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Lightfastness of Ink Jet and Laser Prints

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Abstract

New digital techniques are used also in computer printers in offices of state and public administration, as well as in other institutions and organizations creating records which become potential archival documents. Therefore following and evaluation of their permanence and ageing resistance during long-lasting storage in archives is essential and inevitable.

Keywords: digital printing; ink jet, laser printers; light ageing; color measurement; lightfastness

Introduction

New digital techniques, of which electrography and ink jet printing are the most frequently used for production of optical and graphic records nowadays, are used also in computer printers in offices of state and public administration, as well as in other institutions and organizations creating records which become potential archival documents (Hanus et al. 2002, Jürgens 1999). Therefore following and evaluation of their permanence and ageing resistance during long-lasting storage in archives is essential and inevitable. A record is always an information recorded by any writing or printing ink on a certain type of carrier creating sometime very complicated complex from material point of view; in this case it is a paper and printing inks (Lavery et al. 1998, Ragauskas and Lucia 1998, Havlínová, Babiaková et a.l 2002; Havlínová, Brezová et al. 2002, Hladník et al. 2008).

This paper deals with comparison of stability of records printed by 2 laser printers and 2 inkjet printers on 3 different papers during light ageing.

Materials and Methods

Paper

Three different types of papers suitable for printing in ink jet and laser printers were selected for tests:

BRILLIANT White Paper, Canon Bubble Jet / Ink Jet Paper, A4, 90 $g.m^{-2}$, ultrawhite paper appropriate for ink jet printers;

COLOR COPY, Neusiedler, A4, 100 $g.m^{-2}$, special paper designated for laser printers;

JET 480, Best Quality, A4, 80 $g.m^{-2}$, universal paper suitable for both ink jet and laser printers.

Printers

The ink jet printers used for tests were Epson Stylus 880 (ink jet printer 1) and Hewlett Packard DeskJet 920c (ink jet printer 1). Laser printers used were Minolta Color Page Pro plus (laser printer 1) and Minolta DiALTA Color CF 1501 / 2001 (laser printer 2).

12 squares (side length of 7 mm) in all scale colors - cyan, magenta, yellow and black - were printed in four different printers on the above mentioned papers. Changes of optical properties were measured on the squares after the accelerated ageing.

Samples aged by three different light sources were compared to samples kept at the dark storage room at the Slovak National Archives.

Accelerated ageing by sunlight

Spectral composition and intensity of direct and diffuse sunlight depend on real atmospheric conditions, year season, daytime and place of observation. Printed paper samples were stuck to the inner side of double-glass window on the southern side for 9 month (from June till March) at the average temperature 23-27°C and 32-37% relative humidity. Illumination intensity ranged from 4770 to 93500 lx depending on season, time and cloudiness, exposure intensity fluctuated from 3 to 25 W/m^2. Final ageing period - expressed in hours - was calculated as average 8 hours per day.

Accelerated ageing by radiation middle pressure Hg discharge lamp with luminofor (discharge lamp)

Samples were aged by middle pressure Hg discharge lamp with luminofor - arranged at the Department of Graphic Arts and Applied Photochemistry (irradiating in the visible spectrum with small UV-A portion). Measurement conditions: average temperature of samples 34-38°C, RH 10-16%, illumination intensity 60 000 lx, exposure intensity 29W/m^2, distance of samples from light source - 19 cm. Color co-ordinates were measured after 10, 24, 48, 96 and 196 hours of illumination.

Accelerated ageing by fluorescent tube

Ageing by the light of fluorescent tube was carried out under the following conditions: temperature 15-18°C, RH 18-22%, illumination intensity 600 lx, exposure intensity 0,0031 W/m^2, distance of samples from light source - 150 cm. Color co-ordinates were measured after 100, 300, 600, 1000 and 3000 hours of illumination.

Measurements of samples stored *in dark* strong room of the Slovak National Archives under the same conditions - 17-19°C, 40% RH, darkness - as archival documents were carried out after 60, 120, 180 and 230 days.

Results and Discussion

Evaluation of optical density after accelerated ageing

Optical density is one of the parameters enabling evaluation of quality of printed records. Decreas of optical density values indicates bleaching and means lower lightfastness of inks.

Records made by ink jet printers

Light fastness of prints of two printers on two paper substrates were studied. Corresponding optical densities changes of different samples under different light sources are in the following table and on the following graphs.

