Survey of Environmental Conditions Relative to Display of Photographs in Consumer Homes

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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. In order to correlate the results of accelerated testing in the laboratory with what actually happens to a photographic print under longer-term real-world conditions, it is necessary to better understand the typical ambient environment in which the prints are being displayed and/or stored. To this end, we have measured the long-term light levels, spectral energy distributions, temperatures, and humidities in 32 homes in 4 cities around the world. In this presentation, we will attempt to quantify the typical home display environment and compare similarities and differences among the homes and cities included in this study.

Introduction

The Importance of Image Stability

In the "portrait and social" end-consumer environment, where the majority of images are used and stored for most of their life in low-intensity illumination or dark conditions, it is extremely important to include all the factors that can degrade an image in the design for print longevity. This includes both the light fade impact as well as the thermal fade impact and with newer technologies, image degradation caused by humidity and atmospheric contaminants. In general, images on display can encounter an extremely wide rage of illumination conditions, including not only intensity but spectral quality as well. Conditions such as a room with a low level of illumination in a home or a museum could be as low as tens of lux, with a predominantly low-energy spectral distribution (relatively low UV and blue and high red) while a commercial display at a product point of purchase could be thousands of lux with a higher energy spectral distribution.

Light and heat are not the only factors that can have an image stability impact. For newer imaging technologies, it has been demonstrated that moisture content and levels of atmospheric pollution, specifically ozone, can also have a strong influence.[1,2] Silver halide-based photographic paper has set the standard for customer expectations on print longevity, and it is often used as the reference for newer imaging technologies. Depending on ambient conditions, image lifetimes of 100 to 200 years, or longer, are now possible.[3] However, depending on the conditions and imaging technology, image lifetimes as short as months or even weeks are possible as well.

Consequently, it is very important to have clear definitions of the conditions in which the product will be displayed and stored. This is true from the perspectives of both the end-consumer, who simply wants to know how long the image will last, to the imaging-media product designer, who needs to know how to correctly assess image quality and image stability tradeoffs. Indeed, the current ANSI/ISO standard provides the recommendation that predicting and reporting of image stability be done in reference to conditions that are representative of those in which the image will be displayed or stored.[4] Given the recognition that newer imaging technologies are sensitive not only to the traditional light and thermal degradation mechanisms but also to those of ozone fade and humidity, it is critical to understand and quantify all of these variables so that accurate predictions of image stability can be made to either the end-consumer or the product designer.

As the ANSI/ISO standard correctly points out regarding light levels, there is no right intensity for all display conditions and this can logically be extended to include temperature, humidity, and ozone level. These real-world parameters should be used to define the specific conditions for reporting image stability performance. While the commercial market segment can have very extreme conditions, especially regarding light levels, images that are displayed and stored by end-consumers in the home tend to be less extreme. These applications include snapshots and formal portraits, displayed in the home environment or stored in albums. An imaging material to be used in "portrait and social" home-use applications needs to have print longevity performance that is reflective of the appropriate real-world conditions in the end-consumers' homes. The reporting of that performance should be done in this context as well.

Prior Art on Image Stability Testing

The two primary environmental factors that affect the stability of traditional silver halide images are believed to be heat and light. Although light only affects prints that are on display, heat affects prints under both storage and display conditions. In each case the dominant response to these environmental factors is fading of the dyes that comprise the photographic image and/or staining of the white areas of the print or borders. The current ANSI/ISO standard for the assessing the stability of traditional silver halide images describes methodologies for estimating the natural aging of photographic images with respect to either prolonged heat or light exposure.[4]

For heat-induced fade (or staining), the Arrhenius method is adapted.[5] This involves accelerating the rate of change at multiple temperatures above ambient. The Arrhenius equation can be used to estimate the rate of change over longer periods of time at ambient temperature. To accelerate light-induced fade (or staining), high intensity light exposures are recommended. Assuming the law of reciprocity holds,[6] one can estimate the extent of fade that might occur under ambient lighting conditions.

Because humidity is known to have a secondary influence on the rates of fade in either case, a relative humidity of 50% is specified as a standard test condition for accelerated image stability testing. In order to accurately extrapolate the results of the accelerated test conditions to actual or intended storage or display conditions, it is critical to specify the ambient temperature, relative humidity, light intensity, and the spectral distribution of the light energy under which the photographic print is being displayed or stored.

