Safety of Freezing Inkjet Prints for Long Term Storage

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Abstract

Through the history of inkjet printing, a wide variety of colorants, coatings, and supports have been used to create fine art and professional photographs collected by museums and other cultural institutions. These materials have shown, through anecdotal experience as well as scientific study, a high degree of variability with respect to decay under room condition storage. Theory, as well as experimentation, has indicated that progressively lower storage temperatures should result in progressively longer lifespans. However, there is concern that crossing the threshold into freezing conditions could have adverse effects on the image quality of prints or the physical integrity of coatings and supports as has been found with other fine art and photographic materials through history. The experiments in this project investigated whether freezing and thawing would significantly alter the physical integrity or visual appearance of inkjet prints. Printed targets and non-printed sheets were tested for a variety of common deterioration forms including ink bleed, paper yellowing, change in gloss, coating embrittlement, and increase in abrasion sensitivity. Non-frozen controls and samples that had been frozen at -12° Celsius for one week and then thawed were tested and compared for the above types of decay. The freezing and thawing was shown to have no adverse effects on the prints. Freezing conditions can therefore be used as a storage option to maximize life expectancy for these materials. Validation of the use of below freezing temperature storage conditions for these materials is a critical addition to the literature on the subject of inkjet print care.

Introduction

Throughout the history of inkjet printing, a wide variety of colorants, coatings, and supports have been used to create the fine art and professional photographs collected by museums and other cultural institutions [1]. These materials have shown, through anecdotal experience as well as scientific study, a high degree of variability with respect to decay under room condition storage [2]. Theory, as well as experimentation has shown that progressively lower storage temperatures result in progressively longer lifespans [2, 3]. However, there is concern that crossing the threshold into freezing conditions could have adverse effects on the image quality of prints or the physical integrity of the coating and support as has been found with other fine art and photographic materials through history. In fact, this concern was expressed in the International Organization for Standardization's ISO 18920:2011 *Imaging materials - Reflection prints - Storage practices*, "The rates of degradation and the potential for physical problems with extremely low temperature and/or low relative humidity storage is not well known for rapidly changing technologies such as… the many different ink jet image media (dye, pigment, wax) and base media (porous, swellable, plain paper)." The standard recommends caution when considering freezing prints because it is not known whether such extreme conditions might cause irreparable harm [4]. Therefore, establishing the safety of storage at temperatures below freezing could be extremely beneficial to collecting institutions wishing to maximize the long-term preservation of their inkjet collections. The experiments in this project investigated whether freezing and thawing will significantly alter the physical integrity or visual appearance of inkjet prints.

Methodology

Sample Selection

Fourteen different inkjet photo and fine art prints were evaluated during the following experiments, with the exception of the embrittlement experiment which utilized only nine papers. A chromogenic print was added as a benchmark. The selected products included dye, pigment, and mixed dye (CMY)/pigment (K) ink sets as well as five different paper technologies: polymer-coated RC, porous-coated RC, porous-coated fine art, uncoated fine art, and porous-coated baryta. These papers are listed in Table 1. Two replicates of each were tested and the results averaged.

Table 1: Papers selected for the investigation

Sample	Paper Type	Colorants
1	Polymer RC*	Mixed
2	Polymer RC*	Dye
3	Porous RC*	Dye
4	Porous RC*	Dye
5	Porous RC	Pigment
6	Porous RC	Pigment
7	Porous Fine Art*	Dye
8	Uncoated Fine Art	Pigment
9	Porous Fine Art*	Pigment
10	Porous Fine Art*	Pigment
11	Porous Baryta*	Dye
12	Porous Baryta*	Pigment
13	Uncoated Fine Art	Dye
14	Porous Fine Art	Dye
15	Chromogenic*	Dye

**Used in embrittlement experiments*

The test samples were either printed or non-printed depending on the needs of the particular experiment (Table 2). Note that the "non-printed" chromogenic samples used in the cracking, gloss, and yellowing tests were unexposed and processed to a paper white.

