Title

The Technology Behind the New *Kodak Ultima Picture Paper* – Beautiful Inkjet Prints that Last for Over 100 Years

Authors

D. E. Bugner, C. Romano, G. A. Campbell, M. M. Oakland, R. Kapusniak, L. Aquino, and K. Maskasky

Abstract

The long-term stability of inkjet photographic prints is known to be sensitive to a variety of factors. The chemical composition of the inks (pigments vs dyes) and media (porous vs swellable), as well as the ambient environmental conditions (light, heat, humidity, air quality) under which the prints are stored and/or displayed, are known to affect image stability. The new *KODAK Ultima Picture Paper* with *COLORLAST* technology not only produces great looking photographs with all popular desktop inkjet printers, but now also offers outstanding image stability under typical home display and storage conditions. When printed with current state-of-the-art desktop inks, prints made on *KODAK Ultima Picture Paper* are projected to last in excess of 100 years, even when displayed without additional protection, such as behind glass. In this paper, we will highlight the technological advances responsible for delivering both universal compatibility and best-in-class image stability.

Introduction

When purchasing high quality, glossy inkjet paper for printing photographic images, consumers face two choices: swellable polymer-based coatings or porous particle-based coatings. This decision comes with inherent trade-offs. Although porous coatings dry quickly after printing, and their moisture and humidity resistance is generally good, resistance to environmental pollutants such as ozone is quite poor.[1] Swellable coatings offer improved lightfastness and stability to pollutants, but tend to be sensitive to high humidity from both a dry time and image stability perspective.[2] Clearly, it is desirable to have a photo-quality inkjet paper that can stand up to all of these environmental factors, even under the most demanding consumer application: unprotected display, such as on the refrigerator, on the bulletin board, or in an open frame.[3] With the introduction of the new *KODAK Ultima Picture Paper*, these trade-offs have been addressed head-on. For the first time, customers are now able to purchase a universally compatible photographic inkjet paper that resists all known environmental factors: light, heat, humidity, and air pollution. In this paper we will describe the breakthrough technologies that have enabled these features.

The New *KODAK Ultima Picture Paper*: A Question of Balance

In the last 10 years, tremendous strides have been made in inkjet printing. Today, inkjet prints made on premium photo-quality inkjet papers are indistinguishable from traditional photographs. Although advances in ink, hardware, and software technology have driven most of these image quality improvements, there have also been significant contributions as a result of improvements in the photo quality media.[4] Compared to early glossy coatings that consisted of a single layer with just one or two components, the new *KODAK Ultima Picture Paper* is comprised of 9 layers as shown in Figure 1.

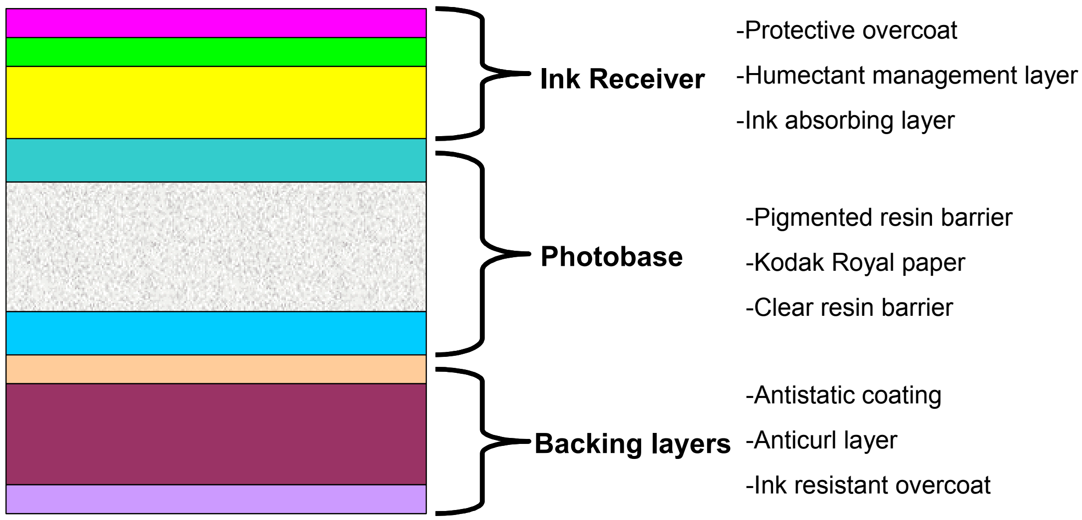

Figure 1. Cross-section schematic of the new KODAK Ultima Picture Paper*, showing the 9 separate layers.*

Balancing superior performance across all desktop printers from different manufacturers and with different ink formulations is a daunting task. Selection of available materials, development of new materials, and optimization of component levels and coating coverages are all critical to the successful development of a new product. These results are achieved through investment in the design and synthesis of novel materials, along with careful experimentation and the use of experimental design. In the following discussion, we'll provide a description of the purpose and function of each of the layers and some of the trade-offs faced in our attempt to balance image quality across such a wide range of printing systems.

From top to bottom, following is a brief description of each layer:

1. Protective overcoat layer

- a thin, highly ink-permeable polymeric layer
- provides a non-tacky, abrasion-resistant surface after drying
- contains a proprietary ceramic nanoparticle, a unique composition of matter that provides improved density and differential gloss without diminishing resistance to light and pollutants[5]

2. Humectant[6] management layer

- Comprised of a swellable polymer and novel cationic resin
- Provides improved compatibility of the paper across a broader range of ink formulations
- Serves as both a humectant "sponge" and a weak dye-fixing layer
- Provides humectant control and good humidity keeping while minimizing the impact on lightfade

3. Solvent-absorbing base layer

- A thicker layer designed to rapidly absorb the primary ink solvent, water
- Comprised of a swellable polymer and a novel cationic latex particle
- Provides for additional, stronger dye fixing capability
- Also contains microscopic beads to control the surface friction or "slipperiness" of the paper, ensuring reliable feeding of the paper through the inkjet printer
- A special "matting" agent is added in the case of the Satin finish to achieve a unique non-textured, semi-gloss appearance

The above three layers form what is collectively referred to as the "ink-receptive formulation". Critical to the success of this product is the *COLORLAST* technology embodied by the cationic polymer additives called "mordants" that are designed to bind and fix the dye molecules, along the ceramic nanoparticle in the protective overcoat. The exact choice, concentration, and location of the mordants are critical to achieving the best balance of image stability across the four main environmental factors: light, heat, humidity, and ozone. Equally important is incorporation of the proprietary ceramic nanoparticles present in the overcoat layer. Taken together this 7th generation ink-receptive technology provides the following key benefits:

- A more uniform gloss appearance between the printed and unprinted areas of the picture
- Greatly improved resistance to fade caused by light and pollutant gases such as ozone
- Faster apparent dry times and improved smudge resistance of the final picture