The explosion of digital images available from scanners, digital cameras, and the Internet has driven a commensurate demand for printing those images. Today, there are multiple technologies available for printing digital images on the desktop in the home and/or office, including inkjet, thermal dye transfer, and electrophotography.

There are concerns regarding image stability and physical durability, however, which have prevented the widespread application of these alternate technologies in the production of photographs intended for long-term storage and/or display. Inkjet, especially, has been the subject of numerous studies for the effect of various environmental factors on long-term display. Recent studies have also compared the stability of digital photographic prints generated from various output technologies with respect to light, heat, humidity, and ozone.[7]

Currently there are no existing standards for testing the stability of digital photographic prints produced by these technologies. It is clear that in addition to heat and light, environmental factors such as humidity and ozone have a significant effect on the long-term stability of the various digital output technologies.

In parallel with the development of standardized methods for the accelerated testing of digital prints against factors such as light, heat, humidity, and ozone, it is important to better understand the typical or average environment in which these prints are being stored and/or displayed. In the context of the present study, the environment of the home consumer is of particular interest.

In the late 1980s and early 1990s, Anderson and coworkers published the first attempts to better understand the home environment in the context of photographic storage and display.[8,9] In a study of several homes in Rochester, New York, they found that light levels averaged between 100–200 lux over the course of a year.[9] Others have postulated different average light levels in different parts of the world based on spot measurements and/or anecdotal observations.[10] The Anderson study also included the spectral distribution of the light energy, indicating a mix of both diffuse daylight and artificial light sources. Of particular note was the relatively low level of light in the ultraviolet (UV) region of the spectrum. This is important because the higher energy UV wavelengths tend to be the most damaging to organic colorants.[10] Clearly, there is a need for a more comprehensive assessment of light levels as well as the spectral energy distribution of light in a broader cross-section of homes around the world.

There is very little published data on long-term temperature and humidity trends in the context of the storage and display of photographs. In addition to the previously mentioned paper by Anderson and Larson,[8] a recent study by HP scientists also reports some temperature and humidity data for consumer's homes.[12]

There have been several studies of museums, as well as other public buildings attempting to correlate the outdoor vs indoor levels of ozone.[13] Published reports on ozone levels in Los Angeles[14-15] and elsewhere[16] in the 1970s established a clear link between indoor and outdoor concentrations of ozone. In the Los Angeles study, indoor ozone levels approaching 0.2 ppm were reported in several office buildings and at least one home. There are no known published reports on long-term ambient levels of ozone in homes in the context of the display and storage of photographs.

Scope of this Study

Given the foregoing discussion, there is a clear need to better understand the ambient environment in the home with respect to the storage and display of photographs and other types of print materials. The primary objective of this study was to determine the ambient levels of light (including the spectral energy distribution), heat, humidity, and ozone in typical homes around the world.

The following cities were chosen for the first phase of this endeavor: Rochester, New York, USA; London, England; Melbourne, Australia; and Los Angeles, California, USA. In each of the above cities, a total of eight homes were chosen for environmental monitoring. The total number of cities/homes that could be monitored during the first phase was primarily limited by budget constraints. Our initial goal was to monitor all homes for at least six months, beginning around the summer solstice and ending around the winter solstice. As will be discussed below, because of issues associated with the availability of ozone monitors, as well as software issues associated with the light monitoring equipment, light and ozone monitoring did not commence until September or October for most of the cities. We were able to extend participation in most cases to enable at least six months of light data. For temperature and humidity, we were able to acquire data for 10–12 months in all cities.

Methods

Choice of Cities

The following criteria were considered in the choice of cities for this study:

- representative of relatively large populations of active photographic consumers;
- at least one city with known high concentrations of air pollution;
- at least one city with greater than average amounts of sunshine;
- at least one city in the southern hemisphere to reflect the opposite seasonality of the northern hemisphere; and
- at least one European city.

Given these constraints, we selected London, England; Los Angeles, California, USA; and Melbourne, Australia. Rochester, New York, USA was included as a fourth city to serve as a crossover with the previous study by Anderson and Anderson.

Selection of Participants

With the help of a trained anthropologist, factors such as socioeconomic status, geographic location and orientation, and the type of heating cooling, and ventilation (HVAC) system were determined to be potential biases against which we should attempt to randomize participant selection. Participants who were eventually selected to have their homes monitored were offered a digital camera and memory cards as compensation. Although most participants selected to participate were either Kodak employees, or their immediate families, care was taken to ensure that they were representative of the population as a whole in that location.

