Micro liquid absorbency of ink-jet media

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Abstract

In ink-jet printing, ink absorption behavior of printing media is closely related to its print quality. The velocity of liquid absorption into paper is regularly evaluated with a Bristow type tester or by measuring the change in contact angle alternatively. In this study, from the shape of a projected hemisphere of water drops, the changes in volume, contact angle, height and radius of circular contact area were measured using a microscopic video camera. Those shape parameters were compared between water drops ejected from a test ink-jet head and landing on a surface of the photo grade and general grade of ink jet papers. The absorption rate was found not to be varied between the grades although more research is necessary for more exact mechanisms. The volume of a water drop that landed on a once-wetted surface decreased more slowly than on an unwetted surface and the contact angle was lower at equivalent times after landing.

Introduction

Demand for Ink-jet print quality is currently polarized to the ultimately high quality surpassing silver halide photography for one thing and the generalized quality aspiring to compatibility with off-set printing or electrophotography for the other. Whichever direction the major trend of development heads toward, behavior of jet inks landing on a media surface and absorbed into the media must be analyzed exactly to enhance the print quality to additionally higher levels or guarantee the desirable minimum quality.

Generally, behavior of liquid penetration into paper is closely related to water-affinity or water-repellency of the paper. The level of this property is termed "sizing degree" and has been measured by several methods. One of the simplest methods is Stöckigt sizing degree [1]. A squared paper sheet formed into a boat-like shape by folding up the four sides is floated on aqueous ammonium thiocyanate. From above, a droplet of aqueous ferric chloride is dropped on the boat. From this moment, time is measured until three red spots are detected visually. Stöckigt sizing degree defined as this period of time does not represent a surface layer property involved in jet ink penetration and visual detection is limited to medium to strongly sized paper. Cobb sizing degree (Cobb value) [2] is defined as the mass of water absorbed in a specific time and called water absorptiveness. For accurate values, long periods of time have to be specified. So, it is difficult to relate to quick ink absorption.

For methods more oriented to printability, Hercules sizing degree [3] is used. An aqueous dye solution is allowed to penetrate into a paper specimen. From the other side, the change in light reflectance is monitored and the time required for the reflectance to drop to the specified value is defined as a sizing degree. More recently, original and modified Bristow type testers have become popular as a tool to measure directly liquid absorption volume as a function of time of contact between the liquid and paper. The test liquid is supplied through a slit at the bottom of a liquid supply head and absorbed into paper. The absorption volume per unit area is determined and plotted against the contact time calculated from the velocity of paper crossing the slit width. The shortest contact time available is about 10 ms.

Contact angle is not direct measures of absorption volume, but, often used to indicate wettability of media surface as well as its change with time. For absorption tests, time required for a drop on a paperboard surface to be absorbed until a sudden loss in the gloss is measured [4]. Assuming that the three-dimensional shape of a liquid drop on a paper surface is isotropic, the side view projection, which is possible to be recorded in contact angle measurements, gives a volume of the drop left on the surface. Measurements of contact angle is made using a droplet with a volume ranging from 1 to 30 µL, which is about 10^{-6} times larger than volumes of common ink-jet droplets. A sphere of even 1 µL has a diameter of about 1.24 mm, which is more than 10 times larger than a common copy paper thickness. Considering the water drop dimension, even after the front end of water reaches the opposite side by penetration, there is still a large volume of water left on the drop side. Such a large droplet could not be used to simulate jet ink absorption.

Some questions arise about sizing effects. Are sizing degrees or water absorption rates measured with bulk water or macroscopic water droplet by the conventional methods applicable to a microscopic water droplet as in ink-jet printing? It was reported that sizing agents distribute with small particles scattered discretely. Although two particles are deposited several or several tens of micrometers apart from each other, the size takes a sufficient sizing effect due to surface tension of water bridging the two particles. Are water droplets with a diameter less than a distance between such two size particles absorbed quickly? So, in this work, a new concept named "micro sizing degree" or "micro liquid absorbency" of paper is proposed. Water droplets of about 30 pL (about 40 µm in diameter and equivalent to pulp fiber width) ejected from a test ink-jet head, was used to determine these properties with the assistance of the high-speed video camera system [5].

Experimental

Samples

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. The liquid ejected as a droplet was only water unless mentioned otherwise.

