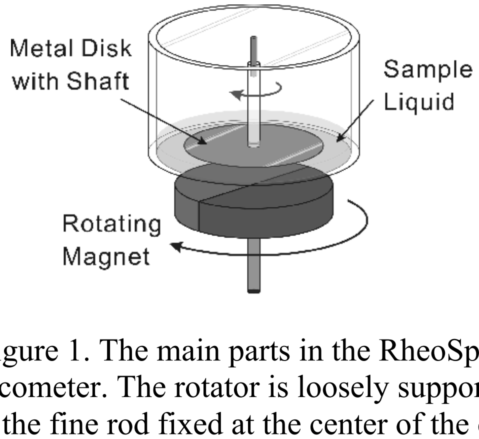

Figure 1. The main parts in the RheoSpec viscometer. The rotator is loosely supported by the fine rod fixed at the center of the cap of the sample cell and can spin smoothly.

Sample liquid is contained in the transparent cylinder-shape small cell with a probe rotator. The magnet set under the sample cell is rotated in appropriate rotational speed by the DC servomotor, whose rotational range can be swept from 1 to 10000 rpm. The magnetic field directing perpendicularly to the magnet penetrates the disk of the rotator. We used an aluminum plate with the diameter of 20 mm and the thickness of 0.5 mm as a rotator disk, in which the eddy current is generated. The probe disk is driven by the electro-magnetic torque, of which intensity depends on the rotation speed of the magnetic field and is written as

$$T_M = A(\Omega_M - \Omega_D) \tag{1}$$

where Ω_M and Ω_D are the rotational speeds of the magnetic field and the probe disk, respectively, and A is the coefficient depending on the magnetic field intensity and the probe disk size. When the disk is submerged in the viscous liquid, the total torque applied to the probe is the sum of the electro-magnetic and the viscous torque, and, contrary, we can measure the liquid viscosity by observing the rotational speed of the rotator with a video camera[1]. We assembled this system so that the rotator can spin quite smoothly, and we can measure the viscosities as low as ~ 0.1 mPa･s.

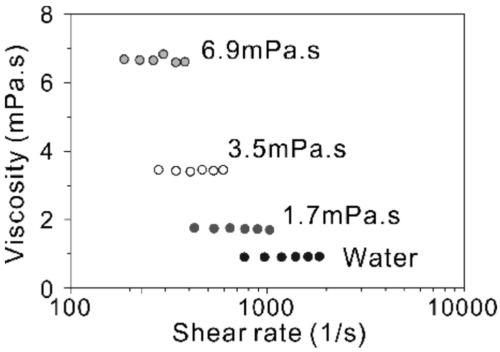

Figure 2. Viscosity curve for low viscous liquids at 25°C. These liquids show the Newtonian fluid behaviour.

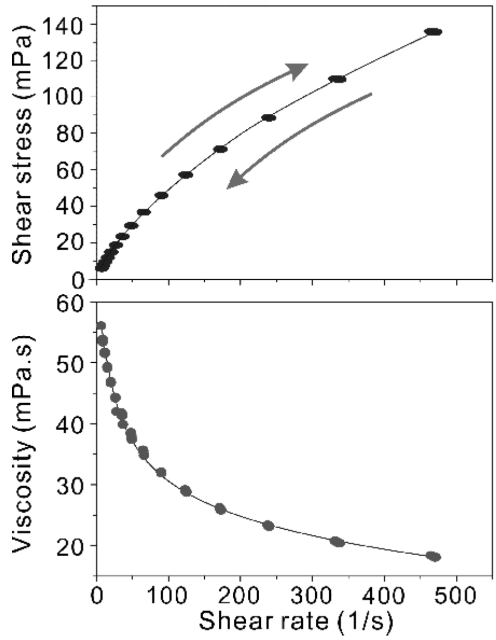

Figure 3. Flow and viscosity curves of a face lotion. The arrows show the direction of the stress sweep and the solid curves are the guide lines.

Figure 2 shows an example of the viscosity curves for water and standard viscosity liquids with 1.7, 3.5 and 6.9 mPa.s at 25°C. From this figure, we can see that the device has a wide range of the shear stress and an ability to measure low viscosity accurately. We made another experiment with a commercially available face lotion as a non-Newtonian fluid (Fig. 3). The data points in this figure are on the same curve regardless of the stress sweep direction. From the result, we found that this liquid is pseudoplastic fluid and has non-thixotropic behaviour. We can simultaneously obtain a flow curve and a viscosity curve as is seen in Fig. 3 at one time without any change in condition and probe.

In addition, the RheoSpec has a key feature that the principle of the method is built with the stress sweep concept. The shear stress remotely applied to the sample is proportional to T_M and fully controllable by changing the motor speed. According to

Eq. 1, the shear stress in this system can be obtained from Ω_M even though the sample has a yield stress, under which the rotator remains still and $\Omega_D = 0$. On the contrary, we can measure the true yield stress value of the sample such as toothpastes.