Table 1. Relative optical densities (in % vs. correspondent unaged sample) during light ageing for inks Cyan (C), Magenta (M), Yellow (Y) and Black (K) printed by 2 different ink jet printers on papers Brilliant (B) and Jet (J)

Ageing	Sunlight (1600 h)		Discharge lamp (196 h)		Fluorescent (3000 h)		Darkness (5520 h)	
Paper	B	J	B	J	B	J	B	J
INK JET PRINTER 1								
C	92	94	91	93	99	100	100	100
M	37	50	48	68	94	97	99	100
Y	58	63	58	70	100	98	100	100
K	47	55	62	71	96	98	99	100
INK JET PRINTER 2								
C	74	79	77	83	95	97	98	98
M	45	57	65	75	94	94	99	98
Y	72	82	84	91	98	98	100	97
K	96	100	98	99	98	99	98	97

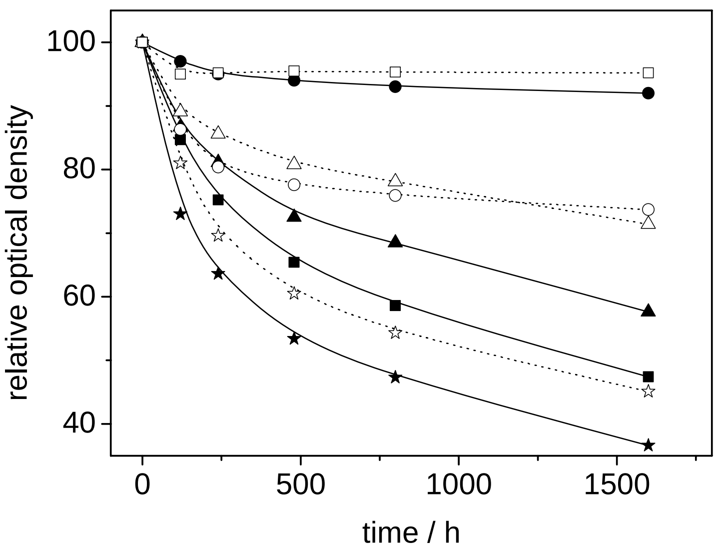

Figure 1. Changes of optical density for inks printed on Brilliant paper during ageing by sunlight (*ink jet printer 1*: cyan ●, magenta★, yellow▲, black ■; *ink jet printer 2:* cyan ○, magenta ☆, yellow Δ, black □)

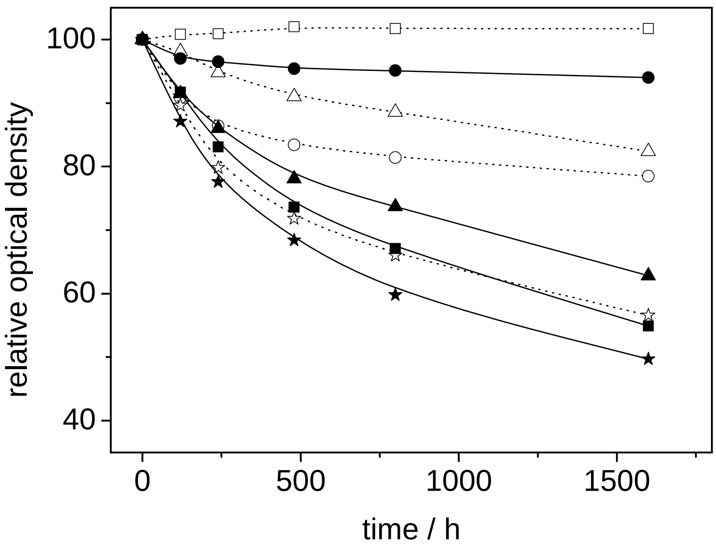

Figure 2. Changes of optical density for inks printed on Jet paper during ageing by sunlight (*ink jet printer 1*: cyan ●, magenta★, yellow▲, black ■; *ink jet printer 2:* cyan ○, magenta ☆, yellow Δ, black □)

Records on Brilliant paper showed bigger changes of optical density for inks from both printers compared to records made on Jet paper (Table 1). The highest change showed magenta ink for both printers on Brilliant paper aged by sunlight (printer 1 - drop to 37%, printer 2 - drop to 45%). The lowest changes of optical density were observed for ageing by fluorescent tube (up to 6% for both printers) and, of course, for samples stored in darkness (up to 1,5 % for printer 1, up to 3% for printer 2). Higher lightfastness against sunlight and discharge lamp ageing were found for inks of printer 2 except of cyan ink, which was more stable for printer 1. Figures 1, 2 show changes of relative optical density for magenta, cyan, yellow and black inks printed by both printers on Brilliant and Jet paper, aged by sun. Low light fastness of yellow and magenta inks corresponds with results published in (Ragauskas and Lucia 1998, Pratt 1997).

