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INVESTIGATION OF UV ARTIFICIAL AGEING OF OPTICAL CHARACTERISTICS OF PRINTED IMAGES

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Abstract: *Over time, the printed images are ageing, and this may be due to different factors like natural ageing of paper and ink, temperature, humidity, sun light and human intervention. The main goal of this research is determination of the influence of artificial UV ageing on the colour characteristics of the printed images for mostly used papers, inks and offset printing technology. Two types of papers have been selected for the experiment in terms of their wide use and distribution on the all printing markets – uncoated offset paper and mat coated paper. Printing test evaluation form designed for this research test has been used. In real printing conditions in printing houses on two selected papers have been printed the test form with big number of control strips and elements for colour measurements. The optical properties of papers, colour characteristics of test charts for used papers, inks and printing presses were measured before and after artificial UV ageing time periods. The colour differences, changes of colour gamut volumes, 3D and 2D gamut are calculated too. Great changes in the colour characteristics of the printed images have been identified. The results show huge changes in many of critical colours from human perception point of view.*

Key words: colour characteristics, offset printing, colour difference, ageing of materials, UV ageing, optical characteristics of papers

1. INTRODUCTION

The main problems encountered in the long storage of some types of print production are associated with deterioration of colour characteristics and loss of information from them. Changing the colour range and the colour difference that arise are due to the aging of the inks (Saldivar-Guerrero et al, 2016; Rosen et al, 2001).

Natural aging is a rather slow process. Therefore, in the present experiment, a study of the changes that occur with the printed output over time in artificial UV radiation with a simulation of the actual conditions under which the different printing outputs can be subjected (Kachin et al, 2004; Dolezalek, 2004).

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;
- Mat coated paper – 130 g/m^2.

On the paper samples the following analyses were made:

- Estimation of weight, [g/m^2] (EN ISO 536:1998);
- Fibre composition, (by microscopic method) (ISO 9184-3:1990);
- 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: Characterization of used papers in experiment

Type paper	Weight, [g/m²]	Fibre composition	pH of the water extract before UV ageing	pH of the water extract after UV ageing
Offset uncoated paper	80	Sulfate Pulp of Softwood 75% Sulfate Pulp of Hardwood 25%	7.9	7.2
Mat coated paper	130	Sulfate Pulp of Hardwood 80% Sulfate Pulp of Softwood 20%	7.7	7.0

The results shows, that in the offset uncoated paper content of coniferous wood is predominantly in the composition of the Sulfate Pulp of Softwood, while the matte coated paper predominates the Sulfate Pulp of Hardwood. At the same time, 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

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. 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 for this experiment (Timar et al, 2016; Sonderegger et al, 2015; ISO 13656:2000; ISO 2846-1:2006).

- 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 Used Papers

Type paper	Cyan	Magenta	Yellow	Black
Offset uncoated paper	1.10	1.10	0.95	1.20
Mat coated paper	1.55	1.60	1.45	1.75

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 aging 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; Rosenberg, 2004; European Color Initiative; ICC.1:2004-10; ISO 2470:2002).

3. RESULTS AND DISCUSSION

3.1 Influence of UV ageing on global colour change expression expressed by $\Delta E_{average}$ and ΔE_{max}

The parameters investigated in this section shows us the global influence of UV radiation on the colour characteristics of printed images. Data from spectrophotometric measurements were used to calculate ΔE*ab from CIE L*a*b* values (ISO 2846-1:2006; ISO 13656:2000; ISO 13655:2017). As reference CIE L*a*b* values, those measured prior to exposure to artificial UV ageing paper - 0 hours were used.
For investigation of the global change in the colour differences of 999 colour patches in the test form, the values of $\Delta E_{ab}^{Average}$, $\Delta \mathrm{E}_{\mathrm{ab}}^{Max}$ and $\Delta E_{2000}^{Average}$, $\Delta \mathrm{E}_{2000}^{Max}$ in the various stages of UV ageing for both types of paper examined were calculated. Following figures (Figures 1 to 4) present the graphical dependence of the colour difference expressed by, $\Delta E_{ab}^{Average}$ $\Delta \mathrm{E}_{\mathrm{ab}}^{Max}$ and $\Delta E_{2000}^{Average}$, $\Delta \mathrm{E}_{2000}^{Max}$ on both types of paper in the duration of artificial UV ageing.

