

Wetting and Liquid Absorption Characteristics of Ink Jet Paper

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Abstract

Various commercially available uncoated ink jet papers were tested with an Ultrasonic Wettability Tester (UWT) and a Bristow Absorption Tester. Wetting time and liquid absorption rate were determined using solutions of deionized water and isopropyl alcohol with lower surface tensions similar to those of ink jet inks. It was shown that test liquid with lower surface tension exhibits shorter wetting time and greater liquid absorption rate as expected. It was also demonstrated that wetting time and liquid absorption rate directly impact on ink - paper interaction. In general, papers with shorter wetting time and higher absorption rate have fast ink drying with liquid ink jet printing.

The differences between the Ultrasonic Wettability Tester and the Bristow Absorption Tester were described and the correlation between the data was examined. Even though both methods rely on different physical mechanisms for wetting and liquid absorption evaluation, the data are significantly correlated. The Ultrasonic Wettability Tester is recommended for ink jet paper evaluation for its ease of use, speedy, objective and reproducible results.

Introduction

Drop-on-Demand liquid ink jet printing market has been growing rapidly in recent years due to the printers' low cost, good quality, color capability and wide range of applications. With this printing technology widely populated in the market place, especially in office and home printing environment, end users pay more and more attention to printing quality as ink jet printout is compared with other technologies such as laser printing. Great deals of efforts have been made on improving the overall printing performance on paper by either joint efforts between the printer and paper manufactures or by each independently. When an aqueous ink is used in ink jet printing, the printing substrate, most of the time paper, is required to have unique physical and chemical properties to achieve a balanced ink holdout for good ink density and color saturation, and fast ink drying. For uncoated paper, it has been found that the content of hardwood and softwood, the filler type and amount, porosity, internal and surface sizing and sheet formation all play important roles in determining the final property of the paper for ink jet printing. For coated paper, the binder and pigment type, binder to pigment ratio, coating weight and the base sheet property are important to define the ink jet print quality.

Paper made with sizing materials having strong film forming property and with strong hydrophobicity usually gives an excellent ink holdout, but ink drying and instant color to color bleed are unsatisfactory. On the other hand, paper with very open structure and weakly sized will have a good ink drying speed, but the image quality usually is poor due to poor ink holdout.[1,2] Therefore, design and control of paper porous structure and the surface hydrophobicity are very important to make uncoated paper for ink jet printing.

In ink jet printing, there are two major ink drying processes on the surface of a paper, absorptive and evaporative drying. With a given ink, evaporative drying is dependent on the printing environment, while the absorptive drying is totally dependent on the structure and surface properties of the paper.[3,4] It is apparent that a test that can quantify and help to understand the absorption and wetting on paper surfaces will be a powerful tool for studying and manufacturing a quality ink jet paper.

At the present time, a common practice for print quality evaluation is still running an actual paper through an ink jet printer. The availability of various ink jet printers has made the actual printing evaluation popular. There is no doubt that running an actual ink jet print is the ultimate test to examine the printing quality. It has many advantages such as direct, visual and realistic. However, there are many disadvantages associated with the print test as well. For example, the print test usually does not provide basic data, and it is not always as simple, as quantitative and as straightforward as the conventional sizing test. Print quality evaluation is often complicated as ink drop volume may change over time when jet nozzles become worn. Printing test is subjective and requires extensive experience to derive cause - effect relationship. It also tends to lead people bypassing important underlying reasons and only emphasis on the end results. Therefore, there is a need to have simple and convenient tests for paper to predict ink jet printing performance.

Different from the conventional sizing tests, such as HST and Cobb test methods, which do not always correlate well with ink jet printability, the Bristow Absorption Tester is capable of providing short time interval wetting and absorption measurements.[5,6,7] It has been widely used in the ink jet paper evaluations with satisfactory results.[8,9,10] However, the Bristow test itself is very labor-intensive and time-consuming, and the data have to be further manually processed for quantitative determination of the parameters including wetting time and liquid absorption rate. This is one of the reasons why Bristow test is largely limited to a research environment. Furthermore, Bristow technique sometimes can not provide useful data for coated ink jet papers due to the headbox clogging by the coating materials from the paper.