Records printed by laser printers

Changes of records printed by laser printers were evaluated for two paper substrates (papers Color Copy and Jet).

Tab. 2: Relative optical densities (in % vs. correspondent unaged sample) during light ageing for inks Cyan (C), Magenta (M), Yellow (Y) and Black (K) printed by two different ink jet printers on papers Color Copy (C) and Jet (J)

Ageing	Sunlight (1600 h)		Discharge lamp (196 h)		Fluorescent (3000 h)		Darkness (5520 h)	
Paper	CC	J	CC	J	CC	J	CC	J
LASER PRINTER 1								
C	99	99	98	68	100	100	97	100
M	80	82	89	63	98	98	100	99
Y	80	79	90	77	100	99	95	100
K	100	100	101	100	100	100	100	99
LASER PRINTER 2								
C	100	100	100	99	100	99	100	100
M	63	64	88	89	97	99	100	99
Y	95	92	95	98	98	100	100	96
K	87	99	100	100	98	98	98	99

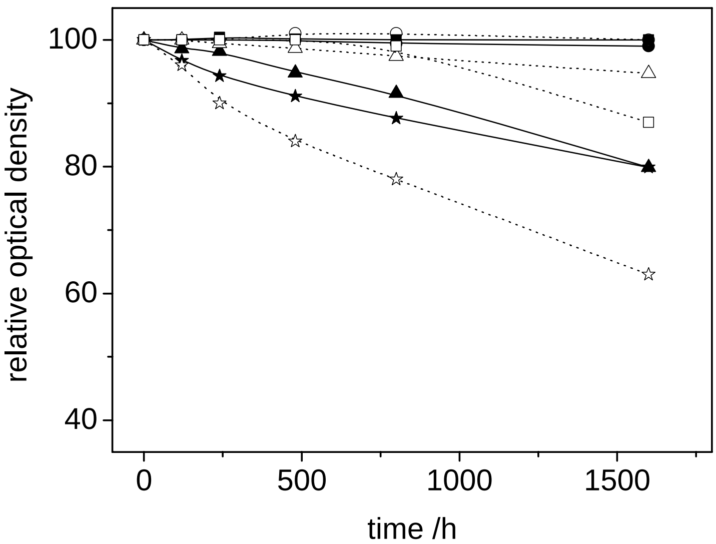

Figure 3. Changes of optical density for inks printed on Color Copy paper during ageing by sunlight (*ink jet printer 1*: cyan ●, magenta★, yellow▲, black ■; *ink jet printer 2:* cyan ○, magenta ☆, yellow Δ, black□

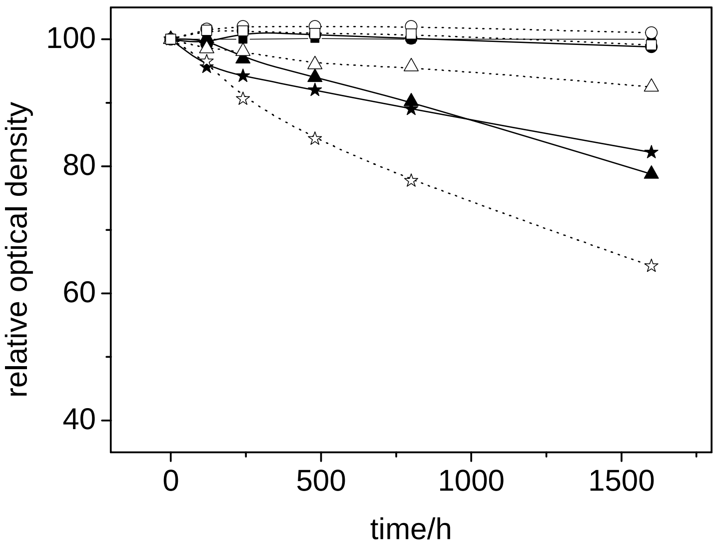

Figure 4. Changes of optical density for inks printed on Jet paper during ageing by sunlight (*ink jet printer 1*: cyan ●, magenta★, yellow▲, black ■; *ink jet printer 2:* cyan ○, magenta☆, yellow Δ, black □)

For both tested laser printers there was no significant influence of paper on changes of optical density observed. The highest changes caused the sunlight and discharge lamp radiation on both papers (Table 2). The lowest lightfastness (printer 1) showed yellow color (Jet paper) under the influence of the sunlight (21% decreases) and magenta aged by discharge lamp radiation (37% decrease). These inks (M, Y) showed the lowest lightfastness also printed on Color Copy paper (decrease up to 20%). As far as the printer 2 concerns, the worst lightfastness was observed for magenta ink; for records on both papers it was found approximately 36% drop caused by the sunlight and approximately 11% drop caused by discharge lamp radiation. On the contrary, yellow ink showed excellent lightfastness in all test ageing procedures (decrease up to 7%). The best lightfastness for both printers and all ageing procedures showed cyan and black inks - optical density decrease up to 5%. Figures 3, 4 show changes of relative optical density for magenta ink printed by both printers on Copy Color and Jet paper.