YIELD STRESS MEASUREMENT

We made some experiments, in which we used a commercially available toothpaste as samples. In general, a toothpaste shows a behavior like a Bingham plastic fluid, and has a yield stress value. As mentioned above, the RheoSpec viscometer has an ability to function as a viscometer in the region of ultra-low shear rates and zero shear rate, and is suitable for observing Bingham liquids. Generally, the viscosity region of the toothpaste is quite high and we used a special rotator with large disk with the diameter of 28 mm to gain the rotational torque and the sample paste was spread only underside of the disk as shown in Fig 4.

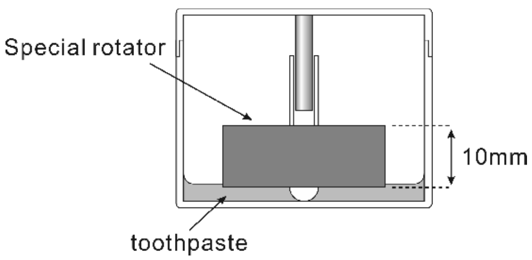

Figure 4. Cross-section view of the sample cell and the rotator especially for measurements of paste.

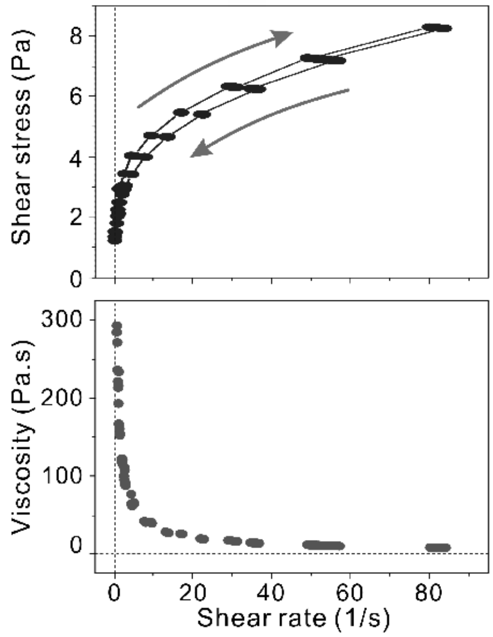

Figure 5. Flow and viscosity curves of a low price toothpaste.

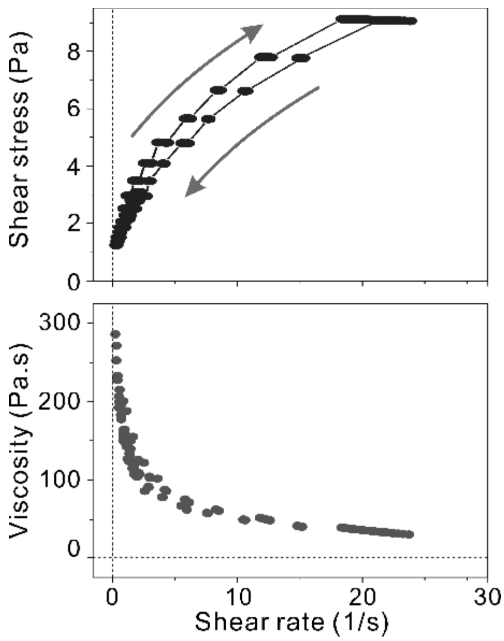

Figure 6. Flow and viscosity curves of a high price toothpaste.

Figure 5 shows the flow and viscosity curves of a low-price toothpaste of which feeling in spreading was smooth. From this figure we can realize that our device can measure not only low viscous liquids but also quite high viscosity, and this sample shows thixotropic behaviour slightly and the value of the yield stress was 1.23 Pa. The result for another sample is shown in Fig. 6. This sample was five times as expensive as that in former toothpaste and the feeling in spreading was a little hard. From Fig. 6, we can estimate the value of the yield stress to be 1.54 Pa, which is a bit larger than that of the low-price one. This difference in yield stress agrees with the human feeling, while the viscosity curves are not so different. Though we cannot unveil the relation between the price and the rheological behaviour of toothpastes, this result shows that our device is effective for the rheology of highly viscous liquids and pastes.

CONCLUSION

We developed the RheoSpec viscometer based on EMS method, which is useful for rheological measurement of low viscous liquids. We could also distinguish the Bingham fluid and the pseudoplastic fluid clearly. Using this device, we can measure the accurate rheological properties and behaviours in many fields such as medical, food, industry and academic.

REFERENCES

1. K. Sakai, T. Hirano, and M. Hosoda, "Accurate Viscosity Measurement using Disk-Type Electromagnetically Spinning System", Appl. Phys. Express, 5, 036601 (2012).