In the present study, we show that short time interval wetting and absorption characteristics of a paper can be effectively evaluated using a dynamic ultrasonic technique. The data obtained ultrasonically were shown to correlate significantly well with ink drying behavior of the paper as well as those determined with the Bristow test. We found that the ultrasonic method is fast, efficient and can produce reproducible results. It combines the data accuracy of the Bristow test with the convenience of a common sizing test, such as the Hercules Sizing Test (HST).

Test Methods and Procedures

Twelve uncoated (plain) papers recommended for ink jet printing were used in this study. All the papers were commercially available products selected from different office stores in the US. All papers were conditioned under TAPPI condition (20°C and 50% RH) for at least 24 hours before testing. Black ink drying on paper was tested with HP DeskJet 500C and 660C printers using the Hewlett Packard Paper Acceptance Criteria test procedure with Plot Generator Rev. 3.4, July 1994.[11] The 98% drying parameter was used as the drying index to correlate with wetting time and absorption obtained from UWT and Bristow tests. The 98% drying is defined as the time (seconds) elapsed when 98% of the ink laid down on the surface of a paper has been dried.

Short Time Interval and Conventional Sizing Tests

Differing from most of the conventional sizing test methods, the Bristow Absorption Tester is capable of providing short time interval (milliseconds) measurement of the liquid - paper interactions.[5-8] In this test, a paper strip mounted on a rotating wheel is moved at a constant speed across a headbox containing testing fluid. The area of the liquid transferred and headbox contact time on paper give information about the wetting and liquid absorption characteristics of the paper.

The Ultrasonic Wettability Tester (UWT) is a new instrument which can be used for paper-liquid interactions evaluation through recording the ultrasonic attenuation with time across the paper-liquid interface.[12] The changes in ultrasound attenuation level are shown to reflect the wetting, absorption as well as saturation processes, and the attenuation - time curve provides quantitative information on wetting and liquid absorption similar to those obtained with the Bristow test.[12,13] There are two basic available designs: vertical insertion type[14] and horizontal contact type.[12] The vertical insertion type drops paper sample into testing liquid with irradiating ultrasound beam and is adequate for longer time duration measurement to simulate conventional sizing tests. The horizontal contact type is designed for short time interval measurement by eliminating the sample insertion process through a simultaneous liquid–paper contact. In this study, a horizontal contact type, UWT-2, manufactured by Shin-Ei Co. of Hiroshima, Japan was used.

Both the UWT and Bristow tests were conducted using deionized water with 5% and 10% by volume of isopropyl alcohol solutions as test fluids to simulate low surface tensions of drop on demand ink jet inks. Cobb and HST tests were conducted on the ink jet samples according to the TAPPI Standard Test Methods T441 om-90 and T530 pm-89.

Results and Discussion

Ultrasonic Wettability Tester vs. Bristow Absorption Tester

Representative UWT attenuation - time curves and Bristow liquid uptake - dwell time curves are shown in Figures 1 and 2. As demonstrated by both testing methods, there are clear differences in wetting times and absorption rates among the samples. Samples of UC-1, UC-3 appeared to have longer wetting times and low slopes indicating stronger sizing effects. On the other hand, UC-7 and UC-12 had much shorter wetting times and higher slopes, a typical tendency exhibited by a weakly sized or porous paper. Both of the testers ranked the sample in an identical order in terms of wetting and absorption rate in this case.

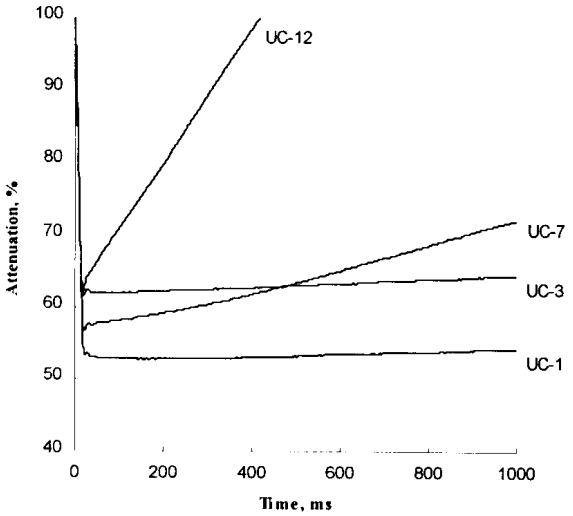

Figure 1. Ultrasonic Wettability Tester Attenuation - Time curves for wetting time and absorption rate determinations

