A Study of Fading Property Indoors Without Glass Frame from an Ozone Accelerated Test

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Abstract

We studied the fading behavior of bare, ink-jet printed samples hung indoors, from the point of view of gas-fastness (ozone-fastness). Bare samples were hung in a home environment for 1 year. The samples showed an average fading tendency similar to that of a 15-ppm · h ozone accelerated test at 24ºC 60% RH. Taking into account wide divergences in home environment and climate, we set 40 ppm · h as the one-year equivalent level of fading, and we studied the influence of temperature, relative humidity and ozone concentration on the ozone accelerated test.

Introduction

Photo-quality prints produced by a color ink-jet printer are now comparable in terms of image quality to traditional "silver-halide" photographs, thanks to improved heads, inks, recording methods, and media. Moreover, the durability of such photo-quality prints has steadily improved. Specifically, improvements efforts have targeted the following six areas:

(1) lightfastness (2) humidity-fastness
(3) thermostability (4) plasticizer-fastness
(5) water-fastness (6) gas-fastness

Durability in each of the first five categories has already reached a practicable level, but the sixth category, gas-fastness, still remains problematic. Improvements in the area of gas-fastness will require that ink and media be improved and that evaluation techniques be established.

Since releasing the six-color PM-700C ink-jet printer in 1996, Epson has advanced its recording technology, increased printing speed, and run through repeated iterations of "photo-quality" improvements. On the PM-970C, released in 2002, the smallest ink droplets fired are a mere 1.8 picoliters, enabling the rendering of pictures virtually devoid of graininess. Furthermore, such features as borderless printing and support for L size and 2L size media have helped to virtually close the gap between traditional photos and those printed using an ink-jet printer.

On another front, improvements in ink and media have brought photo-quality prints to the brink of practical acceptability in terms of durability. The first five types of durability have been discussed by Onishi et al, in NIP17.[1] Their conclusion is that image permanence is excellent with respect to humidity, heat, and plasticizers and that lightfastness, although certainly far from ideal, reaches 10 years on Epson Premium Glossy Photo Paper and 20 years on Epson Matte Paper - Heavyweight (for details, refer to an Epson printer catalog), levels that are adequate for most practical purposes. Gas-fastness, on the other hand, is in need of improvement. As discussed by Hayashi et al at ICIS '02,[2] fading on porous types of ink-jet media is found to occur far more rapidly than could be reasonably imagined considering the lightfastness of the colorant. Moreover, the primary agent of this fading is ozone gas. For this reason, resistance to ozone is the most important area to explore in terms of gas-fastness. At the same time, the necessity of objectively comparing and verifying ozone-resistance capability also makes the establishment of evaluation technology highly significant.

In this paper, therefore, we report the results of observations on the fading of bare, ink-jet printed samples (produced using an Epson Stylus Photo 890) hung indoors. We also discuss the correlation between this fading behavior and ozone accelerated tests.

Experimental

For our evaluation, we used Epson Premium Glossy Photo Paper and Epson Matte Paper - Heavyweight, both of which are porous mediums that provide photo-like results (Table 1).

Table 1. Evaluation Conditions

Ink-jet printer	Epson PM-880C
Recording ink	Genuine inks (six color)
Recording media	Epson Premium Glossy Photo Paper Epson Matte Paper - Heavyweight
Gas	Ozone

1) Fading Behavior of Bare Print Samples Hung Indoors

We evaluated and analyzed the fading behavior of print bare samples that were hung indoors. The print samples, which were hung bare (i.e. not protected by a glass frame), were placed in home environments in 10 locations around Japan (six within Nagano Prefecture, and four in other locations). To account for seasonal fluctuations, we staggered the starting period at three-month intervals. Each sample was evaluated four times in each home. Equivalent evaluations were also performed in other sites around the globe — in four locations in Japan and in three locations each in the US, England, and Singapore.

2) Fading Behavior During Ozone Exposure Tests

Evaluations were performed with the ozone concentration set at 10 ppm. The ozone exposure dose was expressed as the product of the ozone concentration and exposure duration value (ppm · h). As with lightfastness evaluations, the exposure environment was maintained at 24°C and 60% RH.

