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SADRŽAJ / CONTENTS

NEW METHODS OF VARNISHING AND THEIR INFLUENCE ON OPTICAL PROPERTIES OF CARDBOARD PACKAGING

NOVE METODE UV LAKIRANJA I NJIHOV UTJECAJ NA OPTIČKA SVOJSTVA KARTONSKE AMBALAŽE

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Sažetak: Procesom UV lakiranja na otiscima se formira tanki prozirni sloj čiji je sjaj znatno viši od izvorno otisnutog bojila. U ovom radu prikazuje se utjecaj tankog sloja UV laka na sjaj i kromatske vrijednost osnovnih tonskih područja. Diskutira se kako različite metode UV lakiranja mogu utjecati na promjenu obojenja kartonske ambalaže izvorno otisnute u tehnici ofsetnog tiska. Nanos UV laka presudan za kvalitetu reprodukcije. Rezultati istraživanja pokazuju da umjereno povećanje sjaja pozitivno utječe na povećanje kvalitete reprodukcije (gamut), dok preveliki sjaj onemogućava dobru vizualizaciju tonova. Na otiscima sa UV Ink Jet mat lakom smanjuje se gamut reprodukcije, dok kod onih tretiranih sa UV Ink Jet gloss lakom gamut se neznatno povećava. Ofsetno in-line lakiranje (s flekso jedinicom) daje najveći gamut, a samim time i najveću kolornu reprodukciju. Pritom izmjerena vrijednost sjaja otiska ne slijedi kromatske vrijednosti. Akromatski tonovi (crna i tiskovna podloga) imaju najveće kolorne promjene.

Ključne riječi: UV Ink Jet lakiranje, UV ofsetno lakiranje, sjaj otiska, CIE LAB ΔE_{00}

Abstract: In the process of UV varnishing a thin transparent layer is formed on prints, the gloss of which is considerably higher than that of the originally printed ink. The influence of the thin layer of UV varnish on gloss and on the chromatic values of the basic tonal areas is presented in this work. How the different methods of UV varnishing can influence the change of the colour of cardboard packaging originally printed in the offset printing technique is discussed. The layer of UV varnish is crucial for the reproduction quality. The investigation results show that the considerable gloss increase positively influences the increase of the reproduction quality (gamut), while too high gloss makes good tone visualization impossible. On prints with UV Inkjet mat varnish the gamut of reproduction decreases, while on the prints treated with the UV Inkjet gloss varnish the gamut slightly increases. Offset in-line varnishing (with the flexo unit) gives the greatest gamut and consequently the greatest color reproduction. The measured value of the print gloss does not follow the chromatic values. Achromatic tones (black and printing substrate) have greatest color changes.

Keywords: UV Ink Jet varnishing, UV offset varnishing, print gloss, CIE LAB ΔE_{00}

1. Introduction

In the last ten years the varnishing process with UV curing varnish has been increasingly used. The reason for that is the possibility of forming the transparent layers of greater thickness, better mechanical properties and visibly better reflectance from such treated printing substrate. By the effectiveness of the application the two printing techniques are pointed out: flexo printing and Inkjet printing. The flexo printing unit is often applied in the combination with the offset printing unit, which results in better prints which are not necessary to be additionally plasticized *(Tracton, 2006).* The aim of this work is to determine the variations in colour (CIE LAB ΔE_{00}) and in gloss (G%) of the printed cardboard packaging in the technique of the offset printing. The prints were subsequently improve by two types of UV curing varnishes. Two characteristic ways of varnish applications were used: the in-line flexographic printing technique (which is a part of the lithographic printing machine) and the contactless piezo Inkjet head.