Methods

The microscopic high-speed video camera system as shown by Figure 1 was constructed using a high-speed video camera, VFC-1000 black-and-white model, For-A, a common optical microscope with a tenfold objective lens, Olympus, tenfold attachment lens MA44S, Elmo. Ink behavior was recorded at a speed of 500 frames/s and a shutter speed of less than 1/1000 s. The sample stage has a vertical smooth surface to attach a paper specimen with a double-sided tape. The reflecting mirror for illumination is located on the opposite side of the microscope lens in relation to the water drop. Diffuse illumination made by covering the opening with a translucent film works as a backlight. The projected hemisphere of the water drop was recorded on video as a dark object.

The traveling velocity of water droplets was set very low to avoid too quick motions to capture by adjusting the distance between the ink-jet head, KIE-1, Konica-Minolta and the paper surface.

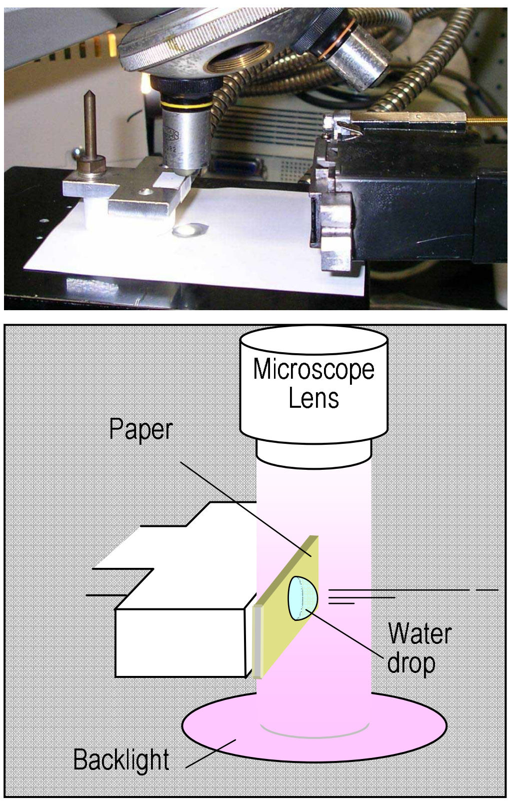


Figure 1. Microscopic high-speed video camera system to capture water penetration behavior (top) and sample stage to record side view projection of water drop on paper surface (bottom).

To measure the shape parameters of the projected hemisphere of the water drop in video images, the coordinates of two ends of the chord and the zenith were determined manually, then the volume, height, radius of the circular contact area and contact angle were calculated from them, on the assumption that the hemisphere is a part of a circle and that the water drop is isotropic in three dimensions.

Results and discussion

Video images of a microscopic water drop

Figure 2 shows an example of projected hemispheres of the water drop on sample QP. Time 0 was set to the first image in which the water drop appeared. This rule of time setting was applied to every water drop analysis although the time scale has an experimental error of 2 ms at the most. Therefore, time scale shift may be needed for exact analysis. At 0 ms, the image includes the faint course of the traveling droplet, suggesting that this frame is very close to the real time 0, which is ideally the time of drop landing. The drop height and contact angle are observed to decrease with time. But, the radius of the circular contact area hardly decreased initially, but started to decrease from 6 ms. Figure 3 shows these changes of the shape parameters numerically as well as the decrease in the volume of this water drop. When the drop height is low like the image at 8 ms, contact angle data is not accurate any more. This difficulty becomes remarkable, the angle approaches 20 °. Although the contact angle decreased, the radius of the circular contact area was maintained almost constant in the earlier stages of absorption. This phenomenon is supposed to be explained by the following hypothesis. On collision of a water droplet on a paper surface, it spreads very quickly over the surface with inertia of traveling to form an advancing contact angle. Even during the penetration of water, the shape of the circular contact area is maintained until the contact angle attains the receding one. After this stage, the receding contact angle is maintained while the contact line recedes towards inside.