Study of changes of total color difference

Colorimetric CIELab values L^*, a^*, b^* of cyan, magenta, yellow and black inks on three various paper printed by two ink jet printers and two laser printers were measured during light aging (Tab. 3, 4). L^* values represent the lightness, chromatic coordinates a^* and b^*

scales from red to green and from yellow to blue. The difference between the colors of two inks ΔE^*_{ab} can be calculated according to the equation

$$\Delta E^*_{ab} = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2} \quad (1)$$

Records made by ink jet printers

Changes of total color difference ΔE^*_{ab}, brightness ΔL^* and color co-ordinates Δa^* and Δb^* arising on printed samples (C, M, Y, K) by different types of light ageing were followed using the same samples as the samples used for studying of optical densities. Nonaged samples ware used as reference color samples

Tab. 3: Total color differences during light ageing of inks Cyan (C), Magenta (M), Yellow (Y) and *Black (K) printed by two ink jet printers on papers Brilliant (B) and Jet (J)

Ageing	Sunlight (1600 h)		Discharge lamp (196 h)		Fluorescent (3000 h)		Darkness (5520 h)	
Paper	B	J	B	J	B	J	B	J
				INK JET PRINTER 1				
C	14	11	15	11	14	14	15	14
M	46	35	37	25	15	13	14	11
Y	29	26	27	20	6	5	6	6
K	31	25	20	15	3	2	2	2
				INK JET PRINTER 2				
C	14	8	23	16	10	10	14	13
M	47	37	29	21	15	14	12	10
Y	18	12	10	7	5	5	6	5
K	2	0.5	1	0.7	1	0.8	1	1.4

Paper Brilliant - ink jet printer 1

The highest color change, ΔE^*_{ab} = 46, showed magenta ink after the sunlight ageing, order of color differences of inks was MKYC, followed by change after discharge lamp ageing (ΔE^*_{ab} =37; order of color difference of inks MYKC) and fluorescent tube ageing (ΔE^*_{ab} =15; order of color difference of inks MCYK). For samples stored in darkness the biggest change was observed for cyan ink, ΔE^*_{ab} = 15, with order of color differences of inks CMYK.

Paper Brilliant - ink jet printer 2

The highest color change showed again magenta ink after sunlight ageing (ΔE^*_{ab} = 47; order of color difference of inks MYCK), discharge ageing (ΔE^*_{ab} = 29; order of color difference of inks MCYK) and fluorescent tube ageing (ΔE^*_{ab} = 15; order of color difference of inks MCYK). For samples stored in darkness the biggest change was observed for cyan ink (ΔE^*_{ab} = 14; order of color difference of inks CMYK).

Paper Jet - ink jet printer 1

The sunlight and discharge lamp caused the highest color change of magenta ink (sunlight ΔE^*_{ab} = 35; order of color difference of inks MYKC, discharge lamp ΔE^*_{ab} = 25; order of color difference of inks MYKC). The fluorescent tube light caused the biggest change of cyan ink; the same change was observed for samples stored in the darkness (for both types of ageing ΔE^*_{ab} = 14; CMYK).

Paper Jet - ink jet printer 2

The sunlight, discharge lamp and fluorescent tube ageing caused again the highest color change of magenta ink (sunlight ΔE^*_{ab} = 37; order of color difference of inks MYCK, discharge lamp ΔE^*_{ab} = 21; order of color difference of inks MCYK and fluorescent tube ΔE^*_{ab} = 14; order of color difference of inks MCYK). For samples stored in darkness the highest color change was observed for cyan ink.

The highest lightfastness was observed for black ink from printer 2 while the lowest lightfastness showed magenta ink under the influence of the sunlight, discharge lamp radiation and fluorescent tube (Tab. 3, Fig. 5). The total color difference sharply changed by fluorescent light ageing within the range of 1000 to 3000 hours and in darkness within 180 and 230 days (3000-5500 hours). Cyan inks from both printers degraded nearly to the same level for all types of ageing regardless to the presence of discharge lamp radiation in light sources (Figures 6).

