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EVALUATION OF THE INFLUENCE OF ARTIFICIAL UV AGEING OF PRINTED IMAGES

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Abstract: *The main problems encountered in the long storage of printed or painted images are associated with deterioration of color characteristics and loss of information from them. The changes, that occur are due to the processes of ageing of the inks and papers. Natural ageing is a rather slow process. Therefore a study of the changes occurring with the printed images over the time under artificial UV radiation has been carried out. For the purpose of this experiment, was designed specialized test form, containing thousands of control patches for estimating the spectral, color and optical density shifts during the artificial ageing. The main goals of this research are to investigate the influence of artificial UV ageing on the optical density, spectral and color characteristics of printed images. The experiment have been performed in real printing conditions on state of art offset printing presses. The printing media used in the experiment are matte coated and uncoated offset paper, which are chosen because they are wide used all over the world. The test images and all the thousands of color control patches have been submitted to UV artificial ageing. The spectral and color characteristics of the inks and paper were examined during the different UV ageing period. The obtained results shows changes in all of investigated parameters during artificial ageing. The results are important from scientific and practical point of view. They might be used for modeling of ageing processes and could be very useful for recovering of original color characteristics of aged images.*

Key words: UV ageing, physical - mechanical and optical properties of papers, color characteristics

1. INTRODUCTION

Printing production has a great variety: books, newspapers and magazines, advertising products, packaging and more (Timar, Varodi & Gurău, 2016; Sonderegger et al., 2015).
Over time, sealed materials get older and can be caused by various factors: the natural ageing of paper and inks, the effects of temperature, the environment and human intervention (Valkova, 2016).
The main problems that occur when storing various printed matter for a long time are related to the deterioration of color characteristics and loss of information from them, the change in color range and the color difference that result from the aging of the ink (Fellers et al., 1989; Spiridonov, Shopova & Boeva-Spiridonova, 2012; Yanbing, 2019).
Each paper changes its physical, mechanical and chemical properties over time. The durability of the paper is its ability to retain unchanged over time certain physical-mechanical, optical and chemical properties (Dolezalek, 2004; Timar, Varodi & Gurău, 2016). This ability is determined by the degree of change in the properties of the paper in artificial ageing. The durability of a paper depends on its composition and the conditions of receipt and storage. It complies with the following standards: for document papers ISO 9706: 1994, for archival papers in ISO 11108: 1996, for writing and printing papers - in ISO 11798: 1999. For example, the pH of the aqueous extract on durable paper should be 7.5-10, be stuck in a neutral environment. The paper should not contain high-fiber material and be high in α-cellulose (ISO 2846-1:2006; Modzelewska, Patelski & Okon, 2013; Sonderegger et al., 2015).
Artificial ageing can also be accomplished by light irradiation with UV rays in a special chamber equipped with a UV lamp (300-400nm). The test samples are irradiated on one side. The duration of treatment is from 5min to 320 min at 48°C. Samples are then conditioned.
Purification of water from the pulp and paper and printing industry and the processing of waste paper are important for environmental protection (Beschkov et al., 2020; Kostadinova et al., 2018; Parvanova-Mancheva et al., 2020; Vasileva, Petrov & Beschkov, 2009).
UV irradiation has a significant impact on the elasticity and flexibility of the fibers and makes the paper more brittle and fragile. Improper storage is most often the cause of the mechanical destruction of works of art, it also changes the colors of textile materials (Boeva & Radeva, 2014; Dolezalek, 2004; ISO 2846-1:2006; Kašiković et al., 2015; Li & Lyu, 2020; Stančić et al., 2014; Valkova, 2016).

Improper storage is most often the cause of the mechanical destruction of works of art (Džimbeg-Malčić et al., 2003; ISO 13656:2000, ISO 13655:2003).

2. METHODS

2.1. Materials and conditions of the experiment

Two wide used and popular types of papers have been chosen for the experiment:

- Uncoated offset paper – with weight 80 g/m^2;
- Matte coated paper – 120 g/m^2.

