Mitigation of Pollution-induced Deterioration of Digital Prints through the Use of Enclosures

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Abstract

The potential for common enclosures to reduce or prevent pollutant-induced deterioration of inkjet materials was investigated, with the specific research question being: Can any of the various commonly-used enclosure designs and materials (envelopes/boxes, paper/plastics) be used to effectively reduce or prevent the damage to digital prints caused by Ozone or Nitrogen Dioxide air pollution? The results indicate clear guidelines how to best proceed to mitigate pollutant gas damage. Polyester sleeves show by far the greatest potential for both pollutants over all tests conducted, which indicates this benefit may extend to the parts-per-billion range. Increasing ppm values and equally reducing exposure times to create the same ppm-days exposure did not always result in the same color change to the prints inside or outside enclosures. This importantly indicates extended time periods and lower concentrations could mean an enclosure's effectiveness in preventing damage from pollution could be in fact much lower than that observed in highly accelerated testing (as seen in this work and elsewhere). This raises questions regarding the suitability of such techniques to appraise the efficacy of enclosures employed to deter pollution damage caused over longer periods (decades) at real world environmental pollution levels.

Introduction

An IPI survey of museums, archives, and libraries found that approximately 87% of cultural heritage institutions already have digital prints in their collections, that they are concerned about continuing influxes of these materials, and that they do not yet feel well informed on how to care for these materials. The same survey showed that objectionable deterioration to these objects has already occurred to portions of these collections including (but not limited to) fading, yellowing, color bleed, surface cracking and delamination. In total, 71% of institutions have already experienced deterioration of some part of their digital print collections [1]. Previous experimental research has established a clear connection between ozone and nitrogen dioxide to each of those forms of decay [2,3]. Ozone has been specifically shown to cause significant fade and delamination/cracking and nitrogen dioxide to induce yellowing and bleed. An understanding of effective methods to mitigate such damage will be critical to the survival of these objects.

This research was the second part of a project aimed at settling a fundamental, long-term preservation policy and strategy question for museums: which will be the better general approach to mitigating the damage by pollutants to inkjet prints, lowered-temperature storage or enclosures [4]? Deterioration due to pollutants occurs through chemical reactions, which may be slowed by low temperature or by minimizing contact between the pollutants and the collection objects through the use of barriers such as enclosures. The specific experiments in this project aimed to define the overall effectiveness of protection afforded by common enclosures (sleeves, envelopes, and boxes) made of paper and plastic in slowing attack by atmospheric ozone and nitrogen dioxide.

There has been previous work to evaluate the effectiveness of enclosures in reducing the damage to collection objects by atmospheric pollutants [5,6,7]. However, this has never been performed for inkjet materials, which can be considerably more sensitive to attack than other collection object types. Also those experiments typically used single high concentration tests for short periods of time to replicate the long-term, low concentration exposures that materials are subjected to in actual use conditions and somewhat overlooked the effects of the gas diffusion rates into the enclosures over time.

Material and Methods

Samples were exposed in ozone and nitrogen dioxide test chambers which were custom built for IPI and capable of automated regulation of pollution levels . The ozone was produced by means of a UV lamp, while the NO_2 was provided by a gas tank (2% NO_2 in air). The gas concentration in each chamber was monitored during the extent of the tests and kept within the target values ($\pm$ 0.5 ppm). Prior to this experiment a uniformity of induced color change was observed for free hanging prints independent of location within the chamber.

The test targets consisted of a color step wedge containing 10 levels of cyan, magenta, yellow, and black (CMYK) and two minimum density (D_{min}) patch (see figure 1).

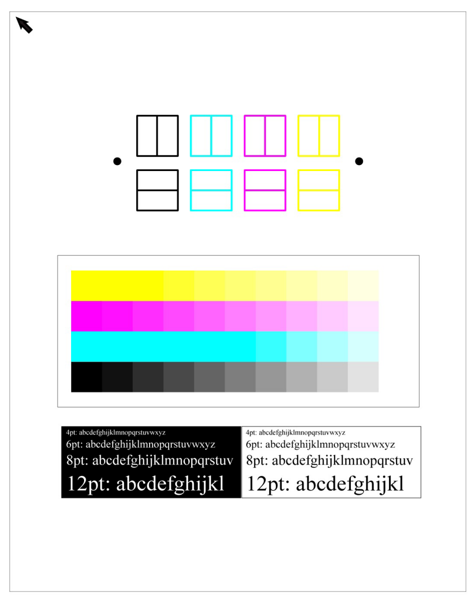

***Figure 1**. Pollution Test Target*

The targets were created using Adobe InDesign and converted to PDF for printing. The print/target was sized to fit common 4"x5" paper storage envelopes and polyester sleeves.

