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Accurate measurement of viscosity curve in wide shear rate range for in-vitro evaluation of fluidity of blood using Rheology-Spectrometer

レオロジースペクトロメータによる粘度曲線の広範囲測定と血液流動性の評価

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1. Introduction

Recently, we have developed a measurement system for obtaining not only viscosity but also rheological properties such as a viscosity curve[1)]. Note here that the viscosity curve is a well kown plot of viscosity data with respect to the shear rate, which is a typical measure for the non-Newtonian property or viscoelastisity. In comparison to the other conventional viscometers and rheometers, our system named Rheology-Spectrometer is specially deseined for measuring lower viscosity in lower shear rate range[2)]. Owing to this feature, a flow characteristic of blood circulating in a human body can be evaluated in vitro over the entire range of shear rate corresponding to the bloodstream.

Blood is a dense disperse system of red blood cells, and its viscosity curve shows a shear thinning behavior, which means that the viscosity decreases with the increasing shear rate. The viscosity of human blood is known to be approximately 10 and 4 mPa·s at the shear rates of the actual blood flow in the thickest and thinnest vessels, respectively[3-5)]. It is extraordinary that the viscosity curve of such a lowly viscous fluid shows large dependence on shear rate. This drastic change in viscosity might be associated with a physical function of red blood cells.

Also from the view point of a health check, estimating fluidity of blood in various vessels is so important, and the viscosity and viscoelasticity are the fundamental parameters for the simulation of flow dynamics. However, a few quatitative data were reports beasuse of the absence of an appropriate measuring device, having both enough accuracy and width of the measurable range of shear rate.

In such a situation, the Rheology-Spectroeter will solve the above mentioned problems. In addition, this system has another advantage of contamination-free due to using noncontact manners of torque induction and rotation detection. Therefore, it would be a powerful tool for testing large number of blood samples without spending time and cost.

First in this presentation, we introduce the measurement principle and the development concept about the Rheology-Spectrometer. Second, the measured data for some liquids with the validated viscosity are shown, and the machine performance of the present system is compaired to that of the commercially available rheometers. Finally, the obtained viscosity curves for human whole bloods are shown, and the individual diferrence between their fluidity is also discussed.

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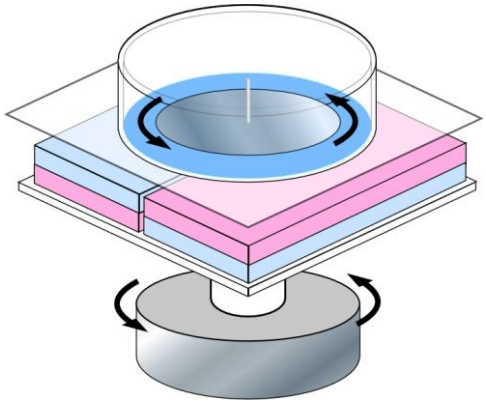

Fig. 1 Schematic image of a newly developed rotor and the experimental setup in Rheology-Spectrometer.

2. Experimental setup

In the conventional methods for measuring viscosity, the driving and/or detecting parts are in contact with the samples. Also these parts should be connected to the main body of the device. Therefore, the measurement can hardly conducted in the perfectly sealed condition, and a cleaning operation is requested every time when replacing the sample. Moreover, the mechanical friction at the connected area is a main cause of the measurement error.

On the other hand, the Rheology-Spectrometer uses the electromagnetically spinning (EMS) method, which was also originally developed to achieve less friction and disposable usage[6,7)]. A schematic image of the experimental setup is shown in **Fig. 1**. In this newly developed system, we use a thin disk-shape probe attached to a spinning shaft. The shaft edge is protruded from the undersurface of the disk by a

constant length, which consequently equals to the thickness of the sample fluids. If an appropriate amount of the sample fluid is put into a container, the probe can stand upright automatically due to the relationship between the gravity and buoyancy, and the buoyancy plays another role of reducing the mechanical friction.