4. Pigmented resin barrier layer

- Extrusion coated polyolefin resin containing white pigments to provide an ultra smooth, ultra-white final substrate
- The resin acts as a barrier to prevent the ink components form penetrating into the base paper, eliminating paper "cockle" and adverse interactions between the paper addenda and the imaging dyes

5. Base paper

- Produced from the finest wood pulps and state-of-the-art paper chemistry
- The same high quality, high purity base paper used for traditional photographs
- The heavy weight of the *KODAK ROYAL* base paper provides a premium feel
- Acid-free, non-yellowing
- Back printed with the *KODAK* name trusted for quality

6. Clear resin barrier layer

- Extrusion coated, clear polyolefin layer
- Allows backprint to show through
- Prevents water from absorbing into the back side of the base paper
- Provides a balanced base sheet

Layers 5-7 comprise what is commonly referred to as RC (Resin Coated) photo paper. These 3 layers control the core optical and physical properties of the product – the so-called look and feel of a photograph. The physical quality of both the base paper itself, along with the precision resin coatings and anti-stat, define the term "true photo paper." Cheaper alternatives, dubbed "faux" photobase or sometimes "barrier-coated" base paper, start with lower quality base paper and/or use a solution-coated water-barrier layer. Inkjet papers coated on these cheaper alternatives are easily differentiable from true photo papers in terms of their poorer surface smoothness, less bright and white appearance, and coarser and less uniform paper formation.

7. Antistat layer

- A very thin coating of proprietary antistatic material
- Prevents charge build-up (static cling) during coating and printing
- Improves transport of the paper through the printer across the temperature and humidity range specified by the printer manufacturer.

8. Curl control layer

- Used to balance the natural curl imparted by the ink-receptive formulations to maintain a flat final picture
- Comprised of a swellable polymer similar to that used in the ink-absorbing base layer

9. Wet stacking layer

- Thinner, ink resistant layer coated over the curl control layer
- Crosslinked polymer with matte particles to give it a textured surface
- Prevents prints from sticking together when making multiple prints unattended

Layers 7-9 complete the package, providing easy, reliable printing of your favorite digital photos on *KODAK Ultima Picture Paper* in any desktop inkjet printer.

Universal Compatibility

Excellent image quality can be obtained on all major brands and models of photo-capable desktop inkjet printers. The new *KODAK Ultima Picture Paper* with *COLORLAST* technology has been and continues to be, tested on hundreds of inkjet printers. Each pack of paper comes with an instruction sheet that shows consumers how to optimize their specific printer driver settings to create high quality, pleasing pictures. To make it even easier, only Kodak provides consumers with literally "one touch" ease of use to create even higher quality pictures. The *One Touch to Better Pictures* feature with *KODAK Easy Share* software automatically chooses the appropriate driver setting and incorporates Kodak Color Science into each and every inkjet print. The result is consistently excellent color and image quality with *KODAK Ultima Picture Paper* on hundreds of the most popular desktop inkjet printers with a single mouse click.

In order to verify this level of performance, a suite of six scenes representative of consumer photo-space (see Appendix) was printed on the new *KODAK Ultima Picture Paper* with 7 of the latest photo quality inkjet printers from the major manufacturers. Prints were made with *One Touch to Better Pictures* activated in the EASYSHARE software. A panel of experts trained in assessing consumer prints judged the overall image quality of the prints. Prints are rated on a scale spanning 5 quality levels: not worth keeping, poor, fair, good and very good.

The prints made on *KODAK Ultima Picture Paper Glossy* yielded prints judged to be in the good to very good range across all 7 printers when printed using *One Touch to Better Pictures*. Figure 2 summarizes the results of the psychophysical study. It can be seen that by using the new *KODAK Ultima Picture Paper* in combination with *One Touch to Better Pictures*, printer-invariant image quality can be obtained. It should be noted that for this same suite of scenes, other manufacturers' inkjet photo papers that claim compatibility with all desktop inkjet printers score significantly lower on several of the printers and in general exhibit much less consistent image quality across the installed base of desktop inkjet printers.

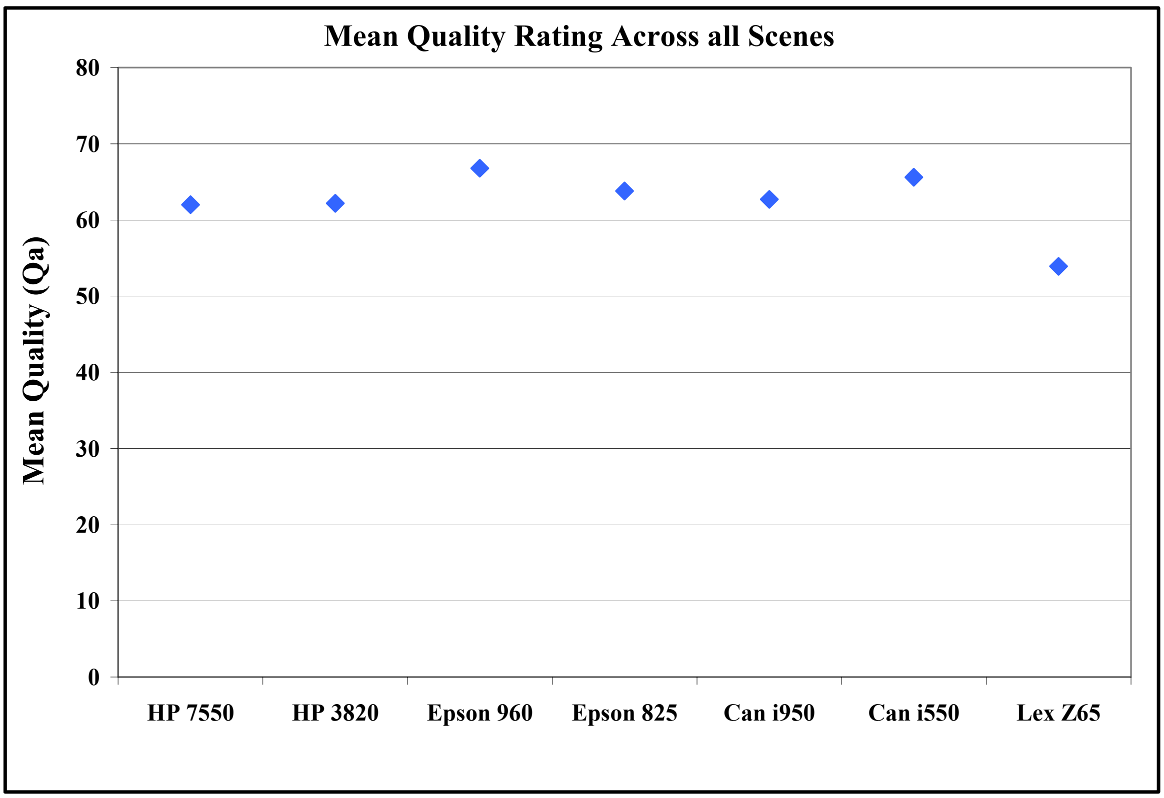

Figure 2. Subjective image quality assessment of the new KODAK Ultima Picture Paper *across representative photo quality inkjet printers.*

Image Stability: Also a Question of Balance

General Observations

To adequately characterize the expected print-life of a photographic print, all known environmental factors must be considered. For example, inkjet prints are known to be affected by to varying degrees to:

- Light
- Heat
- High humidity
- Ozone

Unprotected display is the toughest condition because a print is simultaneously exposed to all four factors. Recent print-life claims made by several brands of inkjet media have been limited to only light fade, and stipulate in the fine print that these estimates are only valid if the print is protected behind glass. In order to estimate the print-life of the new *KODAK Ultima Picture Paper*, we assume unprotected display, and test against all four factors.