*Change of Lightness ΔL**

Lightness of cyan inks on both papers on samples printed by both ink jet printers was not substantially influenced by light ageing regardless of the used light source. Remaining inks (magenta, yellow, black) faded by the influence of ageing. The most substantial fading caused the sunlight and discharge lamp (Fig. 6). The highest changes of lightness were recorded for magenta ink from both printers and black ink from the printer 1.

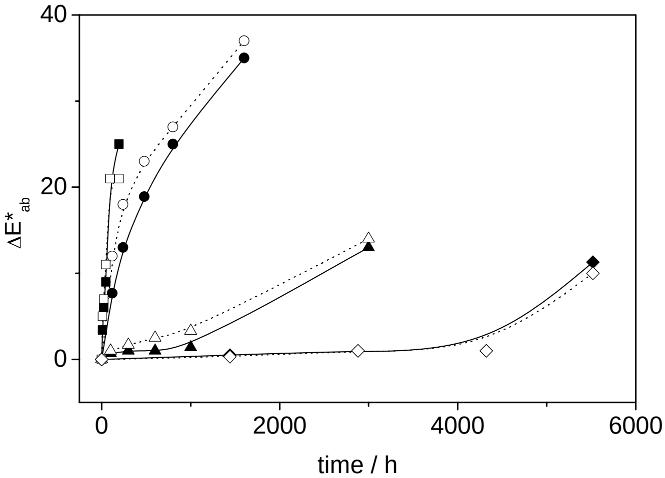

Figure 5. Changes of ΔE^* during light ageing by three different light sources for magenta ink on Jet paper (*ink jet printer 1:* sunlight ●, discharge lamp ■, fluorescent ▲, darkness ♦; *ink jet printer 2:* sunlight ○, discharge lamp □, fluorescent Δ, darkness ◊)

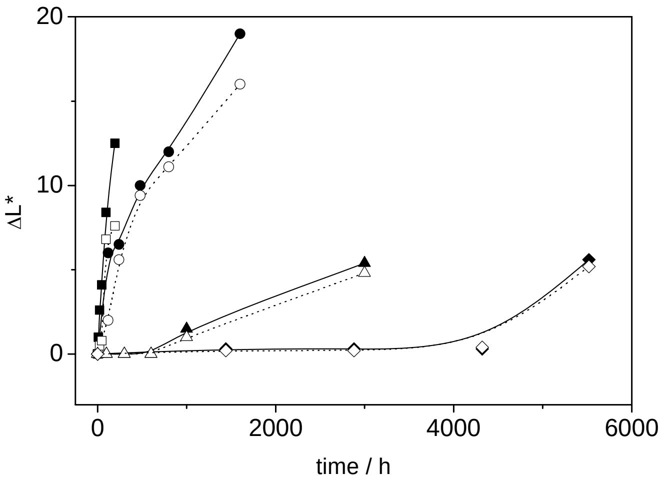

Figure 6. Changes of ΔL^* during light ageing by three different light sources for magenta on Jet paper (*ink jet printer 1:* sunlight ●, discharge lamp ■, fluorescent ▲, darkness ♦; *ink jet printer 2:* sunlight ○, discharge lamp □, fluorescent Δ, darkness ◊)

Change of color co-ordinates Δa, Δb**

Values of a* co-ordinate for cyan inks samples were shifted to green range of the color space CIELAB (negative values of a*) by ageing, however mostly for samples stored in the darkness. Values of the b* co-ordinate for cyan inks samples aged by fluorescent light and in the darkness were shifted to blue range (negative values of b*) and to yellow range (positive values of b*) for samples aged by the sunlight and discharge light. Color of magenta inks was shifted to green (negative Δa*) and to yellow (positive Δb*) range of the color space (Fig. 7, 8). Color of yellow and black inks were shifted to red range (positive Δa*). Positive changes of coordinates Δb* of yellow ink indicates the shift to blue range and contrary – negative shift of coordinates Δb* for black inks indicates the shift to yellow range of the color space.