3.1.1 Study of the average colour difference - $\Delta E_{ab}^{Average}$ for both types of papers

The colour difference $\Delta E_{ab}^{Average}$ - the mean arithmetic colour difference of the measured 999 fields of the TC 6.02 scale before and after being subjected to artificial UV ageing, have been calculated by formula:

$$\Delta E_{AVERAGE} = \frac{\Delta E_{Sample/Original}^{Field\ 1} + \Delta E_{Sample/Original}^{Field\ 2} + ... + \Delta E_{Sample/Original}^{Field\ 999}}{999}, \quad (1)$$

where, $\Delta E_{Sample/Original}^{Field}$ – colour difference between a specific sample colour field and the same field of the original untreated sample.
Table 3 presents the values of $\Delta E_{ab}^{Average}$ in the process of artificial UV ageing for mat coated and offset uncoated paper.

Table 3: Change in $\Delta E_{ab}^{Average}$ for both types of paper in the process of artificial UV ageing

UV ageing hours	0	6	12	24	36	48	72	144	200
$\Delta E_{ab}^{Average}$ – mat	0	0.89	1.2	2.16	2.96	3.79	5.62	9.54	14.34
$\Delta E_{ab}^{Average}$ – offset	0	0.48	0.61	1.11	1.49	2.04	2.85	4.91	6.67

The data in Table 3 shows an increase in colour difference $\Delta E_{ab}^{Average}$ with an increase in UV exposure time. The colour change in the mat coated paper up to the 6th hour of UV ageing $\Delta E_{ab}^{Average} < 1$, therefore has an almost invisible colour difference. By the 36th hour the difference is $\Delta E_{ab}^{Average} < 3$, therefore there is a visually relatively small, slightly distinct difference. After 72 hours, a significant peak is observed, with the colour difference drastically increasing $\Delta E_{ab}^{Average} > 6$ and reaching $\Delta E_{ab}^{Average} = 14.34$ at the 200th hour, therefore there is a relatively large visual difference, very noticeable.
The experimental results for offset uncoated paper shows, that up to 6 hours of UV ageing, $\Delta E_{ab}^{Average} < 1$, therefore there is an almost invisible colour difference. By the 72th hour the difference is $\Delta E_{ab}^{Average} < 3$, therefore there is a visually relatively small, slightly distinct difference. At the 200th hour of $\Delta E_{ab}^{Average} > 6$, there is therefore a visual difference, very noticeable.
From the data obtained in Table 3, it can be seen that the increasing of $\Delta E_{ab}^{Average}$ for mat coated paper and uncoated offset paper is almost uniform over time, reaching values for 200h irradiation for mat paper to $\Delta E_{ab}^{Average} = 14.34$, and for offset paper up to $\Delta E_{ab}^{Average} = 6.67$.
On average, for 1 hour UV ageing, the change in $\Delta E_{average}$ is:

- Mat coated paper - $\Delta E_{ab}^{Average}$=0.07;
- Offset uncoated paper - $\Delta E_{ab}^{Average}$ = 0.03.

$\Delta E_{ab}^{Average}$ for mat paper after 200h UV ageing reaches 2 times higher than offset uncoated paper. The reason is the greater thickness of the ink layer of the mat coated paper relative to the other paper. The thicker layer means more saturated colours and a bigger change in ageing.

3.1.2 Investigation of the maximum colour difference obtained (ΔE_{max}) for both types of paper

The maximum colour difference - ΔE_{max} is obtained from 999 measured fields of the TC 6.02 scale before and after being subjected to artificial UV ageing. Table 4 presents the values of ΔE_{max} in the artificial UV ageing process for mat coated paper and offset uncoated paper.

Table 4: Changes in the maximum color difference ΔE_{max} obtained for both types of paper in the process of artificial UV ageing

UV ageing hours	0	6	12	24	36	48	72	144	200
ΔE_{max} – mat	0	5.48	6.45	9.15	9.67	10.74	17.78	29.86	57.59
ΔE_{max} – offset	0	2.04	2.96	4.17	4.92	5.88	7.88	19.84	31.41

Table 4 shows that for the colour change in the mat coated paper, the values of the maximum colour difference are considerably high, yet at the 6th hour ΔE_{max} = 5.48 units, and from the 72th hour to the 200th it has a significantly high peak reaching ΔE_{max} = 57.59 at the 200th hour. Therefore there is a relatively large visual difference, very noticeable.
For uncoated offset paper the colour difference up to 12 hours is $\Delta E_{max} < 3$, therefore there is a visually relatively small, slightly distinct difference. After 24 hours, up to 200 hours, the colour difference dramatically increased, with a relatively high peak between 72 hours and 200 hours, reaching ΔE_{max} = 31.41 at 200 hours, therefore there is a noticeable colour difference.
On average for 1 hour UV ageing, the change in ΔE_{max} is:

- for coated mat paper - ΔE_{max} = 0.29;
- for uncoated offset paper - ΔE_{max} = 0.16.

