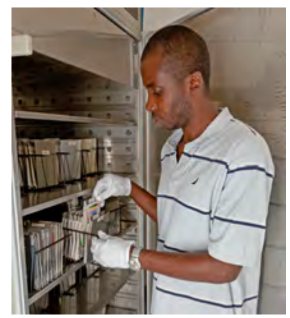
Epson WorkForce Pro WF-C5710 and Epson DURABrite Ultra Pigment Inks[1]

WIR 400-Year Permanence Certification for the Long-Term Storage of Inkjet Printed Plain-Paper Documents with Black and Color Text and Images[2]

The Epson WorkForce Pro WF-C5710 is a fast, ISO 24 pages per minute printer using Epson DURABrite Ultra pigment inks in high-capacity Epson Ink Packs. The printer retails for $249.99.

For long-lasting plain-paper documents, it is essential that the fully pigmented inkjet inks used to print them be highly water-resistant, and that the paper they are printed on be very long-lasting. As shown above, test targets printed on both Epson and Hammermill plain papers are submerged for two weeks in both fresh water and seawater to evaluate ink bleeding or transfer. To the right, Barbara C. Stahl and Kabenla Armah conduct multi-temperature accelerated Arrhenius paper aging tests that continued over a six-year period. The importance of long-lasting documents for personal and family applications, business documents, and legal records is further discussed on the next page.



Water–Resistance, Humidity, Dark Storage, and Display Permanence Ratings **(Years Before Noticeable Fading and/or Changes in Color Balance Occur)[3]**

Plain Paper for Home and Office Applications Printed with Epson DURABrite Ultra Pigment Inks	Resistance to Water[4]	Resistance to High Humidity[5]	Dark Storage Permanence Rating at 73°F (23°C) at 50% RH (incl. Paper Yellowing)[6]	Displayed Prints Framed Under Glass[7]	Displayed Prints Framed With UV Filter[8]	Prints Displayed Under LED Illumination[9]	Unprotected Resistance to Ozone[10]	Are Optical Brighteners Present?[11]
Epson Bright White Paper (plain paper for documents)	**Very High**	**Very High**	**More than 400 years**	**>125 years**	>200 years	now in test	>100 years	yes
Hammermill Inkjet Paper (plain paper for documents)	**Very High**	**Very High**	**More than 400 years**	**>125 years**	>200 years	now in test	>100 years	yes

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Epson WorkForce Pro WF-C5710 and Epson DURABrite Ultra Pigment Inks

Epson WF-C5710 Network Multifunction Color Printer with Replaceable Ink Pack System

Printer Description: Wireless and Ethernet: Print/Copy/Scan/Fax. Automatic two-sided printing with automatic document feeder.

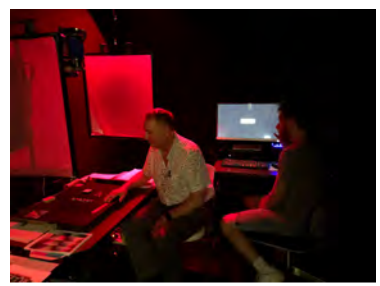
Ink System: Four fully-pigmented inks are provided in four user-replaceable Ink Packs: Black, Yellow, Magenta, and Cyan. The extra-large Epson 902XL Ink Packs have an ISO Page Yield of 5,000 pages in color, and 5,000 pages with black text. The total ink cost per page is **far less** than that of traditional ink cartridge printers.

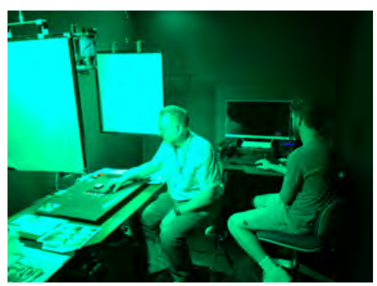
Maximum Paper Size: U.S. Letter size (8.5" x 11"), Legal, A4 with front-loading tray holding up to 250 sheets of plain paper. Handles plain papers and photo papers up to 8.5 inches wide and 47.2 inches long.

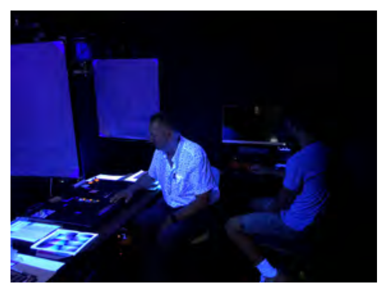
Price: Epson WorkForce Pro WF-C5710, Model C11CG03201, MSRP: $249.99 (USA).

The Essential Permanence Requirements for Long-Lasting Plain-Paper Documents

Considering the many environmental hazards that a document may encounter over the years, including exposure to light, high-humidity conditions, atmospheric ozone, momentary contact with water – or total immersion in water, including seawater – use of fully pigmented inks is essential to ensure long-lasting plain paper documents. Dye-based inks, and pigment black ink together with dye-based color inks, are not water-resistant. Water damage can be caused by accidental spills, broken water pipes, faulty fire sprinkler systems, water inundation resulting from efforts to extinguish a fire, roof and basement leaks, river and stream flooding, hurricanes, typhoons, tsunamis, rain (e.g., damage to mail shipping labels and barcodes), and other causes. This is critically important for personal and family documents, copies of children's drawings, paintings, school work, genealogical records, legal documents, business documents – as well as documents that may eventually find their way to libraries, archives, museums, corporate collections, and other institutions. Simply stated, dye-based inks are not suitable for these applications.







Pictured at the left working in the Wilhelm Imaging Research laboratory are Ryerson University (Toronto, Canada) color scientist Richard Adams, who is collaborating with WIR on a number of research projects, and WIR research associate Charles Wilhelm, capturing images of color targets with the MegaVision Multispectral camera and image analysis system to record high-resolution LAB measurements of the targets to quantify any ink bleeding or ink transfer that may take place. Multiple high-resolution captures are recorded with separate white-image, and red, green, blue, other colors, and UV (365nm) exposures. Refer to the IS&T technical article on the use of multispectral imaging to quantify the water-resistance of inkjet printed plain-paper documents (beginning on page 8 of this report).