2. Theoretical part

The process of improving the graphic products by means of the conventional varnishing methods (out line roller coating, in-line coating head, dry offset via damping system, dry offset via printing plate, lithography and letterpress) showed itself as limiting. The reason for that was the different original viscosity of varnishes which can vary from 0.5 to 15 Pa·s *(Thompson, 2004).* Consistently with it, the differently formed varnish film thickness can be expected on the printing substrate before and after the curing process. So, by printing with the water dispersive varnish the greater mass share (10g/m^2) is formed on the printing substrate which rapidly decreases under the influence of heat. The oil based printing varnishes have the composition most similar to the standard printing inks, which means that the curing mechanism is based on the oxy-polymerization process. The thick film layers of such varnishes are unfortunately not thick and during the curing process no considerable changes will happen in ink film layer (2 gm^2). UV curing varnishes dry momentarily. In this way the UV curing enables the formation of thicker film layers without the oscillation in the thickness of the varnished surface. In order to enable the implementation of the UV curing printing technology it is necessary to adjust many factors. The two most important factors are the UV varnish formulation and their compatibility with the UV radiation sources. UV varnishes which are applied on the offset printing machines usually contain: bisphenol A epoxy acrylic resin (13%), trifunctional polyether acrylic resin (60%), tripropylene glycol diacrylate (5%), amine acrylate (12%), benzophenone (6%), 2,2-dimethoxy-2-phenyl acetophenone (3%) and silicone slip additive (1%) *(Leach and Pierce, 1999).* Such varnish will become solid from the liquid thanks to the UV polymerization process which is performed in 4 phases. The process begins with the application of the varnish layer on the printing substrate (phase1: varnish is a viscous liquid). After that the exposition to the UV irradiation is performed which will activate benzophenone photo initiators (phase 2: varnish is still liquid). After that the photo initiators are transformed into the free radicals which are combined with the neighboring monomers and olygomers, forming the macro molecules (phase 3: the varnishes start to harden). In the reaction the acryl group is participating. In the last phase the epoxy resins take part and the product is the hardened structure *(Chen, 2003; Elias et al, 2006).* For UV varnishing by means of the Inkjet technology it is necessary to apply much more liquid varnishes (viscosity >0,5 Pa·s). Because of that the greater quantity of diluents must be present in such varnishes as well as the smaller part of epoxy resins. By the application of the UV LED curing Inkjet varnishes the photo-initiators change. One characteristic UV LED curing varnish is that it contains: 10-20% acrylic amine synergist, 25-35% hexamethylene diacrylat hexane 1.6 diol diacrylate, 30-40% acrylic ester, 10-20% photosensitive monomers, 5-15% derivates based on phosphine oxides *(Edison, 2010; Lee, 2003).* Mercury lamp is used as the radiation source in the curing process of UV inks and varnishes in the graphic arts sector (Fig. 1a). The components of the mercury lamp are: quartz body, mercury, argon, molybdenum connector, wolfram electrode-cathode, feeding cable and ceramic insulating connector. The satisfactory emission of UV A radiation in the area (315-380 nm), UV-B in the area (280- 315 nm) and UV-C area (200-280 nm) was noticed. In order to achieve somewhat different spectrum it is possible to add iron, lead, cobalt or gallium to mercury *(Kipphan, 2001; Kokot, 2009).* For the effectiveness of UV drying the reflectors in UV lamps have an important role. Their role is to reflect 55% UV radiation from the mercury source on the printing substrate. Aluminum is one of the materials with great reflection (90% UV radiation). As aluminum is very sensitive to heat its surface has to be specially treated. Mercury lamp as the radiation source must have high power (P= 20-240 W/cm^2), and this is one of the reasons for further development in this area. Good results are obtained from the LED semiconductor sources whose power is 3 W/cm^2. The characteristic of such spectra is exactly defined by the choice of semi conductor by which the exactly directed UV electromagnetic radiation is achieved by one peak on the exactly defined wave length (Fig. 1b). In this connection the following semi conductors are used for UV varnishes: boron nitride, aluminum gallium nitride, aluminum gallium indium nitride.