The maximum colour difference for mat coated paper after 200 hours of UV ageing reaches 2 times higher values than uncoated offset paper. The reason is the greater thickness of the ink layer of the coated mat paper relative to the uncoated offset paper. The thicker layer means more saturated colours and consequently a larger change in ageing.

3.1.3 Investigation of the average colour difference for – $\Delta E_{2000}^{Average}$ for both types of papers

Table 5 presents the data for $\Delta E_{2000}^{Average}$ and for mat coated and offset uncoated paper in the process of UV ageing.

Table 5: Changes in $\Delta E_{2000}^{Average}$ for coated mat paper and uncoated offset paper in the UV ageing process

UV ageing hours	0	6	12	24	36	48	72	144	200
$\Delta E_{2000}^{Average}$ – mat	0	0.55	0.72	1.21	1.53	1.93	2.83	4.88	7.68
$\Delta E_{2000}^{Average}$ - offset	0	0.31	0.38	0.69	0.9	1.24	1.68	2.91	4.06

The data in Table 5 shows an increase in the colour difference $\Delta E_{2000}^{Average}$ with gaining of the UV radiation time. The colour change in the coated mat paper up to 12 hours of UV radiation $\Delta E_{2000}^{Average} < 1$, therefore has an almost invisible colour difference. Until 72 hours, the difference is $\Delta E_{2000}^{Average} < 3$, therefore there is a visually relatively small, slightly distinct difference. After 144 hours to 200 hours, the colour difference dramatically increased by $\Delta E_{2000}^{Average} > 6$ to reach $\Delta E_{2000}^{Average}$ = 7.68 at 200h, therefore there is a relatively large visual difference - very noticeable.
There is an almost invisible colour difference for uncoated offset paper up to 36 hours of UV radiation - $\Delta E_{2000}^{Average} < 1$. Up to 144 hours there is a difference of $\Delta E_{2000}^{Average} < 3$, small, slightly distinct difference, and at the 200th hour it reaches $\Delta E_{2000}^{Average}$ = 4.06.

From the data in table 5 it is seen that the increasing of $\Delta E_{2000}^{Average}$ for coated mat paper and uncoated offset paper is almost uniform over time, reaching values for 200h radiation at matte paper to $\Delta E_{2000}^{Average}$= 7.68 and for offset paper to $\Delta E_{2000}^{Average}$= 4.06.
On average for 1 hour UV ageing, the change in $\Delta E_{2000}^{Average}$ is:

- for coated mat paper - $\Delta E_{2000}^{Average}$ = 0.04,
- for uncoated offset paper - $\Delta E_{2000}^{Average}$ = 0.02.

The average colour difference (2000 formula) for mat coated paper after 200 hours of UV ageing reaches 2 times higher than offset uncoated paper.

3.1.4 Investigation in the maximum colour difference - ($\Delta \mathrm{E}_{2000}^{Max}$) for both types of papers

Table 6 shows the data for $\Delta \mathrm{E}_{2000}^{Max}$ for coated mat paper and uncoated offset paper in the UV ageing process.

Table 6: Changing the maximum colour difference $\Delta \mathrm{E}_{2000}^{Max}$ obtained for both types of papers in the process of artificial UV ageing

UV ageing hours	0	6	12	24	36	48	72	144	200
$\Delta \mathrm{E}_{2000}^{Max}$ – mat	0	4.59	5.96	8.56	9.09	9.68	9.25	12.81	19.53
$\Delta \mathrm{E}_{2000}^{Max}$ – offset	0	1.76	2.5	3.62	4.34	4.55	5.9	7.9	10.92