The relationships between the two methods were examined. Figure 3 shows the correlation of the wetting times as measured with both methods using a 5% isopropyl alcohol solution with a surface tension of 51 dyne/cm. Linear regression of the two sets of the data showed a good correlation ($r^2 = 0.782$) between the two techniques even though there is some scattering in the data. Similar correlation between the two measurements on other types of paper has also been observed previously.[12,13]

In Figure 4, the relationship between the absorption rates from UWT and Bristow measurements is shown. A definite and meaningful correlation is apparent, although there is one particular point, sample UC-12, which deviated from the linear relationship. The large deviation for sample UC-12 is thought to be due to the paper's unique surface morphology as a result of special surface sizing treatments to which UWT measurement is more sensitive than the Bristow method. Overall, both methods can differentiate the sample in a similar way in terms of absorption rate. This correlation is important to illustrate the physical meaning of the slope in the attenuation - time curve determined using

the ultrasonic technique. There are apparently many parameters involved in the attenuation of ultrasound propa-gating through a complex material like paper while in contact with a liquid, and there are still a lot to be learned about those parameters. However, the significant correlation in Figure 4 suggests that the slope from the ultrasonic measurement can be treated as an indicator of liquid absorption rate.

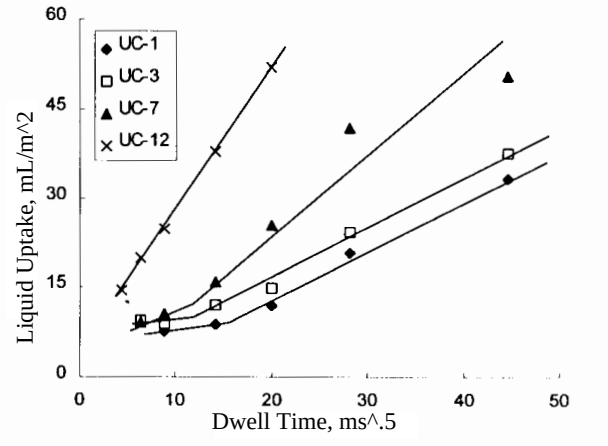

Figure 2. Bristow Absorption Tester Liquid uptake - Time curves for wetting time and absorption rate determinations.

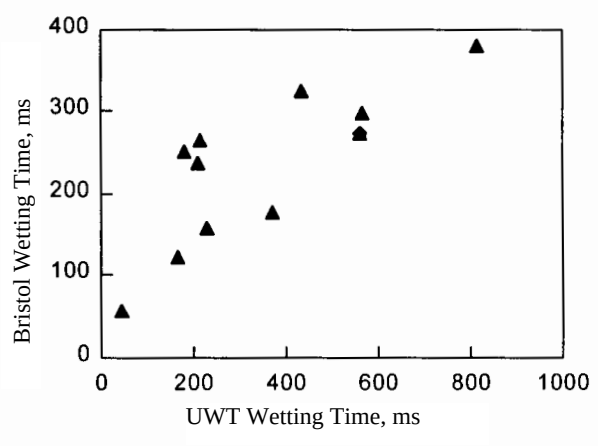

Figure 3. Correlation between the wetting times measured with the UWT and Bristow methods

Effect of Wetting Time on Ink Drying

The relationship between the ink drying index and the UWT wetting time is shown in Figure 5. Similar relationship was also observed with the Bristow test. As shown in Figure 5, there exists positive correlation between the ink drying behavior and the wetting time. In general, the longer the wetting time, the higher the ink drying index or the slower the ink drying speed. It is also noteworthy to note that the difference in the drying index between the HP DeskJet 660C and 500C inks when compared at the same wetting time for the same substrate. The pigmented black ink in HP DeskJet 660C tends to dry slower than the dye-based ink in the HP DeskJet 500C. This is due to the difference in the surface tension and chemical compositions of the inks.

