잉크젯 방울 형성에 있어서의 고분자 및 나노입자 첨가 효과

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The effect of polymer and nanoparticle addition on the inkjet drop formation

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Introduction

Inkjet printing is familiar as a method of printing text and images onto substrates such as paper. In the last few years it has been explored as a way of printing electrical and optical devices with the use of specialty inks. For a successful inkjet printing to be achieved in this area, high resolution patternability is necessary. Therefore it is essential to understand the mechanism of ink drop deformation and to reduce the break-up of drop which can cause defect in printing.

The breakup of viscoelastic jets has been studied by many researchers with a number of dilute and semidilute poly(ethylene oxide) solutions under the gravity. Similarly, the presence of small amounts of polymer in Newtonian solvents can cause a significant change on the drop-on-demand drop formation. This study investigates the effect of elasticity on the drop-on-demand drop formation through the use of low viscosity elastic liquids. The stroboscopic method is employed to get high time-resolution images of drop deformation at the nozzle. Drops are generated using a piezoelectric sleeve that contracts around the nozzle forcing liquid out. The satellite drop produced by breakup of main drop is easily observed with Newtonian fluids. Higher viscosity can suppress this satellite drop formation to some extent, the phenomena become significant when small amount of polymer is added. To quantitatively characterize the deformation of drop we used 10ppm poly(ethylene oxide) solutions because approximately over 20ppm, very thin thread was formed between drop and nozzle and it was hard to observe steady state drop formation. Finally the drop formation when nanoparticles are added to these solutions is briefly observed.

Experimental

A schematic of the experimental equipment is shown in Fig.1. The drop generator consists of an 50μm diameter glass nozzle with a piezoelectric actuator around it. The piezo sleeve is oscillated by an external power supply that can produce several different waveforms over a range of voltage. All experiments were performed with single square waveform, with a 3 sec rise time, 30 sec duration, and 3 sec decay time.

Results from one Newtonian liquid and five different non-Newtonian liquid with different molecular weight polymer in it are presented in this study. A newtonian reference solution was prepared using 47 weight percent glycerol in water. Five different low viscosity elastic liquids were prepared by adding PEO to water first and stirring at 30°C overnight before the addition of glycerol to make sure that the polymer is dissolved homogeneously. The weight percent of glycerol maintained constant because 10ppm addition of polymer doesn't change the shear viscosity much. And as the shear viscosity is high enough to hide the shear thinning behavior by the polymer addition, all test solutions can be regarded as a Newtonian fluid under shear flow. The static surface tension is almost same near the value of 65mN/m. Although the dynamic surface tension will decrease with time, Tirtaatmadja et al.[1] indicate that over the extremely short times associated with the drop formation process in these experiments, very dilute polymer solutions will have an approximately constant dynamic surface tension. Finally the Zimm relaxation time of the fluids is calculated from the equation

$$\lambda_z = 0.463 \frac{[\eta] M_w \eta_s}{N_A k T}$$

where $[\eta]$ is the intrinsic viscosity of the fluids obtained using Mark-Houwink-Sakurada equation for PEO solutions.

$$[\eta] = 0.72 M_w^{0.65}$$

Given the dilute nature of the solutions, the relaxation time is independent of the polymer concentration.

Differences in the concentration of polymer in the fluids will result in different extensional properties of the various solutions. Many researches on similar solutions have shown that the extensional viscosity is a function of both polymer molecular weight and concentration. Although these solutions are extremely dilute, as the polymer concentration or molecular weight increases, the elasticity in the solution is expected to increase. And prominent changes in drop shape and other dynamic properties can be observed in Fig. 2, that means, drop-on-demand inkjet system is very sensitive to extremely small amounts of elasticity.

Result and discussion

During the inkjet drop formation, the ink solution undergoes two different flow condition. When it is first ejected out of a nozzle, the extensional flow dominates under very high extension rate. And just after the end of drop detaches from a nozzle, the free surface shear flow become dominant with very high shear flow of air around the drop. Fig. 3 shows if the shear rate is not high enough, all the elongated drop retracts to form spherical shape with different retraction rates. This retraction rate is a function of capillary number, in this case, the jet speed. Once retraction occurs, even if the main drop breaks up into satellite drops, they commonly get together again without causing defects in inkjet printing. Therefore the critical capillary number which maintains the elongated drop without retraction can be a practical criteria to determine the satellite drop formation. And the retraction rate is a function of viscous force generated by extension flow and capillary force, so it can be used to determine the elastic properties of material as well.

