INFLUENCE OF AGING PROCESS ON UV INKJET BLACK PRINTED PVC FOIL

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ABSTRACT

During the lifespan, graphic products are exposed to various external factors. During their use, their properties (physical, mechanical, visual, etc.) change to a greater or lesser extent. It is necessary to observe/monitor changes and influence of external factors on their properties as soon as the product is created. The aim of this research is to examine the impact of the aging process on the quality of inkjet printing. A different number of layers of black ink (in 10 % tonal value (TV) and 100 % TV) and a different number of varnish layers were printed on PVC foil material. The samples were exposed to xenon light ($\lambda > 300$ nm) to accelerate the ageing process over a period of 72 and 216 h. They were measured by Datacolor spectrophotometer. As expected, with longer exposure time, greater changes occurred. According to the CIE ΔE^*_{00} formula, the differences ranged from an imperceptible to a large colour change. After 72 h, the biggest changes in colour occurred in the K10 % with one ink layer and three layers of varnish. The smallest changes were in K100 % with one ink layer and no varnish. After 216 h, the greatest changes were observed in the K10 % sample with three layers of ink and two layers of varnish. The smallest differences were K10 % sample with one ink layer and without varnish.

Keywords: *UV inkjet, PVC material, print quality, colour difference, aging process.*

INTRODUCTION

Various external factors (sun, rain, humidity, and wind) affect graphic products during their lifetime. Changes in graphic product properties depend on how long the print is exposed to external factors. The changes occur more or less visible to the human eye. This is not exactly a positive phenomenon. It is therefore necessary to take this into account when it is designing and manufacturing the product. It must be ensured that the products have a certain durability during their existence. Sooner or later, change, however, will occur [1].

With inkjet printing as one of the most important and widely used digital printing technique, it is possible to achieve prints with different levels of resistance and durability [2 - 4]. Inkjet printing enables the reproducibility and consistency of patterns with different visual effects and format flexibility, making it more popular every day [5]. This is also supported by data of Global Industry, which estimates that the global digital printing market, including inkjet, will reach USD 37.8 billion by 2027, with a CAGR of 6.54 % [6].

Inkjet printing is based on spraying tiny primary droplets of liquid ink onto the substrate [7]. The ink droplets are mixed using the subtractive colour method. This means that, inkjet printers use their primary inks to create a wide colour gamut by mixing them. In addition to cyan, magenta, yellow and black, there are also light cyan, light magenta, grey, etc., which are used to achieve a higher quality of reproduction. Each colour from the colour gamut can be produced by mixing the required percentage of these colours [8, 9].

It is also important to know that in inkjet printing, black prints not only consist of black ink but may also consist of some yellow, magenta and cyan dots, unless otherwise specified. It is very important, because without black ink there are no dark colours and shades. The addition of black ink therefore provides sharper and more defined edges, which is important for the overall contrast of the print (whether it is documents, labels, or other text - heavy materials). Another important fact is that black ink helps to reduce printing costs [8 - 10].

UV inkjet printing, as one of the inkjet printing technologies, enables precise printing from larger to smaller elements, which can be printed in one or more layers. With a different number of layers, the distance between the printing substrate and the printing head with nozzles must be considered [11]. This technique also allows printing on different substrates such as paper, plastic, textile, wood, glass, metal, etc. [6]. For this research, it is important to emphasise the use of plastic materials, especially PVC foils. By varying their properties (thickness, gloss, etc.), it is possible to obtain different types of graphic products, thus increasing the variety of products on the market. It is also important to emphasise that the quality and durability of the reproduction is influenced by the different number of colour layers and varnish applications [2].

It is important to understand the importance of printing ink, varnish and substrate in inkjet printing systems and the changes that occur after the aging process. When it comes to printing ink, it is particularly important to mention UV inkjet inks. UV inks enable the production of quality prints with different layer thicknesses, and it is important to ensure the compatibility of the ink with UV dryers [12, 13]. The drying process for UV inkjet is based on polymerisation. After exposure (irradiation) to UV light, the active substances in the (photo initiators) ink are converted into reactive radicals. The radicals combine with monomers, oligomers and pigments and form polymer chains. After polymerisation, the prints have excellent mechanical properties (edge strength, heat resistance, chemical stability, and resistance to organic solvents) [14]. There are also several reasons why UV inks are increasingly used in inkjet systems today. They do not contain hazardous organic solvents, they dry instantly, UV lamps require less space than conventional drying equipment, they produce higher quality prints as there is no evaporation or absorption of the ink, and the prints are more durable than other types of inks [12, 13].