Four papers and four printers were used. Two of the test samples were two different micro-porous type photo papers printed with two different dye-based inkjet printers (including dye black). These prints were selected because they were found to be especially sensitive to pollutant-induced fade in previous IPI experiments. In addition, a chromogenic photographic paper and a printing paper commonly used in electrophotographic (EP) digital presses, and previously shown to be sensitive to yellowing were included. Highly sensitive examples were chosen to provide the most conservative results and recommendations. After printing, all samples were allowed to dry for one week in the dark in a climate-controlled room at 21°C and 50% RH before testing.

Table 1 summarizes the printer-paper combinations selected for the tests.

Table 1: Printer Paper Combinations Tested.

	Usage	Paper Type	Printer
1	Photograph	Microporous RC	Dye Inkjet
2	Photograph	Microporous RC	Dye Inkjet
3	Photograph	Chromogenic RC	RA4
4	Document	Coated glossy	Electrophotographic

Measurements of the color step wedge target was made using a Gretag Spectrolino/Spectroscan spectrophotometer. CIELAB (D50, 2° Observer, UV included) and color differences were calculated in the ΔE_{00} color difference unit (DE2000).The enclosures which were tested are shown in table 2.

Table 2: Test samples storage conditions.

Number	Enclosure Type
1	No enclosure (free hanging)
2	Paper envelope (non-buffered paper)
3	Paper envelope (buffered paper)
4	Window matted in a cardboard box
5	Polyester sleeve
6	Cardboard box (archival)
7	Paper envelope (buffered) in a cardboard box
8	Polyester sleeve in a cardboard box

The testing regime for printer paper combinations 1 and 2 which were tested in Ozone is summarized as follows.

Table 3: Tests for Printer Paper Combinations 1 and 2 in O_3.

O_3 Concentration	Pull time	Cumulative Exposure
5 ppm	7 days	35 ppm-days
1 ppm	35 days	35 ppm-days
0.2 ppm	175 days	35 ppm-days

The testing regime for printer paper combinations 3 and 4 which were tested in Nitrogen Dioxide is summarized as follows.

Table 4: Tests for Printer Paper Combinations 3 and 4 in NO_2.

NO_2 Concentration	Pull time	Cumulative Exposure
9 ppm	21 days	189 ppm-days
6 ppm	31.5	189 ppm-days
3 ppm	63 days	189 ppm-days

Results

All color change for the 40 printed patches in 8 different enclosure types (denoted by number as shown in table 2) are shown in figures 2 and 3.

O_3 test of Paper 1 and 2

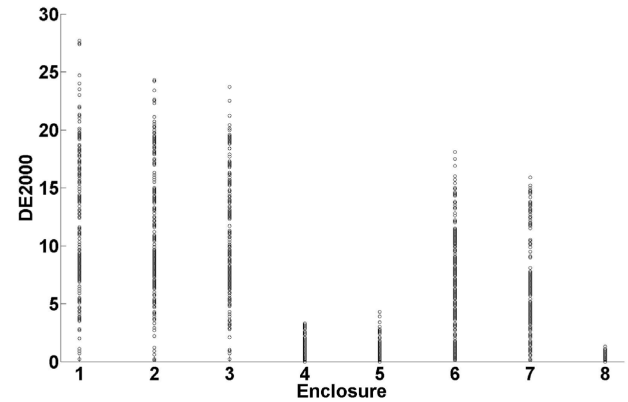

Figure 2. *All pollution induced color change data (y axis) of paper 1 and 2 in 8 different enclosures (x axis).*