Before we characterize the effect of elasticity on drop formation, how the pulse amplitude and the pulse dwell time affect the speed and size of drop is examined with glycerol 47 weight percent solution. While changes of dwelling time don't make much difference, maximum drop length and jet terminal speed is almost linearly dependent on the pulse amplitude. Although the resistance to breakup is improved compared with water, it still generates satellite drops in many cases.

The addition of 100ppm of 8k PEO shows almost same drop retraction behavior with Newtonian fluids. But when PEO molecular weight over 300k is added, the retraction rate is increased and satellite drop formation is highly suppressed. Especially when 100ppm of 300k PEO is added, as seen in Fig.2, its long ligament disappears at a very short time so it is hard to watch the retraction of the drop with micro order time scale. And because the resistance to detach from nozzle is increased as well, we have to apply higher voltage to get acceptable jet speed. It is not a good condition to jet even if it doesn't make satellite drops. Except for the case of 100ppm of 300k PEO, as can be seen in Fig. 4, they show higher retraction rate at constant capillary number as the molecular weight of added polymer increases.

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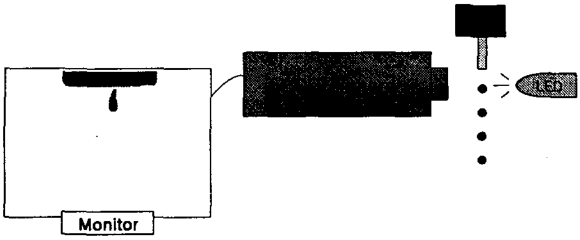

Fig. 1. Schematic of the drop-on-demand drop generation apparatus.

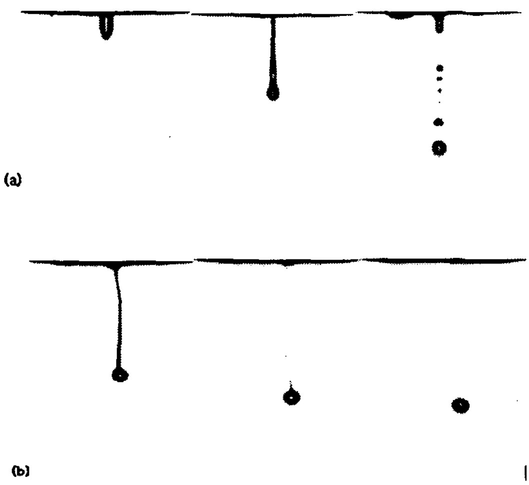

fig.2. The images of ink drop formation. (a) The images of DI water. (b) the images of 10ppm PEO(300k) solution.

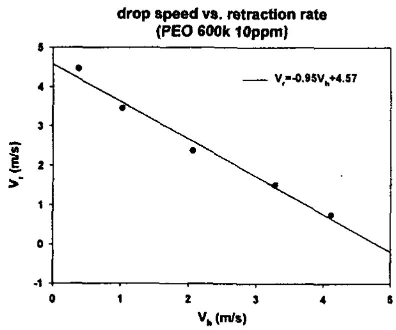

fig. 3. The retraction rate of drop ligament is linearly decreased with the increase of jet speed.

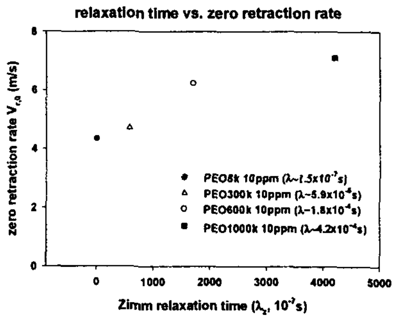

fig. 4. The retraction rate at zero jet speed as a function of Zimm relaxation time