교류 전기장하에서 액적의 진동과 깨짐에 관한 연구

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Oscillation and breakup of droplet in an AC electric field

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1. Introduction

When a liquid drop is suspended in another immiscible liquid, it can be influenced by an externally applied electric field. Especially when the field is varied with a time such as an AC field, a drop oscillates with the field.

The electrohydrodynamic theory proposed by Taylor is based on what came to be known as the leaky dielectric model, which is capable of predicting drop deformations in qualitative agreement with previous experimental observations. Vizika and Saville (1992) carried out an experimental investigation. However, very few researchers have investigated the dynamics of a drop in a time-varying electric field. An attempt was made by Torza, Cox and Mason (1971) and Sozou (1972) extend Taylor's work. Feng and Beard (1991) studied the oscillation of a conducting drop in an alternating electric field using the domain perturbation method.

In this paper, a series of experiments was reported to show the effect of non-Newtonian properties on the oscillation, deformation, breakup of drop in an AC electric field. We could draw the effect of elasticity or viscoelastic properties of drop on the deformation. The breakup of suspension drop which disperesed polystyrene latex was also examined. The breakup occurs when the interfacial tension can no longer support the normal electric stress. The suspension that has a various concentration of the polystyrene has properties varing from Newtonian to non-Newtonian so that the mode of breakup changes with the concentration. There is no theoretical approach to the dynamics of liquid drop that considers the non-Newtonian properties in an electric field. However, the leaky dielectric theory has a good agreement with the experiments so that we consider non-Newtonian drops as Newtonian drops and examine the deviation from it. In that manner, we may observe the effect of non-Newtonian properties qualitatively.

2. Experimental

After a drop was placed in the region between two electrodes, an AC field was applied with a variable peak-to-peak voltage from 0 to 20 kV. A CCD camera recorded the deformation of oscillating drop.

Table 1 lists the material properties of emulsion fluids used in this experiments. We used silicone oils of various viscosities to know the effect of viscosity. In order to examine non-Newtonian properties, we made the polymeric solutions and classified it into two classes. First one is purely elastic fluids which is called Boger fluids, which show elasticity such as normal stress in shear flow but approximately a shear-independent viscosity. The Maxwell relaxation time λ is evaluated in order to determine the degree of elasticity (Figure 1). Second one is fully viscoelastic fluids, which show not only elastic property but also shear-thinning viscosity (Figure 2). Finally, we prepared suspension liquids, which dispersed the polystyrene particle into water. It is highly conductive. It has the elasticity as increasing the volume fraction of particles and shows shear-thinning viscosity, which are shown in Figure 3

Drop	Medium	R	q	γ (N/m)
W	SB	10^{-6}	28.2	0.039
PAA2		10^{-6}	26.9	0.047
XAN2		10^{-5}	21.8	0.021

Table 1 Newtonian and non-Newtonian drop is suspended in another Newtonian fluid. (W: deionized water, PAA: polyacrylamide solution in an aqueous 0.1M NaCl, XAN: Xanthan gum solution) R: resistivity ratio, q: dielectric constant ratio, λ: viscosity ratio.

3. Results and discussion

The deformation of drop in an electric field is denoted by

$$D = \frac{d_1 - d_2}{d_1 + d_2} \tag{1}$$

where d_1 and d_2 are the lengths of drop axes parallel and perpendicular to the applied electric field. Torza et al.(1971) developed a generalized electrohydrodynamic theory for alternating field and the deformation is

$$D = \frac{9\varepsilon_0 K_2}{16\gamma}\Phi(\vec{E}_0^2 b). \tag{2}$$

where $\Phi = \Phi_S + \frac{I\cos(2\omega t + \alpha_T)}{\sqrt{1+k^2\lambda_2^2}}$ (3)

Φ_S is Taylor's discriminating function for steady deformation, λ_2 is a function of viscosity ratio, k is considered as the ratio of the oscillatory hydrodynamic stress and the capillary pressure at the droplet interface. Here, a lag between the oscillation of the drop and the field is occurred according to the complex parameter α_T.

The oscillatory deformation which is calculated by equation (2) is diminished by increasing the frequency. Newtonian drop follows the theory well.

As shown in Figure 4, in the vicinity of 1Hz, the deformation agrees with that of relatively low viscosity. The viscosity of XAN2 decay rapidly with shear rate and the decrease of viscosity appears to be existed when the oscillatory flow is comparable. In the case of PAA2, the theory more or less under-estimates the deformation. We may estimate the representative viscosity when the viscosity decreases with the flow. From the oscillatory deformation which is mentioned above, PAA2 and XAN2 at 1Hz have a viscosity of ca. 8 and 2 Pa·s respectively

Figure 6 shows the phase lag of PAA2. In the case of XAN2, it is difficult to kwon whether the major effect on the shift of phase lag stems from the shear-thinning viscosity of elasticity. But considering the slight shear-thinning viscosity, the lag of PAA2 is more reduced than the predicted value.