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Epson WorkForce Pro WF-C5710 and Epson DURABrite Ultra Pigment Inks

Notes on These Tests:

1) The print permanence data presented here are based on extensive tests with Epson DURABrite Ultra pigment inks printed with a range of Epson DURABrite Ultra ink printers on Epson Bright White Paper, a plain paper for inkjet office printers (24 lbs./90 g/m^2 Epson U.S.A. Product Number SO41586), and Hammermill Inkjet Paper (24 lbs./90 g/m^2 Hammermill U.S.A. Product Number 105050). These Arrhenius multi-temperature dark storage tests for ink fading and paper yellowing have been conducted over a more than six-year period. These permanence tests are being followed up with tests with current DURABrite Ultra pigment ink printers, including an Epson WorkForce Pro WF-C5710 printer and DURABrite Ultra pigment inks purchased at retail by Wilhelm Imaging Research, Inc. in 2019. This WIR print permanence report is based on a large-scale study involving multiple printers and conducted over a more than five-year period. This research was in part commissioned and supported by Seiko Epson Corporation of Japan.

2) The "WIR 400-Year Certification for the Permanence of Plain-Paper Documents Inkjet Printed with Black and Color Text and Images in Long-Term Storage" emphasizes first and foremost a very high level of resistance to water, with the second most important requirement being a very high level of dark storage stability – including paper yellowing – when stored at 73°F (23°C) and 50% RH.

3) There currently is no ISO or ANSI Standard that is applicable to the water-resistance or Arrhenius dark storage permanence of plain paper documents. There are also currently no ISO or ANSI "Specification" standards that provide a means for making "lifetime" or "noticeable change" predictions for the permanence of inkjet or other digitally-printed photographs under a standardized set of indoor display and storage conditions (display illumination levels, spectral power distribution, ambient temperature, relative humidity, and indoor ozone concentrations) together with image-change criteria and limits (endpoints) for fading, changes in color balance, and d-min or paper white stain formation.

As a long-standing member of the ISO/TC 42, WG-5/TG-3 (ISO Technical Committee 42, Working Group 5, Task Group 3) print permanence test methods standards development group, WIR is actively involved in the development of new ISO standards for evaluating the permanence of digital prints. However – after more than 40 years of effort that began in 1978 by the ISO groups charged with developing a consumer-oriented "Specification Standard" for indoor display and storage of photographs – work on such a standard has been abandoned because of a on-going lack of agreement among members on the selection of appropriate fading, color balance, d-min stain endpoint criteria, and on environmental assumptions (including average daily light exposure). It is uncertain when – if ever – such an ISO "Specification Standard" will be published. ISO (International Organization for Standardization), headquartered in Geneva, Switzerland, is a consensus-driven organization with fourteen country members. ISO has no enforcement capability to address misuse or abuse of its standards.

Table 1. "Standard" Home Display Illumination Levels Used by Printer, Ink, and Photo Paper Manufacturers

120 lux/12 hrs/day	450 lux or 500 lux/10 hrs/day or 12 hrs/day
	HP Inc.
	Epson
	Canon
	Fujifilm
	ChromaLuxe
	Ilford
	Canson
	DNP Konica
Kodak Alaris (for Kodak silver-halide papers and Kodak dye-sub prints)	Kodak (for Kodak consumer inkjet prints)
	Ferrania
	InteliCoat
	Somerset
	Harman
	LexJet
	Lyson
	Luminos
	Hahnemuhle
	Premier Imaging Products
	American Inkjet
	MediaStreet

The WIR Display Permanence Ratings (DPR) given here are based on accelerated light stability tests conducted at 25 klux with glass-filtered cool white fluorescent illumination with the sample plane air temperature maintained at 24°C and 60% relative humidity. Data were extrapolated to a display condition of 450 lux for 12 hours per day using the Wilhelm Imaging Research, Inc. "Visually-Weighted Endpoint Criteria Set v3.0." and represent the years of display for easily noticeable fading, changes in color balance, and/or staining to occur. See: Henry Wilhelm, "How Long Will They Last? An Overview of the Light-Fading Stability of Inkjet Prints and Traditional Color Photographs," *IS&T's 12th International Symposium*

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Epson WorkForce Pro WF-C5710 and Epson DURABrite Ultra Pigment Inks

Notes on These Tests (continued from previous page):

Table 2. Filtration Conditions Used by Printer, Ink, and Paper Manufacturers with CW Fluorescent Illumination

UV Filter	Glass Filter
Kodak Alaris (for Kodak silver-halide papers and Kodak dye-sub prints)	HP Inc. Epson Canon Fujifilm ChromaLuxe Ilford Canson DNP Konica Kodak (for Kodak consumer inkjet prints) Ferrania InteliCoat Somerset Harman LexJet Lyson Luminos Hahnemuhle Premier Imaging Products American Inkjet MediaStreet

on Photofinishing Technologies, sponsored by the Society for Imaging Science and Technology, Orlando, Florida, February 2002. This paper may be downloaded in PDF form at no charge from: *<http://www.wilhelm-research.com/pdf/is_t/WIR_IST-paper_2002_02_HW.pdf>.*

For a study of endpoint criteria correlation with human observers, see: Yoshihiko Shibahara, Makoto Machida, Hideyasu Ishibashi, and Hiroshi Ishizuka, "Endpoint Criteria for Print Life Estimation," *Final Program and Proceedings: IS&T's NIP20 International Conference on Digital Printing Technologies,* pp. 673–679, sponsored by the Society for Imaging Science and Technology, Salt Lake City, Utah, November 2004.