3) Temperature and Humidity Dependence in Ozone Exposure Tests

To ascertain the effect on fading of temperature and relative humidity conditions during ozone exposure, evaluations were performed at three temperature levels (15, 24, 40°C / 60% RH, constant) and at three humidity levels (40, 60, 80% RH / 24°C, constant). The ozone concentration was 2 ppm.

4) Reciprocity Failure in Ozone Exposure Tests

In lightfastness evaluations, a phenomenon (reciprocity failure) is sometimes seen where even if the exposure, the product of the amount of light and the exposure duration, is invariable, the level of fading differs according to the amount of light. Therefore, we checked whether this phenomenon occurred in our ozone exposure evaluations. In the tests the ozone concentration was varied within the 0.5 ppm to 20 ppm range and the exposure duration was regulated to control the exposure. The degree of fading was then evaluated. The temperature and humidity environment during exposure was 24°C and 60% RH.

5) Evaluation Samples, Conditions, and Criteria

Our evaluation samples were printed using a color patch of pure color with an OD (optical density) of 1.0 and then allowed to sit for 24 hours after printing. As with lightfastness, fading was evaluated by judging the decline (the percentage of remaining density) in reflection density (OD value of 1.0).

Result

<Fading Behavior of Bare Print Samples Hung Indoors>

Figure 1 shows the results of tests conducted in Japan to determine the fade behavior of cyan on Premium Glossy Photo Paper (PGPP). Indoors, fading was found to occur from spring through summer (April through September), yet almost not at all during the winter season (October through March). Outdoors, however, fading was found to progress regardless of season and, therefore, we are able to infer that the difference in seasonal fading is due to differences in the frequency with which doors and windows are opened to air out the house. Also, regardless of what season the evaluation was started, the degree of fading after one year was the same.

Figure 2 shows the results of tests to determine the fading behavior of cyan (for samples whose evaluations started in March) in 10 locations in Japan. The results show a very large difference in the degree of fading from house to house. Whereas the percentage of density remaining after one year averaged 69.6%, the sample standard deviation (σ_{n1}) was 7.8.

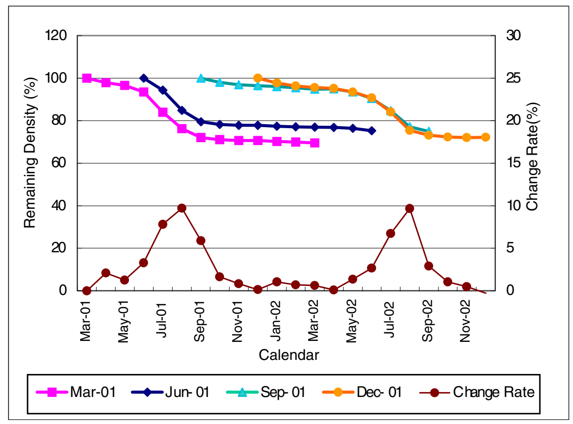

Figure 1. Fading behavior on PGPP of Cyan on bare samples hung indoors in Japan. (Four samples, evaluated from Mar/01 to Dec/02)

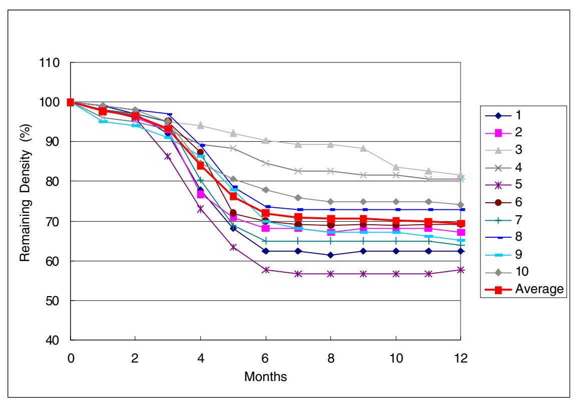

Figure 2. Fading behavior on PGPP of Cyan on bare samples hung indoors in Japan.(Evaluation period: Mar/01-Mar/02)

Figure 3 shows the results of tests to determine the fading behavior of Y, M, C indoors (in Japan) on bare Premium Glossy Photo Paper. The data in Figure 3 is the average of the results for all 40 samples, evaluated at four different times, from the 10 locations in Japan. Cyan and magenta exhibited prominent fading.