Table 2: Printed and non-printed sample tests

Printed	Non-printed
Bleed Abrasion	Yellowing Embrittlement Gloss Change

Sample Preparation

One set of samples, the non-frozen controls**,** was printed and dried for one week at 21°C and 50% relative humidity (RH). The controls were then stored at those conditions for the duration of the project. For the frozen prints, a second set of samples was printed, dried, and pre-conditioned for one week at 21°C and 50% RH. The samples were then sealed in freezer bags and frozen at -12°C for seven days. They were then removed from the freezer and thawed in the bags for 24 hours. Once they had reached room temperature, they were removed from the bags, and reconditioned for three days to 21°C and 50% RH. The tests for bleed, yellowing, embrittlement, abrasion, and gloss change were conducted under those same conditions.

Test Measurements

The samples were tested for a variety of common deterioration forms that included ink bleed, paper yellowing, gloss change, coating embrittlement, and increases in abrasion sensitivity. All ink bleed measurements were made using a Personal Image Analysis System (PIAS II) manufactured by Quality Engineering Associates, Inc., with the line width boundary threshold set to 20%. This setting was chosen because it showed greater correlation with visual observations in preliminary tests than the 70% threshold recommended by ISO 13660:2001 *Information technology - Office equipment - Measurement of image quality attributes for hardcopy output - Binary monochrome text and graphic images* [5]. The line width in millimeters was recorded both before and after freezing, with differences calculated and averaged between two replicates. Only the magenta line was monitored for change, as that color consistently bled more than cyan, yellow, and black in all previous experiments performed by the Image Permanence Institute (IPI) on these specific print materials [6].

Yellowing of the paper substrates was measured on the non-printed inkjet and chromogenic paper samples both before and after freezing, using a GRETAG Spectrolino with the illumination setting at D50, the observer angle at 2°, and no UV filter. Delta E was then calculated and averaged from the CIELab values from the two replicates.

Gloss change was measured on unprinted samples using a BYK Gardner micro-TRI-gloss gloss meter using three different angles of incident light both before and after freezing. Glossy surfaces were evaluated at 20°, semi-gloss surfaces at 60°, and matte surfaces at 85°, as per ISO 2813-2014 - *Paints and varnishes - Determination of gloss value at 20 degrees, 60 degrees and 85 degrees* [7]. Differences in gloss were calculated and averaged between two replicates.

The embrittlement test procedure used is described in ISO 18907:2013 *Imaging materials - Photographic films and papers - Wedge test for brittleness* [8]. The samples were evaluated visually, both with and without magnification, using both 45° and raking light to find the widest wedge diameter where cracking first occurred. Separate controls and frozen samples were tested, as the test is destructive.

The abrasion tests were performed with a Sutherland 2000 Rub Tester using a two-pound weight at 21 cycles per minute for 25 cycles. The abrader surface used was a high-quality photograph storage envelope paper sold by an archival supplier company. The test procedure is described fully in previous work [9]. Again, separate controls and frozen samples were tested, as the test is destructive.

The samples from all tests were also evaluated visually to verify if frozen prints showed less than, equal to, or greater damage than non-frozen control prints.

Results and Discussion

The tables below show the results obtained from the bleed, yellowing, embrittlement, abrasion, and gloss change tests for all the samples and conditions evaluated. Note that the bleed and abrasion tables include columns for colorant as the samples for those tests were printed. The yellowing, gloss, and embrittlement tables do not since only the paper was under investigation.

Bleed

The samples were evaluated to determine if freezing would induce ink bleed resulting in changes in line width. This is of concern as it can cause loss of detail in images, color fringing, color shifts, or darkening of the images overall [6]. The results are shown in Table 3.

Table 3: Change in Magenta Line Width in mm for frozen prints

Sample	Paper Technology	Colorant	Difference
1	Polymer RC	Mixed	-0.01
2	Polymer RC	Dye	0.00
3	Porous RC	Dye	0.01
4	Porous RC	Dye	0.01
5	Porous RC	Pigment	0.00
6	Porous RC	Pigment	0.02
7	Porous Fine Art	Dye	0.01
8	Uncoated Fine Art	Pigment	0.01
9	Porous Fine Art	Pigment	0.01
10	Porous Fine Art	Pigment	0.00
11	Porous Baryta	Dye	0.02
12	Porous Baryta	Pigment	0.01
13	Uncoated Fine Art	Dye	-0.04
14	Porous Fine Art	Dye	0.00
15	Chromogenic	Dye	0.00

Freezing did not cause bleed in samples as the largest line width change was only 0.04 mm. Visual assessments supported this conclusion as none of the frozen samples showed noticeable changes in line width/quality compared to the controls.