See also: Henry Wilhelm, "A Review of Accelerated Test Methods for Predicting the Image Life of Digitally-Printed Photographs – Part II," *Final Program and Proceedings: IS&T's NIP20 International Conference on Digital Printing Technologies,* pp. 664–669, sponsored by the Society for Imaging Science and Technology, Salt Lake City, Utah, November 2004. Also available, with *color illustrations: <www.wilhelm-research.com> <WIR_IST_2004_11_HW.pdf>.* High-intensity light fading reciprocity failures in these tests are assumed to be zero. Illumination conditions in homes, offices, museums, and galleries do vary, however, and color images will last longer when displayed under lower light levels; likewise, the life of prints will be shortened when displayed under illumination that is more intense than 450 lux. Ink and paper combinations that have not reached a fading or color balance failure point after the equivalent of 100 years of display are given a rating of "more than 100 years" until such time as meaningful dark stability data are available (see discussion in No. 5 below).

Eastman Kodak licensed WIR image permanence data for the Kodak line of consumer inkjet printers, and WIR data for these printers was posted on the WIR website (see, for example, *<http://www.wilhelm-research.com/kodak/esp9.html>* WIR's tests with the Kodak consumer inkjet printers are performed using the exact same methodologies employed for all other inkjet printers and other print products posted on the WIR website.

Kodak's internally-developed print permanence test methodologies have been used by the company for many years and the company continues to base its home display-life calculations for Kodak silver-halide (chromogenic) color papers and Kodak dye-sub (thermal dye transfer) prints on 120 lux/12 hours per day, rather than the 450 lux/12 hours per day adopted by WIR. It is important to understand this and other differences between WIR's test methods and Kodak's test methods (see, for example, the article by Charlie Brewer titled "At Least For Ink Jet Print Permanence, WIR and Kodak Mend Fences," *The Hard Copy Supplies Journal,* Lyra Research, Newtonville, MA 02460, March 2008, pp. 1–2. The article is available for download at <http://www.wilhelm-research.com/hc/Kodak-WIR_Permanence2008_03.pdf>). Some of Kodak's display-life predictions for the now-obsolete Kodak Ultima Picture Paper (a swellable inkjet paper designed for dye-based inks) were *almost* 15X longer than the predictions obtained in the more conservative tests conducted by WIR for this ink/media combination, and can be accounted for by differences in the two test methodologies. For example, Kodak uses 80 klux UV-filtered cool white fluorescent illumination; WIR uses 25 klux glass-filtered cool white fluorescent illumination.

Kodak uses a starting density for fading measurements of only 1.0; WIR uses starting densities of both 0.6 and 1.0. Kodak uses the "ISO Illustrative" endpoint criteria set; WIR uses the visually-weighted WIR Endpoint Criteria Set v3.0. Kodak's

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Epson WorkForce Pro WF-C5710 and Epson DURABrite Ultra Pigment Inks

Notes on These Tests (continued from previous page):

display environment light exposure assumption for calculating display life is 120 lux for 12 hours per day (UV filtered); WIR uses 450 lux for 12 hours per day (glass filtered). Kodak maintains 50% RH in their accelerated tests; WIR uses 60% RH. Key aspects of Kodak's test methodology and assumptions for calculation of "years of display" are also very different from those used by most other manufacturers of printers, inks, and media. The display lux level assumption of 120 lux (see Table 1) alone makes Kodak's display-life predictions 3.75X greater than the display-life predictions provided by other manufacturers and by WIR.

With many ink/media combinations, Kodak's use of a UV filter instead of the glass filter used by other companies in accelerated light fading tests (see Table 2) further increases Kodak's display-life predictions. For a description of the Kodak tests, see: D. E. Bugner, C. E. Romano, G. A. Campbell, M. M. Oakland, R. J. Kapusniak, L. L. Aquino, and K. E. Maskasky, "The Technology Behind the New KODAK Ultima Picture Paper – Beautiful Inkjet Prints that Last for Over 100 Years," *Final Program and Advanced Printing of Paper Summaries – IS&T's 13th International Symposium on Photofinishing Technology,* pp. 38–43, Las Vegas, Nevada, February 8, 2004. Together with Kodak's own test data, the articles also include light stability data for Kodak Ultima Picture Paper obtained from ongoing tests conducted by the Image Permanence Institute at the Rochester Institute of Technology (Rochester, New York), and from Torrey Pines Research (Torrey Pines, California). The tests were conducted using the Kodak test procedures and included the use of a UV filter with cool white fluorescent illumination; the Image Permanence Institute and Torrey Pines Research also based print-life calculations on 120 lux for 12 hours per day.

4) Data from water resistance tests are reported in terms of three subjective classes: "high," "moderate," and "poor." Both "total immersion for two weeks," "water drip" tests and "standing water droplets/gentle wipe" tests are employed. Four types of water are employed: 1) Seawater (salt water); 2) Distilled water; 3) Filtered municipal water from river water sources (typical for most large cities, including New York, London, Tokyo, Paris, Berlin, etc.; 4) Filtered municipal water from deep-well sources (in this case, alkaline water supplies in Grinnell, Iowa with a high dissolved solids content, calcium carbonate and magnesium carbonate/ See: Henry Wilhelm (Wilhelm Imaging Research, Inc.); Richard Adams (Ryerson University); Ken Boydston (MegaVision, Inc.); and Charles Wilhelm (Wilhelm Imaging Research, Inc.): "Improved Water-Resistance Test Methods Utilizing a Multispectral Imaging System to Quantify Black and Color Ink Bleeding for Plain Paper Office and Legal Documents Printed With Pigment- and Dye-Based Inkjet Inks," T*echnical Program and Proceedings: IS&T NIP33: The 33rd International Conference on Digital Printing Technologies and IS&T Digital Printing for Fabrication 2017,* Denver, Colorado; November 5–9, 2017. This article is attached to the end of these Notes.