UV varnishes affect the final appearance and durability of the product. They are dried under mercury or LED lamps. They can be based on acrylated amines, hexamethyldiacrylate hexane, acrylic esters, photosensitive monomers, phosine oxide derivatives, etc. [15]. Both colour inks and varnishes, are dried with UV light. The UV light causes the UV ink or UV varnish to polymerise and the printed surface to become solid. The dried and polymerised print layers form a smooth surface for the printed elements [11]. During the exposure of the varnished substrate to UV light and the polymerization process, the printed UV varnish turns yellow. The reason for this is the photo initiators, which turn yellow during the curing process and exposure to UV light. With more layers of varnish, the yellowness is more pronounced [16].

The stability of the prints against external influences is tested using machines that simulate these influences. The samples are exposed to precisely defined conditions (temperature, relative humidity, lighting, with or without rain) and thus show the effect of real conditions on the print. The standards for textiles, paper and plastics (SIST ISO 105 - B02, SIST ISO 105 - B04, SIST ISO 105 - B06, SIST ISO 12040, ISO 4892 and ISO 11341) provide for an accelerated simulation of the external influences to which the print will be exposed during use [17 - 20].

For the test to be considered relevant, temperature, relative humidity, irradiance and other parameters must be constant and programmed according to standard values for these types of tests. It is possible to use different filters that simulate direct sunlight, behind window glass or behind car glass [20].

Colour differences between exposed and unexposed samples are normally determined visually using a blue wool reference [2]. The perception of a colour change depends on the observer as well as the observed object and the environment [22]. However, for a scientific and objective perception, it is necessary to use the instruments intended for this purpose, i.e., colorimetric and spectrophotometric analysis [23, 24].

Nowadays, spectrophotometric analysis is most commonly used to analyse the colour difference of prints. This measurement is based on numerous formulas, such as the basic DE76, the more advanced CMC (l: c) BFD (l : c), CIE 94, and CIE ΔE^*_{00}. What they have in common is the use of the Euclidean distance in a device-independent colour space (ΔL^*, Δa^*, and Δb^*). Today, the CIE ΔE^*_{00} formula is generaly used, which provides the best results for non-uniformities while preserving the L*a*b* colour space [2, 25].

The aim of this research was to determine how the aging process affects the properties of the printed PVC foil and how the different number of printed ink and varnishes affects the lightfastness and quality of the prints. Karlowitz and Gregor - Svetec [25] had a similar type of research, but without varnish. They found that CMYK UV inks applied to synthetic paper proved to be highly resistant to the effects of the moist heat technique of accelerated ageing. The black colour stood out. Its colour differences did not exceed the value of 2.0 [26]. Thus, the effect of varnish and slightly different material is added here to see the effect of these parameters on the research of aging process.

This type of research is very important, both from a scientific and a practical point of view. Investigating the behaviour and changes of colours and materials during exposure to the effects of aging provides important information. The importance of this information is reflected in the possibilities of modelling the aging process, and for restoring the original colour characteristics of an aged image [33].

EXPERIMENTAL

In this research, PVC foil with thickness of 0.5728 mm and luminosity of 5.117 gloss units (GU) was used as the printing material. A special test form was designed to investigate the lightfastness of prints. The test form (Fig. 1) consisted of black in fields measuring 12 × 12 mm with tone values (TV) from 10 % to 100 %, but for this research, only 10 % and 100 % TV were used as representative samples for lightest and darkest tonal values. Test form was designed in Adobe Illustrator CC 2016 and then rasterised using Roland VersaWorks RIP (Raster Image Processor). It consisted of four different numbers of ink layers. There were also variant without varnish, with one, two and three layers of varnish.

Fig. 1. Test form used in the research.

Given that the graphic industry market is changing day by day and requires new opportunities, a greater number of ink and varnish applications is important in order to achieve different effects on graphic products. Thus, the products become more attractive and interesting to the customer. The interaction of the substrate with ink and varnish is also important, so this is also considered in this research. In addition to the possibility of achieving different visual effects, many varnish applications have another important application. This application is related to the manufacture of products for blind and visually impaired people, i.e. the application of Braille to graphic products [27].