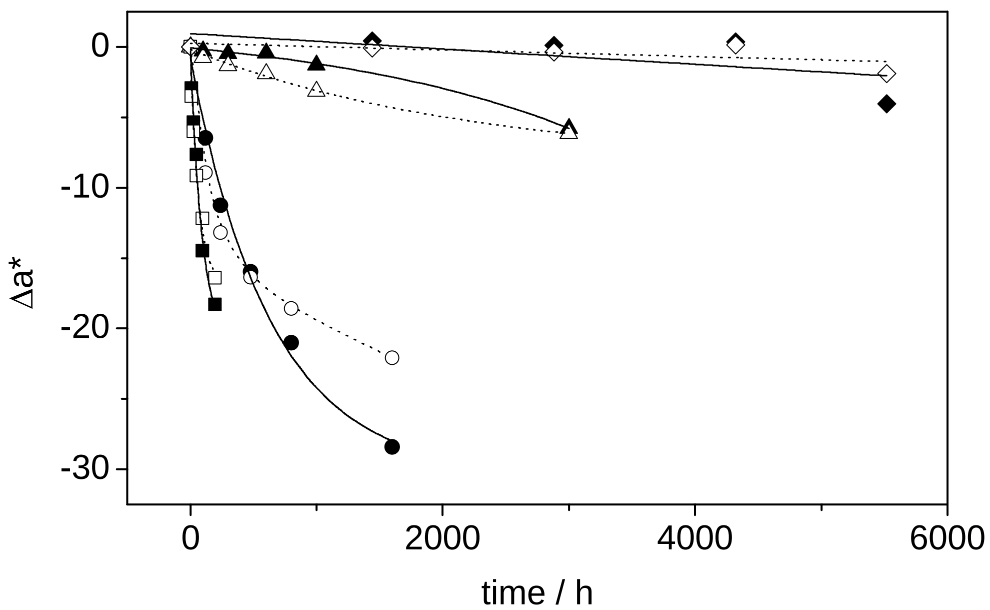

Figure 7. Changes of Δa^* during light ageing by three different light sources for magenta on Jet paper (*ink jet printer 1:* sunlight ●, discharge lamp ■, fluorescent ▲, darkness ♦; *ink jet printer 2:* sunlight ○, discharge lamp □, fluorescent Δ, darkness ◊)

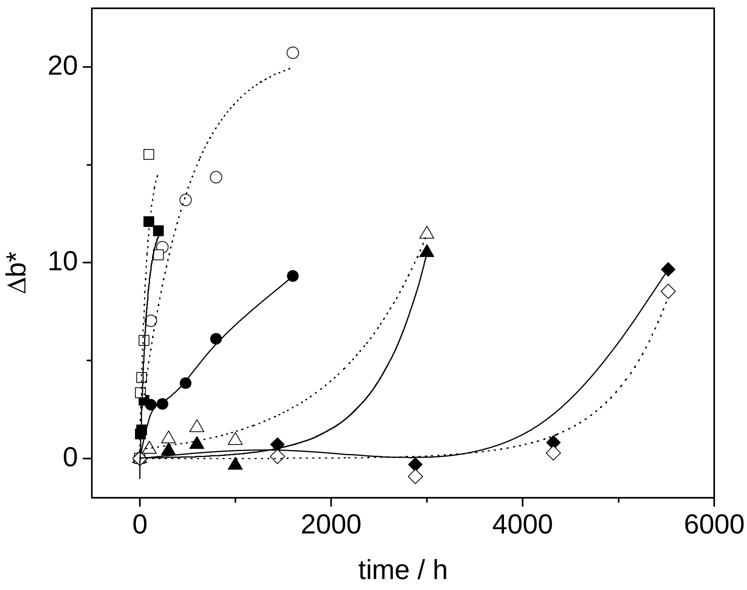

Figure 8. Changes of Δb^* during light ageing by three different light sources for magenta on Jet paper (*ink jet printer 1:* sunlight ●, discharge lamp ■, fluorescent ▲, darkness ♦; *ink jet printer 2:* sunlight ○, discharge lamp □, fluorescent Δ, darkness ◊)

Records printed by laser printers

The color differences were compare also for samples printed by laser printers. Results obtained for inks on papers Color Copy and Jet are summarized in Tab. 4 and on Fig. 9.

Paper Color Copy – laser printer 1

The highest color change caused by all types of the light ageing showed cyan color (ΔE^*_{ab} 21-22). Substantial changes of color difference were recorded also for magenta and yellow inks (ΔE^*_{ab} 10-21). The lowest color changed was observed for black ink (ΔE^*_{ab} 0.3–0.8). There were no significant differences among the final values of particular ageing type for this ink.

Paper Color Copy – laser printer 2

Ageing by the sunlight and discharge lamp caused the highest color changes of magenta (ΔE^*_{ab} 26 and 16) and cyan inks (ΔE^*_{ab} 16 and 15). Fluorescent tube and storage of samples in the darkness caused the highest color change for cyan ink (ΔE^*_{ab} 17 and 16). The highest lightfastness was recorded for black ink.

