Relationship Between Jetting Performance and Surface Tension in Micro Second Order on Water Based Inkjet Ink

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Abstract

Recently, inkjet systems have been used in the field of commercial printing thanks to print-on-demand. To disseminate the IJ widely in the commercial printing field, high speed printing for high productivity would be required. In high speed printing, high jetting performance is needed. Good jetting performance means that a jetted droplet forms a spherical droplet before it reaches the paper surface. From the hypothesis that jetting performance depends on dynamic surface tension in a time scale of micro second order, the relationship between jetting performance and dynamic surface tension was investigated using the ink including pigment, humectant and surfactant. To check the jetting performance, the ink jetting behavior was investigated using a commercial line type print head at high jetting frequency. Dynamic surface tension in micro second order was measured by the Continuous Ink Jet system. The higher dynamic surface tension in the short time range was found to show better jetting performance with its single droplet formation. It was concluded that good jetting performance could be achieved by adjusting the ink composition to control dynamic surface tension.

Introduction

Recently, inkjet systems have been used in the field of commercial printing because of reasonable cost and high-flexibility thanks to print-on-demand. To disseminate IJ widely in commercial printing field, the following items would be required. (i) high speed printing for high productivity, (ii) high image quality on a wide variety of media such as offset-coated paper, film media, and so on.

In this study, high speed printing was mainly investigated. In high speed printing, high jetting performance is needed. Good jetting performance implies that a jetted droplet forms a spherical shape before it reaches the paper surface. On the other hand, in the case of poor jetting performance, droplet irregularities are observed, including satellites, mist, and long tails. In high speed printing, such droplet irregularities cause poor image quality.

From the hypothesis that jetting performance depends on the dynamic surface tension, the relationship between jetting performance and dynamic surface tension was investigated. It was considered that the dynamic surface tension especially in micro second order was important since the time scale of droplet formation was approximately micro-second order. The driving force to form spherical jetted droplets was considered to be the difference of Laplace pressure caused by surface tension. Ink liquid moves from primary droplet tail to the main droplet because pressure in the thin tail is higher than in the wide droplet. Thus a tail is united into main droplet and a spherical droplet is formed.

In previous studies, dynamic surface tensions of inkjet inks were reported. However, their many investigations were carried out with pure solution and clear liquid just with a few additive agents [1, 2]. Furthermore, dynamic surface tension in micro-second order for jetting performance of on-demand type inkjet head has not studied well [3]. The purpose of this study is to understand the relationship between dynamic surface tension and jetting performance using water-based ink which consists of pigment, humectant, penetrant and surfactant.

Measurement Principle

Principle of measurement of dynamic surface tension

To measure the dynamic surface tension in micro second order, the Continuous Ink Jet method (CIJ) was used [4, 5]. CIJ is the method in which liquid is continuously jetted to apply pressure on the liquid. Although the jetted liquid is in the shape of a liquid column at first, the liquid breaks into several droplets due to the instability of liquid column. The breakup is promoted by surface tension. There can be fluctuation in the size of broken droplets due to uncertain disturbances such as environmental convectional and thermal flow. Therefore, in CIJ method, the breakup is controlled by applying the modulation of particular frequency. As a result, CIJ can produce constant radius droplets.

In CIJ method, the surface tension affects the column jetted from the nozzle by pulling some fluid back into the nozzle. The velocity of the droplet after break-up, therefore, is slowed down compared with velocity of jetted column just after jetting. Because this reduction depends on surface tension, surface tension can be analyzed to measure the velocity of jetted column and droplet.

Here, surface tension is obtained to analyze the process from formation of jetted column to generation of droplet. This is a simplified way to analyze without considering the complex wave propagation. In this way, some applications of momentum conservation law were reported. In this paper, a calculation approach which considers the effect of Laplace pressure [6] is used.

Figure 1. Parameters for calculation of dynamic surface tension.

Surface tension (γ) is calculated from eq. 1 and 2 as follows.

$$\pi\rho r_d^2 v_j^2 - \pi r_j \gamma = \frac{4}{3}\pi\rho r_d^3 v_d f \quad (1)$$

$$\pi\rho r_d^2 v_j = \frac{4}{3}\pi\rho r_d^3 f \quad (2)$$

Measurement

Equipment of surface tension measurement

The jetting head had a structure consisting of a glass capillary tube (FS360-100-30-N, New Objective Inc.) held by two piezo actuators (AE0203D08F, NEC Tokin Co., Ltd.). By applying a pulse voltage to the piezo actuators, the vibration was excited into jetted column and the droplet was produced from a glass capillary tube. The velocity of the jetted droplet was approx. 5 m/s and the repeatability was very good. In order to visualize such high speed jetting, the droplet was observed with the stroboscopic method which used the pulse light (NPL-18, Sugawara laboratories Inc.). The camera (SILICON VIDEO9M001, Epix Inc.) equipped with an optical microscope (DZ3 and ZC15, Union Optical Co., Ltd.) was used for picture photography.