From the received data table 6 it can be seen that on the coated mat paper the values of the maximum colour difference are significantly large and at the 6th hour $\Delta \mathrm{E}_{2000}^{Max}$= 4.59 units and at the 200th hour it reaches $\Delta \mathrm{E}_{2000}^{Max}$ = 19.53, therefore it has a relatively large visual difference, very noticeable.
The data obtained for uncoated offset paper shows up to 12 hours the difference is $\Delta \mathrm{E}_{2000}^{Max}$<3, therefore there is a visually relatively small, slightly distinct difference. After 72 hours to 200 hours, the colour difference dramatically increased $\Delta \mathrm{E}_{2000}^{Max}$ > 6 to reach $\Delta \mathrm{E}_{2000}^{Max}$= 10.92 at the 200th hour, therefore there is a marked difference.
Table 6 shows that the increasing of $\Delta \mathrm{E}_{2000}^{Max}$ for coated mat paper and uncoated offset paper is almost uniform over time, reaching values for 200 hours of exposure to matte paper to $\Delta \mathrm{E}_{2000}^{Max}$ = 19.53, and for offset uncoated paper to $\Delta \mathrm{E}_{2000}^{Max}$= 10.92.
On average for 1 hour UV ageing, the change in $\Delta \mathrm{E}_{2000}^{Max}$ is:

- for uncoated mat paper - $\Delta \mathrm{E}_{2000}^{Max}$ = 0.1,
- for uncoated offset paper - $\Delta \mathrm{E}_{2000}^{Max}$ = 0.05.

The maximum colour difference for mat coated paper after 200 hours of UV ageing reaches 2 times higher than offset uncoated paper.

3.2 Investigation of the influence of artificial UV ageing on Brightness, Yellowness and paper colour for both types of papers

The brightness, yellowness and colour are the most important optical characteristics of papers. That is why in the present paper there are performed an experiment over their influence of UV radiation.

3.2.1 Graphic representation of the effect of artificial UV ageing on the Brightness depending on the time of the two types of papers

The paper Brightness was measured with a Gretag Macbeth SpecroEye Spectrophotometer at a standard light illuminant - CIE D65, Brightness R457 (according to ISO470: 2002).
Figure 1 shows the graphical dependence of the influence of artificial UV ageing on the Brightness of coated mat and uncoated offset papers.

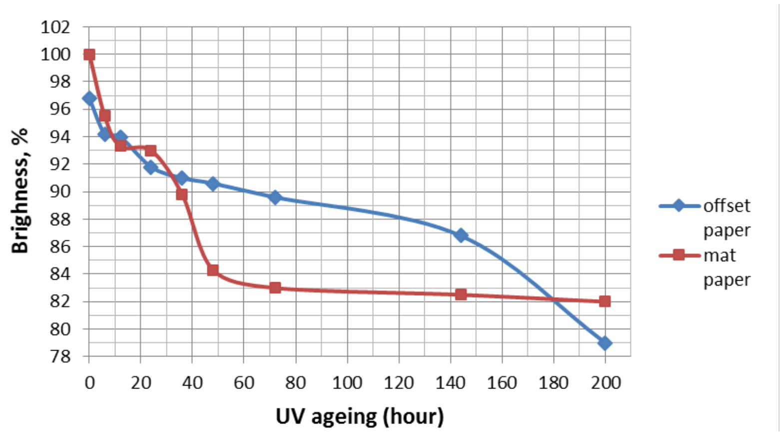

Figure 1: Influence of artificial UV ageing on Brightness of coated mat and offset uncoated papers

From Figure 1 it can be seen that with increasing hours of artificial UV ageing the Brightness decreases. On the coated mat paper from 0 hour to 48 hour, a drastic reduction in Brightness of ≈ 16 units is observed and reaches 18 units at 200 hours. While uncoated offset paper, a drastic reduction in Brightness occurs almost throughout the UV exposure range, reaching 17.8 units for 200 hours of exposure.

3.2.2 Graphic representation of the effect of artificial UV ageing on the Yellowness depending on the time of the two types of papers

The Yellowing of the paper is a very important indicator, especially for printing papers. The reason for its increase is the influence of UV rays, the increase of the temperature and humidity of the environment, the harmful gases in the atmosphere (especially SO_2), the type of used fibrous materials and the ways of their production. Figure 2 shows the graphical dependence of the influence of artificial UV ageing on the Yellowness coated mat and offset uncoated paper.