On the paper samples the following analyses were made:

- Estimation of weight, [g/m^2] (EN ISO 536:1998);
- The pH of the water extraction according to (ISO 8947-83). Based on estimation of the pH of the water extract the alkalinity or acidity is determined of the paper.

The results of the analysis of the two types of printed papers are given in Table 1.

Table 1: Characteristics of used the papers

Type of Paper	Weight of papers, (g/m^2)	pH of the water extract before UV ageing	pH of water extract after UV ageing
Uncoated offset paper	80	7.8	7.3
Coated matte paper	120	7.6	7.0

The pH of the water extraction for both types of paper changes slightly, indicating no significant changes in the chemical composition of the fibrous material components.

2.2 Selection of prints that meet all the offset printing technology requirements

Implemented print plates were positive acting and were exposed by Computer to Plate System – Kodak. A special test form, which contains a multiple test charts and patches, have been designed. The printing of the test sheets in this experiment was carried out on a Heidelberg Speedmaster four-color offset printing machine, size 35x50 cm, model SX 52-5-L with ANICOLOR inking unit.
Room conditions: temperature ~ 25^{o}C and relative humidity ~ 65%. Inks - Huber Group - Maxima Series: Cyan - 43 F 50 MX, Magenta - 42 F 50 MX, Yellow - 41 F 50 MX, Black - 49 F 50 MX; Dampening solution – 6% isopropanol content, pH = 5.3, to 10 ± 1°C. The printing of the test forms is carried out under the following conditions: sequence of the inks – Black, Cyan, Magenta, Yellow.
Optimal inking quantity is predetermined by the ISO (ISO 12647-2:2013) recommendation and maximum print contrast method for each combination of paper-ink-printing machine. Table 2 gives the test values for optimal inking.

Table 2: Optimal inking values for paper

Type of Paper	Cyan	Magenta	Yellow	Black
Uncoated offset paper	1.10	1.10	0.90	1.20
Coated matte paper	1.55	1.60	1.45	1.85

2.3. Experiment conditions

Artificial UV ageing was conducted in a Q-SUN Xenon Tests camera, which uses a full-spectrum xenon lamp to reproduce the material damaging wavelength. The camera for UV ageing irradiation in the UVA and UVB spectrum in the range of 320 - 800nm. In experiment are used fluorescent UV lamps (UVA – 351 and UVB - 313EL). They provide the ability to simulate sunlight with a peak at 340 nm.
The measurements were done on intervals: 0 hours, 6 hours, 12 hours, 24 hours, 36 hours, 48 hours, 72 hours, 144 hours and 200 hours. Colour measurements were performed with spectrophotometer GretagMacbeth Spectrolino and X-Rite i1i0: GM Profile Maker, GM Measure Tool и GM Profile Editor and

i1Profiler. Measurement conditions – standard light source D50, measuring geometry 45°/0° or 0°/45°, 2° standard observer (ISO 13655:2017; European Color Initiative; ICC.1:2004-10; ISO 2470:2002). For the purpose of the experiment, about 36,000 color measurements were performed in the CIE Lab and CIE Lch systems.

Artificial UV ageing is subjected to printed TC 6.02 control scales, which are used to generate ICC color profiles. The scale contains 999 colored boxes measuring approximately 5x5mm. The colors of the fields in the TC 6.02 scale are specially selected because they are important, and some of them are even "critical" in color reproduction. The scale contains "remembering" colors, such as body colors, colors of the surrounding nature (grass, sky), etc.

3. RESULTS AND DISCUSSION

3.1 Influence of artificial UV ageing on the densitometric characteristics

Investigation of the effect of artificial UV ageing on the of printed images. The quality of the printed image is shaped by a number of conditions, including those of the printing process. Optical density measurement refers to solid and raster images obtained with the main colors cyan, magenta, yellow and black. The optical density is determined by the thickness of the ink layer.

3.1.1. Influence of artificial UV ageing on the optical density

Graphic representation of the change in optical density (D) for Cyan, Magenta, Yellow, Black at 100%, 40% and 7% of the raster fields for both papers, depending on the time of artificial UV ageing.