Here, the average remaining optical density after one year and the sample standard deviation (σ_{n-1}) were 73.0% and 7.4 for cyan, 80.6% and 7.0 for magenta, and 89.8% and 3.5 for yellow, respectively.

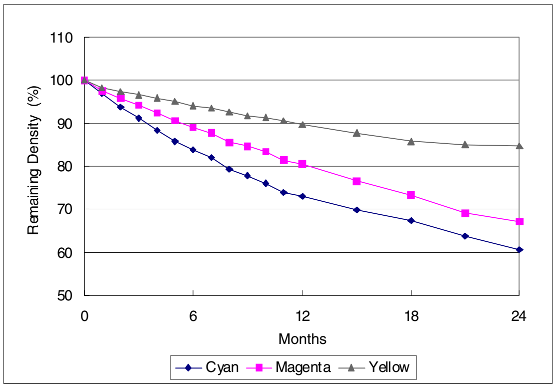

Figure 3. Fading behavior of pure color bare samples on PGPP indoors in Japan. (Average of 40 samples)

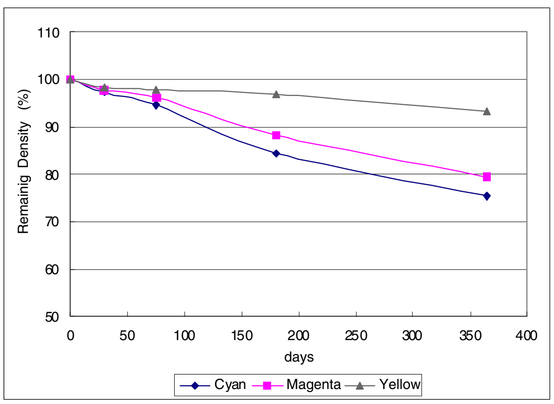

Figure 4. Fading behavior on PGPP of pure color bare samples hung indoors around the world.

Figure 4 shows the results of tests performed at the various sites around the globe to determine the fading behavior of Y, M, C indoors (worldwide) on bare Premium Glossy Photo Paper. The level of fading after one year was found to be essentially the same as it was in Japan.

< Fading Behavior During Ozone Exposure Tests >

Figure 5 shows the fading behavior of Y, M, C on Premium Glossy Photo Paper during ozone exposure tests.

As shown in Figure 5, cyan and magenta noticeably fade on Premium Glossy Photo Paper; they exhibit fading behavior similar to that described in Figures 3 and 4.

Yellow, on the other hand, evidences no fading when subjected to ozone exposure, whereas it exhibits fading of approximately 10% over the period of one year when hung bare. The fading of yellow on bare samples hung in home environments is assumed to be caused by factors (such as light) other than ozone gas.

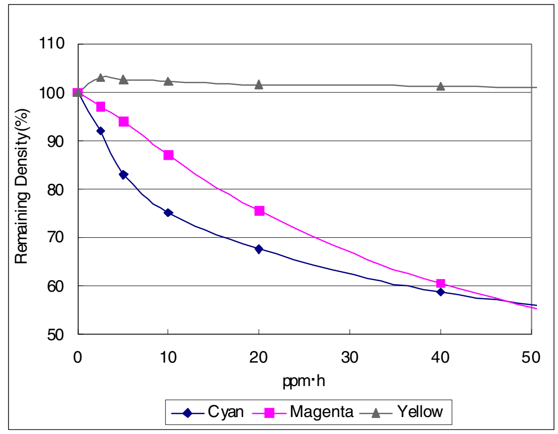

Figure 5. Fading behavior of pure color on PGPP under ozone exposure.

Next, Figure 6 was created by overlaying the graphs in Figures 3 and 5. The graphs have the same vertical axis (percentage of remaining optical density). The horizontal axis is adjusted so that the fading curves match.