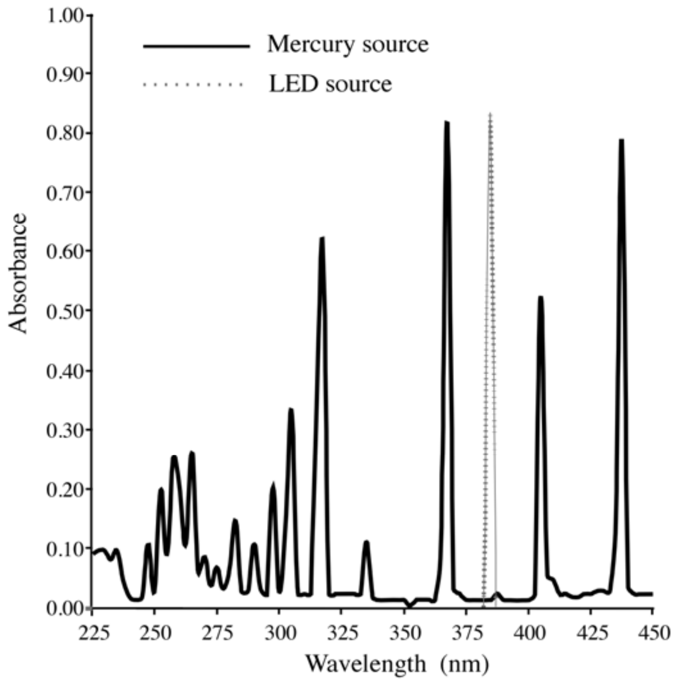


Fig.1. Emission spectra of electromagnetic sources for UV curing (mercury and LED lamps)

2.1. Ecological sustainability and varnishing of the cardboard packaging

UV curing systems compared with the traditional varnishing process are more efficient, energy saving and environment friendly. The UV equipment in graphic arts sector has been researched and developed during the past few years. The researches comprise the domain of the traditional production technology of high pressure mercury lamp primarily because of high costs of equipment, high temperatures of irradiated components, mercury pollution etc. There are now some UV curing systems (H-UV system), which in comparison to the traditional ones are saving energy and have low running cost, emit less ozone's thanks to the reduction of the light emitted in the ozone-generating wavelength of the spectrum *(Jügers, 2008).* However, the UV LED curing systems have revolutionized the UV curing industry. Unlike medium pressure mercury lamps, LEDs have only a very narrow wavelength window (Fig.1). Inks and varnishes must be precisely adapted to these narrow wavelength, in order for them to be cured using UV-LEDs. The advantages of UV LED technology versus mercury lamp are in energy saving, environment friendly and pollution free technology, no thermal radiation, ultra high illumination. The energy savings results from the fact that by the application of the UV LED technique during the standby time, its consumption is nearly none *(Fälch, 2008).* Opposite to that the high-pressure mercury lamp is continuously irradiating regardless the effective irradiation. In this case most of the energy is wasted. In dependence to the energy source, from the ecological aspects, the domain of the consumption of the non renewable resources is important as well as the emission of the carbon dioxide, one of the gasses of the greenhouse. UV LED curing system can indirectly reduce the carbon dioxide emission for several times. Mercury lamps contain a small quantity of mercury in the light bulbs and it is troublesome to handle them. The lamps may cause a hazard to human health or the environment when improperly managed. Due to this concern, the rule regulates the managements of universal waste lamps so as to promote the recycling, pollution prevention and safe handling methods. Mercury is a heavy metal that can accumulate in living tissue and cause adverse health effects (Mercola and Klinhgardt 2004). Unlike the UV-lamps, the UV-LED curing system doesn't contain mercury. Also, the UV-LED technology allows printing without ozone emissions. There is no need to provide extra protection for equipment and personnel health. However, UV-lamps generate ozone during the printing process. Because that UV-LED system does not contain mercury as already mentioned the recycle costs and the costs in permitting, reporting, and personnel protection can be decreased in relation to the UV systems. Because of the use of 365 nm wavelength emitting diodes there is no infra red and other wavelengths' radiating. The temperature rise of irradiated area is below 5^0 C versus traditionally one, were it can be 60, even higher Celsius grades. Except that the LED curing system won´t reduce the illumination and all channels can be maintained at maximum. Because of the high illumination, UV LED curing systems shortens the irradiation time. In this way the production efficiency can be improved. The development in this area includes the LUV LED UV system. The cascade system can provide the wavelength mix from five different wavelength zones within one module *(Rüter, 2007).* All in all, the UV-LED technology offers advantages over the lamp systems and provides significant benefits. However these new technologies which were discussed about were safer in terms of migration process in the food and pharmaceutical packaging. The sources of migration can be: inks, varnishes (UV photo initiators), printing substrate, environment and presses. In the production of packaging for food industry and the pharmaceutical industry there are defined directions which limit the usage of some graphic materials. However few inks and varnishes do not have toxicological information defined through the life cycle of the product. The manufacturers of the graphic materials: printing substrates, inks and varnishes do not guarantee in all the cases the low migration solutions, including the production of materials, printing, finishing and the distribution. The presented basic propositions point in this domain at essential directions of the further development, including the postulates of sustainability.