Yellowing

The samples were evaluated to determine if freezing would induce yellowing or any other discoloration of the paper support. The results are shown in Table 4.

Table 4: Yellowing of frozen prints

Sample	Paper Technology	Delta E
1	Polymer RC	0.1
2	Polymer RC	0.1
3	Porous RC	0.3
4	Porous RC	0.0
5	Porous RC	0.1
6	Porous RC	0.0
7	Porous Fine Art	0.1
8	Uncoated Fine Art	0.1
9	Porous Fine Art	0.1
10	Porous Fine Art	0.1
11	Porous Baryta	0.1
12	Porous Baryta	0.0
13	Uncoated Fine Art	0.0
14	Porous Fine Art	0.1
15	Chromogenic	0.1

Delta E values of less than 1 are likely not visually observable and all of the test samples had Delta E values at 0.3 or less. Therefore, freezing did not cause yellowing in the inkjet papers. Also, upon visual assessment, there were no differences in yellowness between the frozen papers and the controls.

Embrittlement

Samples were visually assessed to determine the widest diameter at which cracking can be seen. The ISO standard states that a difference of more than a millimeter, or .04 inches, in the radius to cracking between samples is significant [8]. Results are shown in Table 5. Positive values indicate embrittlement increase, while negative values indicate embrittlement decrease.

Table 5: Change in inches for average radius to crack

Sample	Paper Technology	Difference
1	Polymer RC	0.02
2	Polymer RC	0.02
3	Porous RC	-0.01
4	Porous RC	0.00
7	Porous Fine Art	-0.03
9	Porous Fine Art	-0.01
10	Porous Fine Art	-0.05
11	Porous Baryta	-0.07
12	Porous Baryta	0.03
15	Chromogenic	0.00

Only two papers, one porous-coated fine art and one porous-coated baryta, showed differences of more than 0.04 inches; however, the differences were in the direction of *decreased* embrittlement and material improvement, which was not expected and cannot be explained. For these reasons, freezing can be considered safe with respect to print embrittlement.

Abrasion

The samples were evaluated for various forms of abrasion (scratching, burnishing, loss of ink in the printed area, and smear of colorant into the white area). After the tests, the frozen samples were evaluated visually to determine if they abraded less than, equally to, or greater than non-frozen samples.

Table 6: Effect of freezing on abrasion sensitivity

Sample	Paper Technology	Colorants	Relation to Control
1	Polymer RC	Mixed	Frozen samples slightly more scratched than controls
2	Polymer RC	Dye	Frozen samples slightly more scratched than controls
3	Porous RC	Dye	Equal damage
4	Porous RC	Dye	Equal damage
5	Porous RC	Pigment	Controls slightly more scratched than frozen samples
6	Porous RC	Pigment	Equal damage
7	Porous Fine Art	Dye	Equal damage
8	Uncoated Fine Art	Pigment	Controls significantly more abraded than frozen samples
9	Porous Fine Art	Pigment	Equal damage
10	Porous Fine Art	Pigment	Equal damage
11	Porous Baryta	Dye	Equal damage
12	Porous Baryta	Pigment	Equal damage
13	Uncoated Fine Art	Dye	Equal damage
14	Porous Fine Art	Dye	Equal damage
15	Chromogenic	Dye	Controls slightly more scratched than frozen

Most print types behaved the same whether then had been frozen or not indicating that freezing has no adverse impact on the objects. The frozen *polymer* samples were slightly more prone to scratching than the non-frozen samples; however, with careful handling and proper enclosures the benefit of low temperature storage may outweigh the risk of minor surface scratches. Two of the pigment prints showed *reduced* abrasion sensitivity due to freezing. This is a similar outcome to the embrittlement tests.

Gloss Change

The samples were evaluated to determine if freezing would induce change to the surface reflectivity of the prints. The changes could be either increases or decreases in gloss. Results are shown in Table 7. Positive values indicate gloss increase, while negative values indicate gloss decrease.