Printing specifications

The printing specifications were defined as follows: media type (Generic), print quality (Standard), resolution (720 × 720 dpi), mode (CMYK(v) + PASS), non - direction printing, dither screening and high-quality mode (lower speed but higher varnish and resolution). The samples were printed with a DX4 Epson piezo inkjet head with a dot size of 3.5 pL [28]. The height of the head was changed to a higher level after printing five (5) layers. The prints differed in the number of applications of inkjet ink (1 - 4 layers of ink) and varnish (0 - 3 layers of varnish).

Printing machine

The samples were printed on a Roland Versa UV LEC 300 printer/cutter with ECO - UV 220 - cc inks and ECO - UV varnish. This device offers a wide range of variation possibilities for materials and effects. In addition to PVC foils, this device can also print on paper, transparent and metallic materials (labels, stickers, displays, posters), cardboard, BOPP, PE films, etc. It can also create texture patterns, provided by an exclusive library for the creation and output of print data. A variety of effects can be created, from matt or glossy finishes to customised-textured effects. The curing lamps operate at low heat, which is particularly important for heat-sensitive substrates. They heat up immediately without the need for a warm - up time [29, 30].

ECO - UV inks and ECO - UV varnish

The ECO - UV 220 - cc inks enable low high colour density and a wide colour gamut and do not crack on flexible materials. The inks are formulated to be used at a wide range of print speeds and adhere to a variety of coated and uncoated materials - foils, papers, vinyl, etc. Once cured, the prints can be bent without cracking. These inks also contribute to increased scratch resistance, chemical resistance and outdoor durability [31, 32].

As mentioned in the introduction, most modern printers produce black with a colour ink that is technically referred to as “composite black“. This can be very useful, especially if the printing machine does not contain black ink. However, it is important to note that the quality of black produced with coloured ink may not be as deep as when using black ink [10].

The ECO - UV varnish, EUV - GL v.4, was used for the final step. Low viscosity, high gloss, good adhesion to a variety of coated or uncoated materials (including foils, paper, films and vinyl), good resistance to cracking, scratching and chemicals, and outdoor durability are just some of the properties of the UV varnish used in this research. Its composition, as well as the composition of the inks, is shown in table 2 below [32]. The thicknesses of ink, varnish, as well as the average thickness of varnish are shown in Table 2.

The light influence

Xenotest Alpha was used to observe the changes in the samples during their real exploitation. In order for the test to be considered relevant, temperature, relative humidity, irradiance and other parameters must be constant and programmed according to standard values for these types of tests. It is possible to use different filters that simulate direct sunlight, behind window glass or behind car glass [21]. Thus, this process becomes more relevant and credible for scientific research, compared to the natural aging process. Also, this way of aging gave much faster results, which is another of its advantages [33, 34].

Xenotest Alpha (Atlas, USA) was used with a xenon arc lamp simulating intense daylight at a constant temperature of 35°C and a relative humidity of 35 % to simulate the ageing process. The Xenochrome 300 philtree was used, which means that shorter wavelengths are included included (λ > 300 nm) and the spectrum simulates outdoor daylight - therfore, samples were exposed to part of UV light (partially UVB and full UVA) as well as daylight (visible part of electromagnetic spectra) in open space. The samples of the prints and the printing material (unprinted) were exposed to xenon light for 72 and 216 h.

The influence of light on the colour fastness of prints was investigated spectrophotometrically, using Datacolor 1050 spectrophotometer (Datacolor, Switzerland). The measurement was carried out under the folowing condidtions: XUSAV aperture plate with 3 mm diameter, d/8° measurement geometry and D65/10°. For each TV, the CIE values L*, a* and b* were measured three times and then the mean value was

Table 1. Ink and varnish layers thickness (in mm).