Typical examples of the measured viscosity curves are shown in **Fig. 2**. The samples used are the distilled water and the standard liquids for calibrating viscometers (JS5, JS10, JS20, Nippon Grease Co., Ltd.). These samples are known to be Newtonian fluids showing no viscosity change at any shear rate. Since the Rheology-Spectrometer is a kind of stress-control type viscometer, the measured range of shear rate depends on the viscosity of the samples, as shown in **Fig. 2**.

Note here that the typical viscosities of human blood are 10 and 4 mPa・s at the shear rate of 20 and 600 s^{-1}, respectively. Then, the magnitude of the usable torque in this setup was found to be adequate to observe the fluidity of human blood over the entire region of the corresponding shear rate to the inner body circulation.

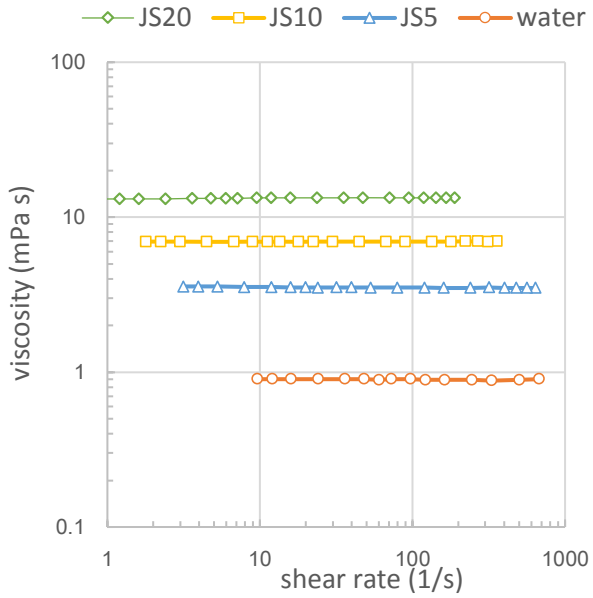

Fig. 2 Viscosity curves (viscosity vs. shear rate) obtained for lowly viscous fluids having Newtonian properties.

3. Results and discussions

Figure 3 shows the obtained viscosity curves of fresh blood samples of different adult males. Each blood was sealed with EDTA, which was used as an anticoagulant so that the concentration ratio of each blood remains unchanged rather than using heparin solutions. The sample temperature was controlled before and during the measurement to be 37 °C. The all measurements of viscosity curves were conducted with sweeping the shear rate from high to low.

The data in the higher shear rate than 20s^{-1}, corresponding to the bloodstream in human body, show similar curve shapes due to the shear thinning behaviors. The viscosity in this region is known to mainly depend on the volume fraction of red blood cell and the intrinsic viscosity of blood plasma. On the other hand, the data below the shear rate of 10s^{-1} show large individual difference, and an exchange of the magnitude relation was found.

We now have special interest on these behaviors in the lower shear rate region, which have been accurately measured using the Rheology-Spectrometer. The viscosity curve over the wide range of shear rate gives the information on the degree of freedom in molecular kinetic mode. Consequently, the physical properties of red blood cell such as rigidity and flexibility can be investigated, and then their contribution degree to the fluidity of blood will be clarified.

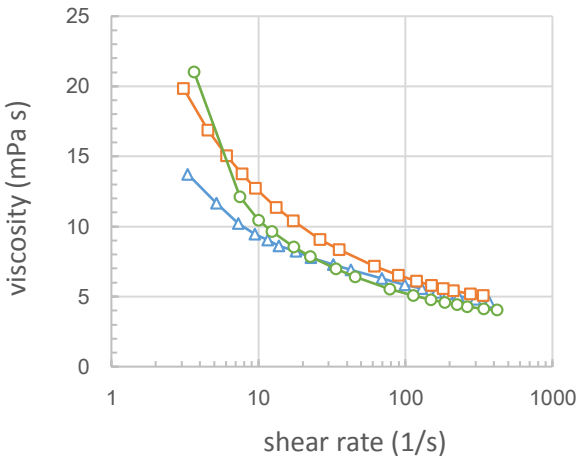

Fig. 3 Measured viscosity curves for fresh blood specimens of different human males at 37 °C.

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