Table 7: Gloss change for frozen prints

Sample	Paper Technology	Difference
1	Polymer RC	1.0
2	Polymer RC	0.2
3	Porous RC	0.1
4	Porous RC	-0.2
5	Porous RC	0.0
6	Porous RC	-0.2
7	Porous Fine Art	-0.1
8	Uncoated Fine Art	-0.1
9	Porous Fine Art	-0.1
10	Porous Fine Art	0.0
11	Porous Baryta	0.1
12	Porous Baryta	-0.2
13	Uncoated Fine Art	0.0
14	Porous Fine Art	-0.1
15	Chromogenic	0.2

Freezing did not cause significant change in gloss in any of the samples. Visual assessments between the frozen and control samples found no observable difference in gloss.

Conclusions

In terms of ink bleed, paper yellowing, gloss change, embrittlement, and abrasion, it is safe to freeze inkjet prints during storage to increase material life. This will provide an important option to those attempting to maximize collection usability over long periods of time. It should be noted that while freezing is safe, it may not always be desirable since low temperature storage capacity in institutions may be limited, and other collection objects may have a greater need for storage at the lowest temperatures available. Since not every inkjet print type is as sensitive to thermal or pollutant decay, those items most likely to show rapid changes should be prioritized for cold or frozen storage [2, 3, 11]. Also, very low temperature storage is costly to maintain, so cold, but not sub-freezing conditions may be more sustainable. Each institution will need to weigh their capacity for creating and maintaining frozen storage areas with their specific preservation goals.

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References

[1] H. Wilhelm, "A 15-Year History of Digital Printing Technology and Print Permanence in the Evolution of Digital Fine Art Photography – From 1991 to 2006", Proc. IS&T's NIP 22 (IS&T, Springfield, VA 2006) pp. 308-315.

[2] D. Nishimura, D. Burge, J-L. Bigourdan, and N. Gordeladze, "Reanalysis of Yellowing of Digitally Printed Materials in Cultural Heritage Collections", AIC Book and Paper Group Annual 32: 123-128 (2013).

[3] D. Burge, N. Gordeladze, and D. Nishimura, "Mitigation of Pollution-induced Deterioration of Inkjet Prints through Low Temperature Storage", Proc. IS&T's NIP 29 (IS&T, Springfield, VA 2013) pp. 44-47.

[4] ISO 18920-2011 Imaging Materials – Reflection Prints – Storage Practices (International Organization for Standardization (ISO, Geneva) www.iso.org.

[5] ISO 13660-2001 Information technology - Office equipment - Measurement of image quality attributes for hardcopy output - Binary monochrome text and graphic images (ISO, Geneva) www.iso.org.

[6] E. Salesin, D., D. Nishimura and N. Gordeladze, "Short-Term High Humidity Bleed in Digital Reflection Prints", Proc. IS&T's NIP 26 (IS&T, Springfield, VA 2010) pp. 386-389.

[7] ISO 2813-2014 - Paints and varnishes - Determination of gloss value at 20 degrees, 60 degrees and 85 degrees (ISO, Geneva), www.iso.org.

[8] ISO 18907-2013 Imaging Materials - Photographic films and papers - Wedge test for brittleness (ISO, Geneva) www.iso.org.

[9] E. Salesin, J. Scott, D. Nishimura, P. Adelstein, J. Reilly, and D. Burge, "Abrasion of Digital Reflection Prints", Proc. IS&T's NIP 24 (IS&T, Springfield, VA 2008) pp. 228–230.

[10] D. Burge, N. Gordeladze, D. Nishimura and J-L. Bigourdan, "Effects of Ozone on the Various Digital Print Technologies: Photographs and Documents", Fourth International Conference on Preservation and Conservation Issues Related to Digital Printing and Digital Photography (IOP London, UK 2010) pp. 1-6.

[11] D. Burge, N. Gordeladze, J-L. Bigourdan, and D. Nishimura, "Effects of Nitrogen Dioxide on the Various Digital Print Technologies: Photographs and Documents", Proc. IS&T's NIP 27 (IS&T, Springfield, VA 2011) pp. 205–208.

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