As can be seen from Figure 6, for cyan and magenta the average fade value found for bare samples hung indoors for one year was correlated to be approximately equivalent to 15 ppm · h ozone exposure.

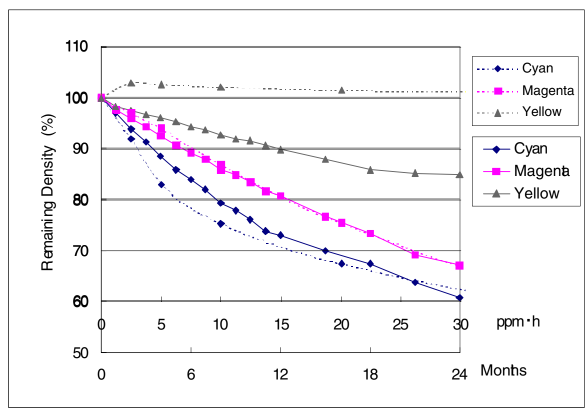

Figure 6. The correlation between the bare samples hung indoors in Japan and ozone exposure on PGPP. (Solid Line: Indoors, Dotted Line: Ozone)

Figure 7 was created using the results of the same type of studies using Matte Paper Heavyweight. On this type of paper, too, the average fade value for one year on bare samples hung indoors was correlated to be equivalent to 15 ppm · h ozone exposure.

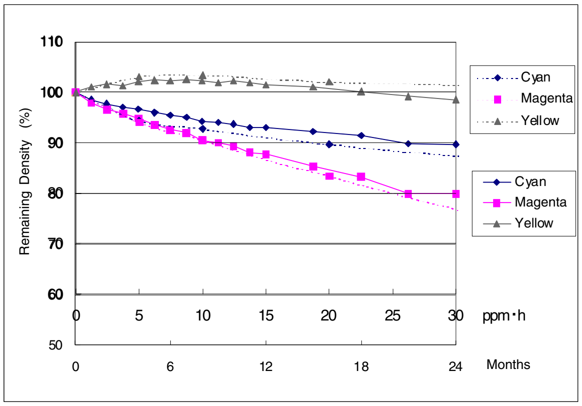

Figure 7. The correlation between bare samples hung indoors in Japan and ozone exposure on MPHW. (Solid Line: Indoors, Dotted Line: Ozone)

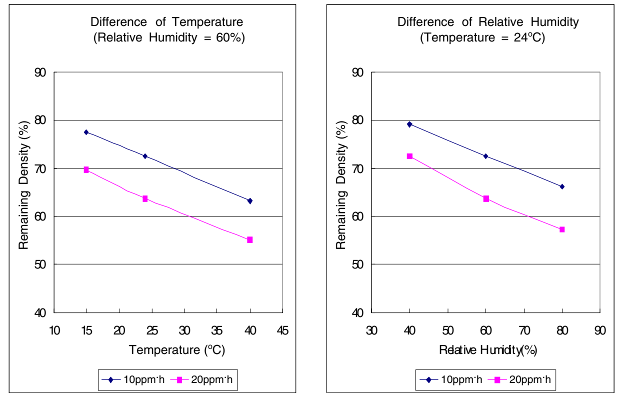

Figure 8. The effect of temperature and relative humidity on fading behavior on PGPP during ozone exposure.

However, as stated earlier, when seeking a measure of life for bare prints hung indoors, it is necessary to bear in mind that environmental factors trigger large variations in fading behavior. (Even in our tests, fading occurred at double the average rate in the worst cases.)

Therefore, for estimating the life of a bare print hung indoors, we decided to use 40 ppm · h as the assumed equivalent of one year. This value, which was arrived at by factoring in the 2σ (of the sample standard deviation) to the results obtained, can serve as a measure that can fully cover even individual differences (among home environments).

This 40 ppm · h value is the equivalent of airing out one's home for an average of about five hours per day, based on an average airborne oxidant concentration of 0.023 ppm · h [the average of measured values for the 10 years from 1990 to 1999 from six selected locations in Japan, according to data published by the National Institute for Environmental Studies].