5) Changes in image color and density, and/or image diffusion ("image bleeding"), that may take place over time when prints are stored and/or displayed in conditions of high relative humidity are evaluated using a humidity-fastness test maintained at 86°F (30°C) and 80% RH. Depending on the particular ink/media combination, slow humidity-induced changes may occur at much lower humidities – even at 50–60% RH. Test methods for resistance to high humidity and related test methods for evaluating "short-term color drift" in inkjet prints have been under development since 1996 by Mark McCormick-Goodhart and Henry Wilhelm at Wilhelm Imaging Research, Inc. See: Mark McCormick-Goodhart and Henry Wilhelm, "New Test Methods for Evaluating the Humidity-Fastness of Inkjet Prints," *Proceedings of "Japan Hardcopy 2005" – The Annual Conference of the Imaging Society of Japan,* Tokyo, Japan, June 9, 2005, pp. 95–98. Available in PDF format from <www.wilhelm-research.com> <WIR_JapanHardcopy2005MMG_HW.pdf>

See also, Henry Wilhelm and Mark McCormick-Goodhart, "An Overview of the Permanence of Inkjet Prints Compared with Traditional Color Prints," *Final Program and Proceedings – IS&T's Eleventh International Symposium on Photofinishing Technologies,* sponsored by the Society for Imaging Science and Technology, Las Vegas, Nevada, January 30 – February 1, 2000, pp. 34–39. See also: Mark McCormick-Goodhart and Henry Wilhelm, "Humidity-Induced Color Changes and Ink Migration Effects in Inkjet Photographs in Real-World Environmental Conditions," *Final Program and Proceedings – IS&T's NIP16: International Conference on Digital Printing Technologies,* sponsored by the Society for Imaging Science and Technologies, Vancouver, B.C., Canada, October 15–20, 2000, pp. 74–77.

See also: Mark McCormick-Goodhart and Henry Wilhelm, "The Influence of Relative Humidity on Short-Term Color Drift in Inkjet Prints," *Final Program and Proceedings – IS&T's NIP17: International Conference on Digital Printing Technologies,* sponsored by the Society for Imaging Science and Technology, Ft. Lauderdale, Florida, September 30 – October 5, 2001, pp. 179–185; and: Mark McCormick-Goodhart and Henry Wilhelm, "The Correlation of Line Quality Degradation With Color Changes in Inkjet Prints Exposed to High Relative Humidity," *Final Program and Proceedings – IS&T's NIP19: International Conference on Digital Printing Technologies,* sponsored by the Society for Imaging Science and Technology, New Orleans, Louisiana, September 28 – October 3, 2003, pp. 420–425.

6) Plain paper prints stored in the dark may suffer slow deterioration that is manifested in yellowing of the print paper, image fading, changes in color balance, and physical embrittlement. These types of deterioration may affect the paper

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Notes on These Tests (continued from previous page):

support, the image layer, or both. Each type of print material (ink/paper combination) has its own intrinsic dark storage stability characteristics; some are far more stable than others. Rates of deterioration are influenced by temperature and relative humidity; high temperatures and/or high relative humidity exacerbate the problems. Long-term dark storage stability is determined using Arrhenius accelerated dark storage stability tests that employ a series of elevated temperatures (e.g., 57°C, 64°C, 71°C, and 78°C) at a constant relative humidity of 50% RH to permit extrapolation to ambient room temperatures (or other conditions such those found in sub-zero, humidity-controlled cold storage preservation facilities). Because many types of inkjet inks, especially those employing pigments instead of dyes, are exceedingly stable when stored in the dark, the eventual life of prints made with these inks may be limited by the instability of the paper support, and not by the inks themselves. Due to this concern, as a matter of policy,

Wilhelm Imaging Research does not provide a Display Permanence Rating of greater than 100 years for any inkjet or other photographic print material unless it has also been evaluated with Arrhenius dark storage tests and the data indicate that the print can indeed last longer than 100 years without noticeable deterioration when stored at 73°F (23°C) and 50% RH. Arrhenius dark storage data are also necessary to assess the physical and image stability of a print material when it is stored in an album, portfolio box, or other dark place. The Arrhenius data given here are only applicable when prints are protected from the open atmosphere; that is, they are stored in closed boxes, placed in albums within protective plastic sleeves, or framed under glass or high-quality acrylic sheet. If prints are stored, displayed without glass or plastic, or otherwise exposed to the open atmosphere, low-level air pollutants may cause significant paper yellowing within a relatively short period of time. Note that these Arrhenius dark storage data are for storage at 50% RH; depending on the specific type of paper and ink, storage at higher relative humidities (e.g., 70% RH) could produce significantly higher rates of paper yellowing and/or other types of physical deterioration.

7) In typical indoor situations, the “Displayed Prints Framed Under Glass” test condition is considered the single most important of the three display conditions listed. *All* prints intended for long-term display should be framed under glass or plastic to protect them from staining, image discoloration, and other deterioration caused by prolonged exposure to cigarette smoke, cooking fumes, insect residues, and other airborne contaminants; this precaution applies to traditional silver-halide black-and-white and color photographs, as well as inkjet, dye-sub, and other types of digital prints.

8) Displayed prints framed with ultraviolet filtering glass or ultraviolet filtering plastic sheet generally last longer than those framed under ordinary glass. How much longer depends upon the specific print material and the spectral composition of the illuminate, with some ink/paper combinations benefiting a great deal more than others. Some products may even show reduced life when framed under a UV filter because one of the image dyes or pigments is disproportionately protected from fading caused by UV radiation and this can result in more rapid changes in color balance than occur with the glass-filtered and/or the bare-bulb illumination conditions. For example, if a UV filter protects the cyan and magenta inks much more than it protects the yellow ink in a particular ink/media combination, the color balance of the image may shift toward blue more rapidly than it does when a glass filter is used (in which case the fading rates of the cyan, magenta, and yellow dyes or pigments are more balanced in the neutral scale). Keep in mind, however, that the major cause of fading with most digital and traditional color prints in indoor display conditions is visible light and although a UV filter may slow fading, it will not stop it. For the display permanence data reported here, Acrylite OP-3 acrylic sheet, a “museum quality” UV filter supplied by Cyro Industries, was used.