Cyan, magenta, yellow, and black were selected in 100%, 40%, and 7% of the raster fields, respectively, because they represented the dark (100%), medium (40%), and light (7%) tones, respectively. The following several figures (Fig. 1 and Fig. 2) show graphically the dependences of optical density on the duration of artificial UV ageing.

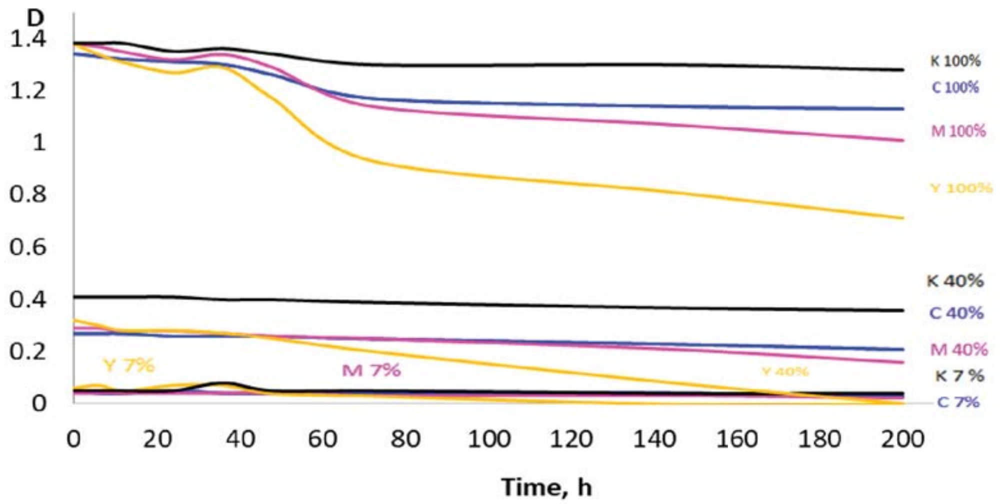

Figure 1: Influence of artificial UV ageing on the optical density of coated matte paper

Figure 1 shows that, as a result of artificial UV ageing of coated matte paper, the reduction of optical density in the dark and medium tones from 0 h to 24 h is relatively small for the 4 colors. After 36 h serious decrease was observed in Yellow and Magenta. In light tones there is a slight decrease in optical density up to the 36th hour, and after the 48th hour there is a serious decrease and even expressed in vanishing of the raster elements for Yellow. In Cyan and Black, the decrease in optical density is almost not observed.

Figure 1 shows that as a result of artificial UV ageing of surface-coated matte paper, a decrease in optical density is observed at 100% Yellow from 6 hours to 200 hours, with a significant difference and a change in the negative direction ($\Delta D_{0/200}$=0.67). For a 40% Yellow decrease in the optical density values is observed from 6 hours to 144 hours, then the values of D = 0 at 200 hours, therefore there is a deletion of the raster elements. At 7% Yellow, a decrease in D was observed from 6 hours to 72 hours, after which

at 144 hours and 200 hours the yellow color "disappears". At 100% Magenta, a significant difference was observed from 48 hours $\Delta D_{0/200}$= 0.37, and for 40% Magenta after 144 hours from UV ageing. For 100% Cyan the losses are relatively small. For the other raster fields 100% Black, 40% Cyan, 40% Black, 7% Cyan, 7% Magenta, 7% Black, the decrease in optical density is almost not observed.
Figure 2 shows that as a result of artificial UV ageing of uncoated offset paper, the decrease in optical density in the dark and medium tones from 0 h to 48 h is relatively small for the 4 colors. After 72 h of ageing - serious decrease was observed in Yellow and Magenta. In the light tones occurs a change between the 72 and 144th hours at Yellow. In Cyan and Black, the decrease in optical density is almost not observed.