Composition	Cyan	Magenta	Yellow	Black	Gloss
Colorant	1 - 5 % (Copper phtalocyanine)	1 - 5 %	1 - 5 % (Pigment yellow 150)	1 - 5 % (Carbon black)	-
Hexamethylene diacrylate	20 - 30 %	5 - 10 %	10 - 20 %	10 - 20 %	20 - 30 %
2-Methoxyethylacrilate	20 - 24 %	20 - 30 %	20 - 24 %	20 - 24 %	20 - 24 %
Exo-1,7,7-trimetylbi-ocyclo[2.2.1]hept-2-ylacrylate	1 - 10 %	10 - 20 %	10 - 20 %	5 - 10 %	-
Benzylacrylate	20 - 30 %	20 - 30 %	10 - 20 %	10 - 20 %	10 - 25 %
1-vinylhexahydro-2H-azepin-2-one	10 - 20 %	10 - 20 %	10 - 20 %	10 - 20 %	10 - 20 %
Diphenyl(2,4,6-trimethyl-benzoyl) phosphine oxide	5 - 15 %	5 - 10 %	5 - 10 %	5 - 10 %	5 - 10 %
Other polymerization initiator	1 - 5 %	1 - 5 %	1 - 5 %	1 - 5 %	-

Table 2. Ink and varnish layers thickness (in mm).

	1_ink_layer	2_ink_layers	3_ink_layers	4_ink_layers	1_VL - NV	2_VL - NV	3_VL - NV
NV	0.0156	0.0226	0.0231	0.0390	0.0176	0.0803	0.1108
1_VL	0.0331	0.0320	0.0430	0.0495	0.0095	0.0742	0.1100
2_VL	0.0958	0.0967	0.1001	0.1050	0.0199	0.0770	0.1130
3_VL	0.1263	0.1325	0.1361	0.1393	0.0105	0.0660	0.1003
Average					0.0144	0.0744	0.1085

**NV - no varnish, 1_VL - one varnishing layer, 2_VL - two varnishing layers, 3_VL - three varnishing layers.*

calculated. The colour differences were then calculated based on the ΔE^*_{00} formula and compared.

RESULTS AND DISCUSSION

Colour differences of the substrate

Observing the relationship between the substrate and the varnishing layers, and their variation with the aging process, it can be observed that there are changes in the L*a*b* values of the substrate by varnishing the substrate with different layers of varnish, and then with the aging process. The values are compared to a standard, the L*a*b* values of the substrate without varnish and before aging. Like it can be seen in table 3, the difference becomes medium with one layer of varnish and massive with the two and three layers of varnish. After the aging process, the unvarnished sample recorded an imperceptible difference, the sample with one layer of varnish a medium one, the samples with two layers and three layers of varnish a massive colour difference.

Table 3. L*a*b* and ΔE^*_{00} of the substrate.

	Datacolor			
Samples	L*	a*	b*	ΔE^*_{00}
TM_STD	92.24	-1.53	-2.33	0.00
TM_1VL	89.63	-1.93	1.33	3.90
TM_2VL	86.87	-2.57	6.43	8.66
TM_3VL	84.78	-2.60	8.79	10.80
TM_STD_72h	91.83	-1.45	-2.71	0.44
TM_1VL_72h	89.93	-1.99	-1.36	2.58
TM_2VL_72h	85.86	-2.23	0.62	5.02
TM_3VL_72h	84.44	-2.39	1.57	5.87
TM_STD_216h	91.76	-1.36	-2.46	0.40
TM_1VL_216h	89.65	-1.84	-1.10	2.33
TM_2VL_216h	85.91	-2.19	0.41	5.21
TM_3VL_216h	84.49	-2.29	1.14	6.25

**TM_STD - standard material. TM_1VL - material with one varnishing layer. TM_2VL - material with two varnishing layers. TM_3VL - material with three varnishing layers.*

Observing the parameters L*, a* and b* individually, values were recorded in the blue - green and yellow - green areas, relatively proximate to the neutral axis, and the brightness values recorded a small change compared to the initial value.

Colour differences of the tonal fields

When it comes to the values of ΔE^*_{00} for 10 % and 100 % for each of the ink and varnish applications. they are shown respectively in figures 2 - 5. Their corresponding L*a*b* values are shown in tables 4 - 7.

Fig. 2 shows the diagram of the effect of the number of varnish applications on the difference in colour of prints printed with one layer of ink after artificial aging for 72 h and 216 h. Thus. for the samples with one application of ink. there are minimal changed values for K100 % TV so that the difference in colour is imperceptible after 72 h. With K10 %. the differences are more noticeable. and as the layers of varnish increase. they go in order from a medium difference. to large and then to massive differences in colour. After 216 h corresponding curves show that certain differences appear in certain samples. K100 % samples gives much higher values. Thus. the values of the colour difference become massive already from the first layer of varnish. The biggest colour difference is for two layer of varnish ΔE^*_{00} = 9.29.