Tab. 4: Total color difference after light ageing of inks Cyan (C), Magenta (M), Yellow (Y) and *Black (K) printed by two different laser printers on papers Color Copy (C) and Jet (J)

Ageing	Sunlight (1600 h)		Discharge lamp (196 h)		Fluorescent (3000 h)		Darkness (5520 h)	
Paper	CC	J	CC	J	CC	J	CC	J
				LASER PRINTER 1				
C	21	20	21	11	22	21	20	22
M	17	17	15	23	14	15	15	14
Y	21	20	15	18	10	10	11	10
K	0.4	0.5	0.7	0.8	0.3	0.3	0.5	0.6
				LASER PRINTER 2				
C	16	16	15	14	17	15	16	15
M	26	25	16	16	12	12	12	11
Y	9	9	10	9	9	8	9	9
K	1	1	1	0.2	1	1	2	1.5

Paper Jet – laser printer 1

The change of color difference was the highest for cyan ink for the samples aged by the sunlight, fluorescent tube and samples stored in the darkness (ΔE^*_{ab} 20; 21 and 22). Samples aged by discharge light showed the highest color change for magenta ink (23). The highest lightfastness (the least change) was observed for black ink (ΔE^*_{ab} from 0.3 to 0.8).

Paper Jet – laser printer 2

The sunlight and discharge ageing caused the biggest color change of magenta (ΔE^*_{ab} 26 and 16) and cyan inks (ΔE^*_{ab} 16 and 14). Samples aged by fluorescent light and samples stored in darkness showed the biggest color change for cyan ink (ΔE^*_{ab} 15). Again, the least change was observed for black ink (ΔE^*_{ab} from 0.2 to 1.5).

Lightfastness of records printed by laser printers was not affected by the paper substrate. Lightfastness of cyan and yellow inks printed by printer 2 was higher than that from the printer 2 for all types of ageing. Magenta ink from the printer 1 was more stable against the sunlight and discharge lamp; on the contrary magenta ink from the printer 2 was more stable against fluorescent light and in dark storage. The highest lightfastness was observed for black ink from the printer 1. In general, it can be stated that lightfastness of inks from the printer 1 was higher for all tested ageing conditions.

*Change of lightness ΔL**

Lightness of cyan inks on both papers printed by both laser printers was not substantially influenced by light ageing regardless of the used light source. Magenta (Fig. 9) and yellow inks faded during light ageing. Changes of lightness of black inks were not significant (not exceeding ΔL^* 1.4).

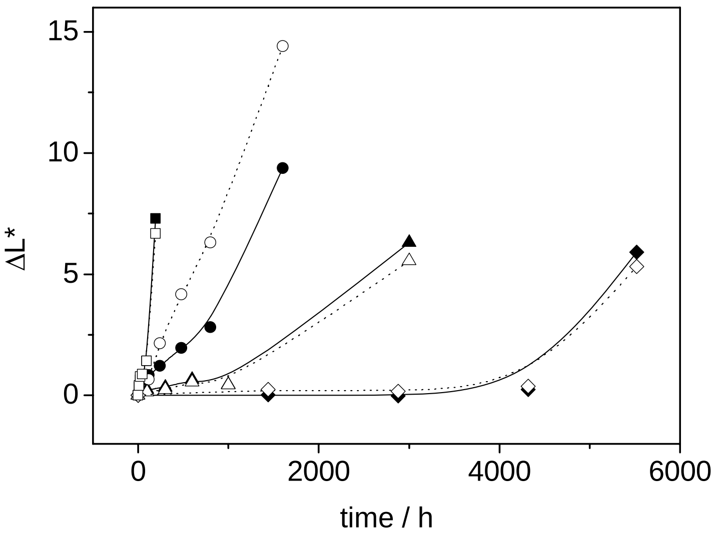

Figure 9. Changes of ΔL^* during light ageing by three different light sources for magenta on Color Copy paper (*ink jet printer 1:* sunlight ●, discharge lamp ■, fluorescent ▲, darkness ♦; *ink jet printer 2:* sunlight ○, discharge lamp □, fluorescent Δ, darkness ◊)

Change of color co-ordinates Δa, Δb**

Values of a* co-ordinate of cyan inks printed by both laser printers were shifted to green range (shift towards negative values) and values of the b* co-ordinate to blue range (shift towards negative values) of the color space CIELAB by ageing. Values of a* co-ordinate of magenta inks were shifted to green range (shift towards negative values) (Fig. 10) and values of the b* coordinate to blue range (shift towards negative values) of the CIELAB color space (Fig. 11). Color of yellow inks were shifted to red range (positive Δa*) and blue range (negative Δb*) of the CIELAB color space. The lowest changes of both co-ordinates were recorded for black inks (Δa* from -0.6 to 0.01; Δb* from -0.9 to 1.9).