Instrumentation

The measuring equipment was placed in a room in the home used for displaying photographic images. Temperature and humidity were collected continuously in each home. Because of equipment limitations, ambient levels of light were monitored for two weeks in only four homes at a time in each city. For the following two weeks, the monitoring equipment was transferred to the other four homes in each city. This cycle for measuring ambient levels of light continued for the duration of the study.

In this manner, ambient light levels were measured every 30 minutes with a spectroradiometer (Ocean Optics USB2000 UV-VIS with CC-3-UV cosine corrector filter, P400-2-UV-VIS 400 micron patch cord fiber) connected to a laptop (Dell Inspiron 2500, Windows Me) for data logging with OOIBase32 Spectrometer Operating Software.

A single ozone measurement in each home was collected every other week. In addition, several days of continuous monitoring in select homes was performed in both Melbourne and London. Ozone measurements were made with an optics-based detector (Dasibi 1008-PC).

The heat and humidity levels in each home were monitored every 30 minutes using a combination data logger (OM-NOMAD-RH-32 by Omega) with NOMAD Datalogger Omegasoft version 2.0 software.

Results and Discussion

Temperature and Humidity

The temperature and humidity data are summarized by city in Tables 1. Two measures of humidity are reported: dew point and relative humidity. Dew point is a measure of the absolute humidity, while relative humidity is a function of both dew point and temperature. In the table, we show the mean and standard deviation of the temperature, dew point, and relative humidity, for each city, and overall. The aggregate data for each city were symmetrically distributed about the mean. Overall, for the cities included in this study, the average temperature and relative humidity was found to be 20°C ± 3.5°, 51 ± 11% RH (± 1σ). This is very close to the current recommended condition of 23°C ± 2°, 50 ± 5% RH for accelerated light fade testing,[4] and is also consistent with the earlier study by Anderson and Larson.[8]

Figure 1 shows an example of the relationship of temperature and humidity to each other and to the diurnal cycle over a six-day period for House 6 in Melbourne. It can be seen that absolute humidity, as measured by dew point, is much less variable than relative humidity. As the air temperature rises and falls during the course of a typical 24-hour cycle, the relative humidity moves in the opposite direction, even though the dew point stays relatively constant. This is especially evident on Tuesday in Figure 1. Thus, the relatively large variability in RH in a given home may have more to do with diurnal temperature variations than with changes in the actual moisture content of the air.

Table 1. Temperature, dew point, humidity summary.

	Mean Temp (°C)	σ (°C)	Mean DP (°C)	σ (°C)	Mean RH (%)	σ
Rochester	20	3.3	1.2	6.2	44	11
London	20	2.4	5.8	4.7	53	8.8
Los Angeles	21	2.4	4.1	6.7	49	13
Melbourne	20	2.8	7.6	3.8	56	7.9
Overall	20	3.5	4.7	5.9	51	11

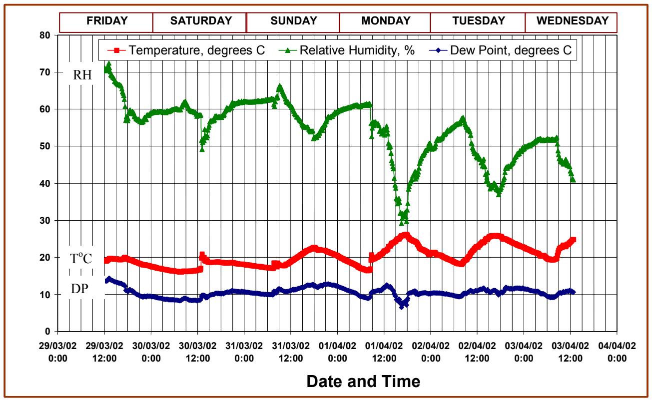

Figure 1. Diurnal relationship between temperature, relative humidity, and dew point for House 6 in Melbourne.

