Micro-sizing degree as a property of ink-jet media printability

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Abstract

As well as supreme image quality realized by specialized paper, industrial and office printing markets demand uncoated general papers compatible with both offset printing and non-impact printing. The present work aims at clarifying the behavior of a micro-liquid droplet of water-based ink-jet inks or simply water absorbed into uncoated paper. In the experiment, laboratory handsheets were prepared by adding alkyl ketene dimmer (AKD) as a sizing agent at different levels of water repellency; none, 0.05, 0.10 and 0.20 % on dry pulp mass. The landing action and the absorption into paper of micro-droplets of water ejected from an ink-jet head were recorded by the microscopic high-speed video camera system every millisecond. The period of time between the landing and the completion of absorption was defined as "micro-sizing degree". The micro-sizing degree was approximately 2 to 3 ms up to 0.10 % AKD addition. It is lower than that of commercial silica-coated ink-jet papers which was approximately 8 ms although silica-coated papers are known to absorb water very quickly. However, the micro-sizing degree was approximately 45 ms for the handsheets of 0.20 % AKD addition. This result implies that the water-repellency by AKD is distributed over fiber surfaces so homogeneously that micro-water droplets of diameters of as small as a few micrometers are absorbed stably at similar rates.

Keywords

Alkyl ketene dimmer, ink-jet printing, micro-sizing degree, paper

Introduction

Nowadays, the target of ink jet printing systems is not only personal use, but advanced commercial printing capable of outputting variable information continuously etc. On the other hand, commercial high-grade ink-jet papers with a silica or alumina coating seek supreme image quality. In addition, package printing on curved surfaces by use of the non-contact system or textile printing on nonwoven fabrics or cloths have been applied recently. Ink-jet technologies such as precise positioning have been applied widely to industries other than printing, for example, production of color filters for liquid crystal TV and nano-patterning of semiconductors as new growing areas.

For paper as ink-jet media, ink-jet paper reproducing photo-like quality has developed and spread widely. At the same time, the print quality of plain paper of low quality —feathering and bleeding troubles— in the past has been improved using microscopic sizes of ink droplets and non-feathering types of inks. Printing paper compatible with both offset and ink-jet printings are being developed for efficient variable data printing. In short, ink-jet is oriented towards generalized printing compatible with all types of paper as well as particularly high image quality with specialized paper.

From this viewpoint, absorption of micro-droplets of ink into plain paper without any ink receptive layer was reconsidered in this work. The water absorption rate is generally measured by Bristow's apparatus and interpreted based on Lucas-Washburn's equation. In this case, supplied liquid is assumed to be abundant unlimitedly and the surface area reduction during absorption is ignored. As compared to such a bulk liquid, intermolecular attraction and surface tension have a great influence for a micro-liquid droplet. The surface tension of a semi-spherical micro-droplet on a paper surface is considered to lead to a high pressure comparably with capillary force. In this manner, micro-liquid droplet is potential to behave differently from a bulk liquid from the aspect of absorption mechanisms. In addition, surface tension and capillary force of liquids can be applied to stable patterning of microstructure and the knowledge of the liquid absorption into a substrate with a micro-porous structure is useful prospectively.

The absorption rate of micro-water droplets for ink-jet papers with a homogeneous ink receptive layer was reported [1] by the authors. In this report, the absorption rate "micro-sizing degree" for plain paper with pulp fibers exposed on the surface will be presented and compared to the silica-coated ink-jet papers commercially available.

Experimental

Samples

Handsheets of different sizing degrees (water repellency degrees) were prepared by adding different amounts of the sizing agent, alkyl ketene dimmer [= AKD] (Harima Chemicals, Inc., AK-720H) at 0.05, 0.10 and 0.20 % on dry fiber mass. The retention aid, poly-amide amine epichlorohydrin [= PAE] (Seiko PMC Corp., WS-4002) was added as well at half the amount of AKD, respectively. PAE was added initially and stirred for 5 min, then AKD was added subsequently. As a blank sample, handsheets with no AKD and no PAE were prepared. The preparation processes followed ISO 5269-1:2005 except the pressure of 310 kPa for 5 min with no repetition in the wet-press process.

Ink-jet papers commercially available were used. Sample PM is PM photo-grade gloss-type, Epson. Sample QP is Photo-like QP, gloss-type, Konica-Minolta. Sample HG is Hi-Grade, Mitsubishi Chemical.