9) Illumination from LED lamps contain no significant UV or IR emissions. LED tests are currently in progress. However, because of the lack of UV radiation, the final results are expected to exceed the >150 years rating of Display Prints Framed Under Glass with Cool White Fluorescent illumination.

10) “Gas fading, or ”Resistance of Atmospher Ozone” is another potential problem when prints are displayed unframed, such as when they are attached to kitchen refrigerator doors with magnets, pinned to office walls, or displayed inside of fluorescent illuminated glass display cases in schools, stores, and offices. Epson DURABrite Ultra pigment inks printed on plain paper exhibit very high resistance to ozone. This type of premature ink fading is not caused by exposure to light. Polluted outdoor air is the source of most ozone found indoors in homes, offices and public buildings. Ozone can also be generated indoors by electrical equipment such as electrostatic air filters (“electronic dust precipitators”) that may be part of heating and air conditioning systems in homes, office buildings, restaurants, and other public buildings to remove dust, tobacco smoke, etc. Electrostatic air filtration units are also supplied as small “tabletop” devices.

Potentially harmful pollutants may be found in combustion products from gas stoves; in addition, microscopic droplets of cooking oil and grease in cooking fumes can damage unframed prints. Because of the wide range of environmental condi-

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Epson WorkForce Pro WF-C5710 and Epson DURABrite Ultra Pigment Inks

Notes on These Tests (continued from previous page):

tions in which prints may be displayed or stored, the data given here will be limited by the “Unprotected Resistance to Ozone” ratings. That is, when ozone resistance tests are complete, in cases where the “Unprotected Resistance to Ozone” predictions are less than the “Display Permanence Ratings” for displayed prints that are NOT framed under glass (or plastic), and are therefore exposed to circulating ambient air, the “Display Permanence Ratings” will be reduced to the same number of years given for “Unprotected Resistance to Ozone” even though the “Display Permanence Rating” for unframed prints displayed in ozone-free air is higher. For all of the reasons cited above, all prints made with microporous papers and dye-based inks should always be displayed framed under glass or plastic. For that matter, ALL displayed prints, regardless of the technology with which they are made, should be framed under glass or plastic sheets. This includes silver-halide black-and-white and color prints, dye-sub prints, and inkjet prints made with dye-based or pigmented inks on swellable or microporous papers, canvas, or other materials.

Tests for “Unprotected Resistance to Ozone” are conducted with an accelerated ozone exposure test using a SATRA/Hampden Test Equipment Ltd. Model 903 Automatic Ozone Test Cabinet (with the test chamber maintained at 23°C and 50% RH) and the reporting method outlined in: Kazuhiko Kitamura, Yasuhiro Oki, Hidemasa Kanada, and Hiroko Hayashi (Seiko Epson), “A Study of Fading Property Indoors Without Glass Frame from an Ozone Accelerated Test,” *Final Program and Proceedings – IS&T’s NIP19: International Conference on Digital Printing Technologies,* sponsored by the Society for Imaging Science and Technology, New Orleans, Louisiana, September 28 – October 3, 2003, pp. 415–419.

WIR test methods for ozone resistance are described in: Henry Wilhelm, Kabenla Armah, Dmitriy Shklyarov, Barbara Stahl, and Dimitar Tasev, “A Study of ‘Unprotected Ozone Resistance’ of Photographs Made with Inkjet and Other Digital Printing Technologies,” *Proceedings: Imaging Conference JAPAN 2007, The 99th Annual Conference of the Imaging Society of Japan,* June 6–8, 2007, pp. 137–140. See also: Michael Berger and Henry Wilhelm, “Evaluating the Ozone Resistance of Inkjet Prints: Comparisons Between Two Types of Accelerated Ozone Tests and Ambient Air Exposure in a Home,” *Final Program and Proceedings: IS&T’s NIP20 International Conference on Digital Printing Technologies,* pp. 740–745, sponsored by the Society for Imaging Science and Technology, Salt Lake City, Utah, November 2004. The IS&T article is also available in PDF format from <www.wilhelm-research.com> <WIR_IST_2004_11_MB_HW.pdf>.

11) Optical Brightening Agents (OBA’s) which are also called “UV brighteners” or “optical brighteners,” are white or colorless compounds added to the image-side coatings of many inkjet papers – and nearly all “plain papers” – to make them appear whiter and “brighter” than they really are. Optical brighteners absorb ultraviolet (UV) radiation, causing the brighteners to fluoresce (emit light) in the visible region, especially in the blue portion of the spectrum. Optical Brightening Agents can lose activity – partially or completely – as a result of exposure to light. OBA’s may also lose activity when subjected to high temperatures in accelerated thermal aging tests and, it may be assumed, in long-term storage in albums or other dark places under normal room temperature conditions. With loss of brightener activity, papers will appear to have yellowed and to be “less bright” and “less white.”

In recent years, traditional chromogenic (“silver-halide”) color photographic papers have been made with UV-absorbing interlayers and overcoats and this prevents brighteners that might be present in the base paper from being activated by UV radiation. It is the relative UV component in the viewing illumination that determines the perceived “brightening effect” produced by fluorescent brighteners. If the illumination contains no UV radiation (for example, if a UV filter is used in framing a print), optical brighteners are not activated and, comparatively speaking, the paper appears to be somewhat yellowed – and not as “white.”

The spectral dependency of OBA’s makes papers containing such brighteners look different depending on the illumination conditions. For example, prints displayed near windows are illuminated with direct or indirect daylight, which contains a relatively high UV component, and if an inkjet paper contains OBA’s, this causes the brighteners to strongly fluoresce. When the same print is displayed under LED or incandescent tungsten illumination, which have a low UV component, the brighteners have little effect..