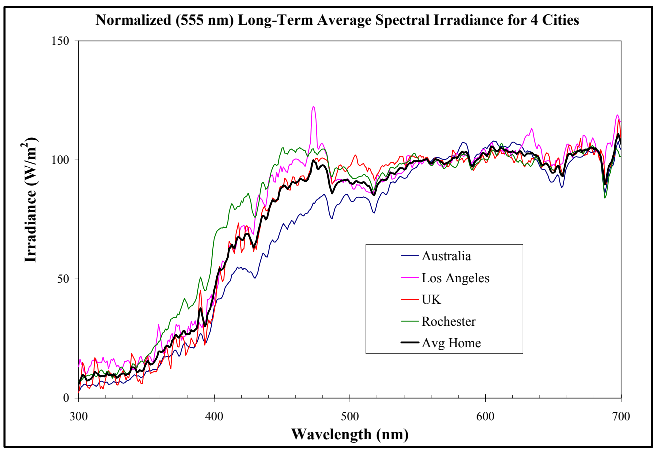

Figure 2. The long-term average spectral irradiance for the four cities included in this study, along with an overall average spectrum.

Light Levels and Spectral Distributions

The spectroradiometers used in this study measure the spectral distribution of the light energy. Therefore, in addition to measuring the intensity of the light, it is also possible to differentiate window-filtered sunlight from fluorescent lights from tungsten lights, for example. Figure 2 shows the long-term average spectral irradiance for each of the four cities, along with an overall average spectrum. Table 2 summarizes the light level data by city and overall.

From the shape of the spectra in Figure 2, it is evident that indoor display lighting for the homes in this study is dominated by indirect window-filtered daylight. Note the relatively low energy levels in the UV region, below 400 nm. This is likely due to the combination of glass-filtration and partial absorption of light reflected off interior surfaces.

The distribution of indoor light levels is inherently skewed because of the day/night light cycle, and this can be readily seen in the histogram of all lux measurements shown in Figure 3. Figure 4 is the same type of plot but for the daytime measurements only. In considering summary statistics of day/night light cycles, it can be concluded that the mean statistic is not appropriate for this distribution, as it is heavily influenced by the few values in the tail of the distribution. For asymmetric distributions, it is more appropriate to use the median statistic – classic examples of the median include statistical summaries of home prices or salaries, which have similar distributions to that shown in the figure. Alternatively, the distribution can be evaluated in terms of percentiles. This analysis also reports the 90th percentile or the light level below which 90% of the measurements fall (recall that the median is the same as the 50th percentile). The mean, median, and 90th percentile are shown on the histograms, and also included in Table 2.

When all measurements are included, including both daytime and nighttime spectra, the median light levels are quite low, under 10 lux in all four cities. The 90th percentile values are much higher, ranging from near 50 lux in Rochester, to over 100 lux in Los Angeles. When the results from all four cities are combined and the nighttime spectra are removed from the analysis, the median light level becomes 16 lux, and the 90th percentile becomes 137 lux. Based on these results, the estimate of 120 lux per 12 hours per day for a typical home consumer display environment seems reasonable.[3,8,9]

One of the underlying assumptions of this study is that a six-month monitoring period would be sufficient to capture any long-term seasonal variations in interior light levels. Seasonal variations were expected to be the result of a longer photoperiod in the summer and/or climatological influences, e.g., rainy seasons. It was hoped that six months of data would be sufficient to model a full year.

The data, indeed, show long-term seasonal trends for some of the houses, but the trends are sometimes in opposite directions, and other houses display no clear long-term trends. For example, House 2 in London illustrates a clear increase in light levels as one goes from the winter toward the summer months, as might be expected based simply on the increase in photoperiod. On the other hand, House 2 in Los Angeles and House 1 in Melbourne show the opposite trend of higher light levels in the winter months.

One explanation for the observed higher light levels during the winter months is that the angle of the sun is much lower. Homes with overhanging eaves will let less sunlight in during the summer months and more in during the winter months. Also, any shade trees will be much less effective in the winter. It is also possible that shades or curtains are closed during the daytime in the summer to keep the indoor temperatures cooler. Based on these observations, it is recommended that future studies be carried out for at least one year if possible. Also, given the logistics and equipment sensitivity, it is recommended that for future studies the spectroradiometers be left in place for the duration of the study and not moved every two weeks as we did for the current study. For these reasons, we recommend that the light levels reported for this study should be used for comparative purposes at this time. Additional in-home studies are underway to address the limitations of the current study.

Table 2. Light level statistics.