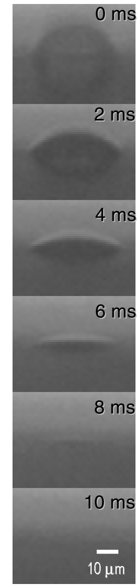


***Figure 2.** Change of projected hemisphere of water drop on sample QP recorded every 2 ms.*

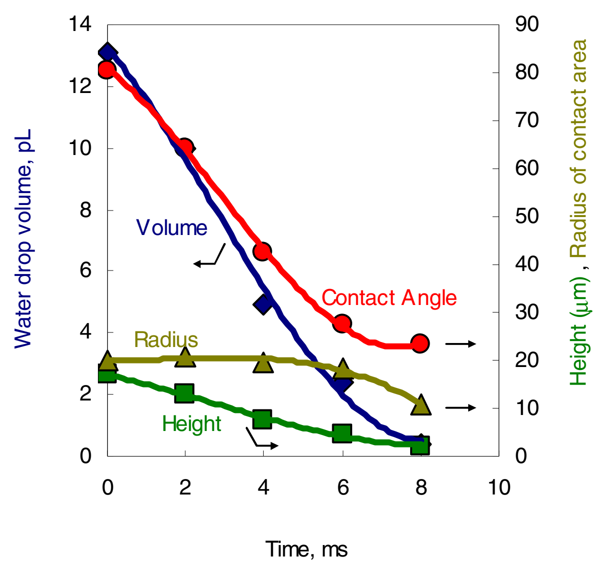


***Figure 3**. Changes in volume and shape parameters of a single water drop recorded as video images shown in Figure 2.*

Video images of a microscopic water drop

Figure 4 shows changes in volume of water drops on sample QP. The volume of droplets was varied a lot from 10 to 100 pL because every droplet was not ejected from the same opening for one reason. Against the elapsed time, the volume decreased non-linearly. The same data re-plotted as a function of square root of time provided Figure 5, where there is a liner region in the middle of the penetration time for many of the volume change curves. This linearity implies the penetration based on Lucas-Washburn's equation shown below:

$$l=\sqrt{\frac{r\gamma\cos\theta}{2\eta}t} \qquad (1),$$

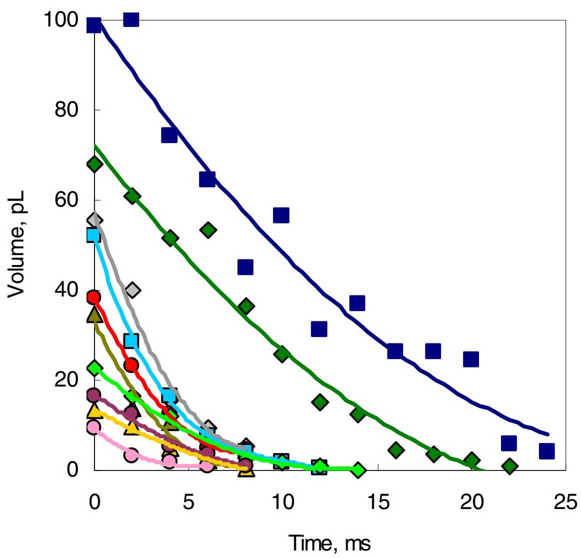


Figure 3*. Changes in volume of water drops on sample QP surfaces with time.*

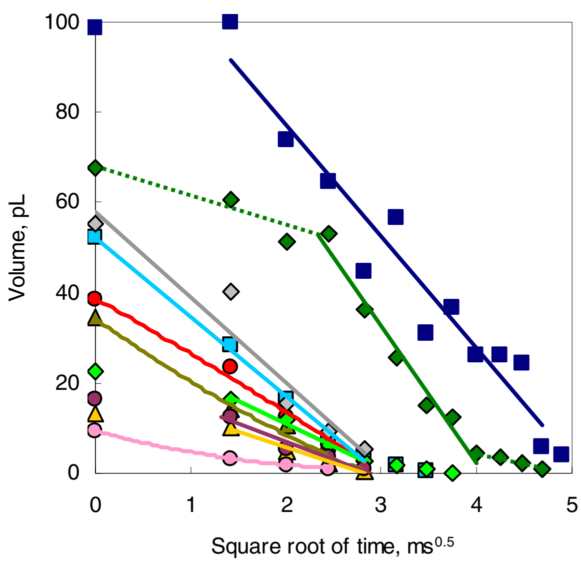


Figure 4*. Changes in volume of water drops on sample QP surfaces with square root of time.*

where l is the penetration depth, r is the capillary radius, γ is the surface tension of liquid, θ is the contact angle, η is the viscosity of liquid and t is the time. This equation represents that wetting of surfaces by liquid is a driving force of penetration and holds well for micro liquid penetration into porous media. The initial gentle slope is probably explained in terms of the time required to wet the surface. At the other end, there is also a gentle slope region. Considering the result that the radius of the circular contact area decreased with the receding contact angle maintained as found in Figure 3, the droplet contracts towards inside with its relative shape maintained. Figure 6 shows schematically the mechanism of water drop penetration