Figure 7 shows the breakup of low concentration and highly concentrated polystyrene suspension that has the non-Newtonian properties. The PS suspension of low concentration breaks up through end pinch-off but there occurs tip streaming in highly concentrated suspension. Ha and Yang (1998) did experiments and concluded that the tip streaming results from the non-Newtonian properties of the constituent fluids, at least when the amount of dissolved polymer is considerable. It is interesting that a form of tip-streaming is different from the previous results. While tip-streaming occurs, the drop stretched and the size of tip-streamed droplet is very small.

4. References

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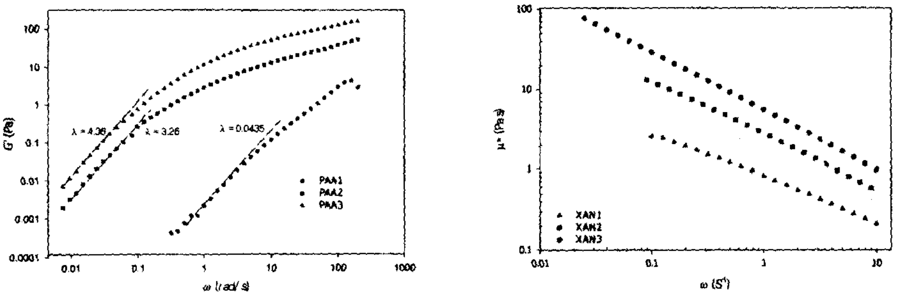

Figure 1 Complex viscosity PAA and XAN.

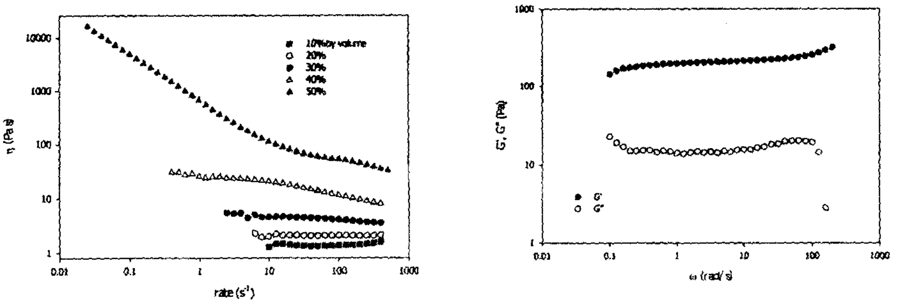

Figure 3 Rheological properties of PS suspension.

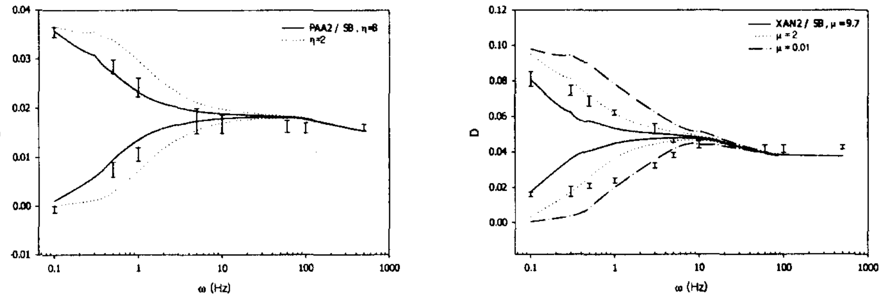

Figure 4 PAA2 and XAN2 in silicone oil SB XAN2 in silicone oil SB.

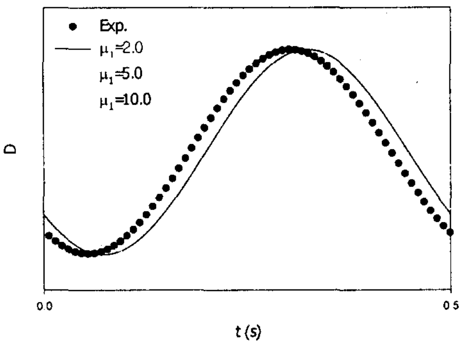

Figure 6 Effect of elastic property of the drop phase suspended in Newtonian fluids. The applied electric fields is 2.85 kV/cm, 1 Hz. the dots represent the experiments. PAA2

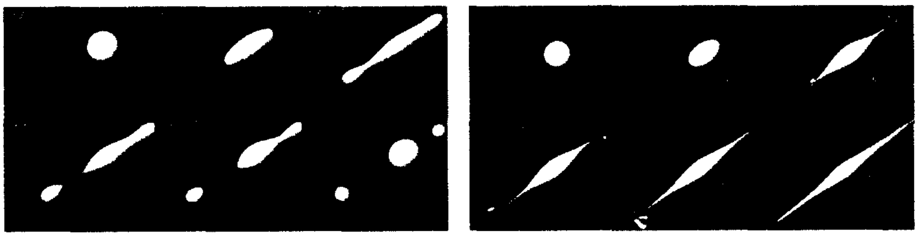

Figure 7 Breakup of 10% PS suspension drop (2.10 kV/cm & 0.5Hz) and >50% suspension in partially fluorinated oil FL100. (2.29 kV/cm & 0.5 Hz)