There are no current standard test methods that address the estimation of print-life for digital photographic output across the relevant environmental factors listed above. However, the current ANSI/ISO standard[7] that has been used for traditional chromogenic silver halide materials does offer some guidance with respect to accelerated testing for the effects of light and heat.

Overall print-life is assumed to be only as good as the "weakest link", i.e., print-life will be limited by the factor that produces the lowest overall estimate. Thus, a print that might be projected to last 100 years based on light fade, but only 6 months with respect to ozone fade, would result in a print-life estimate of 6 months.

The End-User Environment

Before any estimate of print-life can be made, one must first determine the typical environment that represents the intended use of the product. For the new Ultima Picture Paper, the intended use environment is the typical home consumer. Published studies by Anderson and coworkers in the1980s suggest that the typical home environment is represented by a temperature of about 20°C (68°F), a relative humidity (RH) of about 50%, and a light intensity in the range of 100-150 lux for 12 hours during the day.[8,9] We have recently completed an even broader study of 32 homes in 4 cities around the world, and the results are essentially the same: 20°C ± 3.5° (± 1σ), 51 ± 11% RH (± 1σ), and ≤ 137 lux per 12 hour daytime cycle (90th percentile).[10] For the purposes of accelerated print-life testing, we have therefore defined the typical home display environment as 23°C, 50% RH, and 120 lux per 12 hour daytime cycle (1440 lux-hr/day). This is the same assumption used previously for traditional silver halide as well as thermal dye transfer prints.[11]

For imaging materials that are sensitive to ozone, one must also define the typical ozone levels that might be encountered in the home display environment. A recent study by Epson, in which the fade of inkjet print samples placed in homes was monitored for almost a year and correlated to controlled laboratory ozone-faded samples, concluded that long-term ozone levels may be closer to 5 ppb.[12] Our own studies,[10] and those of others,[13] are consistent with this estimate. Therefore, for the purpose of estimating the long-term effects of ozone on the new *KODAK Ultima Picture Paper*, we assume a typical home level of 5 ppb, at the temperature and humidity levels listed above.

In summary, we define our typical home display environment for the purpose of estimating print-life as:

- Temperature: 23C (73F)
- Relative Humidity: 50%
- Light Level: 120 lux/12 hr/day
- Ozone Level: 5 ppb

Of course, for other applications, such as museum display, or commercial display, different long-term environmental conditions are likely to be encountered. In general, higher levels of any of the four factors listed above will result in shorter print-life. In the case of ozone and light, the effect on estimated print-life is directly proportional, i.e., twice the level of either factor results in a 50% reduction in estimated print-life. The same is not true for temperature and humidity, as discussed in more detail below.

End-Points

Another key assumption for the estimation of print-life is the definition of how much image quality loss is acceptable before a print is deemed "dead". For environmental factors such as light and heat, which are known to primarily cause prints to fade, loss of optical density, as measured by Status A densitometry, has long been used to measure loss of image quality. The current ANSI/ISO standard[7] that has been used for estimating print-life for traditional chromogenic silver halide materials,[11] contains "illustrative end-points" based on the loss of density measured from an initial density of 1.0, corrected for D_{min}. There are also end-points based on background staining or yellowing leading to an increase in D_{min}. See Table 1 for a list of the ANSI/ISO illustrative end-points.

Recent psychophysical studies have shown that these end-points are in fact quite conservative with respect to typical end-users' expectations.[14,15] For this study we will use these same end-points to estimate the print-life of the new *KODAK Ultima Picture Paper* with respect to light and heat. Because the primary effect of ozone on prints is also loss of density, it makes sense to use the same end-points for these estimates as well.

As opposed to simple dye fade, humidity is known to have a more complicated effect on image quality degradation.[2] Density gain, hue shift, and loss of sharpness are all common observations for prints that are sensitive to humidity. In contrast to loss of density, there are no existing guidelines for what constitutes an end-point with respect to these types of image quality degradation. The good news is that at 20-25°C and 50% RH, representing the typical home environment as defined above, the effect of humidity on image quality of most inkjet prints is negligible.[2,16] In other words, at 20-25°C and 50% RH, humidity is not considered to be a limiting factor with respect to print-life for the new *KODAK Ultima Picture Paper*.

Table 1. ANSI/ISO illustrative end-points for reflection color prints, all relative to 1.0 initial density.

Property	**End-point**
Pure yellow patch	30% density loss
Yellow in neutral patch	30% density loss
Pure magenta patch	30% density loss
Magenta in neutral patch	30% density loss
Pure cyan patch	30% density loss
Cyan in neutral patch	30% density loss
Yellow-cyan color balance in neutral	15% differential
Yellow-magenta color balance in neutral	15% differential
Magenta-cyan color balance in neutral	15% differential
Magenta-yellow color balance in neutral	15% differential
Cyan-yellow color balance in neutral	15% differential
Cyan-magenta color balance in neutral	15% differential
Yellow in D_{min}	+ 0.10 density units
Magenta in D_{min}	+ 0.10 density units
Cyan in D_{min}	+ 0.10 density units
Magenta-yellow color balance in D_{min}	± 0.06 density units
Cyan-yellow color balance in D_{min}	± 0.06 density units
Cyan-magenta color balance in D_{min}	± 0.06 density units

For systems that are sensitive to humidity, noticeable changes are not observed until the RH at room temperature rises above about 70%.[2,16] Although the typical home display environment is closer to 50% RH, the range of humidities can sometimes exceed 70%.[10] Since no metrics and end-points are currently available for humidity-induced image quality degradation, we assessed end-user acceptability of image quality after treatment at high humidity by two methods: (a) Status A density change and (b) a psychophysical study.

For the densitometric method, we used the same relative end-points as used for fade. In other words, a 30% gain in density would be considered an end-point in the case of humidity, just as a 30% loss of density would be in the case of light, ozone, or thermal fade.

For the psychophysical study, the same methodology as described above for image quality evaluations was used. One set of six prints representative of consumer photo-space was treated at the specified high humidity condition, and the other set was kept at ≤ 50% RH at room temperature in the dark. A panel of judges trained to evaluate consumer image quality rated both sets of prints, single stimulus. A system was deemed to have failed if the image quality dropped below a specified threshold of quality after humidity treatment.