NO_2 test of Paper 3 and 4

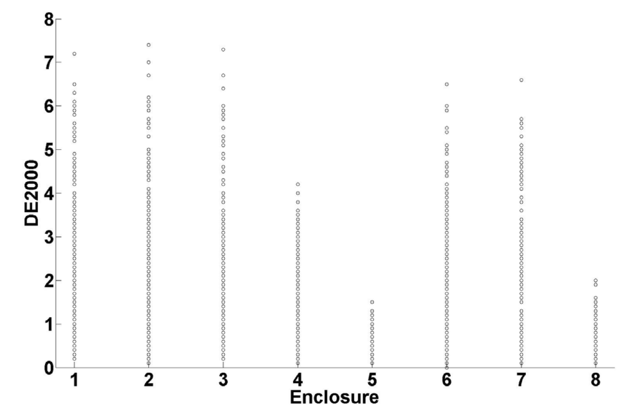

Figure 3. *All pollution induced color change data (y axis) of paper 3 and 4 in 8 different enclosures (x axis).*

Result across O_3 ppm range for Papers 1 and 2

The results for a mid grey patch for papers 1 and 2 are shown in figure 4 and 5.

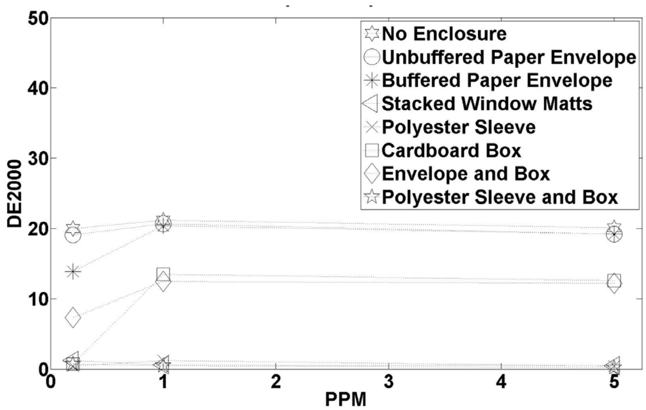

Figure 4*. Pollution induced color change of a mid grey patch printed on paper 1, for the same ppm-days exposure (y axis) at 3 different ppm levels (x axis).*

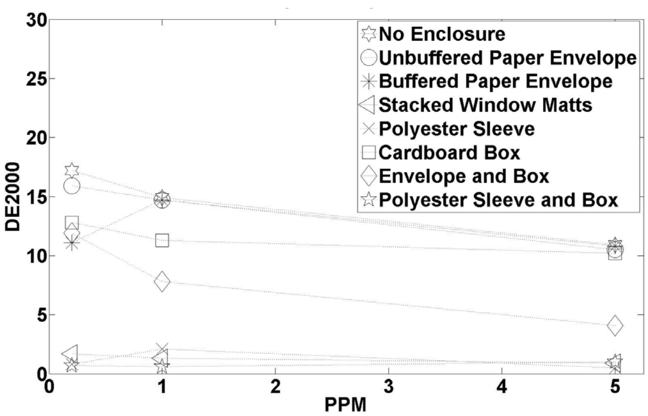

Figure 5*. Pollution induced color change of a mid grey patch printed on paper 2, for the same ppm-days exposure (y axis) at 3 different ppm levels (x axis).*

Result across NO_2 ppm range for Papers 3 and 4

The results for the minimum density (D_{min}) patches for papers 3 and 4 are shown in figure 6 and 7.

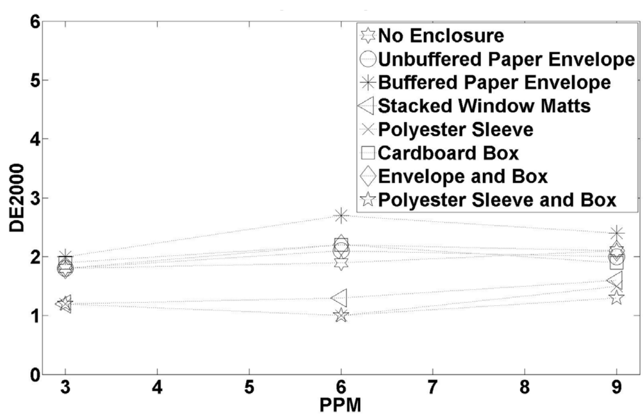

Figure 6*. Pollution induced color change of a minimum density (D_{min}) patch on paper 3, for the same ppm-days exposure (y axis) at 3 different ppm levels (x axis).*