Fig. 3 shows diagram of the influence of the number of varnish applications on the difference in colour of prints printed with two layers of ink after artificial aging for 72 h and 216 h. As in the previous

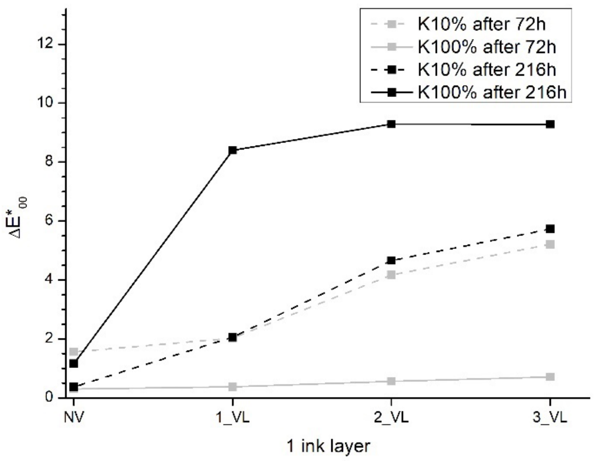

Fig. 2. Influence of number of varnishing layers (0. 1. 2 and 3) on ΔE^*_{00} for samples printed with one ink layer after 72 and 216 h of illumination (NV - printed samples without varnish. 1_VL - printed samples with one varnish layer. 2_VL - printed samples with two varnish layers and 3_VL - printed samples with three varnishing layers).

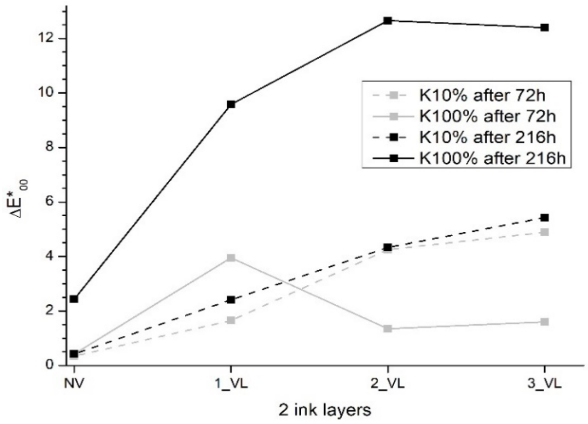

Fig. 3. Influence of number of varnishing layers (0. 1. 2 and 3) on ΔE^*_{00} for samples printed with two ink layers after 72 and 216 h of illumination (NV - printed samples without varnish. 1_VL - printed samples with one varnish layer. 2_VL - printed samples with two varnish layers and 3_VL - printed samples with three varnishing layers).

case, K100 % TV after 72 h has very small differences. The only exception is the sample with one layer of varnish. which has a colour difference value of ΔE^*_{00} = 3.95, which is characterized as a large difference. With K10 % TV, the differences are more pronounced and increase, as with the previous figure, by increasing the number of varnish layers. So, they go from imperceptible, through very small to large differences with two and three layers of varnish.

After 216 h there are also significant differences here for K100 % TV. The sample without varnish has a medium change in colour, and already by adding the first layer of varnish, it becomes massive and remains through all other varnish applications. The biggest color difference is sample with two layers of varnish ΔE^*_{00} = 12.66, K10 % TV notes imperceptible changes in the sample without varnish, a medium difference for the sample with one layer of varnish and a large difference for two and three layers of varnish.

The same is the case for Fig. 4 where the influence of the number of varnish layers on the difference of samples with three ink layers are shown. Here, the highest value of the difference in colour was obtained for the ink with two layers of varnish, measured after 216 h ΔE^*_{00} = 13.08.

Fig. 5 shows diagrams of the influence of the number of varnish applications on the difference in colour of prints printed with four layers of ink after artificial aging for 72 h and 216 h. For K100 % colour differences after 72 h imperceptible differences were obtained, K10 % has imperceptible colour differences for the sample without varnish, very small with one layer, medium with two layers and large with three layers of varnish.

When it comes to colour differences after 216 h there is a more significant difference for K100 % TV and three layers of varnish, ΔE^*_{00} = 12.35, while the change for K10 % increases quite linearly compared to the measurement after 72 h.