<Temperature and Humidity Dependence In Ozone Exposure Tests>

Figure 8 shows the effect of temperature and relative humidity in ozone exposure tests. It was confirmed that temperature and humidity affect fading and that the higher the temperature and the higher the humidity, the faster fading progresses. The effect of humidity is especially large, and fading is slow to occur in low humidity environments. We thus found that we are unable to reproduce fading of bare print samples hung indoors.

< Reciprocity Failure in Ozone Exposure Tests >

Figure 9 shows the results of tests to determine the dependence of ozone concentration on fading in ozone exposure tests. At a minimum, it was confirmed that at an ozone concentration of from 0.5 ppm to 20 ppm, fading follows a uniform progression at an exposure dose (ppm · h), the product of ozone concentration and exposure duration, and that there were no reciprocity failures due to ozone concentration.

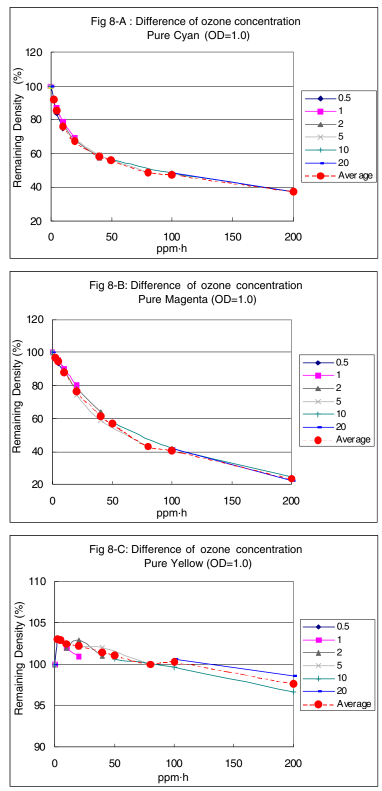

Figure 9. The impact of ozone concentration on fading behavior on PGPP during ozone exposure.

Conclusions

The correlation between the fading of bare samples hung indoors and the fading of samples exposed to ozone was evaluated using a PM-880C ink-jet printer and Premium Glossy Photo Paper and Matte Paper - Heavyweight. Using ozone exposure tests, we were able to roughly reproduce the fading of bare samples hung indoors. However, temperature and humidity have a major impact on ozone exposure tests, and to reproduce the type of fading that occurs when bare samples are hung indoors, we found that we would need an environmental setup of 24°C and 60% RH. Reciprocity failures in ozone exposure tests were also investigated. At an ozone concentration in the range of 0.5 ppm to 20 ppm, the exposure dose (ppm · h) can be considered to be the product of the ozone concentration and the exposure duration, without the reciprocity failures often seen during lightfastness tests.

From the above, it was determined that the life of a bare print hanging indoors in any home environment under various conditions can be calculated. This can be done by evaluating the performance of ink sets in ozone exposure tests in a 24°C and 60% RH environment where a 40 ppm · h exposure was considered to be equivalent to one year of hanging bare indoors.

Here, by using print samples with widely divergent lightfastness performance and ozone-resistance properties, we were able to correlate the fading behavior of bare samples hung indoors to the fading that occurs under exposure to ozone. The durability of printed matter is expected to improve further in the future as colorants and media are modified, but more data and further studies — including on complex fading — will be needed to develop techniques for calculating life and to develop accelerated fade test methods for bare samples hung indoors over a long period of time.

References

1. Hiroyuki Onishi, Masahiro Hanmura, Hidemasa Kanada, Teruaki Kaieda, *Image Performance of Ink Jet Photographic Prints*, IS&T Proc. NIP17, 192-196 (2001)
2. Hiroko Hayashi, Kazuhiko Kitamura, Yasuhiro Oki, Gas-fastness of Photographic Prints of EPSON PM-950C, ICIS'02, Tokyo 539-542 (2002)

Biography

Kazuhiko Kitamura received his B.S. in Chemistry from Keio University in 1986. That year, he joined Seiko Epson Corporation and has been engaged in research and development of inkjet inks