Microscopic high-speed video recording

The microscopic high-speed video camera system as shown in Figure 1 was constructed using a high-speed video camera (For-A, Japan, VFC-1000 black-and-white model), an optical microscope (Olympus, CX41) with a tenfold objective lens. The sample stage has a vertical smooth surface to attach a paper specimen with a double-sided tape. Diffuse illumination made by covering the opening for a cold light source with a translucent film works as a backlight. The liquid used was not ink, but only de-ionized water. Landing and absorption of micro-droplets ejected from an ink-jet head (Konica Minolta KIE-2) was recorded at a speed of 1000 frames/s and a shutter speed of 1/2000 or 1/5000 s. The projected hemisphere of the micro-droplet was recorded on video as a dark object. The period of recording time was 4 s per ejection and the resolution of the recorded images was 256 × 212 pixels. The distance between the ink-jet head and the paper surface was set to 2 to 3 mm so that the landing velocity would be very low to ensure capture of the moment of landing.

To evaluate the absorption rate of the micro-droplet of water, the volume of the hemisphere was calculated form the shape of the projected hemisphere. The coordinates of two ends of the chord and the zenith was determined visually in the image analysis operation. The shape of the projected hemisphere was assumed to be a part of a circle and isotropic in three dimensions. The scale preparation was recorded and the hemisphere volume was calibrated to be true values based on a scale of 0.746 µm per pixel.

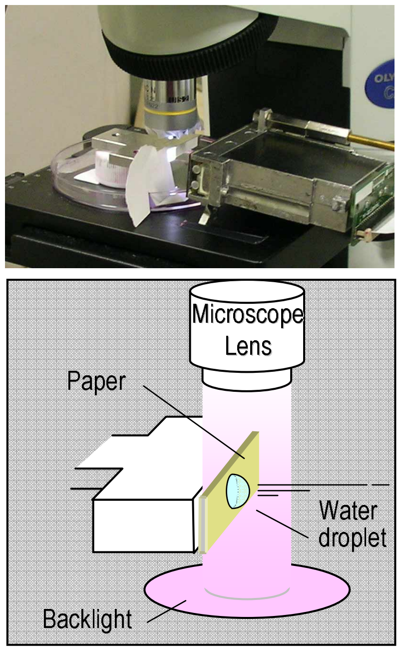

***Figure 1**. Microscopic high-speed video camera system to capture water penetration behavior (top) and sample stage to record side view projection of water drop on paper surface (bottom).*

Results and discussion

Size of micro-water droplets

The volume of micro-droplets of water ejected from the ink-jet head ranged widely. As Figure 2 shows from left to right, they are grouped roughly into tiny droplets (satellite), intermediate droplets (planet) and huge droplets (coalescent). For the droplets in this figure, the diameter is 8.0, 20.5 and 36.9 µm, respectively. Accordingly, the estimated volume is 0.3, 4.5 and 26.4 pL. It seems that on ejection, some droplets merge and increase the volume. Actually, the volume of the recorded droplets ranged between 0.3 and 29.2 pL.

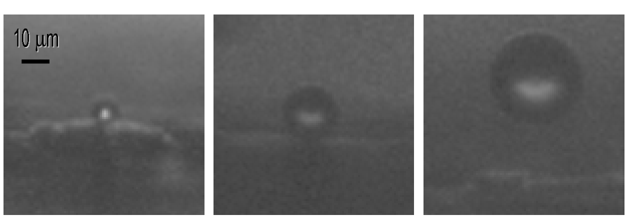

***Figure 2.** Satellite drop (left), primary planet drop (middle) and coalescent drop (right) of water.*

Landing of micro-water droplets

Figure 3 shows the changes in shape of micro-droplets over time after landing on the handsheet prepared with 0.05 % (a) and 0.20 % (b) of AKD. The first frame with a droplet wetting a paper surface was set to time 0 ms although the true moment of landing exists at some point between this frame and the previous one. A horizontal white line visible in those frames previous to landing is the top surface of a fiber present at paper surface. The location was selected so that the fiber axis was found to be as horizontal as possible. Out-of-focus micro-droplets were found faintly to pass the front or back side of the fiber and fell into the adjacent pore. Therefore, those micro-droplets never spread over the fiber surfaces. There were some cases where micro-droplets hung on the tip of fibrils of the fibers for several ms and then they were absorbed suddenly. This phenomenon is explained in terms of the lotus effect, that is, a water droplet that rolls off the hydrophobic lotus surface with a porous micro structure containing trapped air. The handsheets prepared, even with no AKD, pulled in micro-droplets less easily than commercial silica-coated ink-jet papers and many micro-droplets were seen to drift away above the paper surfaces. Repulsive electrostatic forces might have developed between surfaces of micro-droplets and fibers. Some micro-droplets drifting for several ms near fiber surfaces were absorbed quickly as they were suctioned abruptly.