Now that we have defined the end-user display environment and the end-user expectations for acceptable loss of image quality, we can describe the specific test methods and results for evaluating the effects of each environmental factor independently.

As we discuss the results for each factor, we will use prints made with the new *KODAK Ultima Picture Paper* on the Hewlett-Packard PhotoSmart 7550 and the Hewlett-Packard Deskjet 3820 as examples. The 7550 printer uses a combination of 6 dye-based inks for printing photographic output (HP ink cartridges HP57 & HP58). The 3820 printer uses a combination of 3 dye-based inks (ink cartridge HP57). It is worth noting that the older HP78 ink cartridge uses the same inks as the HP57. These printheads and inks are used in printers that comprise 72% of all inkjet photo quality printers sold in the United States over the past three years as reported by NPD Intellect and are considered "state-of-the-art" and representative of the best-selling photo-capable inkjet printers today. Additionally the new *KODAK Ultima Picture Paper* was tested on 5 other popular inkjet printers: Canon i550, Canon i950, Epson Stylus Photo 825, Epson Stylus Photo 960, and Lexmark Z65. Including all seven printers (and all similar models that use the same ink sets), approximately 94% of the U.S. installed base is represented. All of the tests were conducted using ink and media purchased at retail in the fall of 2003. The following competitors' photo inkjet papers were also included in each of the tests discussed below:

- HP Premium Plus (Q1785A)
- Epson Premium Glossy (SO41667)
- Canon Photo Paper Pro (PR101)
- Hammermill Jet Print Pro (10830-0)
- Ilford Printasia (199 9488)

These papers were chosen as benchmarks because they either represent the current, comparable premium inkjet photo papers from the different printer manufacturers, or, in the case of Hammermill and Ilford, are representative aftermarket products with the next largest market shares in the U.S. and Europe, respectively. Future updates will report print-life estimates on additional printer/ink combinations, including pigmented ink photo printers such as the Epson Stylus Pro 2200. It should be noted that the historical trend in print-life for dye based inkjet photo printers has shown systematic improvement. It is expected that future versions of dye based inkjet photo printers will continue to show longer print-life estimates.

Light Fade

For accelerated light fade, polycarbonate-filtered fluorescent lighting at various intensities was used as the accelerating condition.[18] The temperature and humidity were maintained as close as possible to 23°C and 50% RH, and ozone was kept below detection.[19] This is the same condition commonly used for traditional silver halide testing[11] and is adapted from the current ANSI/ISO standard.[7]

For this study, we are testing at the following intensities and locations:

A. 80 klux, Kodak Image Stability Center
B. 50 klux, Image Permanence Institute
C. 50 klux, Torrey Pines Research
D. 7 klux, Image Permanence Institute
E. 5.4 klux, Kodak Image Stability Center

The use of both very high intensity (50–80 klux) and moderately high intensity (5–7 klux) light is necessary to assess any significant deviations from reciprocity. At this time, only the high intensity conditions have produced enough fade to project an estimate of print-life. These are the results that are reported below. We will continue to monitor the lower intensity tests to make sure there are no surprises. However, we fully expect that for many of the current ink sets we will not see end-points reached for close to 2 full years of treatment at the 5–7 klux level.

At each condition, measurements of density loss are made as a function of exposure until at least one end-point is reached. The projected light fade print-life is based on the first end-point reached. Figure 3 below shows the light fade results (test condition A) for a 6-ink HP ink set (HP 57 & HP 58 cartridges as used in the HP Photosmart 7550 printer) on the new *KODAK Ultima Picture Paper*. Shown are the density changes for the red (cyan), green (magenta) and blue (yellow) components of a 1.0 (interpolated) neutral density patch. It is the yellow in the neutral that is fading the fastest at this point. Note that the test has not yet reached an end-point. A linear extrapolation of the current yellow component of the neutral projects that it will reach a 30% fade at approximately 166,000 klux-hr of cumulative exposure. At an ambient light level of 120 lux for 12 hours per day, this translates to a projected print-life of over 300 years! These results will be updated every 4 to 8 weeks until the samples are well past at least one end-point.

Table 2 summarizes our current results for the new *KODAK Ultima Picture Paper* in combination with the six ink HP ink set (HP 57 & HP 58 cartridges as used in the HP Photosmart 7550 printer) and the three ink HP ink set (HP 78 cartridge as used in the HP Deskjet 3820 printer). Although the range of print-life projections based on very similar test conditions A, B, and C is wider than expected, even the lowest estimate (condition B) is greater than 100 years of print-life with respect to light as a single factor.

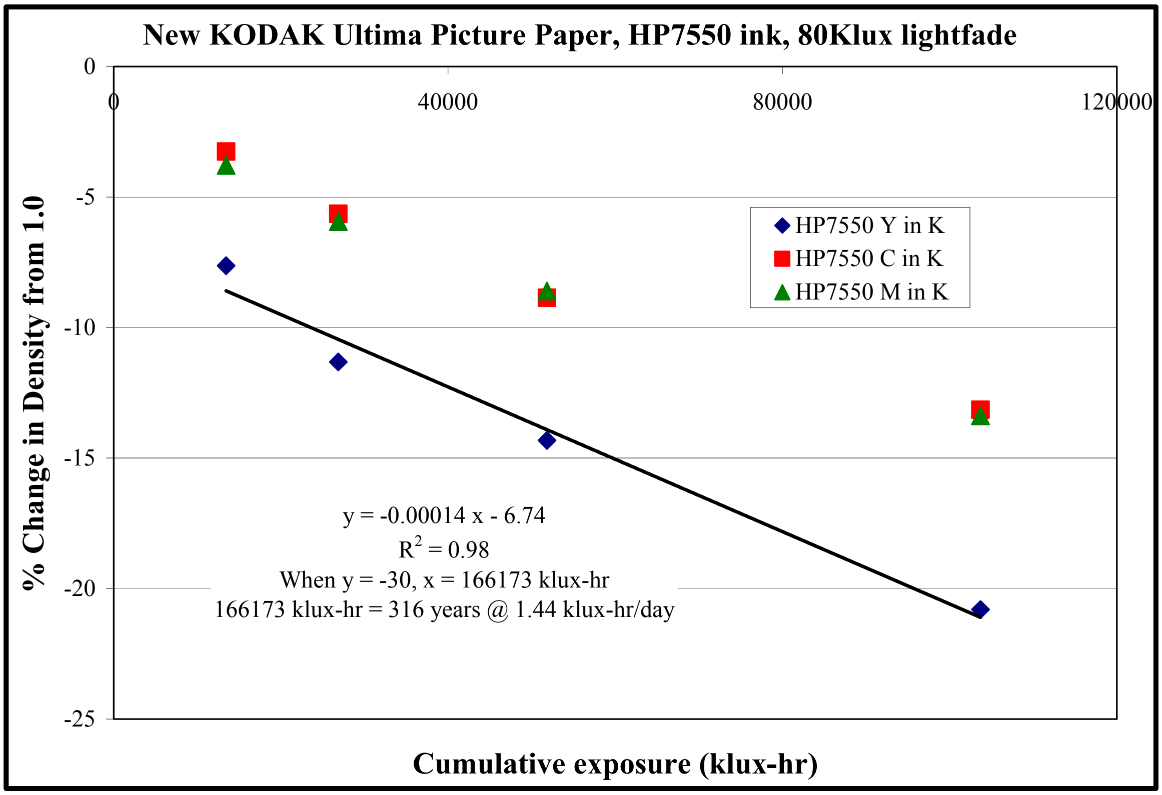

Figure 3. Plot of % density change for the yellow, magenta, and cyan components of a 1.0 initial density for a neutral gray patch printed with the HP 7550 inks on the new KODAK Ultima Picture Paper.