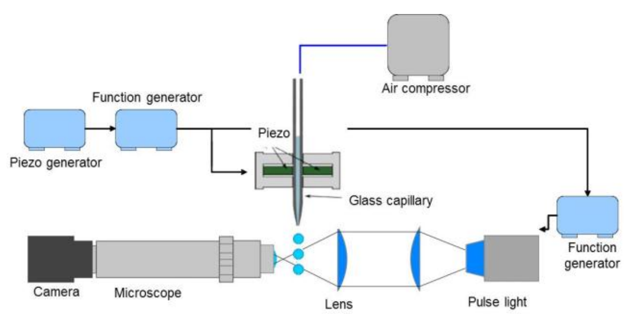

Figure 2. Diagram of equipment of surface tension measurement.

Measurement of physical properties

Static surface tension was measured by Wilhemy type surface densitometer (FACE CBUP-Z, Kyowa Interface Science Co. Ltd.). Dynamic surface tensions were measured by maximum bubble pressure tension meter (MPT2, LAUDA).

Jetting performance

To check the jetting performance, the jetting behavior was observed using a commercial line type print head at high jetting frequency with a camera equipped with an optical microscope. The quality of jetting performance was determined by how many jetted droplets formed spherical droplets before reaching the paper surface.

Results and Discussion

Before analyzing ink, we measured a simple system without pigment or surfactant. At first, the accuracy of this measurement equipment was confirmed using pure solvent. In the next steps, we measured mixed-solvent, mixed solvent with the surfactant, and ink with pigment. Finally, the relationship between jetting performance and dynamic surface tension was confirmed.

Measurement of pure solvent

To confirm the accuracy of this measurement equipment, pure solvent was used in this measurement because it was expected that a change between static surface tension and dynamic surface tension is not so large.

Table 1 shows the results of triethylene glycol monobutyl ether as an example of measurement. From the obtained jetting photograph, the analysis result of parameters required for surface tension calculation and surface tension analyzed from the momentum conservation law were shown. In addition, parameters obtained from measurement of jetting weight and surface tension calculated from the weight method were also shown. For reference, the static surface tension measured by Wilhelmy method was included.

Table 1. Measurement of triethylene glycol monobutyl ether

	Radius of droplet r_d, μm	Velocity of droplet v_d, m/s	Radius of jet r_j, μm	Velocity of jet v_j, m/s	Surface tension γ, mN/m
Photograph method	30.43	1.30	15.92	2.16	29.15
Weight method	30.90	↑	↑	2.17	29.15
Wilhelmy method					31.0

Since a measurement error of about ±10% occurs with the photograph method due to optical measurement, high accuracy measurements were attained by weight method in the case of non-volatile solvent. In this measurement, both the photograph method and the weight method had approx. 6% difference compared with the Wilhelmy method.

Measurement of mixed solvent

Next, some surface tensions of mixed solvents were measured. These mixed solvents had the composition of water-soluble solvent diluted with water. It was expected that the difference between static surface tensions and dynamic surface tensions of these mixed solvents is not so large, because these mixed solvents are easily soluble in water. The details of the compositions of measured mixed solvents are shown in Table 2.

Table 2 Vehicle composition

	Vehicle 1	Vehicle 2
Diethylene glycol	20%	20%
Diethylene glycol monobutyl ether	1.5%	10%
Glycerol (Viscous Cont. agent)	Balance	Balance
Water	Balance	Balance

The measurement results of the surface tensions of mixed solvents are shown in Fig. 3. The blue points described the result of vehicle 1 and the red points showed the results of vehicle 2, which was a version of vehicle 1 containing a low surface tension solvent. Only the results of the photograph method were shown since the weight method could not be applied to the volatile samples. Additionally, the results of measurement by the bubble pressure method were shown in Fig. 3.

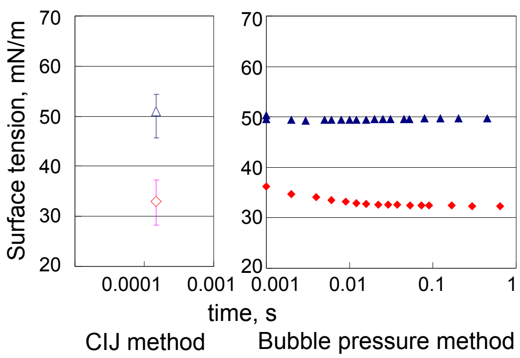

***Figure 3.** Surface tension of vehicle 1 and 2.*

The time range of CIJ measurements was approximated from the time from beginning jetting generation to droplet generation. As the result, it was approx. 200 μs, and the CIJ method was found to be better than conventional bubble pressure method for measuring the dynamic surface tension in micro second order. It was found that the difference between static surface tension and dynamic surface tension is not so large in mixed solvent.