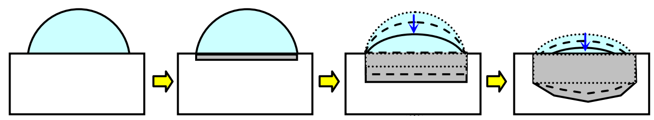


Figure 6*. Schematic of water drop absorption mechanism.*

Figure 7 shows changes in volume of water drops on sample PM. The volume of the water droplets happened to be all less than 40 pL. The volume decreased linearly as a function of square root of time as well as for sample QP. The water absorption rate should be compared in terms of the slope of the volume changes. Consequently, the two photo grade ink-jet papers QP and PM did not show a significant difference.

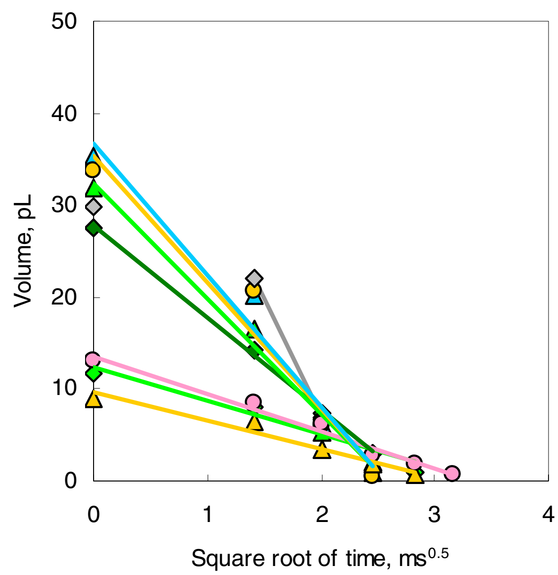


Figure 7*. Changes in volume of water drops on sample PM surfaces with square root of time.*

Figure 8 shows the video frames and volume changes of water drops on sample HG, a general grade of coated ink-jet paper. Aggregated particles of silica appear to be 5 to 20 µm in diameter in scanning electron micrographs and pulp fibers are visible between silica particles (not presented here). Therefore, the surface is defined as rough large silica aggregates including partially pulp fiber surfaces. Usually, base paper for ink-jet coating is weakly sized and the water absorbency is supposed to be lower than silica particle coatings. However, the slopes of the changes of water

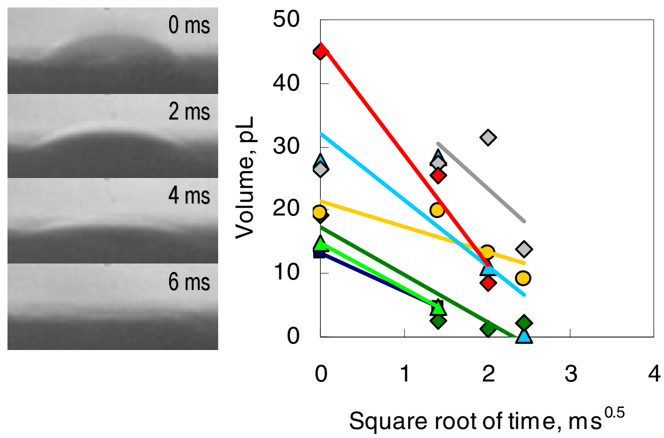


Figure 7. Change of projected hemisphere of water drop on sample HG recorded every 2 ms (left) and changes in volume of water drops with square root of time (right).

absorption volume are similar to those of samples QP and PM. By Bristow's testers, apparently higher water absorption rate has been found for the photo grade ink-jet papers like QP and PM. Whether the water drop absorption really shows a different tendency should be examined more for exact absorption mechanisms.