Table 2. Summary of current light fade results for the new *KODAK Ultima Picture Paper* printed on representative Hewlett Packard 3 ink and 6 ink printers.

Condition	Printer	Current Cumulative Exposure (Mlux-hr)	End-point Reached?	Light Fade Print-life Estimate (years)	End-point	R^2
A	7550	103	No	316	Y in K	0.979
B	7550	67	Yes	111	M-Y shift in K	0.949
C	7550	67	No	539	Y in K	0.993
D	7550	4.7	No	N/A		not enough fade to extrapolate
E	7550	7.2	No	N/A		not enough fade to extrapolate
A	3820	103	Yes	179	Pure magenta	0.990
B	3820	67	No	187	Yellow in neutral	0.994
C	3820	67	No	228	Pure cyan	0.988
D	3820	4.7	No	N/A		not enough fade to extrapolate
E	3820	7.2	No	N/A		not enough fade to extrapolate

<u>Ozone Fade</u>

Some manufacturers' inkjet media do not require accelerated ozone testing because noticeable fade occurs after just a few weeks' exposure to ambient air containing just a few ppb of ozone.[12] However, more stable products such as the new *KODAK Ultima Picture Paper* require the use of much higher concentrations of ozone. For accelerated ozone fade, we have developed a methodology very similar to that used for light fade.[1] The test chamber and methods have been documented in detail elsewhere.[20,21]

As with accelerated light fade, we assume a reciprocal relationship between ozone concentration and time of exposure. In order to verify this assumption, we test at least two ozone concentrations, as summarized below:

A. 1.0 ppm, 23°C, 50% RH, dark
B. 5.0 ppm, 23°C, 50% RH, dark

As with light fade, measurements of density loss at each condition are made as a function of treatment until at least one end-point is reached. The projected ozone fade print-life is based on the first end-point reached. Figure 4 shows the current ozone fade results for the HP 7550 primaries printed on the new *KODAK Ultima Picture Paper*. Table 3 summarizes our current results for the new *KODAK Ultima Picture Paper* in combination with the HP 7550 and HP 3820 ink sets.

Table 3. Summary of current ozone fade results for test prints made with the new *KODAK Ultima Picture Paper Glossy* on the Hewlett Packard 3 ink (3820) and 6 ink printers (7550).

Condition	Printer	Current Cumulative Exposure (ppm-hr)	End-point Reached?	Ozone Fade Print-life Estimate (years)	Comments
A	HP7550	2016	No	> 130	M density loss at 18%; linear extrapolation; R^2 = 0.98
B	HP7550	8760	No	> 400	C density loss at 18%; linear extrapolation; R^2 = 0.98
A	HP3820	2016	No	> 200	C of K loss at XX%; linear extrapolation; R^2 =0.996
B	HP3820	8760	No	> 600	Magenta density loss at XX%; log extrapolation; R^2 = 0.98

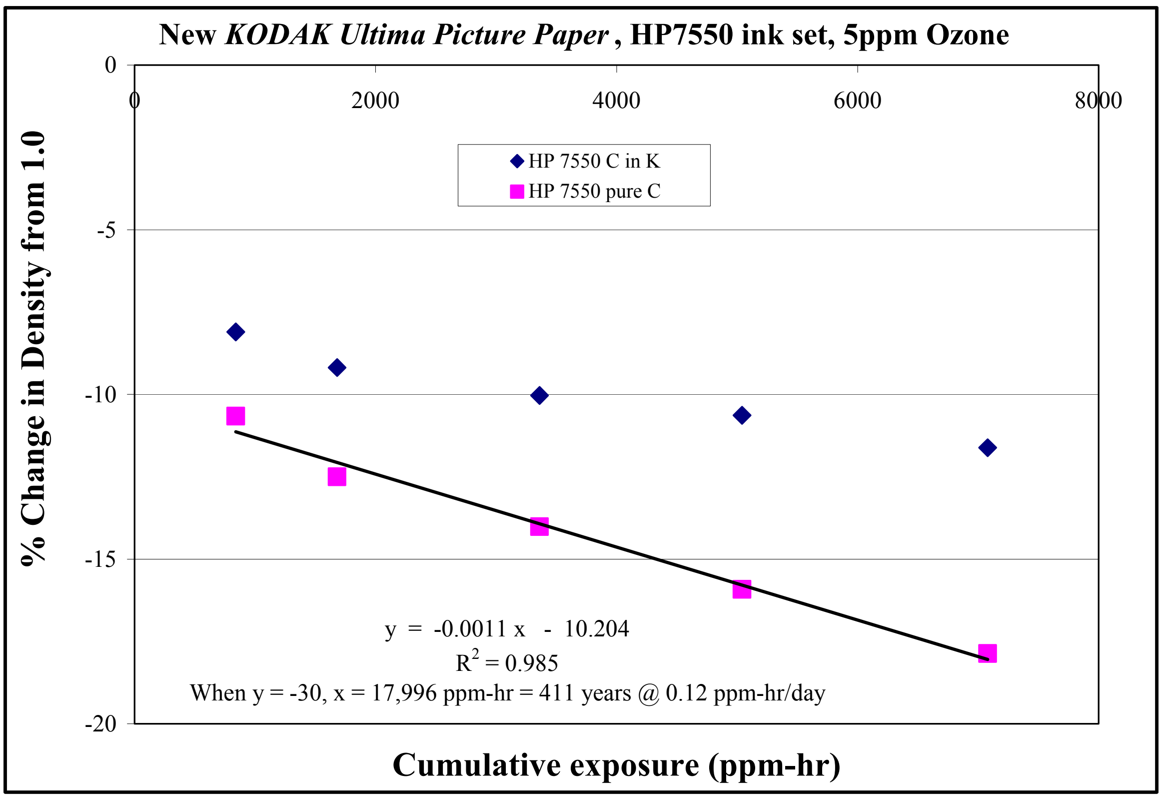

Figure 4. Plot of % density change (from 1.0 initial density) for the HP 7550 yellow, magenta, and cyan inks printed on the new KODAK Ultima Picture Paper.