Experimental

For sample preparation the standard ECI printing form was used (1535 defined patches), whose digitalized version is illuminated on CTP (Luscher XPose 160). For the investigation in the area of the printing process of the cardboard packaging the high quality cardboard coated on both sides was used (Zenith-Europapir). The prints were made on six color offset printing machine KBA Rapida 105/6+L, which can in-line print ink and varnishes. In this way the CMYK prints were obtained (sample 1) and CMYK + UV varnish prints (sample 2). In this process the UV varnish 14- HC-144 was used (SunChemical). For the experimental UV Inkjet varnishing the UV Inkjet printer Cutter Roland Versa LEC 300 was used. In Versa Work RIP the following parameters were defined: varnishing mode (gloss), resolution (740 x 740 dpi), head moving (un-indirection) and screening method (dither), and two varnishing modes Gloss (Sample 3) and varnishing mode Mat (Sample 4). The optical properties of the varnished and unvarnished prints were measured with two devices: with spectrophotometer X-rite DTP 20 (measuring geometry 0/45° and standard observer 10°) and the device for gloss measuring Elcometer 407 (measuring geometry 20°, 60°). CIE Lab and GU (gloss unit) results were obtained from which the color differences (CIE ΔE_{00}) and gloss difference ΔGU were calculated. Final construction of color gamut (volume) is made with software Monaco Platinum version.

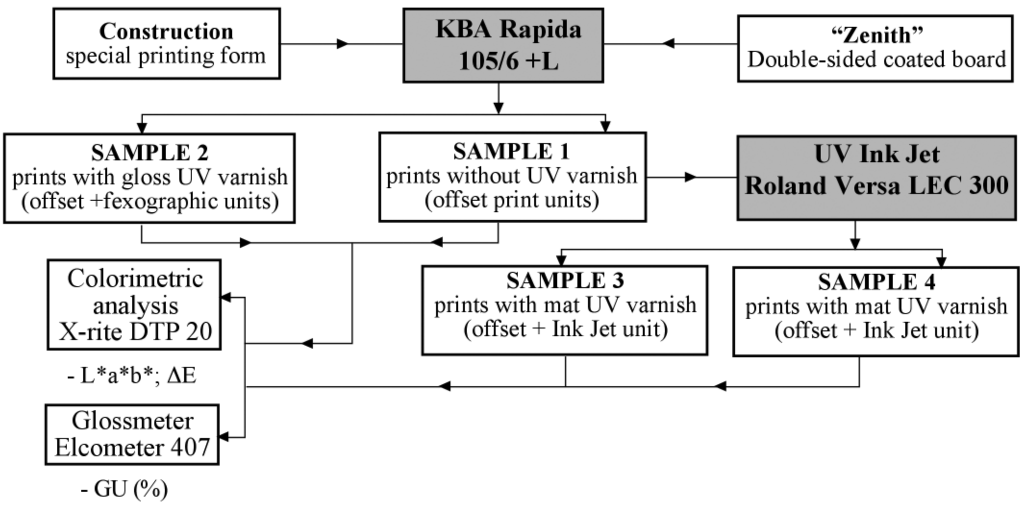


Fig. 2. Schematic presentation of the experiment flow

Results and discussion

The influence of different UV varnishing methods on the color reproduction can be best presented by comparison the volume gamut printed with only offset inks in relation with the volume gamut of prints which were made with the corresponding layer of UV varnish. The dependence of volume gamut on average gloss which was calculated as the mean value of full tones of the basic chromatic areas (R, G, B, C, M, Y, K and the printing substrate) is presented in figure 5. Because of the different reflectance from the printed substrate two angles were used in measuring (20° and 60°)