Absorption of a water drop on the wet surface

Coincidentally, several water drops landed nearby on sample PM. The video frames with the four water drops are shown in Figure 9. The second and third water drops landed away from the first and second, respectively, by a distance approximately of half the radius of the circular contact area. The absorption pattern of the second and third water drops are similar to that of the first drop that landed on the unwetted surface in terms of the changes in the volume, the radius of the circular contact area and the contact angle. If about 14 % of the area of the circular contact area is already wetted, it does not seem to affect the absorption behavior of the water drop. However, for the forth drop that happened to land right on the same location with that of the first one, its volume decreased more slowly than that of the other drops and its contact angle was lower at equivalent times after landing.

References

[1] Japanese Industrial Standard, JIS P 8122 Paper and board - Determination of sizing - Stöckigt method.

[2] TAPPI TEST T 441 om-98 Water absorptiveness of sized (non-bibulous) paper, paperboard, and corrugated fiberboard (Cobb test).

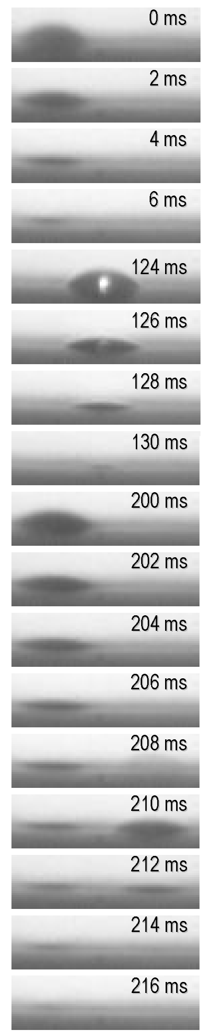
[3] TAPPI TEST METHODS T 530 om-02 Size test for paper by ink resistance (Hercules-type method).

[4] TAPPI TEST METHODS T 835 om-03 Water absorption of corrugating medium: water drop absorption test.

[5] D. Ivutin, T. Enomae and A. Isogai, "Ink dot formation in coating layer of ink-jet paper with modified calcium carbonate", Proc. NIP21, (IS&T, Baltimore, MD, 2005) pg. 448.

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 and physics for printing. In NIP21, presented on Ink dot formation in coating layer of ink-jet paper with modified calcium carbonate.



First drop (0 to 6 ms) and fourth drop (200 to 216 ms) on left, second drop (124 to 130 ms) in middle and third drop (210 to 216 ms) on right of sample PM

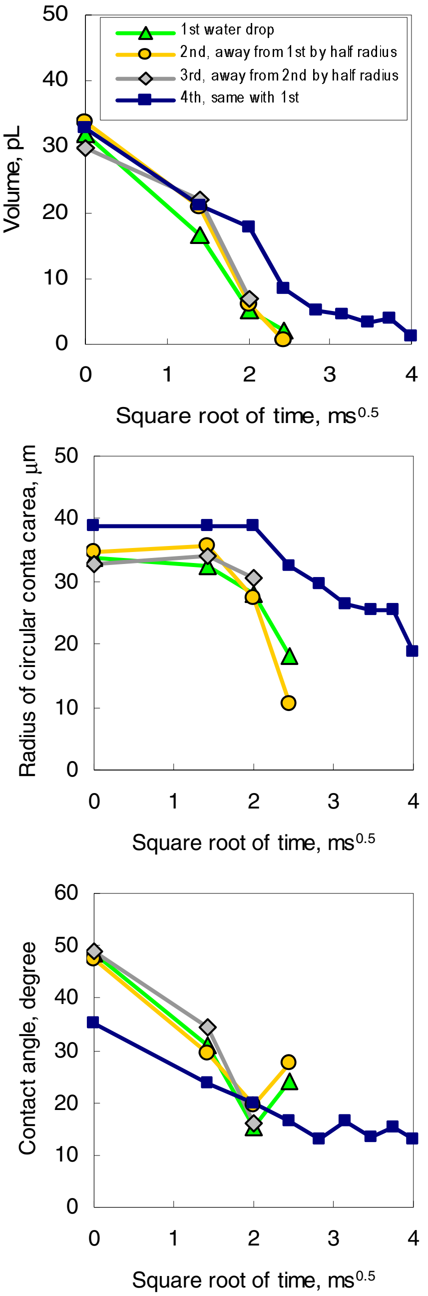


***Figure 9.** First water drop in the frames, second drop away from the first by half drop, third (actually fourth in order of time) drop additionally away from the second by half drop and fourth (third in order of time) drop immediately on the same site with the first drop [left] with graphs of volume [top], radius of circular contact area [middle] and contact angle [bottom].*