Another potential drawback of OBA’s is that brightener degradation products may themselves be a source of yellowish stain. These problems can be avoided by simply not adding fluorescent brighteners to inkjet photographic papers and plain papers during manufacture. When long-term image permanence is of critical importance – with museum fine art collections, for example – papers with Optical Brightening Agents should be avoided where possible.

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Improved Water-Resistance Test Methods Utilizing a Multispectral Imaging System to Quantify Black and Color Ink Bleeding for Plain Paper Office and Legal Documents Printed with Pigment- and Dye-Based Inkjet Inks

Henry Wilhelm, Wilhelm Imaging Research, Inc., Grinnell, Iowa, USA; Richard Adams, Ryerson University, Toronto, Ontario, Canada; Ken Boydston, MegaVision Inc., Santa Barbara, California, USA; Charles Wilhelm, Wilhelm Imaging Research, Inc., Grinnell, Iowa, USA

Abstract

Current ISO standards that pertain to water-resistance testing with inkjet prints were developed for moisture-impermeable RC photo papers and do not take into account the kinds of ink diffusion behavior that can occur with inkjet printing on highly absorbent plain papers, especially with dye-based inks. Even momentary contact of water with plain paper documents can result in significant lateral ink bleeding, migration of inks through the paper to the backside of the sheet, transfer of ink from one sheet to adjacent sheets, and two-way transfer of inks with double-sided printed documents. Shipping labels and envelopes can become illegible should they become wet, and Barcodes and QR codes may be rendered completely unreadable. This study attempts to better understand the water-resistance behavior of plain paper documents printed with dye-based and pigment inkjet inks. The use of high-resolution multispectral imaging and colorimetric analysis systems to provide a quantitative assessment of ink bleeding, migration, and ink transfer to adjacent pages is explored as an alternative to the subjective, qualitative, water-resistance evaluation methods specified in current ISO standards.

Introduction

Inkjet-printed plain paper documents are playing an increasingly important role in office applications and in the printing of legal documents that are expected to be retained in good condition in often less than ideal environments for long periods of time. The development of full-page-width array inkjet heads, automatic two-sided printing, improved dye-based and pigment ink formulations, large capacity ink cartridges and refillable ink tank systems, and other advances in inkjet printing technology have led to greatly increased print speeds together with significantly reduced cost of ownership and costs per page – and this in turn has allowed inkjet to move into market areas previously dominated by monochrome and color laser printing.

As most business documents now contain critical color information – business logos, color typography, graphs and spreadsheets, and color photographs and illustrations – printing in color has become the expectation in most plain paper office printing markets. Pigment inks, dye-based inks, and “hybrid” pigment black/dye color inksets are presently being used in office markets and there is increased interest in understanding the differences in the permanence characteristics of the different types of inks with plain paper prints. This is especially true in terms of water resistance, because plain paper documents printed with inks having poor water resistance can be catastrophically damaged in just seconds or minutes by contact with water.

Water damage can be caused by hurricanes, typhoons, tornadoes, river and stream flooding, broken water pipes, faulty sprinkler systems, water inundation resulting from efforts to extinguish a fire inside a home, office, or other building, roof leaks, basement leaks, mail exposed to rain, and so on. The current ISO standards that pertain to water-resistance test-

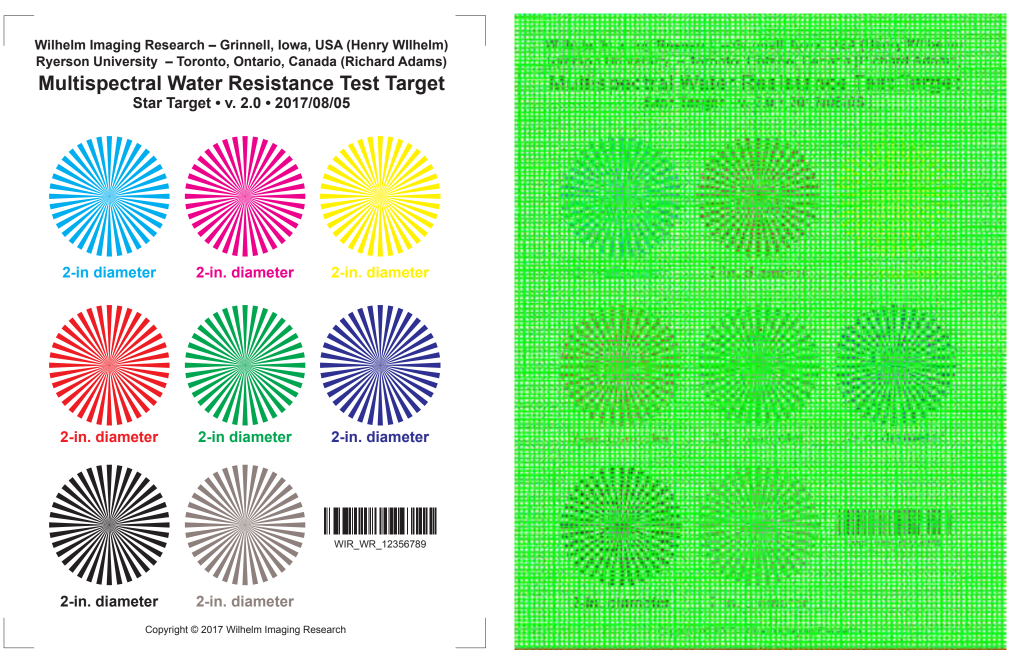

Figure 1. A circular spoke-pattern water-resistance test target designed for multispectral imaging and analysis. The ever narrowing distance between the spokes toward the center of the target can be a very sensitive indicator of ink bleed. The target is printed on an 8.5 x 11-inch letter size(or A4 size) sheet of plain paper. To the left is a newly-printed target, not yet exposed to water. The MegaVision multispectral imaging and analysis system can capture up to ten-thousand – or more – spectral data points, which can be exported in LAB space. The image to the right shows an overlay grid for 400 x 450 measurement locations – 180,000 individually addressable data points on a target. After the target has had contact with water and dried, the “before and after” images can be compared to quantify ink bleeding. To measure the amount of ink migration that takes place from the front to the back of a sheet, both sides of the sheet can be imaged and compared.