Tables 4, 5, 6 and 7 show L*a*b* values for each sample and their ΔE^*_{00} values. In this way. the differences that have occurred can also be observed numerically. The Lab values of samples with one layer of ink. show that even before aging the prints have a higher value of yellow colour with increasing layers of varnish. It is interesting to emphasize that the value of parameter a* is slightly higher. and the value of parameter b* is significantly increased. Considering to this. the values for K100 % are slightly shifted towards red-yellow tones. All other values are in the green yellow, ie. green-blue quadrant. The value of the parameter L* is the lowest for K100 % 3_VL, and the highest for K10 % NV, which was expected. After the aging process. the values did not change significantly. The exception is the sample K100 % with varnish after 216 h of aging. where the

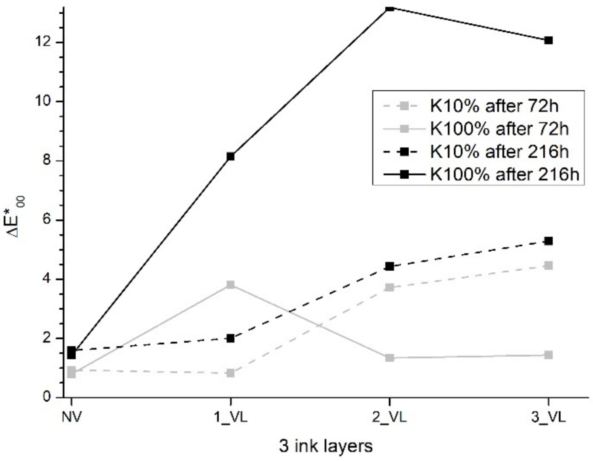

Fig. 4. Influence of number of varnishing layers (0. 1. 2 and 3) on ΔE^*_{00} for samples printed with three ink layers after 72 (a) and 216 (b) h of illumination (NV - printed samples without varnish. 1_VL - printed samples with one varnish layer. 2_VL - printed samples with two varnish layers and 3_VL - printed samples with three varnishing layers).

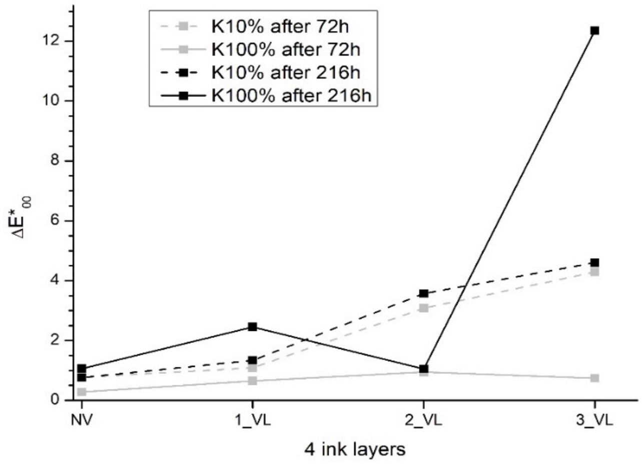

Fig. 5. Influence of number of varnishing layers (0. 1. 2 and 3) on ΔE^*_{00} for samples printed with four ink layers after 72 and 216 h of illumination (NV - printed samples without varnish. 1_VL - printed samples with one varnish layer. 2_VL - printed samples with two varnish layers and 3_VL - printed samples with three varnishing layers).

Table 4. L*a*b* and ΔE^*_{00} values before and after ageing for sample with one ink layer.

	Before aging				After 72 h				After 216 h			
Samples	L*	a*	b*	ΔE^*_{00}	L*	a*	b*	ΔE^*_{00}	L*	a*	b*	ΔE^*_{00}
K10_NV	86.83	-1.70	-2.89	-	86.27	-1.67	-2.95	1.56	86.37	-1.80	-2.70	0.37
K10_1VL	83.49	-3.17	0.86	-	83.38	-3.18	-1.31	2.03	84.99	-2.66	-0.94	2.06
K10_2VL	80.63	-3.19	5.62	-	80.48	-3.13	0.77	4.17	82.43	-2.93	0.41	4.66
K10_3VL	55.56	-3.27	2.30	-	79.19	-3.41	1.39	5.21	79.19	-3.41	1.39	5.73
K100_NV	31.09	1.97	1.40	-	31.11	1.95	1.72	0.30	32.51	2.04	1.71	1.16
K100_1VL	20.54	0.33	0.97	-	20.10	0.35	1.20	0.38	31.87	0.28	0.58	8.40
K100_2VL	19.08	0.95	2.20	-	19.04	0.82	1.62	0.56	31.61	0.46	0.89	9.29
K100_3VL	19.58	0.69	2.36	-	19.47	0.47	1.66	0.71	32.04	0.47	0.92	9.28