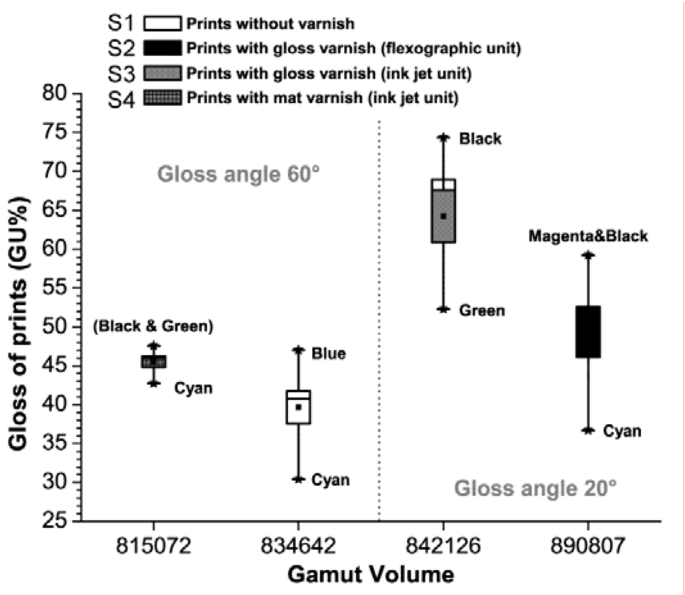


Fig.3. The volume gamut and the gloss of prints before and after the UV varnishing

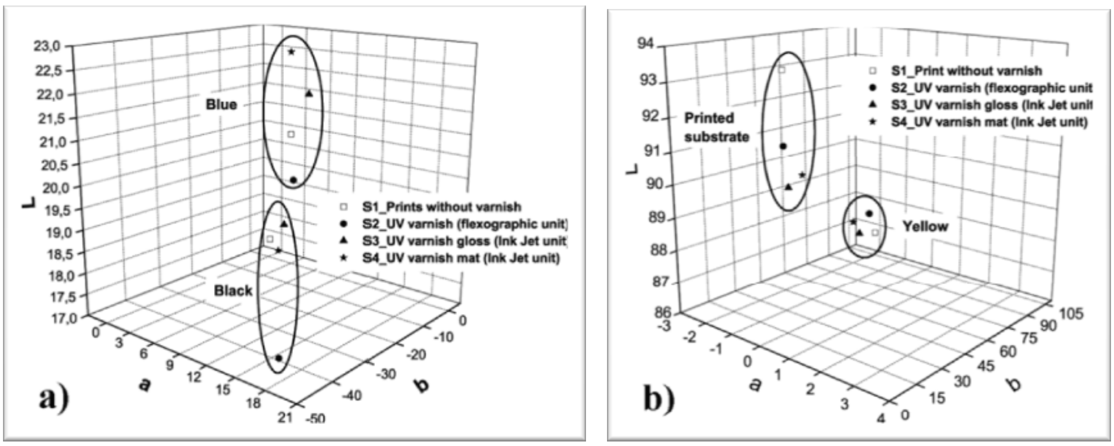
For the offset prints without the applied UV varnish the satisfactory great gamut is characteristic, whose volume is V_{S1}=834 642 gamut unit. The gloss of such print in all the tone areas is not the same. It oscillates ΔGU_{S1}=16,61%. The extremes appeared in violet – blue tonal area (the maximal gloss) while the minimal gloss appeared in cyan tonal area.

By the mat UV Inkjet varnishing of prints the smaller space volume gamut is obtained ΔV_{S1-S2}= 19 570 gamut unit. However the average increase of gloss is ΔGU_{S1-S2}=5,48%. By the UV Inkjet mat varnishing the gloss value difference between the extremes (black and cyan) is ΔGU_{S2}=4,83%. The gloss UV varnishing methods give generally greater gloss values. Because of that it is necessary to apply the other measuring geometry (the incident illumination angle is 20°). From all the used varnishing methods, the gloss UV Inkjet varnishing gives the greatest gloss (GU_{S3}= 63,31%). In this case the great deviation within the different tonal areas is characteristic (ΔGU_{S3}=22,08%), where the maximum is achieved in the black tonal area and the minimum in the green tonal area.

It was found out that the greatest gloss does not give chromatically the best print. The UV Inkjet varnished print gives the reproduction gamut which is greater for ΔV_{S3-S1}=7484 gamut units in relation to the unvarnished offset print.

The greatest color gamut is given by the UV varnished print on the flexographic printing unit (V_{S4}=890 807 gamut units). So in relation to the unvarnished offset print the increase of gamut of ΔV_{S4-S1}=56165 gamut units is realized. The print varnished with the UV Inkjet technique in relation to the print varnished with the UV flexographic unit gives smaller gloss (ΔGU_{S3-S4}=13,98%). In this case the greater deviation of certain tonal values (ΔGU_{S4}=22,51%) is obtained. The tonal areas which are emphasized as the extreme ones are magenta and black (max. gloss) and cyan (min. gloss).