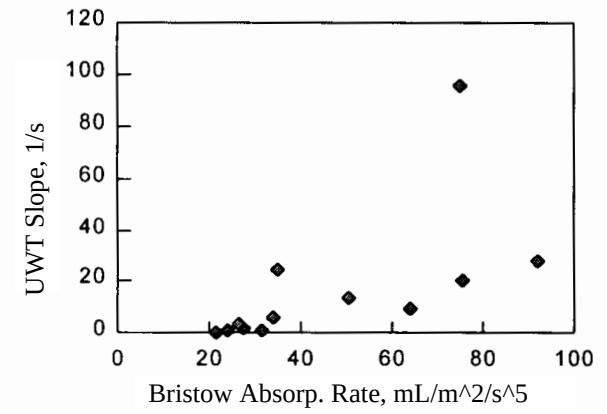

Figure 4. Correlation between the absorption rates measured with UWT and Bristow methods

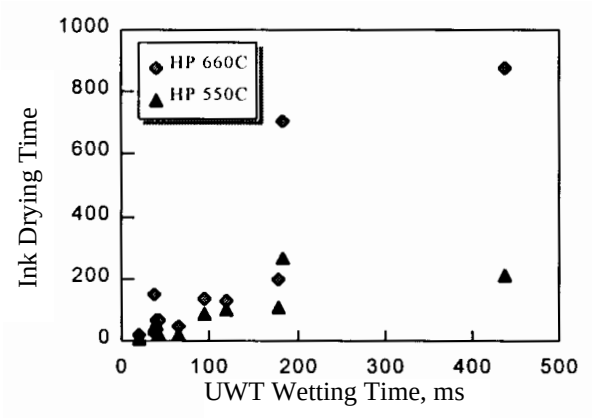

Figure 5. Ink drying index vs. wetting time measu red with the Ultrasonic Wettability Tester

The correlation coefficients between the ink drying index and various sizing parameters are summarized in Table 1. In most of the cases, the wetting times determined with the UWT correlated better with the ink drying indexes than did with the Bristow test. The correlation coefficients (r^2) for the UWT ranged from 0.621 to 0.810 as compared to 0.458 to 0.754 for the Bristow test.

As a comparison to the UWT and Bristow tests, standard HST and Cobb sizing tests were also conducted on the same set of ink jet papers. The results were correlated with the wetting time and absorption rate respectively. The correlation coefficients (r^2) between the HST and ink drying indexes ranged from 0.205 to 0.389 as shown in Table 1, which were significantly lower than those obtained with UWT test. It is, therefore, not surprising to conclude that the short time interval wetting time is a better indicator for the ink drying than the parameters measured using traditional sizing tests.

Effect of Absorption Rate on Ink Drying

Figure 6 shows the relationship between the absorption rate and ink drying. Ink drying index decreased exponentially with increases in the absorption rate and quickly leveled off. Very similar trend has been reported on subjective ink jet print quality rating versus Bristow absorption

Table 1. Correlation Coefficients Matrix (r^2) of Drying Indexes and Sizing Parameters

Test	Test Liquid	Wetting Time		Absorption Rate*	
		HP 660C	HP 500C	HP 660C	HP 500C
HST		0.389	0.347	—	—
Cobb*		—	—	0.142	0.421
Bristow	*5%IPA*	0.549	0.458	0.361	0.482
	10%IPA	0.64	0.754	0.365	0.482
UWT	*5%IPA*	0.740	0.751	0.691	0.679
	10%IPA	0.810	0.621	0.739	0.819

*The absorption rate and Cobb data were plotted against drying index on a log - log scale for improved linear regression.

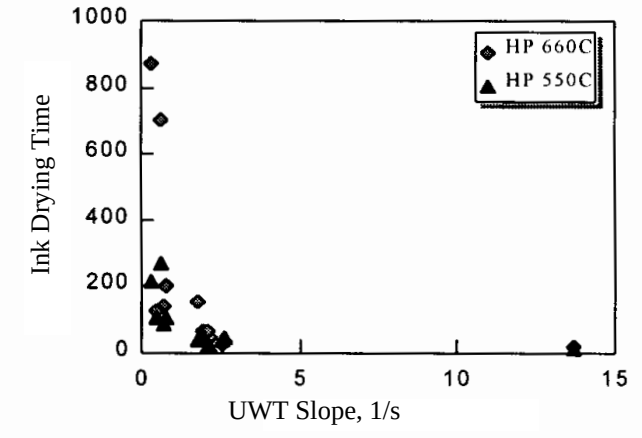

Figure 6. Ink drying index vs. absorption rate measured with the Ultrasonic Wettability Tester.