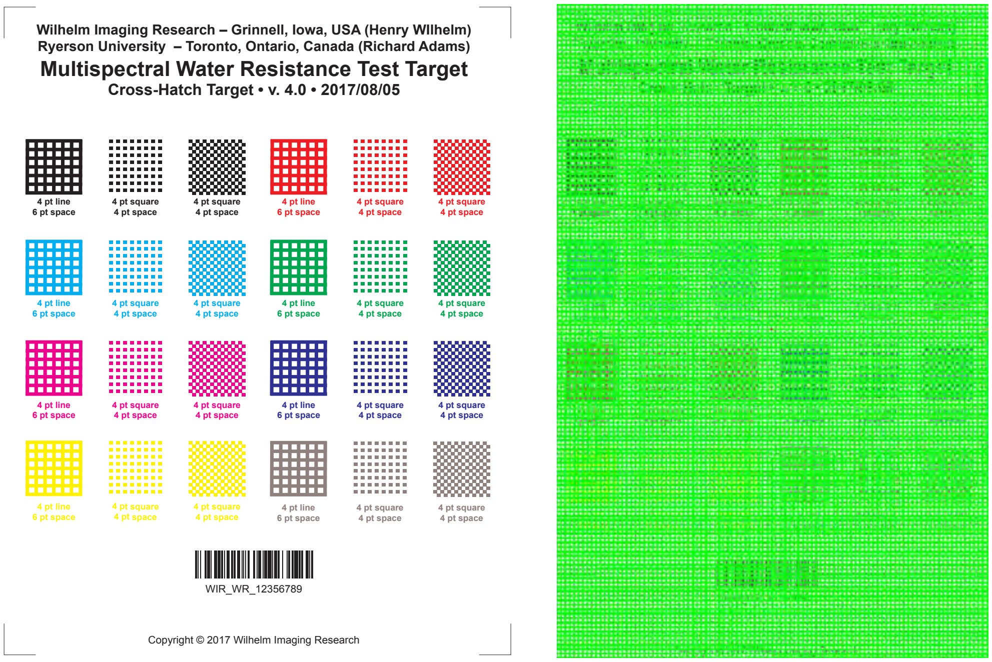

Figure 2. A square cross-hatch-pattern water-resistance test target designed for multispectral imaging and analysis. The degree of ink bleed that fills the interiors of the cross-hatch elements in the target can be measured and quantified with the multispectrical imaging and analysis system. The target, which consists of cyan, magenta, yellow, black, CMY gray, red, green, and blue segments, is printed on an 8.5 x 11-inch letter size (or A4 size) sheet of plain paper. To the left is a newly-printed target, not yet subjected to contact with water. The image to the right shows an overlay grid for 400 x 450 measurement locations – 180,000 individually addressable data points on a target. After the target has been in contact with water and dried, the "before and after" images can be compared to quantify ink bleeding. As with the circular spoke-pattern target, this target is useful to assess the amount of ink migration that takes place from the front to the back of a sheet, both sides of the sheet can be imaged and compared.

Figure 3. Test samples printed with pigment-based and dye-based inkjet inks undergoing the 24- hour "edge immersion" water-resistance test specified in Sec. 6.5 of ISO 18935:2016(E). This test was originally designed for RC-base and other multi-layer-structure photo papers and, in terms of applicability to commonly encountered types of water damage, the test may not be well-suited for evaluating the water-resistance of inkjet-printed plain paper documents.

ing were not developed to evaluate inkjet printing on plain paper. ISO 18935:2016(E),[1] originally published in 2005, is intended primarily for use with digital and analogue printed RC-base and other photographic materials; text is not included in the test target design. ISO 11798:1999(E),[2] published eighteen years ago in 1999, was developed primarily for offset printed book papers, xerographic printing on copy papers, and manual pencil and ink writing on writing papers – and was intended for books and other documents intended to be stored in libraries, archives, and "other protected environments."

Goals of This Project

1. A principal focus of this research is to better understand the types of water damage that can occur to inkjet-printed plain paper documents in real world conditions. This includes momentary exposure to water resulting from a spill that is wiped with a paper towel or other absorbent material, or rain drops that might contact a mailing envelope or shipping label; longer-term partial or total water exposure that could occur to an inkjet print in a plastic sleeve restaurant menu should a customer spill water on it during a meal; rain exposure on a "lost dog" or other plain paper signs posted outdoors; or prolonged, "total immersion" water exposure to documents caused by hurricanes, floods, broken water or sewer pipes, faulty sprinkler systems, and similar calamities.
2. Design new water exposure tests that take into account the specific behaviors of dye-based inkjet inks printed on plain papers and pigment-based inkjet inks printed on plain papers.

Figure 4. From the MegaVision LAB values, Delta-E was computed with Chromix ColorThink software to compare the test targets overall, or in areas of particular interest, before and after they were subjected to contact with water, including short-term or long-term total immersion in water.

Figure 5. Water resistance of envelopes, shipping labels, barcodes, and QR codes is of critical importance, as ink bleed can easily render them unreadable. In this example, a FedEx shipping label printed on plain paper with an inkjet printer is shown on the left. The label has not yet been subjected to contact with water. The image to the right shows an overlay grid for 200 x 250 measurement locations – which amounts to 50,000 individually addressable data points. After contact with water, at what point a barcode or QR code is no longer readable is a very useful way to evaluate water resistance of different plain paper printing systems, inks, and xerographic toners. A multipectral analysis provides a way to characterize barcode failure in a quantitative way.

