Relaxation behavior of blood viscosity assessed by RheoSpec viscometer

RheoSpec 粘度測定システムを用いた血液粘度の緩和挙動評価

Taichi Hirano†, Miki Hirano, Shujiro Mitani, and Keiji Sakai (I.I.S., UTokyo)
平野太一†，平野美希，美谷周二朗，酒井啓司 (東大生研)

1. Introduction

Blood is one of the most familiar fluids, showing a viscoelastic or shear tinning property. Its rheological behavior is, however, extraordinary [1-3]; its shear viscosity is only 4 to 10 times of water, even though it is a highly concentrated dispersion of microparticles. In fact, in human blood the volume fraction of the red blood cells is as large as 45%.

From the view point of analyzing fluid dynamics, the viscosity and viscoelasticity are the fundamental physical properties. Therefore, the presice values of them should be required to simulate blood flow in various vessels. However, few quantitative measurements of them for the individual bloods have been reported.

One of the possible reasons is the absence of useful tools for measuring such low visocosity except for the capirally-type viscometer. Additionally, equipment contamination from the blood samples is also a serious problem.

Recently, we originally developed a technique for measuring viscosity, wchih is named the electro-magnetically spinning (EMS) method [4-7], and have manufactured a measurement system desined for accurately evaluatig the viscosity of a large number of blood samples.

First in this presentation, the newly designed type of viscometer (RheoSpec) based on the EMS method is introduced. Second, the obtained data for human blood specimens and a pseudo blood sample are shown, and the difference of their shear thinning behaviors is verified. Finally, the relationship between the kinetic degrees of freedom of dispersoids in these fluids and the observed range of shear rate is discussed.

2. Experimental setup

In the conventional methods for measuring viscosity, the driving and/or detecting parts are in contact with the samples. Also the samples are exposed to the ambient air. On the other hand, the EMS technique employs noncontact driving and detecting mechanisms using and electromagnetically induced torque and an optically observed device, respectively [4-7]. Therefore, our originally developed system has great advantage of contamination free, sealed state, and disposable usage.

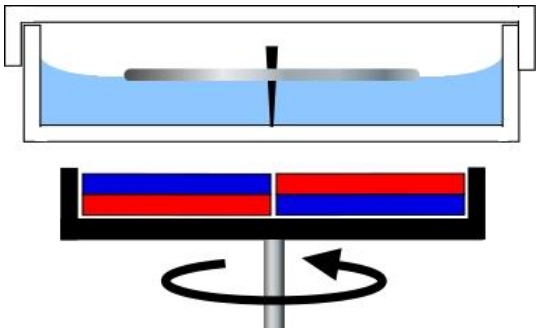

Fig. 1 Schematic image of an originally developed system (RheoSpec) designed for more accurate measurement in low viscosity region.

A schematic image of the experimental setup is shown in **Fig. 1**. In this system, we use a thin disk-shape probe, to which a spinning shaft and an outer brim are attached. This type of probe has been developed to achieve high accuracy in measuring low viscosity. It can take an upright position due to the relationship between the buoyancy and gravity, if it is soaked partially or fully in an appropriate amount of sample fluids. In addition, the buoyancy is adjusted to reduce the mechanical friction that has been the main cause of errors in the measurement.

The source of the driving torque is a temporally modulated magnetic field penetrating in perpendicular direction to the disk plane. Then, the driving torque is generated by the Lorentz interaction between the eddy currents induced in the probe and the rotating magnetic field. On the other hand, the rotating probe is suffered from the resistant torque due to viscous flow, which is balanced with the driving torque in a steady state. Therefore, we can determine the viscosity of the sample from detecting the angular speed of the probe under the control of a constant torque.