rate.[10] From Figure 6, it seems that a paper with a slope (indicator of absorption rate) from UWT greater than 2 second^{-1} will assure a good ink drying characteristic for an uncoated ink jet sheet. When the ink drying index - absorption rate curve was plotted in a log vs. log scale, a linear relationship exists. The correlation coefficients (r^2) were then calculated and the results were summarized in Table 1. The log - log linear relationship of drying time vs. absorption indicates a higher order of reaction process for drying, which will be a subject of further study. In general, the UWT showed significantly better correlation with the ink drying indexes than the Bristow and the Cobb tests. This finding clearly demonstrates that the ink drying speed depends on liquid absorption characteristic of the paper. The higher the absorption rate, the faster the ink drying.

Conclusion

The wetting time and absorption rate of the paper substrate measured with the Ultrasonic Wettability Tester (UWT) and the Bristow Absorption Tester are important parameters to the drying behavior of ink jet inks. They more directly reflect short time interval ink - paper interactions at paper surface than the traditional HST or Cobb sizing degrees. The direct relationships between the surface measurements and ink drying suggest that short wetting times and high absorption rates are highly desirable for fast ink drying speed. The traditional sizing tests could not provide as useful information as the surface measurements due to their intrinsic test limitations.

The Bristow test is a well-established testing method which provides unique short time interval wetting and dynamic liquid absorption information on the paper surface. However, it is very labor-intensive and time-consuming. The UWT method not only can provide the short time interval wetting and liquid absorption information, it also has the advantage of providing the information at a fast speed with reproducible results. It compresses hours of the Bristow tests into just a few minutes if not less. The superior productivity of the UWT should benefit the ink jet paper design and manufacturing, and be a very useful in both the mill and research environment.

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References

1. J. Borch, "Paper design characteristics for DOD ink jet printing at medium to high resolution", *IS&T's 47th Annual Conference/ICPS*, p. 352 (1993).
2. J. Borch, "The effect of paper sizing treatments on DOD ink jet printing at medium to high resolution," *IS&T's 47th Annual Conference/ICPS*, p. 820. (1994).
3. J. F. Oliver, "Initial stages of ink jet drop impacting, spreading, and wetting on paper," *Tappi J.* **67**(10): 90 (1984).
4. J. F. Oliver, "Wetting and penetration of paper surface", "Colloids and Surfaces in Reprographic Technology," *ACS Symposium Series 200*: 435 (1982).
5. J. S. Aspler, S. Davis and M. B. Lyne, "The dynamic wettability of paper," *Tappi J.* **67**(9): 128 (1984), **67**(10): 96 (1984).
6. J. A. Bristow, "Liquid absorption into paper during short time intervals," *Svensk Papperstidning.* **70 (19):** 623 (1967).
7. M. B. Lyne and J. S. Aspler, "Wetting and the sorption of water by paper under dynamic conditions," *Tappi J.* **65 (12):** 98 (1982).
8. M. B. Lyne and J. S. Aspler, "Paper for ink jet printing," *Tappi J.* **68 (5):** 106 (1985).
9. Y. Kurabayashi, M. Sakaki, and H. Sato, "Recording medium and method of recording using the same," U.S. Patent 5,124,201, June 23, (1992).
10. S. J. Bares and K. D. Rennels, "Paper compatibility with next generation ink-jet printers," *Tappi J.* **73 (1):** 123 (1990).
11. J. Collins, *Hewlett Packard Paper Acceptance Criteria for HP DeskJet Printers, 2nd Ed., July 1994* © Hewlett Packard.

12. Y. L. Pan, S. Kuga, M. Usuda and T. Kadoya, "Ultrasound can evaluate paper sizing," *Tappi J.* **68** (9): 98 (1983).
13. Y. L. Pan, S. Kuga, F. Onabe and M. Usuda, "Correlation between ultrasonic method and Bristow's test in evaluation of wetting and penetration of paper," *Sen-i Gakkaishi* **44** (6): 271 (1988).
14. Y. L. Pan, S. Kuga and M. Usuda, "An ultrasonic technique to study wetting and liquid penetration of paper," *Tappi J.* **71**(5):119 (1985).