Humidity Keep

For accelerated humidity testing, we test at the following conditions and locations for up to 56 days of exposure:

A. 30°C/70% RH, ozone free, dark, Kodak Image Stability Center
B. 38°C/80% RH, ozone free, dark, Kodak Image Stability Center
C. 30°C/70% RH, ozone free, dark, Torrey Pines Research

In terms of absolute humidity, both of these conditions are equivalent to $\geq$ 100% RH at 23°C (72°F). For example, at 30°C/70% RH, the corresponding dew point is 23.9°C. From our recent study of the typical home environment,[10] we found that this level of humidity is approximately 3σ (3 standard deviations) from the mean. Stated another way, the typical home would be expected to experience this condition less than about 0.14% of the time. Thus, in order for an unprotected print to experience the equivalent of one week of continuous exposure at 30°C/70% RH, it would take roughly 700 weeks (~ 13 years) in a typical home environment.

For dye-based inks on most inkjet media, the kinetics of humidity-induced change are such that nearly all of the measurable change occurs within the first 7 to 14 days at 38°C/80% RH.[2] At 30°C/70% RH, the rate of change is slower overall, but the results eventually plateau near the same levels observed at 38°C/80% RH. This is also what we observed for the new *KODAK Ultima Picture Paper* (see Figure 5). Note that unlike light, ozone, and heat, the effect of humidity is primarily observed as a density increase. The total change does not result in any end-points being reached, nor does it cause the image quality to degrade to an unacceptable level based on subjective evaluation. Results for the new *KODAK Ultima Picture Paper* with the HP 7550 inks are summarized in Table 4.

At this time, the results of the psychophysical evaluation of the humidity-treated prints are inconclusive. The rated image quality of the untreated control prints for several of the ink-media combinations was so low that the further effect of the humidity-induced image degradation was insufficient to produce a significant additional loss of quality. Visual inspection of these prints, however, clearly shows noticeable hue shift and/or loss of sharpness. We are in the process of addressing this limitation by adjusting the driver settings for these ink-media combinations in an attempt to improve the initial image quality to a level similar to that found for the other combinations. We will then repeat the humidity treatment on one set of prints, followed by a subjective image quality evaluation of both the treated and untreated sets of prints. Suffice it to say at this point that none of the prints made on the new *KODAK Ultima Picture Paper* exhibit an unacceptable loss of sharpness even after 28 days of treatment at the more severe 38°C/80% RH condition.

Given that the typical home rarely, if ever, experiences humidities as high as those used for these tests, we conclude that the prints made with the new *KODAK Ultima Picture Paper* will not be limited in terms of overall print-life by humidity.

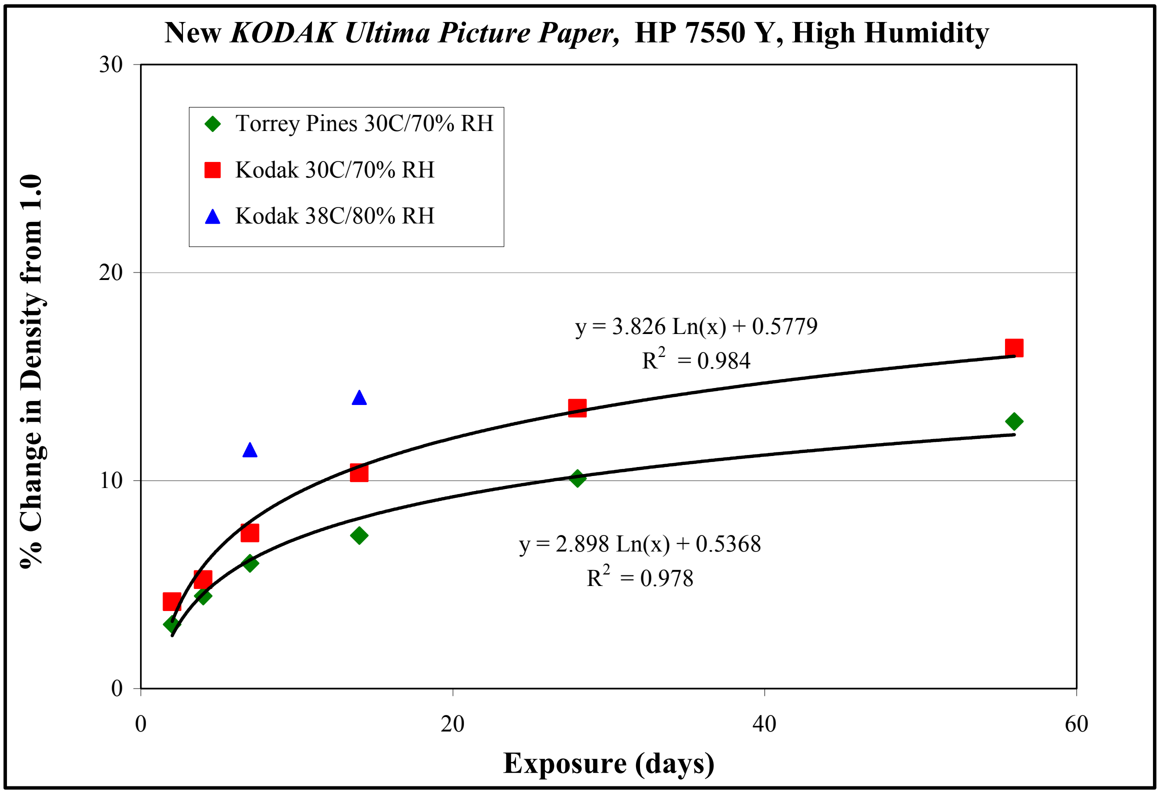

Figure 5. Plot of % density change for a 1.0 initial density for the HP 7550 yellow ink on the new KODAK Ultima Picture Paper *observed in the high humidity treatment test.*

Table 4. Summary of current high humidity keep results for test prints made with the new *KODAK Ultima Picture Paper Glossy* on the HP 7550 printer.

Test Condition	Days to fail	Humidity Keep Print-life Estimate (years)	Limiting color
A	2188	>>100	Yellow
B	Not enough data	Not enough data	Yellow
C	>10000	>>100	Yellow

<u>Thermal Fade</u>

For estimating the long-term effects of thermal dye stability, we adapted the Arrhenius method as described in the current ANSI/ISO standard.[7] We chose the free-hanging condition as more representative of an unprotected print on display. Because of the known interactions of heat and humidity for inkjet prints, we have used the constant dew point approach in order to measure the rates of fade at multiple temperatures above ambient.[16] As with the light fade and high humidity testing, we have taken care to exclude ozone from the test chambers used for the Arrhenius study. Of course, this test was carried out in the dark to avoid interaction with light-induced fade. For this study, we chose the following conditions, all at a constant absolute humidity equivalent to a dew point of 13°C (this is equivalent to 50% RH at 24°C):

A. 24°C[22]
B. 35°C
C. 45°C
D. 55°C
E. 65°C
F. 75°C

Because the rate of change is very slow at the lower temperatures, this test can take many months or even years to complete. Currently, we have not seen enough fade at even the higher temperatures for the new *KODAK Ultima Picture Paper* in combination with the HP 7550 ink set to be able to establish a meaningful rate of fade. Figures 6-8 show an example of current results for the HP 7550 magenta, yellow and cyan inks on the new *KODAK Ultima Picture Paper* across the 6 temperatures listed above. Similar results are observed for the primary components of a neutral patch, and also for the other ink sets included in this test. This is consistent with our previous Arrhenius results on earlier versions of *KODAK Ultima Picture Paper*, and allows us to conclude that thermal fade will not likely be a limiting factor for an unprotected print on display. We will update these results and conclusions as more data become available.