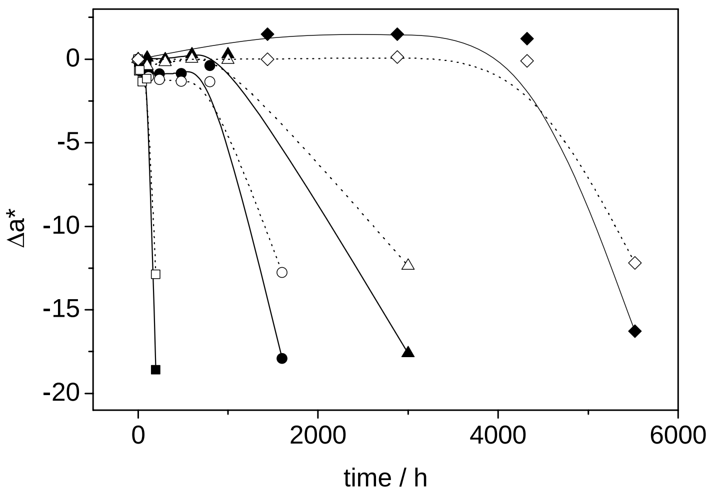

Figure 10. Changes of Δa^* during light ageing by three different light sources for magenta ink on Color Copy paper (*ink jet printer 1:* sunlight ●, discharge lamp ■, fluorescent ▲, darkness ♦; *ink jet printer 2:* sunlight ○, discharge lamp □, fluorescent Δ, darkness ◊)

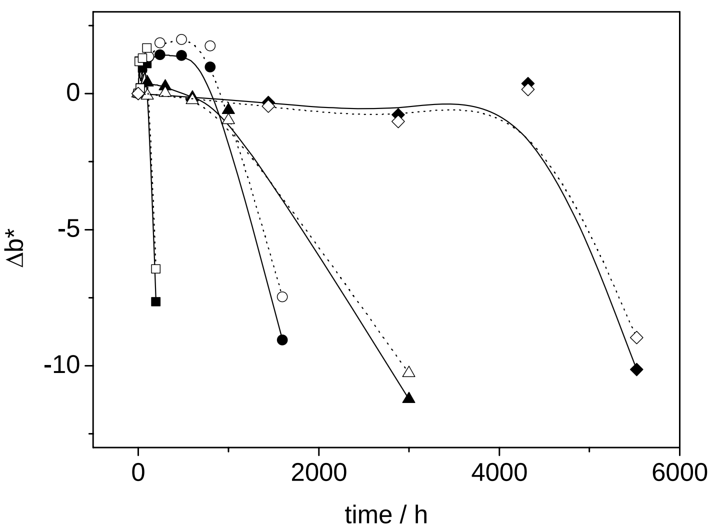

Figure 11. Changes of Δb^* during light ageing by three different light sources for magenta ink on Color Copy paper (*ink jet printer 1:* sunlight ●, discharge lamp ■, fluorescent ▲, darkness ♦; *ink jet printer 2:* sunlight ○, discharge lamp □, fluorescent Δ, darkness ◊)

Conclusion

The aim of this work was evaluation and comparison of lightfastness of color records (cyan, magenta, yellow, black) printed by ink jet and laser printers on three different types of papers artificially aged by different types of light sources. The highest changes of color difference were observed for records and inks samples aged by the sunlight and middle pressure mercury discharge lamp with luminofor.

The significant influence of paper type was observed for color records made by ink jet printers. Changes of color difference for records by the influence of light showed that Jet paper was more suitable for archiving purpose and observed color changes were smaller than changes observed on other papers. Different paper supports had no significant influence on color changes of records printed by laser printers.

The highest color difference were observed for magenta ink printed by ink jet printers and cyan inks printed by laser printers. On the basis of obtained results it can be stated that lightfastness of inks printed by ink jet printers increased in the following order: Magenta < Cyan < Yellow < Black. The lightfastness of inks printed by laser printers increased in the following order: Cyan < Magenta < Yellow < Black. These orders were not observed for all combinations of tested samples and types of light ageing; however they occurred the most frequently in our experiments. The highest permanence and lightfastness was observed for black inks printed by laser printers as well as black inks printed by printer Hewlett Packard 920c. Very significant color difference was that of cyan ink; it was observed for all samples printed by ink jet and laser printers for all types of light ageing.

The most permanent ink among all tested laser printers inks was black ink; the other inks – cyan, magenta, yellow – showed more or less the same lightfastness as tested ink jet printers inks. So, it can be stated that from the point of view of lightfastness the color records printed by laser printers are comparable with ink jet color records. However, this lightfastness – for laser printers as well as for ink jet printers - can be significantly influenced by color pigment used for their preparation.

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