Fluidity measurement of gel-like microparticle dispersion by EMS system for assessing mechanical properties of dispersed particle

EMS システムによるマイクロゲル分散液の流動性測定と分散体の力学特性評価

Taichi Hirano[1†], Shujiro Mitani[1], and Keiji Sakai[1] ([1]Inst. Indust. Sci., UTokyo)
平野太一 [1†]，美谷周二朗 [1]、酒井啓司 [1] ([1] 東大生研)

1. Introduction

Viscotic and elastic properties of fluids are well known fundamental parameters determing the degrees of freedom of microscopic motion as well as the strength of interactions among them. In most cases, they show relaxation behaviors or resonance phenomena, and then spectroscopic study is a useful means to reveal their dyanamics. Note here that fluidity measurement such as the flow and viscosity curves is a kind of the spectroscopy, since shear rate has the dimension of the inverse of time, that is frequency.

The Electro-Magnetically Spinning (EMS) method is an originally developed technique for the fluidity measurement[1,2]. In this method, the induction of driving torque and the detection of rotated motion can be conducted in noncontact manners. In contrast, in the conventional viscometers, the driving and detecteing parts are connected to the main body. Since the mechanical friction at the connected area is a fatal cause of measurement error, the more accurate measurement is achieved by the EMS method. In addition, a completely sealed condition is realized owing to this noncontact feature, and also a contamination-free operation for setting and removing samples can be available.

Recently, we have developed a measurement system based on the EMS method to obtain the fluidity of blood over the entire range of shear rate corresponding to the circulation in a human body[3]. Blood viscosity shows a downward tendency with the increasing shear rate, which means that the fluidity of blood becomes higher in the thinner vessel. Such functinonal change in fluidity might be associated with mechanical properties of blood cells. So, the final goal of this study is to assess health condition of blood through the fluidity measurement.

At present, there are few quantitative data that cover the shear rate range of the bloodstream in all the vesseles, beasuse of the absence of an appropriate measuring device, having both accuracy. Here, the viscosity of human blood is known to range approximately 10 to 4 mPa·s at the shear rate of 20 to 600 s^{-1} [4-6]. The latest experimental system using the EMS method showed potantial for solving these problems[3].

Towards archieving our goal, the suitable procedure for measurement and analysis should be determined. If possible, to use a model sample of microbeads dispersion with similar fluidity of human blood is preferred in the initial step. However, threre is no comeercial product satisfying such a request. Then, we have tried to generate gel-like particles with the diameter of 10 micron order using an inkjet technique developped by us.

First in this study, the microfabrication technique of gel-like particles is introduced. Second, the measurement results of fluidity for the dispersion liquid of the generated microparticles is shown. Finally, the differences in the obtained data are discussed with regards to the sample temperature and concentration.

2. Experimentals

The fluidity of blood mainly depends on the mechanical properties of red blood cells (RBC). The occupation volume of other blood cells such as white corpuscles and platelets are much less than that of RBCs. Plasma is an aqueous solution containing proteins, ions, vitamins etc., and its viscosity shows no shear rate dependence, i.e. it is the Newtonian fluid. A schematic form of RBC is supposed to be a capsular structure having liquid content and viscoelastic membrane. Then, we considered a microparticle like an artificial roe would be a substitute for RBC.

The used raw materials are two aqueous solutions of sodium alginates and calcium chlorides. The latter solution is mixed with ethanol, since the latter will enclose the former due to the balance of surface and interface tensions. When the both droplets collide in the air, a capsular structure is spontaneously generated. Gelation reaction between

hirano22@iis.u-tokyo.ac.jp

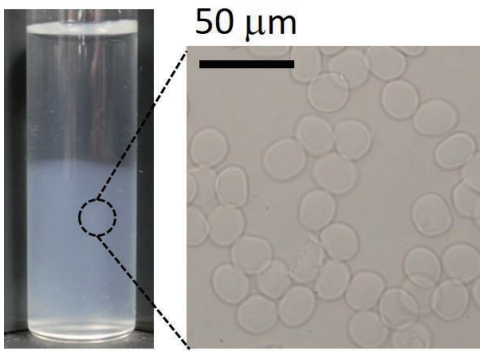

Fig. 1 Macro and microscopic photo images of generated dispersion liquid and particles.

the alginate acids and the calcium ions progresses only at the contacted area of each liquid, and then the thickness of the gel-like layer would be controlled with adjusting the concentrations of each sample solution. The key feature of this method is that all process of the reaction and transportation are conducted in an airborne situation. Compared to other methods using microfluidics, the throughput of particle generation is increased by around 100 times.

Figure 1 shows photo images of the generated dispersion liquid. The liquid was separated into two layer after still-standing for 10 minutes. We also confirmed that the separated sample reverted to the homogeneously dispersed state by stirring. From the observation by an optical microscope, the dispersed particle was only in the lower clouded layer, and they keep their initial shape.

The fluidity of the generated samples was measured by the EMS system using the newly developed rotor like an auto-standing top[3]. In this type of setups, the sample volume must not be too much or too little. The appropriate volume is 0.5 ml, which is acceptable to practical usage for the medical study of human blood. All the measurements of viscosity curves were conducted with sweeping the shear rate from high to low. In advance of the measurements, the sample was stirred to be homogenized by high speed rotation of probe rotor.

3. Results and discussions

Figure 2 shows the comparison data of obtained viscosity curves for a real human blood, a commercial product of pseudo blood, and the generated dispersed liquid. The fluidity of the commercial product is nearly equal to that of Newtonian fluid. This fact probably resulted from the stiffness of the dispersed particles, which are made from a polymeric resin. On the other hand, the fluidity of the generated liquid showed similar tendency as the real blood. It indicates that the

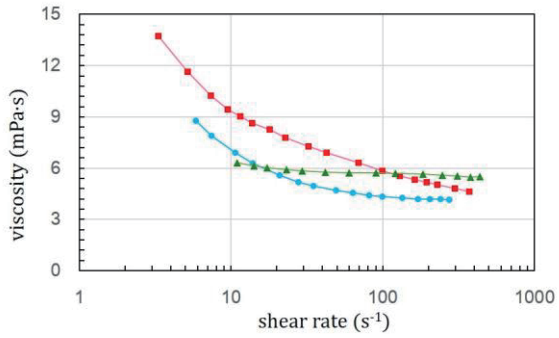

Fig. 2 Viscosity curves for the real blood (■), the commercial product of pseudo blood (▲), and the generated dispersion liquid (●).

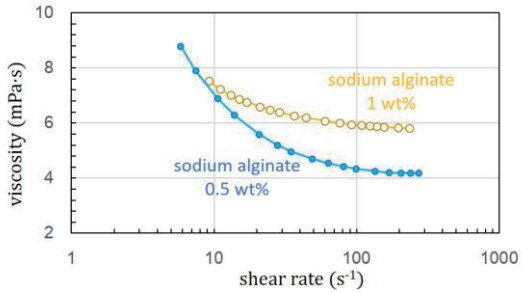

Fig. 3 Viscosity curves of the gel-like particle dispersion for different concentrations of sodium alginate.

microparticles generated by our inkjet technique might have some kind of flexible structure.

The concentration dependence of fluidity for the generated dispersed liquid is show in Fig. 3. The variation of fluidity became wider for the lower concentration of alginate acid. This change is expected to be caused by the change of mechanical properties of the gel layer. We are planning to determine a well-fitted function to the viscosity curve for assessing the mechanical properties of dispersed particles.

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