Such results can be the consequence of adding the calcium to UV varnishes determined for the application in combination with the offset printing unit. With the addition of calcium the possible harmful activity of the dampening fluid is eliminated (the chromatic saturation of the printed pigments is decreased). However, the decrease of gloss effect of the UV drying varnish appears as the negative consequence. From the point of graphic design the changes of colour of the printed graphic products are considerable as well as the influence of the varnish film layer on the visual impression. In Fig. 4 the CIE LAB values for characteristic tones are presented, obtained by the UV Inkjet varnishing (mat and gloss) and UV flexographic varnishing (gloss) of prints. In Table 1 the color deviation CIE ΔE_{00} is presented in relation to the unvarnished offset prints.



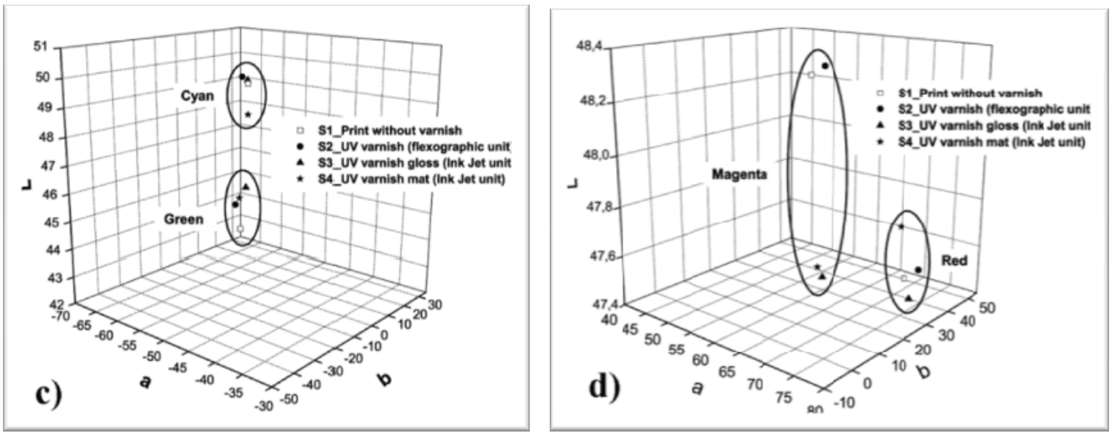


Fig. 4. CIE LAB values of UV varnished and unvarnished offset prints for the following solid patches: a) violet-blue and black; b) printing substrate and yellow; c) cyan and green; d) magenta and red

It is characteristic for the prints obtained by the experimental UV varnishing that there is no defined lawfulness. It means that for each characteristic tone the different maximal and minimal deviations (table 1) are formed by different methods of UV varnishing. In further discussion, in relation to color changes only the most characteristic ones, i.e. those which by their formation and color characteristics considerably deviate are taken into consideration.

Table1. Color changes of prints formed after the different ways of UV varnishing

a)Black 100%	ΔE_{00}	ΔL_{00}	ΔC_{00}	ΔH_{00}	Blue 100%	ΔE_{00}	ΔL_{00}	ΔC_{00}	ΔH_{00}
K_S1 - K_S2	3.14	2.46	-1.91	0.40	B_S1 - B_S2	0.71	0.55	-0.40	0.21
K_S1 - K_S3	2.62	-0.27	-2.53	0.61	B_S1 - B_S3	2.07	-0.49	0.58	-1.93
K_S1 - K_S4	1.94	0.23	-1.91	0.25	B_S1 - B_S4	1.28	-1.01	0.55	-0.57

b)Yellow 100%	DE_{00}	DL_{00}	DC_{00}	DH_{00}	Substrat 100%	DE_{00}	DL_{00}	DC_{00}	DH_{00}
Y_S1 - Y_S2	0.60	-0.36	-0.45	-0.17	S_S1 - S_S2	2.64	1.21	-1.81	-1.48
Y_S1 - Y_S3	0.57	0.06	0.49	-0.28	S_S1 - S_S3	3.85	1.91	-2.79	-1.84
Y_S1 - Y_S4	0.92	-0.21	0.81	-0.38	S_S1 - S_S4	2.72	1.62	-1.96	-0.94