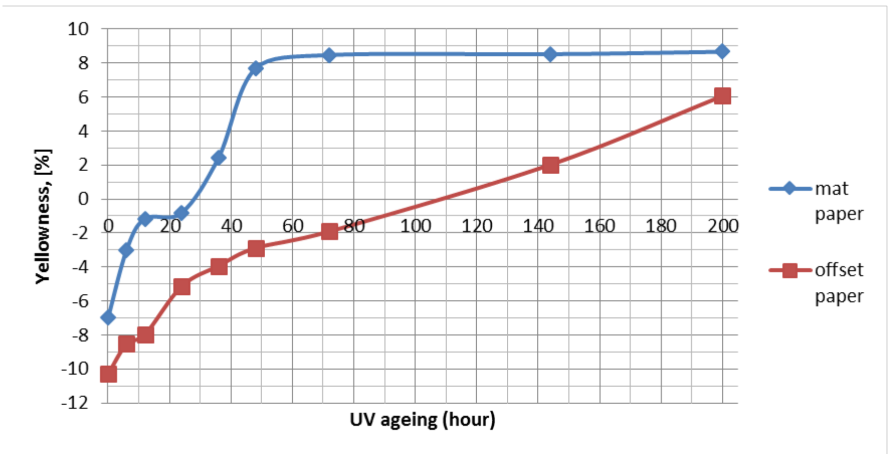

Figure 2: Influence of Artificial UV Ageing on the Yellowness coated Mat and Offset uncoated Paper

From Figure 2 it can be seen, that for both papers - the Yellowness is increasing for longer exposure. For coated mat coated papers, the UV radiation observed a drastic increase in yellowness to 48 hours was 14.68 units. After 48 hours the yellowness changed relatively little, reaching 15.66 units. For offset uncoated paper, the increase in yellowness is almost constant throughout the UV ageing interval, reaching 16.9 units.

3.3 Investigation of the change in 2D and 3D colour gamut, depending on the time of artificial UV ageing, and examination of the variation of the volumes of the colour gamut depending on the time of artificial UV ageing.

By estimating of changing of the colour gamut it can be judged the presence and direction of change of colour characteristics. They are presented in two ways in a 3D and 2D form. In a 3D form, the colour range gives a lot of general information about the colour changes of the three axes L, a and b.
The 2D representation is a cross-section of the 3D gamut graph on the CIE L axis, thus a colour gamut gives very accurate colour information characteristics at each specific L (light) value.
Test charts TC 6.02 were measured with a X-Rite SpectroScan Spectrophotometer before and after being subjected to artificial UV ageing at 0, 6, 12, 24, 36, 48, 72, 144 and 200h.
The data obtained from the spectrophotometer were used to create ICC colour profiles. ICC colour profiles are created with ProfileMaker 5.10 and i1Profiler. The Colour Setting settings of the created profiles (for 6, 12, 24, 36, 48, 72, 144 and 200 hours of artificial UV ageing) differ only in the total amount of dark tones (TAC), as it is different for different types of paper.
The following figures (Figures 3 to 6) show 3D visualizations and 2D incisions before and after UV ageing for both types of papers.

3.3.1 Determination of influence of UV ageing on the 3D colour gamut of mat coated paper and offset uncoated paper

With specialized software and hardware, colour patches are measured, ICC colour profiles are generated and a 3D colour model of the gamut is selected. The resulting 3D gamut's have a characteristic pear-shaped shape and show the colour change during artificial UV ageing.
The chart of Figure 3 compares the colour gamut (viewed at different angles) of engraved mat coated paper before (the outer triangular contour) and after (inner triangular contour) subjecting it to UV ageing. During UV ageing for the mat coated paper there is a decrease in the volume of the 3D body shape in light, medium and dark tones. The greatest change in volume is in the light, then in the middle and the smallest in the dark tones.
The chart of Figure 4 compares the colour gamut (viewed at different angles) to offset uncoated paper before (outer triangular contour) and after (inner triangular contour) subjected to UV ageing. During UV ageing on uncoated offset paper there is decreasing tendency in the volume of the 3D body in light, medium and dark tones. The greatest change in volume is in the light, then in the middle and the smallest in the dark tones.