It should be noted that we are seeing evidence of thermal-induced fade for the Epson yellow ink on several manufacturers' media. So far, the overall levels of fade are insufficient to derive an Arrhenius relationship, but we fully expect that thermal fade will become a limiting factor for some papers with this ink set.

Image Stability Summary

In summary, the new *KODAK Ultima Picture Paper* in combination with current state-of-the-art inks (as embodied by the current HP 3-ink and 6-ink photo printers) are projected to last for over 100 years when displayed unprotected in a typical home environment. Total print-life appears to be limited by light fade, followed by ozone fade. Humidity and thermal effects are less significant, and do not appear to be limiting factors.

Upon comparing the overall results obtained thus far for the new *KODAK Ultima Picture Paper* to the other glossy photo papers included in this study, we currently project that prints made with the new *KODAK Ultima Picture Paper* will last the longest under typical home display conditions for the vast majority of head-to-head comparisons.

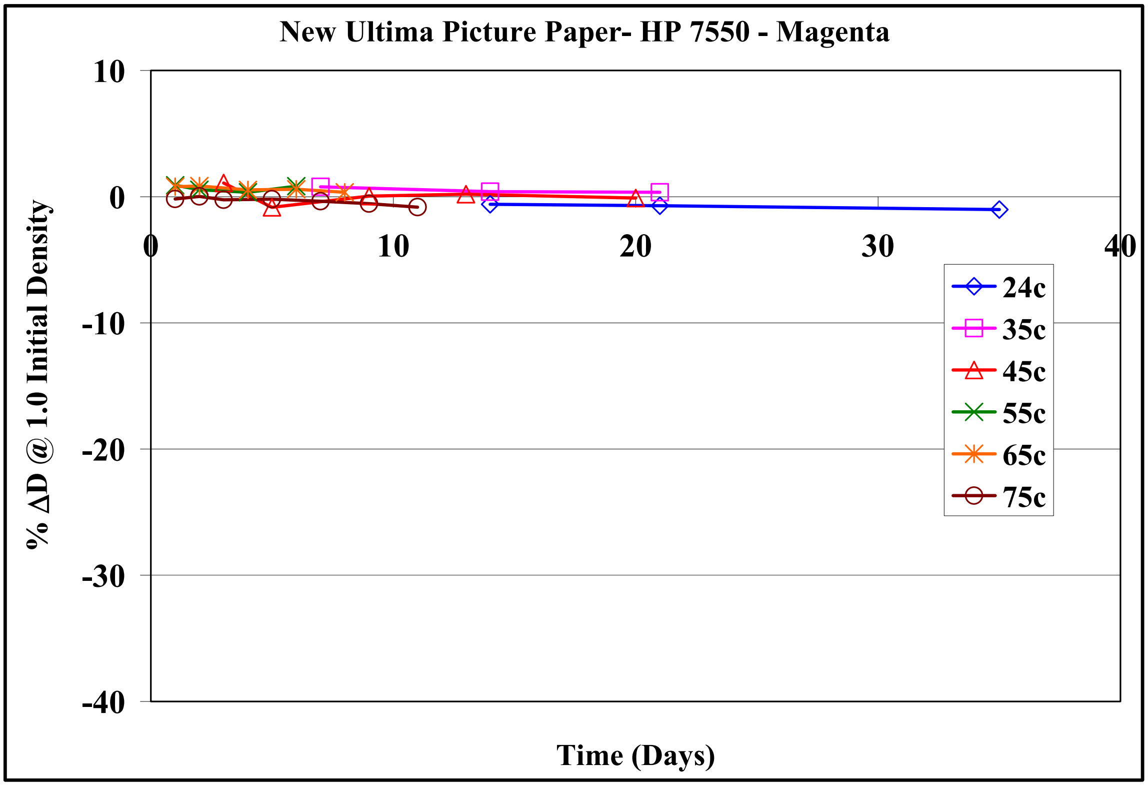

Figure 6. Current Arrhenius fade data for the HP 7550 magenta ink on the new KODAK Ultima Picture Paper.

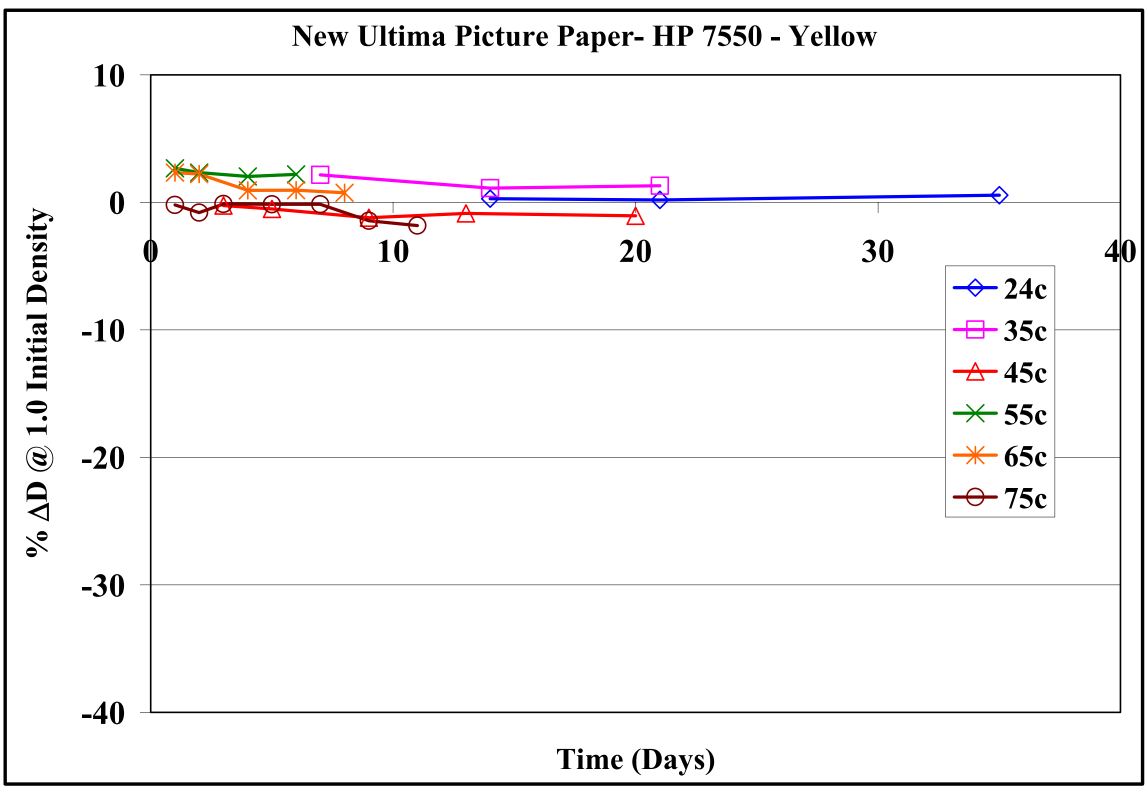

Figure 7. Current Arrhenius fade data for the HP 7550 yellow ink on the new KODAK Ultima Picture Paper.