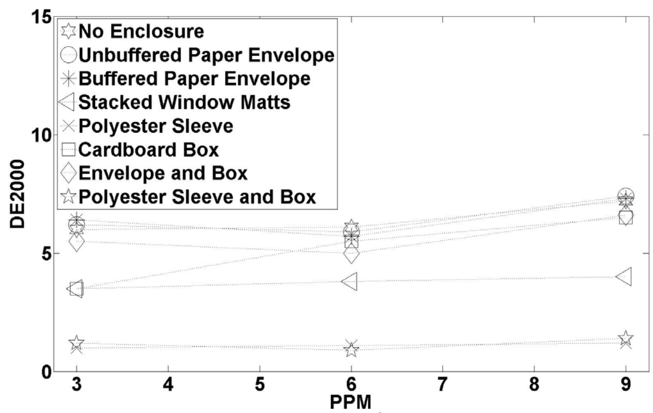

Figure 7*. Pollution induced color change of a minimum density (D_{min}) patch on paper 4, for the same ppm-days exposure (y axis) at 3 different ppm levels (x axis).*

Conclusions

As all the test conditions for a particular gas provided the same cumulative exposure, any difference in the color change observed for a particular colored patch can be thought to be due to differences of the diffusion rates of the pollutants into the enclosures, the possible reduction in gas concentration due to reaction with materials on entry and the potentially varied response of the colorant's degradation pathway to different pollutant ppm levels for the same total number of ppm-days. These results indicate varied combinations of ppm level and exposure time resulting in the same ppm-days exposure does not obey a "reciprocal relationship" [8,9,10]. This means decreasing ppm values and equally extending exposure time to create the same ppm-days exposure may not always result in the same color change to the prints inside or outside enclosures. This importantly indicates extended time periods and lower concentrations could mean an enclosures effectiveness in preventing damage from pollution could be in fact much lower/higher than that observed in highly accelerated testing (as seen in this work and elsewhere).

This could be thought to raise questions regarding the ability of such techniques to quantitatively appraise the efficacy of enclosures employed to deter real pollution damage caused over longer periods in the parts-per-billion range. Despite this uncertainty the results from the tests indicate clear guidelines on how to best proceed to mitigate damage to inkjet prints due to pollutant gases. Polyester sleeves showed by far the greatest potential to prevent damage from either pollutant or pollution exposure. They show clear benefit across the ppm and time range of exposures for both gases. This indicates that this same benefit is more likely to extend to the parts-per-billion range. Polyester sleeves when in a cardboard box showed the same change indicating that again polyester sleeves are responsible for the observed damage mitigation. Window matted prints stacked in the center of a cardboard box also show large benefits although no test was conducted for the top and bottom of the stack.

Paper envelopes (buffered and non-buffered) either alone or in a cardboard boxes provided little to no protection against pollutants.

Acknowledgements

The authors would like to acknowledge the Institute of Museum and Library Services for their support of the project.

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Author Biographies

Daniel M. Burge, Senior Research Scientist has been a full-time member of the Image Permanence Institute (IPI) staff for over 25 years. He received his B.S. degree in Imaging and Photographic Technology from the Rochester Institute of Technology in 1991. He managed IPI's enclosure testing services from 1991 to 2004. In 2004, he took over responsibility for all of IPI's corporate-sponsored research projects.
Since 2007, he has been leading IPI's investigations into digital print stability and developing recommendations for the use, storage and display of these materials in cultural heritage institutions.

Dr. Andrew Lerwill, Research Scientist, joined IPI in 2013 after completing a postdoctoral fellowship at the Getty Conservation Institute in Los Angeles, which he entered after working in research as a scientist at the Tate Gallery in the UK. He has a BSc in Physics from the University Of Hertfordshire, an MSc in Applied and Modern Optics from reading University and his PhD dissertation "Micro-fading Spectrometry: an Investigation into the Display of Traditional Watercolour Pigments in Anoxia" was published in 2011 at the Nottingham Trent University. His research interests have surrounded the use of diverse technologies to measure, predict and control photochemical damage to cultural heritage, which is a subject on which he publishes and consults.