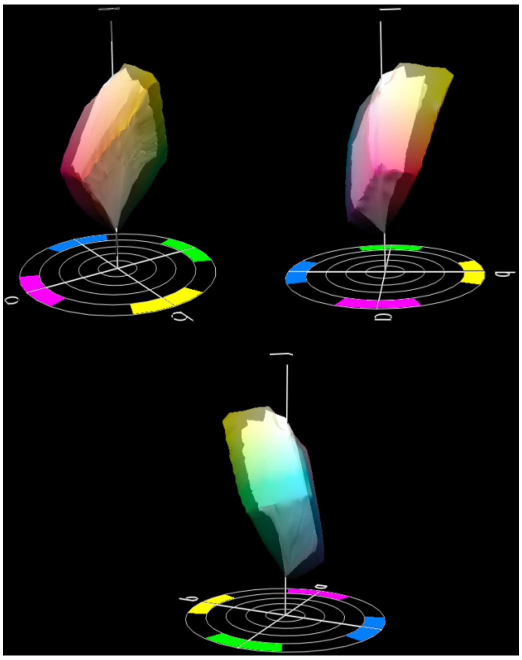

Figure 3: Influence of UV ageing on 3D color gamut on mat coated paper (before ageing – outside contour, after ageing – smaller (inside) contour

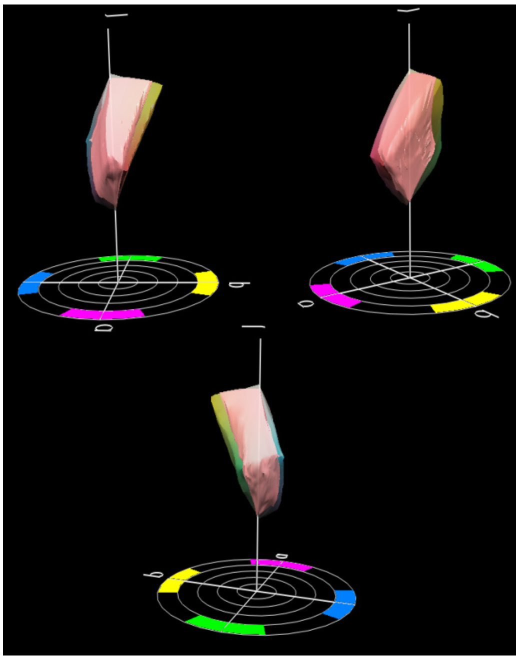

Figure 4: Influence of UV ageing on 3D color gamut on offset uncoated paper (before ageing – outside contour, after ageing – smaller (inside) contour

3.3.2 Determination of influence of UV ageing on 2D colour gamut of both types of papers

The graphical representation of the colour gamut in the 3D colour space gives a comprehensive assessment of the variety of colours that are reproduced at the given paper-machine-ink combination. In order to make a more complete characterization of the colour change of the print image as a result of UB ageing for coated mat paper, a cut of the 3D body of the colour gamut at L = 25 (dark tones), L = 50 (medium tones) and L = 75 (light tones), where L is the coordinate of the light colour.

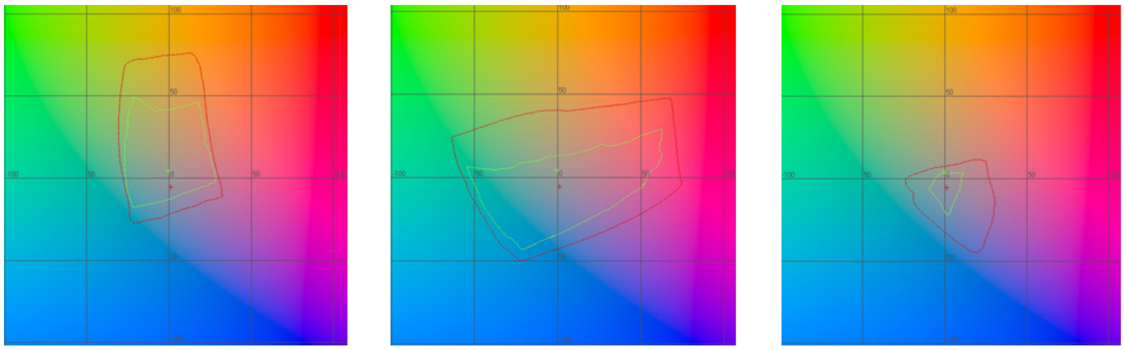

Figure 5: CIE Lab colour space gamut for L = 75, L = 50 and L = 25 for coated mat paper (outside red contour – before UV ageing; inside green contour – after UV ageing)

From Figure 5 it can be seen that in mat coated paper in light, medium and dark tones the colour gamut before UV ageing is significantly greater, than that after UV ageing.
In cross section of CIE L = 75 the colour shift in the yellow-red and blue areas is noticeable after ageing. The shift is to the yellow area, which can be explained by the yellowing of the paper itself. In section L = 50 there is an even greater displacement in all areas, with a relatively large difference in the red-green area. At L = 25 there is a significant change in the blue area. This means that these colours either "disappear" or are replaced with the same, but with less intensity and with another colour tone.
In Figure 6 is a sectional view of the 3D body of the colour gamut at L = 38 (dark tones), L = 50 (average tones) and L = 75 (light tones).