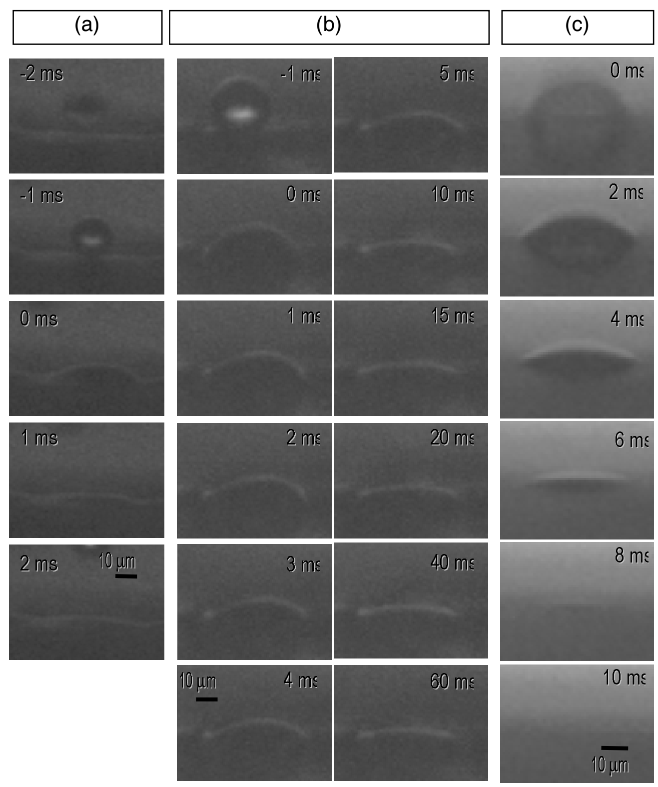

***Figure 3.** Landing of water droplet on pulp sheets prepared with AKD added at (a) 0.05 and (b) 0.20 %, respectively and on commercial photo-quality ink-jet paper (c).*

Micro-sizing degree

Figure 3(a) has two frames in which micro-droplets appear to be in the course of wetting and spreading over the fiber surface. This state is expected to last for more than 1 s but less than 3 s. To generalize the absorption time, it follows that *n* frames including a micro-droplet in contact with a fiber surface is visible mean that the micro-sizing degree is *n* s in average with maximum errors of ±1 s. Micro-sizing degree was determined for every droplet recorded appropriately and its mean, standard deviation and 95 % confidence intervals were calculated. The micro-sizing degree was also determined for the ink-jet papers commercially available that were subjected to the measurement and the result was presented in the previous report [1]. Table 1 shows micro-sizing degrees of all the samples. Up to 0.10 % AKD addition, there was no significant difference in micro-sizing degree, but at 0.20 % it was extremely high. Ink-jet papers with ink-receptive layers consisting of silica or alumina are known to absorb water quickly immediately after contact. However, the hydrophilic fiber surfaces of unsized or weakly-sized handsheet absorb water even more quickly. This fact, therefore, suggests that silica does not increase the absorption rate of water-based inks for ink-jet. Among the silica-coated ink-jet papers used, sample HG showed the lowest value probably because weakly-sized fiber surfaces are exposed and can contact water directly, resulting in quicker water absorption than the other.

Figure 4 shows the changes in volume of individual micro-droplets on paper. A square root of time was taken as the horizontal axis because of the linear relationship found so far between the decrease in volume and a square root of time for the silica-coated ink-jet papers. This linear relationship theoretically follows Lucas-Washburn's equation. The volume of micro-droplet ejected from the head ranged widely. However, large droplets did not always show higher micro-sizing degrees. Some micro-droplets hung on the tip of fibrils of fibers for several ms before initiation of absorption. This phenomenon was observed often for the handsheest of 0.20 % AKD addition, but observed even for the handsheest of 0.05 % AKD addition.

It was predicted that on a microscopic scale of micro-droplet, sizing agents such as AKD might not function properly. Emulsified particles of AKD adsorb on fiber surfaces during dehydration in the papermaking processes. Those particles melt by heat treatment and cover some percentage of all the surfaces. Exposed surfaces might be wetted easily by micro-water droplet and trigger the quick absorption even for strongly-sized paper. However, for the handsheets of 0.20 % AKD addition, it takes several tens of milliseconds for every micro-droplet to be absorbed completely. This period of time is significantly longer than those for the handsheets of 0.10 % AKD addition or less. It was found that strongly-AKD sized paper has homogeneous water repellency to micro-water droplets with diameters of as small as a few micrometers.

Table 1 Micro-sizing degree of handsheets of different AKD addition and commercial silica-coated ink-jet papers

	AKD addition, %				QP	PM	HG
	0	0.05	0.10	0.20			
Micro-sizing degree, ms	**2.1**	**3.4**	**2.3**	**44.9**	**6.3**	**4.8**	**3.3**
Standard deviation, ms	0.7	4.7	1.0	28.6	3.0	1.7	1.0
95% confidence interval, ms	0.4	2.5	0.7	21.2	1.4	1.0	0.7
Number of measured droplets	11	14	7	7	17	10	7

Acknowledgement

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References

[1] T. Enomae, Y. Mori and A. Isogai, "Micro liquid absorbency of ink-jet media", Proc. NIP22, (IS&T, Denver, CO, 2006) pg. 604.