**(K10_NV - K10 % without varnish. K10_1VL - K10 % with one layer of varnish. K10_2VL - K10 % with two layers of varnish. K10_3VL - K10 % with three layers of varnish. K100_NV - K100 % without varnish. K100_1VL - K100 % with one layer of varnish. K100_2VL - K100 % with two layers of varnish. K100_3VL - K100 % with three layers of varnish)*

brightness value changed a lot, which also affected the difference in colour.

A relatively similar trend of change occurs in samples with two. three and four layers of ink. Major changes were measured for samples: K100 % two layers of ink and one layer of varnish after 72 h, K100 % three layers of ink and one layer of varnish after 72 h, K100 % two layers of ink, 1, 2 and 3 layers of varnish after 216 h, K100 % three layers of ink, 1, 2 and 3 layers of varnish after 216 h, K100 % four layers of ink, 1 and 3 layers of varnish. The changes are caused by a greater difference in brightness. or in a* parameter.

CONCLUSIONS

The impact of the aging process on printed materials is an important category of research in the graphic industry, because sooner or later all products of the graphic industry are subject to the aging process. As inkjet is one of the leading printing techniques, especially when it comes to the production of increasingly present personalization, it was the leading one to produce samples. This research focused on the spectrophotometric evaluation of the impact of multiple printed layers of ink and varnish on PVC foil and their

Table 5. L*a*b* and ΔE^*_{00} values before and after ageing for sample with two ink layers.

	Before aging				After 72 h				After 216 h			
Samples	L*	a*	b*	ΔE^*_{00}	L*	a*	b*	ΔE^*_{00}	L*	a*	b*	ΔE^*_{00}
K10_NV	82.04	-2.32	-2.35	-	81.58	-2.25	-2.46	0.34	81.95	-2.42	-1.93	0.42
K10_1VL	78.29	-3.66	0.60	-	78.39	-4.21	-1.05	1.65	80.41	-3.54	-1.45	2.41
K10_2VL	75.81	-3.74	5.13	-	75.90	-3.83	0.24	4.25	78.36	-3.74	0.58	4.33
K10_3VL	75.02	-3.74	7.25	-	74.95	-3.95	1.38	4.89	77.53	-3.94	1.12	5.43
K100_NV	27.11	2.40	1.15	-	27.54	2.57	1.43	0.42	30.22	2.65	1.62	2.43
K100_1VL	13.63	0.73	-0.15	-	7.40	1.02	-0.30	3.95	27.38	0.37	-0.39	9.58
K100_2VL	8.68	0.66	-0.48	-	8.73	0.91	-1.37	1.35	27.35	0.45	-0.19	12.66
K100_3VL	9.53	0.37	-0.04	-	9.90	0.69	-1.41	1.60	27.70	0.38	-0.32	12.40

**(K10_NV - K10 % without varnish. K10_1VL - K10 % with one layer of varnish. K10_2VL - K10 % with two layers of varnish. K10_3VL - K10 % with three layers of varnish. K100_NV - K100 % without varnish. K100_1VL - K100 % with one layer of varnish. K100_2VL - K100 % with two layers of varnish. K100_3VL - K100 % with three layers of varnish)*

Table 6. L*a*b* and ΔE^*_{00} values before and after ageing for sample with three ink layers.

	Before aging				After 72 h				After 216 h			
Samples	L*	a*	b*	ΔE^*_{00}	L*	a*	b*	ΔE^*_{00}	L*	a*	b*	ΔE^*_{00}
K10_NV	78.12	-2.62	-1.83	-	78.25	-1.97	-2.16	0.93	77.57	-1.83	-3.01	1.59
K10_1VL	74.46	-3.81	0.23	-	74.89	-4.07	-0.54	0.83	76.78	-4.21	-0.85	2.01
K10_2VL	71.96	-3.77	4.71	-	72.48	-4.21	0.54	3.72	74.81	-3.72	0.25	4.43
K10_3VL	71.61	-3.89	6.70	-	71.54	-4.70	1.57	4.46	74.06	-3.88	0.79	5.29
K100_NV	27.52	2.39	1.13	-	26.47	2.52	1.21	0.80	29.34	2.61	1.41	1.43
K100_1VL	15.37	0.59	-0.47	-	9.57	0.59	-1.31	3.81	26.99	0.33	-0.54	8.15
K100_2VL	7.51	0.67	-0.23	-	7.83	0.74	-1.61	1.34	27.09	0.38	-0.26	13.18
K100_3VL	9.92	0.13	-0.84	-	9.92	0.13	-0.84	1.44	27.48	0.36	-0.35	12.07