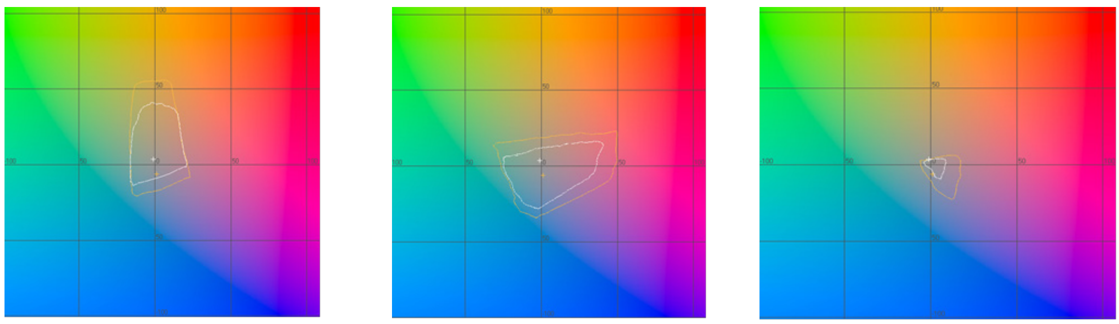

Figure 6: CIE Lab colour space gamut for L = 75, L = 50, and L = 38 for uncoated offset paper (outside red contour – before UV ageing; inside white contour – after UV ageing)

From Figure 6 it can be seen that for offset uncoated paper in light, medium and dark tones the colour gamut before UV ageing is significantly higher than that after UV ageing. In cross section of CIE L = 75, the colour shift in the yellow and blue areas during ageing is noticeable, while in the cabbage and the red area there is almost no change. The shift is to the yellow area, which can be explained by the yellowing of the paper itself. In section L = 50, offset is visible in all areas except in light blue areas. In L = 25 there is a significant change in the blue and red areas. This means that these colours either "disappear" or are replaced with the same, but with less intensity and with another colour tone.

4. CONCLUSIONS

During the experiment, the obtained results shows significant changes in colour characteristics observed in the UV ageing process, and a correlation between UV irradiation and colour difference ΔE. The colour difference reached, after 200h of ageing, $\Delta E_{ab}^{Average}$ is 14.34 units for coated mat paper and twice as low as 6.67 units for uncoated offset paper. With the 2000 colour difference formula $\Delta E_{2000}^{Average}$, for offset uncoated paper the difference is - 4.06, and for mat coated papers $\Delta E_{2000}^{Average}$- 7.68. The maximum difference obtained ΔE_{ab}^{Max} for coated mat paper is 57.59 units and there are twice lower values of 31.41 unsuitable offset uncoated paper. For mat coated paper, ΔE_{ab}^{Max}= 19.53 units and 10.92 units for offset uncoated paper. This indicates that some of the colours undergo a huge change - they "disappear" or go into another colour gamut.

After exposure to the UV ageing of papers, it was found that paper Brightness was reduced. In the coated mat paper the reduction reaches 18 units, the most drastic being this reduction to about 48 hours. On uncoated offset paper there is a more uniform Brightness reduction throughout the irradiation process of 17.8 units. Accordingly, the Yellowness is increased, with the coated mat paper being 16.9 units, and the uncoated offset paper is 15.66 units.

After the 3D visualization analysis and the 2D sections of the colour gamut in the UV ageing process, a significant decreasing of 38 ÷ 40% was recorded in the volumes of the 3D body. The reduction of area of the 2D cross sections after irradiation for both types of papers is - for the mat paper 38 % and for offset is 21%. A large colour shift from the blue and red areas of the colour gamut of the printed images is found after the UV ageing of papers. In the field of light tones there is a significant displacement from green and red to yellow areas and less displacement in blue areas. In the middle tones there is a contraction in all areas, and in the dark tones there is a significant shift in the blue regions. In all key tones the colours are transforming with less saturation and different colour hue.

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