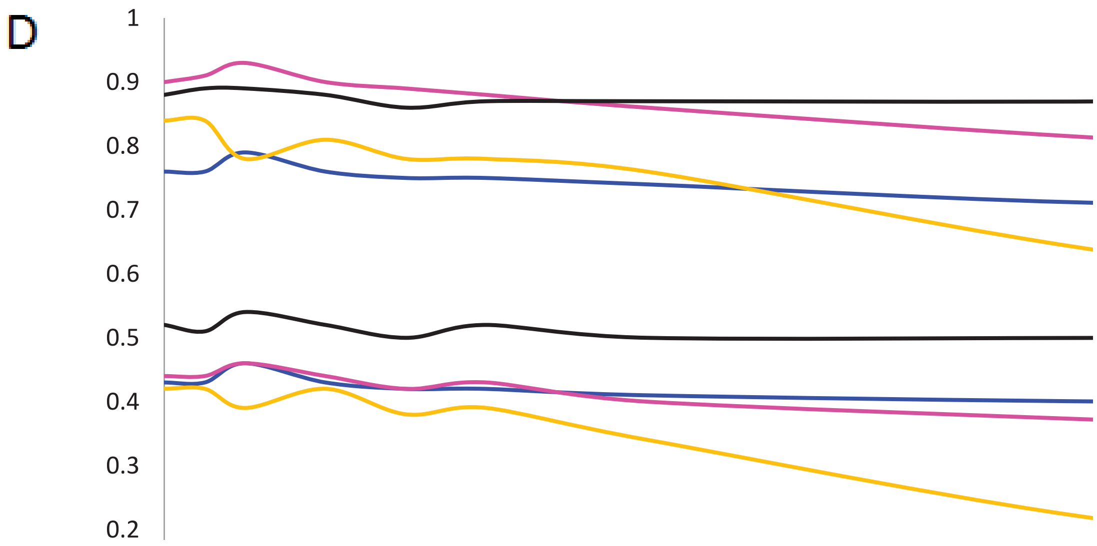

Figure 2: Influence of artificial UV ageing on the optical density of uncoated offset

Figure 2 shows that as a result of artificial UV ageing of uncoated offset paper, a decrease in optical density values is observed at 100% Yellow and 40% Yellow from 6 hours to 200 hours, with a relatively large difference - at 100% $\Delta D_{0/200}$=0.25, and at 40% $\Delta D_{0/200}$=0.24. A decrease of D for 7% Yellow and 100% Magenta has been observed for 72 h.
For 40% Cyan, reductions in optical density values are relatively small and are observed after 24 hours. At 100% Black and 7% Black, no change in optical density was observed. For the other raster fields 100% Cyan, 40% Magenta, 40% Black, 7% Cyan, 7% Magenta, 7% Black, values in the optical density are almost not observed.

3.1.2. Differences in optical density of Cyan, Magenta, Yellow, Black

Table 3 shows the differences in optical density of Cyan, Magenta, Yellow, Black between 0h - 200h of UV ageing for coated matte paper.

Table 3: Difference in optical density for C, M, Y, K on coated matte paper

$\Delta D_{0/200}$	Cyan	Magenta	Yellow	Black
7%	0.02	0.02	0.06	0.01
40%	0.06	0.13	0.32	0.05
100%	0.21	0.37	0.67	0.1

Table 4 shows the differences in optical density of Cyan, Magenta, Yellow, Black between 0h - 200h of UV ageing for uncoated offset paper.

Table 4: Difference in optical density for C, M, Y, K on uncoated offset paper

$\Delta D_{0/200}$	Cyan	Magenta	Yellow	Black
7%	0.01	0.02	0.06	0
40%	0.04	0.09	0.24	0.02
100%	0.04	0.11	0.25	0

The optical color density for both papers is changed in the following order:

Yellow > Magenta > Cyan > Black

3.1.3. Investigation of the change in the color characteristics for both types of papers

Changing the Color Characteristics of Paper in the UV Ageing Process for uncoated Offset Paper (ISO 5631).

- The change in the color characteristics of uncoated offset paper

*Table 5: The change in the color characteristics by CIE*Lch in the UV ageing for uncoated offset paper*

Time, [h]	CIE*L	CIE*C	CIE*H
0	*94.21*	*6.80*	*280.07*
200	*93.97*	*5.14*	*100.14*

From the data in Table 5 shows that lightnes (CIE*L), saturation (CIE*C) and color tone (CIE*H) on offset paper show a decrease in values for 200 hours of irradiation.