**(K10_NV - K10 % without varnish. K10_1VL - K10 % with one layer of varnish. K10_2VL - K10 % with two layers of varnish. K10_3VL - K10 % with three layers of varnish. K100_NV - K100 % without varnish. K100_1VL - K100 % with one layer of varnish. K100_2VL - K100 % with two layers of varnish. K100_3VL - K100 % with three layers of varnish)*

Table 7. L*a*b* and ΔE^*_{00} values before and after ageing for sample with four ink layers.

	Before aging				After 72 h				After 216 h			
Samples	L*	a*	b*	ΔE^*_{00}	L*	a*	b*	ΔE^*_{00}	L*	a*	b*	ΔE^*_{00}
K10_NV	73.96	-3.09	-1.61	-	73.55	-2.89	-2.31	0.77	73.79	-2.81	-2.30	0.76
K10_1VL	71.15	-4.54	0.21	-	71.51	-4.87	-0.88	1.09	70.76	-4.04	-1.50	1.34
K10_2VL	69.95	-3.62	4.20	-	70.01	-4.17	0.81	3.08	69.86	-3.72	0.16	3.57
K10_3VL	68.93	-3.91	5.56	-	68.74	-4.34	0.63	4.29	71.84	-3.76	0.84	4.60
K100_NV	27.39	2.56	1.19	-	27.44	2.65	1.47	0.28	28.77	2.53	1.39	1.06
K100_1VL	7.66	0.85	-0.53	-	8.50	0.82	-0.93	0.65	11.55	0.69	-0.77	2.45
K100_2VL	8.38	0.46	-0.83	-	8.73	0.69	-1.76	0.95	8.36	0.74	-1.87	1.05
K100_3VL	9.19	0.06	-1.20	-	9.11	0.54	-1.43	0.74	27.33	0.36	-0.52	12.35

**(K10_NV - K10 % without varnish. K10_1VL - K10 % with one layer of varnish. K10_2VL - K10 % with two layers of varnish. K10_3VL - K10 % with three layers of varnish. K100_NV - K100 % without varnish. K100_1VL - K100 % with one layer of varnish. K100_2VL - K100 % with two layers of varnish. K100_3VL - K100 % with three layers of varnish).*

persistence through the aging process of 72 and 216 h.

First, it can be concluded that PVC foil changes its color by increasing the layers of varnish and the aging process. Further looking at the samples of K10 % TV, and K100 % TV in the mentioned exposure period, it was observed that there is a uniform increase in the value of ΔE^*_{00} by hours. The curves of the influence of the number of varnishing layers on the ΔE^*_{00} value show that increasing the varnish application changes the original tonal value. This change comes to the fore even more after exposure to the influence of aging. The print is yellow, varnished, and the base itself changes colour, so this affects the entire visual aspect of the samples. The visual change, larger and smaller, was also recorded by the numerical values of ΔE^*_{00}.

Thus, it was observed that:

- The greatest changes in colour after 72 h occurred with K10 % TV with one ink layer and three layers of varnish (ΔE^*_{00} = 5.21). Differences are massive.
- The smallest changes in colour occurred with K100 % TV, one ink layer and no varnish (ΔE^*_{00} = 0.30).
- The greatest changes in colour after 216 h occurred with K10 % TV with three ink layers and two layers of varnish (ΔE^*_{00} = 13.18).
- The smallest changes in colour occurred with K100 % one ink layer and no varnish (ΔE^*_{00} = 0.37). Light values are more susceptible to change, so in this case there are more pronounced colour differences.

To expand the existing knowledge and in order to form more coherent models. it is desirable to extend the examination to a larger number of tonal values. Also, the examination could be extended to a larger number of types and coatings of varnish, and substrates that undoubtedly affect the final print.

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