Typical examples of the measured viscosity curves are shown in **Fig. 2**. The samples used are the distilled water, an ethylene glycol aqueous solution, and a glycerol aqueous solution. Since the EMS method is a kind of stress-control type, the measured range of shear rate depends on the viscosity of the samples. Compared to those obtained by the

hirano22@iis.u-tokyo.ac.jp

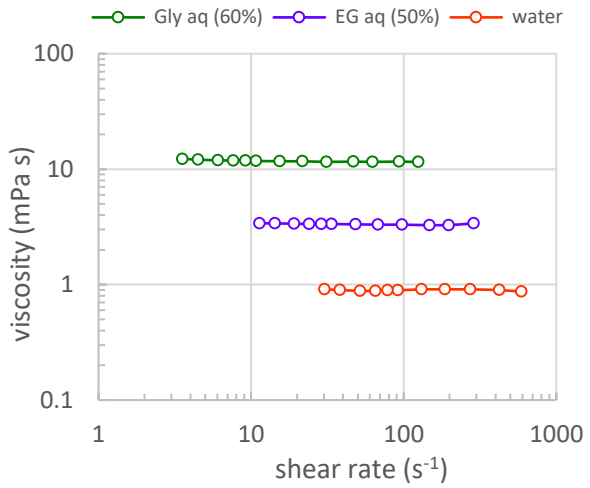

Fig. 2 Viscosity curves (viscosity v.s. shear rate) obtained from this experimental setup for low viscous fluids at 25 °C.

previous type of RheoSpec viscometer [8], the lower limit of measurable shear rate has become better by an order of magnitude.

Note here that the typical viscosities of human blood are 10 and 4 mPa・s at the shear rate of 20 and 500 s^{-1}, respectively. Then, the usable torque magnitude in this setup was found to be adequate to observe the relaxation behavior of blood viscosity in wide range.

3. Results and discussions

Figure 3 shows the obtained viscosity curves of human whole bloods sealed with anticoagulant and a pseud blood (PB-10W-F, Yasec) being a non-living sample with the similar physical properties to human blood. The anticoagulant used in these experiments was EDTA, which hardly affects the concentration ratio of each blood component. The blood specimens A, B, and C are drawn by different healthy persons.

The region of shear rate from 20 to 400 s^{-1} corresponds to that of the actual blood flow in the body environment. In this region, the viscosity curve of the pseudo blood shows no dependence on the shear rate, in other words, the Newtonian behavior. In contrast, the real blood specimens show relaxation behaviors of viscosity with the increasing shear rate, which is commonly known as the shear thinning behavior.

The difference might be caused by the solidity or the deformation ability of the main substance in the dispersion medium. Namely, a red blood cell in the real blood have a structure covered with cell membranes, and show viscoelastic property, whereas microbeads in the pseudo blood are spheres made of solid polymers.

Furthermore, it is interesting that the clear difference in the slops of the relaxation curves is found. This result shows the difference only due to the individual difference, but the viscosity curve of the same person probably changes depending on the day, or the hours. Examination of such data would be a diagnosis technique for vascular insufficiency.

We now have special interest of the relaxation behavior in the region of shear rate less than 10 s^{-1}, which was successfully observed using the present type of RheoSpec viscometer. In the slower region, the viscosity is supposed to be affected by interactive dynamics of the dispersed substances, such as aggregation, piling, and networking. Hence, the relationship between the shape of viscosity curve in wide range and the kinetic degrees of freedom of red blood cells will be investigated.

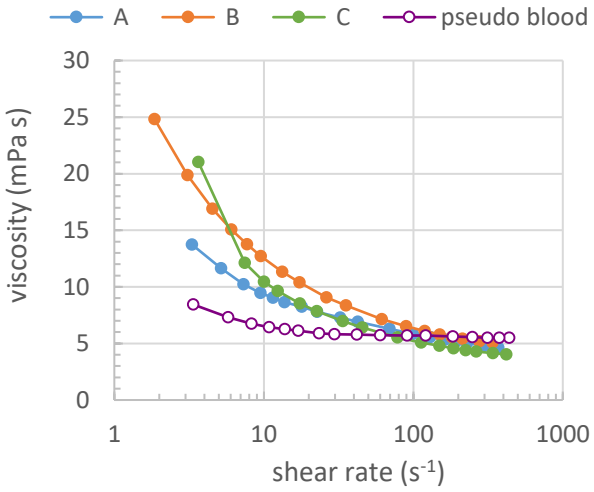

Fig. 3 Measured viscosity curves for human blood specimens (closed circles) and a commercially available pseudo sample of human blood (open circles).

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