	Median (lux)	Mean (lux)	90^{th} %ile (lux)	Std. Error (mean)	N
Rochester	5.3	29	49	0.8	21991
London	6.1	37	82	0.5	48335
Los Angeles	3.9	36	110	1.1	44080
Melbourne	4.5	48	89	1.2	38709
Overall	4.9	39	91	0.5	153115
Overall (daytime only)	16	56	137	0.7	71336

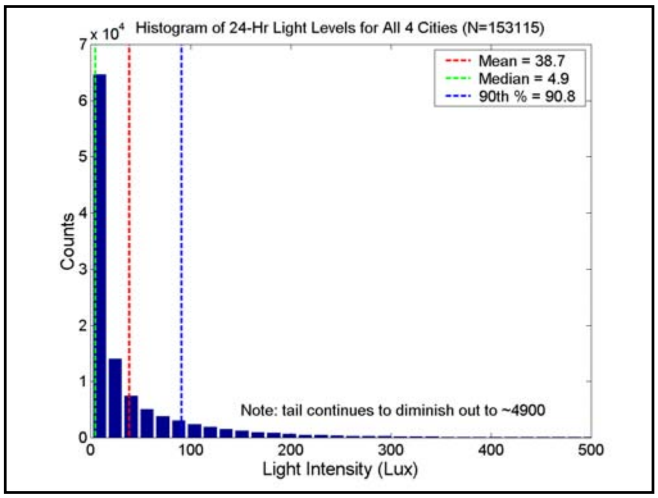

Figure 3. Histogram of all light levels for all home, all cities.

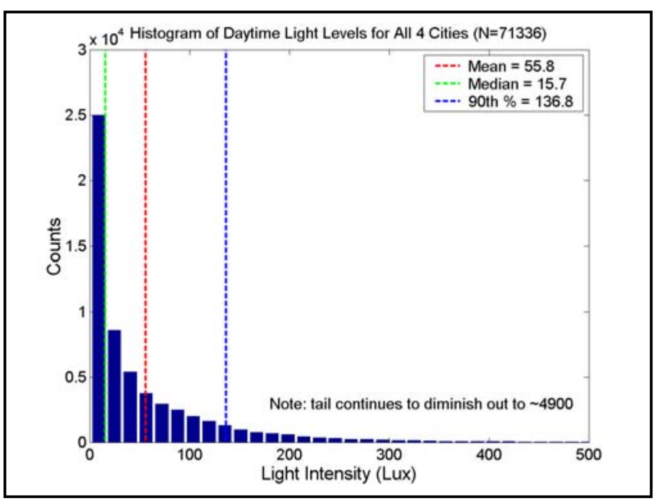

Figure 4. Histogram of daytime light levels for all home, all cities.

Ozone Levels

Our original plan called for taking a "spot" ozone measurement in each house every two weeks at the same time that we either picked up or dropped off the spectroradiometers. In hindsight, this plan turned out to be flawed. This is because most visits were scheduled for either early morning (before work) or evening (after work), causing us to often miss the peak times of the day for ozone.[13] Upon realizing this, we connected an automatic datalogger to the ozone monitor and solicited participants who would allow us to monitor the ozone continuously for a period of several days or longer.

Figure 5 demonstrates the sensitivity of interior ozone levels to infiltration of outside air. When the patio door was left open at U.K. House 7 during late afternoon on May 31 and mid-afternoon on June 4, ozone levels quickly rose to around 40 and 20 ppb, respectively. A longer-term view of the ozone levels in the same house later in the summer of 2002 is shown in Figure 6. In this case, several peaks can be seen ranging between 15–40 ppb ozone. Although not readily discernible from the figure, examination of the raw data indicates that significant peaks occurred at 1:41 PM on July 18 (17 ppb), 2:41 PM on July 28 (23 ppb), 6:21 PM on July 29 (39 ppb), and 6:01 PM on July 30 (16 ppb). The occurrence of the observed peaks in the mid- to late-afternoon hours is consistent with previous studies.[13,14,16] Similar results were observed over a six-day period in Melbourne. Our spot ozone measurements ranged from 0 to 28 ppb but averaged < 5ppb.