Author Biography

Toshiharu Enomae graduated from The University of Tokyo in 1984, Received M.Sc. in 1986 and Ph.D. in 1993 under a title of "Studies on coating applicability of basepaper and evaluation of coated paper structure" Currently Associate Professor. In 1993-1995 post-doctorate research fellow for Dr. Pierre LePoutre at Univ. of Maine. Backgrounds are paper coating, paper physics for printing. This presentation is an extended study of "Micro liquid absorbency of ink-jet media" presented in NIP22.

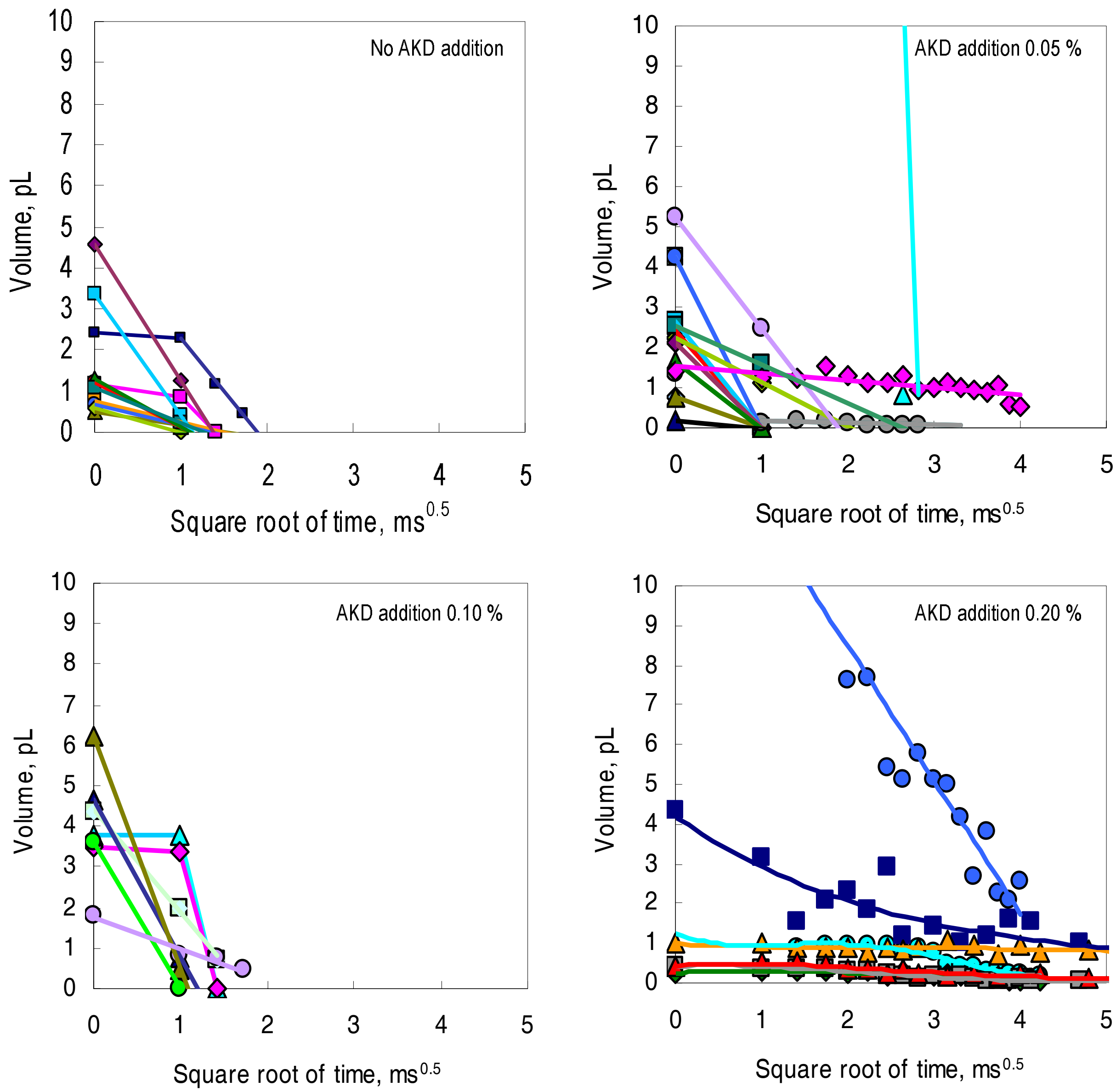

Figure 4. *Volume changes of water drops above surface plane of handsheets prepared by adding different amounts of size (AKD) on dry pulp mass as indicated.*