Measurement of mixed solvent with surfactant

The details of the compositions of measured mixed solvent with surface tension in this paragraph are shown in Table 3.

Table 3 Vehicle composition

	Vehicle 3
Butyl triglycol ether	1.5%
2−pyrrolidone	3%
Trimethylolpropane	4%
Glycerol (Viscous Cont. agent)	Balance
Water	Balance

(HLB of surfactant A and B was 13.4 and 4 respectively.)

The surface tension of mixed solvent with the surfactant is shown Fig. 4. The measurement results were respectively vehicle 1, vehicle 1 added surfactant A, vehicle 1 added surfactant A in large amounts, vehicle 3 and vehicle 3 added surfactant B.

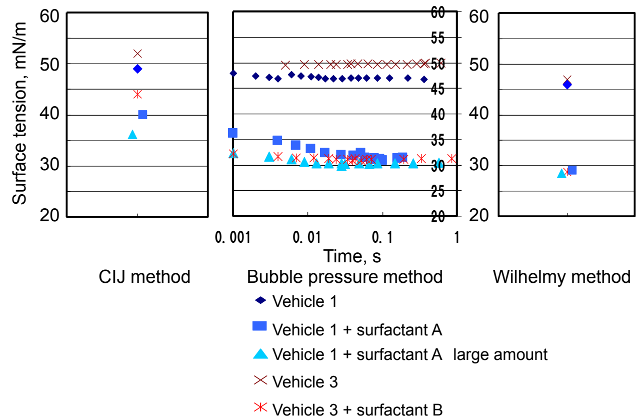

***Figure 4.** Surface tension of vehicle and vehicle added surfactant.*

It was found that a change between static surface tension and dynamic surface tension was larger in mixed solvent with surfactant compared to mixed solvent.

Measurement of water based pigment ink

Lastly, the measurement of water-based pigment ink was carried out. The result of surface tension of water-based pigment ink is shown in Fig. 5. The details of the ink compositions are shown in Table 4. (Some additives in Fig. 5 were added to ink composition of Table 4.)

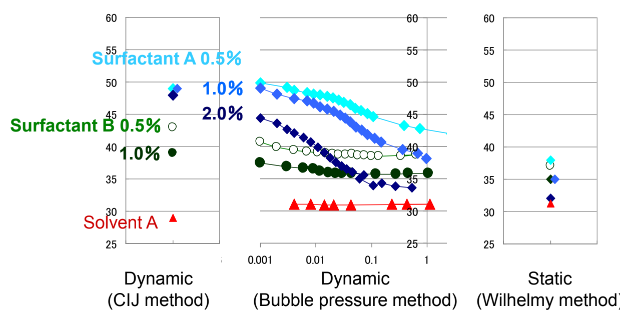

***Figure 5.** Surface tension of water-based pigment ink.*

Table 4 Ink composition

Pigment (carbon black 7)	7%
Acrylic polymer dispersant	5%
Diethylene glycol (Viscous Cont. agent)	Balance
Water	Balance

Also in evaluation of ink, the CIJ method was found to be better than the conventional bubble pressure method for measuring the dynamic surface tension in micro second order.

Correlation between jetting performance and dynamic surface tension

Finally, the relationship between jetting performance and dynamic surface tension was confirmed. The result of the relationship is shown in Fig. 6.

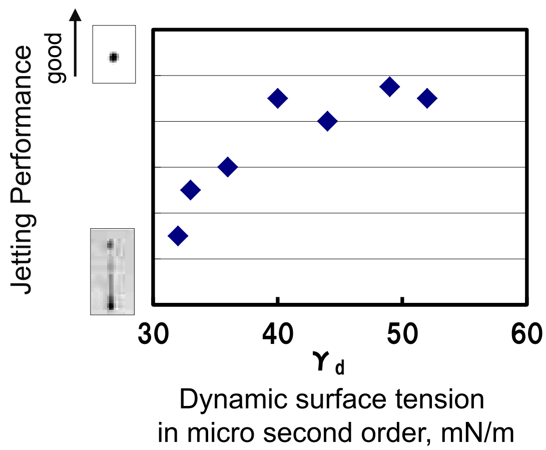

Figure 6. *Relationship between jetting performance and surface tension on water based pigment ink.*

The higher dynamic surface tension in short time range was found to have better jetting performance with single droplet formation.

Conclusions

It was concluded that good jetting performance could be achieved by adjusting the ink composition to control dynamic surface tension. Further study to achieve good print quality on various media such as offset coated paper has been carried out based on the above mentioned ink formulation knowledge.

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Author Biography

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