Unlike the temperature, humidity, and light level measurements, we did not gather enough ozone data to yield a statistically significant measure of typical long-term ozone levels. Data such as that shown in Figure 6, taken during what is typically the peak time of the year for ozone in the U.K., suggest that long-term indoor ozone levels may be quite low, on the order of 10 ppb or less. 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, concludes that long-term ozone levels may be closer to 5 ppb.[17] In-home studies with a goal of better quantifying long-term typical indoor ozone levels are ongoing. In the meantime, an estimate of 5 ppb for the typical home display environment seems reasonable.

Summary

In this study, we attempted to characterize the typical consumer environment (light, temperature, humidity, and ozone) for the display of photographic images. We monitored 32 homes in 4 medium-to-large cities around the world for 6–10 months. The overall typical environment across all 32 homes was found to be 20°C ± 3.5° (± 1σ), 51 ± 11% RH (± 1σ), and ≤ 137 lux per daytime cycle (90^{th} percentile). Insufficient ozone data was collected to establish a statistically significant measure of long-term levels inside the typical home.

The average spectral irradiance is dominated by indirect window-filtered daylight. Only 8% of the total irradiance is in the UV region (300–400 nm), with 26% in the blue (400–500 nm), 31% in the green (500–600 nm), and 35% in the red (600–700 nm).

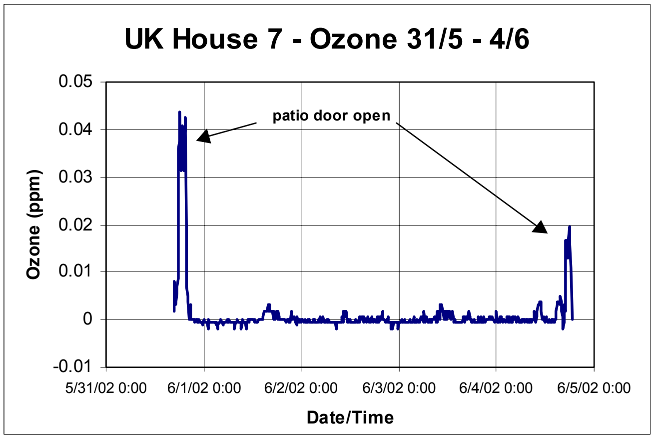

Figure 5. Continuous ozone monitoring, U.K. House 7, May 31, 2002 through June 4, 2002.

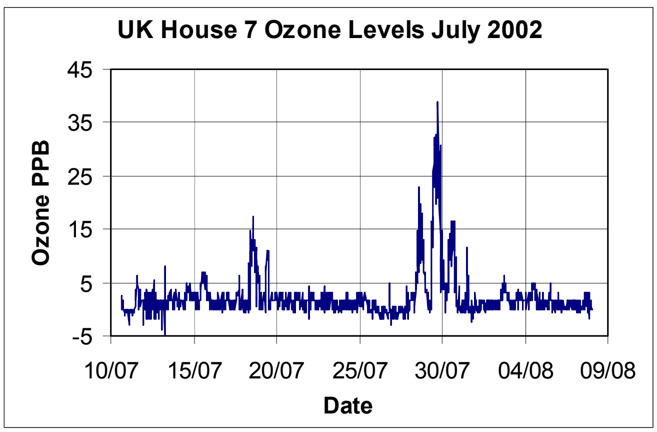

Figure 6. Continuous ozone monitoring, U.K. House 7, July 10, 2002 through August 9, 2002.

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Biography

Douglas Bugner received his BS in Chemistry from the Ohio State University in 1975, an MS in Organic Chemistry from UCLA in 1980, and a Ph.D. in Organic Chemistry from UCLA in 1982. In 1982, Dr. Bugner joined the Chemical Technology Laboratory in the Photomaterials Division of Eastman Kodak Company. In 1988, he accepted an assignment in the Photoconductor Technology Laboratory and, in 1991, he was appointed manager of the Chemical Technology Lab. In 1993, Dr. Bugner established a research effort in the area of inkjet materials and is currently Senior Laboratory Head, Desktop Commercialization Laboratory, Inkjet Materials and Printing Systems Division, Research and Development, and Director of Product Development, Inkjet Media, Digital and Film Imaging Systems, Eastman Kodak Company.

In 1994, Dr. Bugner received the Distinguished Inventor Award and, in 1997, he completed the Executive Development Program at the Tuck School of Business at Dartmouth. He currently holds 58 U.S. Patents, and has authored over 30 scientific publications. He is a member of the American Chemical Society, the Society for Imaging Science and Technology, and the Project Management Institute.