Change in light (CIE*L) of the paper color for 200 hours of artificial UV aging is relatively small $\Delta L^*_{0/200}$ = 0.35. With saturation (CIE*C), a difference of $\Delta C^*_{0/200}$ = 1.58 is observed. The biggest change is in the color tone – hue (CIE*H), which reaches $\Delta h^*_{0/200}$ = 11.37. The color difference resulting from 200 hours UV radiation is ΔE = 11.48.

*Table 6: The change in the color characteristics by CIE*Lab in the UV ageing for uncoated offset paper*

Time, [h]	CIE*L	CIE*a	CIE*b
0	93.77	1.40	-6.48
200	94.89	-0.94	4.04

The data in Table 6 shows, that the change in light (CIE*L) and red-green (CIE*a) area is relatively small, whereas for yellow-blue (CIE*b) the area is much larger Δb* = 10.54, that the color of the paper goes to the yellow area when the surface is offset with offset paper. The color difference resulting from 200 hours UV radiation is ΔE = 10.85, which indicates that there is a very noticeable difference.

Changing the Color Characteristics of Paper in the UV Ageing Process for coated Matte Paper (table 7).

- The change in the color characteristics of coated matte paper

*Table 7: The change in the color characteristics by CIE*Lch in the UV ageing process for coated matte paper*

Time, [h]	CIE*L	CIE*c	CIE*h
0	97.33	5.42	284.11
200	95.71	7.31	92.92

Table 7 shows that the change in light (CIE*L) of the paper color for 200 hours of artificial UV ageing is relatively small $\Delta L^*_{0/200}$=1.32. For saturation color coordinate (CIE*C), a difference of $\Delta C^*_{0/200}$ = 2.09 is observed. The biggest change is in the color tone (CIE*H), which reaches $\Delta h^*_{0/200}$ = 12.69.

The color difference resulting from 200 hours UV radiation is ΔE = 12.93.

*Table 8: The change in the color characteristics by CIE*Lab in the UV ageing process for coated matte paper*

Time, [h]	CIE*L	CIE*a	CIE*b
0	97.32	1.33	-5.33
200	95.71	-0.29	7.51

The data in Table 8 shows that the change in light (CIE*L) and red-green (CIE*a) area is relatively small, whereas for the yellow-blue (CIE*b) area it is significantly large Δb*= 12.79, which means that that the color of the paper goes to the yellow area with the coated matte paper. The color difference resulting from 200 hours UV radiation is ΔE = 12.95, which indicates that there is a very noticeable difference.

4. CONCLUSIONS

After performing of artificial UV ageing of 200 hours of irradiation, it was found that the greatest changes occurred for the saturation color coordinate, for the coated matt paper reaching values of $\Delta C_{matte\ 0/200}$ = 50.82 and 2 times larger than the uncoated offset paper $\Delta C_{offset\ 0/200}$ = 24.99 units. There is a significant change in the color tone (hue), for the coated matt paper reaching ΔH = 16.53, and for the uncoated offset paper up to ΔH = 11.52. In the process of UV irradiation, for both types of papers there was almost no change in the light (CIE*L) of the selected fields, except for magenta ink, for matt paper $\Delta L_{matte\ 0/200}$=10.72 and twice more for offset paper $\Delta\ L_{offset\ 0/200}$=4.36 units.

After 200 hours of UV irradiation, it was found, that the optical density become smaller with increasing of time of UV ageing. In some cases, in the light and medium tones of the 7% and 40% Yellow fields, the vanishing of the raster elements is observed.

There is observed the same for both papers optical density changes in light tones (7%). At medium tones (40%), the change in optical density is almost the same, but for matt coated paper the values being slightly higher. For dark tones (100%), it is evident that for matt coated paper occurs three times more changes in density ($\Delta D_{0/200}$= 0.1 ÷ 0.67 units), than for offset uncoated paper ($\Delta D_{0/200}$ = 0 ÷ 0.25 units).

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