c) Cyan 100%	ΔE_{00}	ΔL_{00}	ΔC_{00}	ΔH_{00}	Green 100%	ΔE_{00}	ΔL_{00}	ΔC_{00}	ΔH_{00}
C_S1 - C_S2	0.57	-0.15	0.01	0.55	G_S1 - G_S2	1.01	-0.87	-0.47	0.20
C_S1 - C_S3	0.96	-0.03	0.45	0.85	G_S1 - G_S3	2.01	-1.60	-0.24	1.19
C_S1 - C_S4	0.96	0.87	0.20	0.35	G_S1 - G_S4	1.32	-1.26	0.13	-0.38

d) Mag. 100%	ΔE_{00}	ΔL_{00}	ΔC_{00}	ΔH_{00}	Red 100%	ΔE_{00}	ΔL_{00}	ΔC_{00}	ΔH_{00}
M_S1 - M_S2	0.62	-0.03	-0.38	-0.50	R_S1 - R_S2	1.22	-0.04	-0.69	-1.01
M_S1 - M_S3	1.57	0.69	-0.12	-1.40	R_S1 - R_S3	0.84	0.09	-0.33	-0.77
M_S1 - M_S4	0.76	0.64	-0.18	-0.37	R_S1 - R_S4	0.55	-0.23	0.23	0.44

Achromatically black tones have great color changes when varnished which can be visible with the naked eye (ΔE>3). Such prints have their maximal change with the gloss offset UV varnishing. The smallest change appears with mat Inkjet varnishing. The analysis of the color changes showed greater deviations in chromaticity (C). The only exception is the UV offset varnishing with the flexo unit which gives much deeper tone (the lightness value L is decreased). From the other process inks, after UV varnishing, the smallest color change has the 100% printed yellow.

Because of the yellowish patina of the dried UV varnish layers such color changes are absolutely not visible by the human eye. Mat Inkjet varnishing whose result gives the greatest value on the coordinate +a, has greater colorimetric change, which means that the share of red is the greatest. In the process of the multi colors printing the spot tones are created by overlapping two or more process inks. From the color point of view the violet – blue tones have the greatest changes in color when UV varnishing is performed. The greatest color change resulted in gloss UV Inkjet varnishing, and the smallest one resulted in offset UV varnishing. The deviation in lightness (L) in relation to chromaticity is responsible for such color oscillation.

The UV varnishing process of the unprinted substrate gives far the greatest color oscillations chromatically. The whiteness of the original cardboard disappears, i.e. the change on coordinate +b appears (slight yellowing). It results in the change of lightness (decreased values of L). In this way the UV Inkjet gloss varnishing gives the greatest color change and the offset UV varnishing gives the smallest one.

Conclusion

The Inkjet UV varnishing and the offset UV varnishing differently influence the print quality which is confirmed by the measured values of the volume gamut (offset varnishing gives greater color gamut). The mat UV method Inkjet varnishing will not give considerable color changes and it cannot be recommended as the possible effect of visual emphasizing.

The optical property of print gloss is not in the direct correlation with the colorimetric measurements. It means that the greatest reproduction gamut is not at the same time the glossiest print. The in-line gloss offset UV varnishing gives lesser gloss than the UV Inkjet, because of the short drying time of the ink. In order to achieve the additional value, the

varnishing process can serve as the tool for emphasizing the defined oriented surface (segment varnishing).The tone of the previously made print can considerably influence the noticeability. Because of that the varnishing of darker tones (black and violet – blue) it is recommended which will oscillate ΔE_K=2,81 and ΔE_B=2,57 depending on the varnishing method. Similar results can be achieved with the varnishing of the gloss coated printed substrate. However the minimal deviation of the substrate ΔE_S=0,70 is achieved by different varnishing methods. In the case of the cardboard packaging which must not deviate from the original because of the demand of the standardized color management the UV varnishing of the yellow tones is recommended which will have then slight changes. The different methods of UV varnishing will not considerably influence the changes of the yellow tone ΔE_Y=1,03.
From the point of view of the cardboard packaging specimen printing the effect of gloss of the printed UV varnish is not possible to include into color management.
With the influence of the varnish layer on the visual experience of the packaging product, in the early phase of graphic design, the ecological prepositions of the life cycle through all its phases have to be included. The continuation of investigations will be based on the parameter analysis of gloss and color value with the creation of the mathematical model and inclusion of the UV varnishing process in color management. The composition of UV varnish, the radiation sources in the drying processes, migration processes (especially when speaking about the packaging determined for food and pharmaceutical industry) with the postulates of ecological sustainability will be important frame of reference.

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