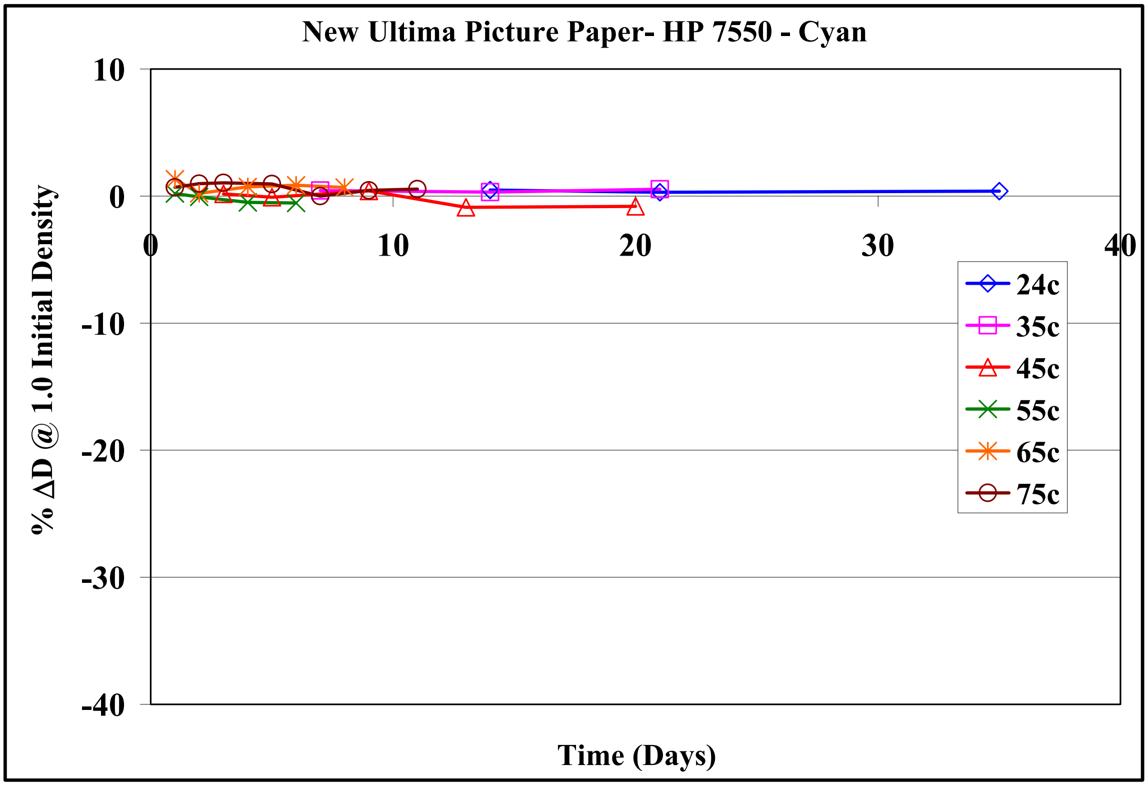

Figure 8. Current Arrhenius fade data for the HP 7550 cyan ink on the new KODAK Ultima Picture Paper.

Notes and References

1. M. Oakland, D. E. Bugner, R. Levesque, and R. Van Hanehem , *Proc. NIP 17*, 175-178 (2001).
2. P. Hill, K. Suitor, and P. Artz, *Proc. NIP 16*, pp. 70–73 (2000).
3. D. Bugner and C. Romano, "Printing Memories to Last a Lifetime: Understanding Image Stability of Inkjet Prints," *Recharger Magazine*, September 2001.
4. For a general review of inkjet media technology, see: D. E. Bugner, "Films and Papers for Inkjet Printing," Chapter 15 in The Handbook of Imaging Materials, A. Diamond and D. Weiss, eds., (Marcel Dekker, New York, 2001).
5. Patents pending.
6. Humectants are organic ink co-solvents that are required for reliable firing of the inkjet printhead.
7. ANSI IT-9.9 (1996) (soon to be ISO 18909).
8. S. Anderson and G. Larson, *J. Imaging Technol*., 13, pp. 49–54 (1987).
9. S. Anderson and R. Anderson, *ibid*., 17 (3), pp. 127–131 (1991).
10. D. E. Bugner, J. LaBarca, D. Kopperl, J. Phillips, D. Skye, I. Baker, C. Cunningham, P. Miller, and T. Kaltenbach, *Proc. IS&T's 13th Int. Symp. on Photofinishing*, in press, (2004).
11. J. LaBarca and S. F. O'Dell, *Proc. of IS&T's12th Int. Symp. on Photofinishing*, pp. 38–47 (2002).
12. K. Kitamura, Y. Oki, H. Kanada, and H. Hayashi, *Proc. NIP 19*, pp. 415–419 (2003).
13. M. Thornberry and S. Looman, *ibid*, pp. 426–430 (2003).

14. D. Oldfield, G. Pino, R. Segur, J. P. Twist, and S. O'Dell, *ibid*., p. 396 (2003).
15. H. Ishizuka, Y. Seoka, Y. Shibihara, and E. Sakai, *ibid*., pp. 411–414 (2003).
16. M. Oakland, D. E. Bugner, R. Levesque, and P. Artz, *Proc. NIP 17*, pp. 167-170 (2001).
17. D. E. Bugner and P. Artz, *Proc. NIP 18*, pp. 306-309 (2002).
18. D. E. Bugner and C. Suminski, *Proc. NIP 16*, pp. 90–94 (2000).
19. D. E. Bugner, D. Kopperl, and P. Artz, *Proc. of IS&T's12th Int. Symp. on Photofinishing*, pp. 54–57 (2002).
20. D. E. Bugner, R. Van Hanehem, P. Artz, and D. Zaccour, *Proc. NIP 19*, pp. 397–401 (2003).
21. D. E. Bugner, R. Van Hanehem, M. Oakland, P. Artz, D. Zaccour, and R. Levesque, paper to be submitted to *J. Imaging Sci. Tech*.
22. This condition also serves as the control for the light, ozone, and humidity studies.

Appendix

Suite of prints representative of consumer photo space used for the psychophysical evaluations used for this study.