This includes evaluation of ink "bleed-through" to the backside of a page printed on one side, and "bleed-through" of inks in two directions for pages printed on both sides. The authors designed two color targets intended to quantify the effects of water exposure to inkjet and other printed materials with a multispectral imaging and analysis system. The Multispectral Water Resistance Cross-Hatch Target consists of a series of finely-spaced, 4-point lines and squares that can be imaged in CMYK, RGB, and gray colors. The Circular Spoke-Pattern Target, with its ever-narrowing distance between the spokes toward the center of the target can also offer a sensitive indication of lateral ink bleeding or diffusion. In designing these targets, the authors sought a method of assessing water resistance through color comparisons of the solid-color lines with the white spaces in between. The presumption was that, if an ink was soluble or suspendable in water, molecules of color dye or pigment particles could migrate from solid to white areas, thereby lightening the solids and darkening the white spaces in between. Thus, the evaluation strategy was to compare the colorimetric values of the solids with those of the white areas. From the MegaVision LAB values, Delta-E was computed in Chromix ColorThink comparing the black and magenta inked patches to the surrounding paper (see Fig. 4).

3. Develop new methods to characterize and quantify ink transfer from one printed page to an adjacent page when a stack of pages (e.g., pages in a bound report, between pages stapled together, and between multiple pages placed together in a file folder) are partially or totally immersed in water for both short or extended periods of time.
4. Develop new methods to measure color ink bleeding, intermixing, and to quantify ink spread (bleeding) using a camera-based multispectral imaging system and associated software.[3] The longer-term goal of this research is to develop

Figure 6. To simulate the effects of immersion in water of multi-page plain paper documents or of multiple pages in a file folder, lightly spraying a blank unprinted sheet with water and then placing a printed test target page on top of it and lightly spraying and, finally, placing another blank page on top of it and spraying it proved to provide better assessments of ink bleeding, ink migration through to the back of the page, and ink transfer to an adjacent page proved to be more meaningful than completely immersing a whole stack of pages in water at the same time.

meaningful, quantitative standards for water resistance tests with inkjet-printed plain paper documents that will replace the types of subjective evaluations currently used in water resistance tests.[1,2,4] An imaging-based measurement system can enable characterization and quantification not practical – or even possible – with single-point measurement devices.

5. Work with ISO, other standards groups, archive and library organizations, and manufacturers of inkjet and xerographic printer, ink, toner and paper manufacturers to develop improved test methods, specifications and standards.
6. In a future research project, the authors plan to conduct paired-comparison tests with selected inks and plain papers using various surface and deep-well municipal sources, seawater, and distilled water to understand what effects different kinds of water might have on water-resistance behavior in both short-term and long-term contact with water.

References

[1] *International Standard ISO 18935:2016(E): Imaging materials – Colour images – Determination of water resistance of printed colour images.* The International Organization for Standardization (ISO), Geneva, Switzerland, 2016.

[2] *International Standard ISO 11798:1999: Information and documentation – Permanence and durability of writing, printing and copying on paper – Requirements and test methods.* The International Organization for Standardization (ISO), Geneva, Switzerland, 1999.

[3] Henry Wilhelm, Ken Boydston, Kabenla Armah, and Barbara C. Stahl, "Use of a Multispectral Camera System and Very Small, Comprehensive 'Micropatch' Test Targets for Full Tonal Scale Colorimetric Evaluation of the Permanence of Digitally-Printed Color and B&W Photographs," *Proceedings of Imaging Conference Japan 2011,* p. 131, The Imaging Society of Japan, Tokyo, Japan, 2011.

[4] Henry Wilhelm, Kabenla Armah, and Dmitriy Shklyarov, "Improved Test Methods for Evaluating the Permanence of Digitally-Printed Photographs," *Proceedings of Imaging Conference Japan 2009,* p. 213, The Imaging Society of Japan, Tokyo, Japan, 2009.

Author Biographies

Henry Wilhelm is Founder and Director of Research at Wilhelm Imaging Research, Inc. Grinnell, Iowa. With work beginning in 1971, Wilhelm and his colleagues have assembled the world's largest reference collection of analog and digital color print materials and associated permanence data. Wilhelm has authored or co-authored more than 25 technical papers that were presented at conferences sponsored by the Society for Imaging Science and Technology (IS&T), the Imaging Society of Japan (ISJ), and the American Institute for Conservation (AIC). He has been involved with ANSI and ISO print permanence test methods standards development since 1978. With contributing author Carol Brower Wilhelm, he wrote "The Permanence and Care of Color Photographs: Traditional and Digital Color Prints, Color Negatives, Slides, and Motion Pictures," published in 1993. The complete 761-page book is available in PDF-A format at no cost from www.wilhelm-research.com. Wilhelm is currently serving with Shigeo Suga of Suga Test Instruments Co., Ltd., Tokyo, Japan, as Co-Project Leaders for the development of the new ISO 18937-4 accelerated test methods standard for LED illumination sources.

Ken Boydston is the President and Chief Color Scientist of MegaVision, Inc., Santa Barbara, California. Boydston led the development of the high-resolution, MegaVision Multispectral Imaging and Analysis System which was introduced in 2007 and, with Boydston's collaboration, has been used to image, monitor with very large colorimetric data sets, and conduct forensic analysis of The Dead Sea Scrolls in Israel, President Abraham Lincoln's handwritten draft of the Gettysburg Address, and many other cultural heritage treasures in the United States and throughout the world.

Richard M. Adams II, Ph.D., is an Associate Professor in the School of Graphic Communications Management at Ryerson University, Toronto, Canada. He teaches courses in document design, web design, and material science for print. His research focus include color management, electronic documents, and web design. Before coming to Ryerson University, Adams was a color management specialist with the training division of X-Rite, Inc., and he was also a research scientist at the Graphic Arts Technical Foundation (now the Printing Industries of America). After completing his Ph.D., he went on to study for a master's degree in printing technology from the Rochester Institute of Technology. Adams has recently been collaborating with Wilhelm Imaging Research on a number of research projects.

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Richard Adams (Ryerson University); Ken Boydston (MegaVision, Inc.);
and Charles Wilhelm (Wilhelm Imaging Research, Inc.) entitled:

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