ISSN 1330-3651 (Print), ISSN 1848-6339 (Online)
https://doi.org/10.17559/TV-20220725151112
Original scientific paper

Influence of Paper Properties and Printing Machines Properties on Optical Density in Electrophotography

Nemanja KAŠIKOVIĆ, Ivana JURIČ*, Danijela RANDJELOVIĆ, Iskren SPIRIDONOV, Zuzanna ŻOŁEK-TRYZNOWSKA, Rumyana BOEVA, Saša PETROVIĆ

Abstract: Electrophotography is affected by several parameters, including printing machines and paper type, which determine the final quality of reproduction. For the investigation of those effects, tests were done on the three types of electrophotography printing machines and eight types of uncoated paper with different properties of weight, surface roughness, whiteness, brightness and opacity. Samples were printed with cyan, magenta, yellow and black toner under the standard, identical conditions. The assessment of standard print quality parameter (optical density) was done using spectrodensitometer Techkon Spectro Dens. At the same time, the paper substrates were characterized using the atomic force microscopy (AFM) as well as by spectrophotometric measurements (X Rite Eye-One, i1). Obtained results showed that the reproducibility significantly depends on the type of printing machine rather than optical and mechanical properties of paper.

Keywords: electrophotography; optical density; optical paper properties; surface roughness

1 INTRODUCTION

Traditional print markets have experienced more fundamental and dramatic changes in the last 20 years than in any similar period since Gutenberg [1]. The trend of print circulation decrease is present all across the printing industry, but regardless of this fact, printing income grows every year. Reduction of circulation has adversely affected the part of conventional printing techniques, while digital printing techniques are more suitable for the newly emerging situation and are increasingly winning the market [2]. Also, it is essential to say that digital printing is user-friendly and economical [3]. The most essential digital printing techniques are inkjet as well as electrophotography [4], with the second mentioned process becoming more common due to the much easier operation. [5].

The quality of printing in electrophotography is influenced by many factors, the most important of which is the printing machine itself, as well as the quality of the selected paper. Within the printing process based on electrophotography, variations of several parameters are possible: a variety of inks or toners, charged areas of the photoreceptor, type of fuser, etc.

Apart from that, paper properties affect the quality of colour print reproduction. [6]. Printing substrate characteristics such as porosity, surface roughness, optical properties (whiteness, opacity, light scattering and gloss) as well as the interaction between the substrate and the ink are a crucial factor that determines the final print quality. One of the key characteristics of paper for high quality printing is its absorption power [7, 8].

Also, the biggest influence on print quality is the paper surface roughness. A smooth surface of the material enables good ink transfer on paper, and vice versa. Rougher surfaces have their pronounced peaks and valleys, which makes it difficult for the ink to adhere to the surface. [9]. Besides, an increase in smoothness of the surface leads to the rise of the print density [10].

Optical paper properties (whiteness, brightness, opacity) are also essential factors that influence print quality. In the paper [11], it was proven that the whiteness of paper is mostly affected by residual lignin, although pulp bleaching, adding fillers and FWA (Fluorescent Whitening Agent) to the paper, and paper coating are used to improve its optical characteristics [12]. It has been shown that the contrast in printing is most affected by paper whiteness [13].

Brightness is an optical parameter of paper defined as the percentage of blue light reflection measured at a wavelength of 457 nm [14]. Therefore, it can be determined that two papers with the same brightness value visually look different.

The third most important optical parameter of paper is opacity. Opacity is defined as the amount of light that cannot pass through the paper [15]. The opacity can be increased by adding a greater amount of fillers. It also depends on the type of fiber used [11]. During the papermaking process, the degree of bleaching in addition to the whiteness of the paper can also affect the opacity [16].

1.1 Literature Review

A review of previous literature has shown that optical properties such as whiteness, brightness and opacity have some influence on the print quality.

In papers [8, 9], the authors came to the conclusion that higher values of whiteness and gloss increase the color gamut, while higher values of roughness affect the reproducibility of the print, reducing it. In the aforementioned works, a smaller number of samples and only one printing machine were used, so the goal of this work was to fully supplement the previous research with additional analyses.

In another found paper [10], the author concluded that the quality of digital printing is influenced by both the printing machine and the paper itself, but that paper plays a greater role. They found that print quality was most affected by brightness, opacity, basis weight, gloss, roughness and density. The mentioned parameters are interdependent and a change in one of them leads to a significant change in the others. It was also concluded that a higher opacity value increases the print quality.

Some authors examined the influence of the paper optical properties only on the perceived quality of the print samples. Norberg and Andersson [17] tested several papers with different CIE whiteness values and concluded that the perceived print quality increases by increasing the whiteness of the paper, but up to a certain value, where further increasing the whiteness has no effect. Coppel made the same conclusion [18].

In the paper [19] authors concluded that paper properties affect colour gamut. They found that higher gamut volume was achieved by using paper with low roughness and porosity and high paper gloss, brightness and whiteness.

Young analyzed the effect of opacity on print quality [20]. He concluded that reducing the opacity leads to a reduced effect of ink penetration, which directly affects the reduction of print quality.

The aim of this paper is to supplement the analysis of existing works by taking into account a larger number of different papers and a larger number of printing machines. The key paper parameters for testing are: basis weight, surface roughness, whiteness, brightness and opacity.

2 MATERIALS AND METHODS

The digital, electrophotographic printing machines used in this research were Xerox DocuColor 250, Konica Minolta Bizhub C224e as well as Xerox WorkCentre 7228. All the printing machines had similar technology specifications in terms of the electrophotographic working process (laser imaging unit, powder toner, fuser unit). Xerox DocuColor 250 uses Xerox 6R1222 (cyan), 6R1221 (magenta), 6R1220 (yellow) and 6R1219 (black) toners. Konica Minolta Bizhub C224e uses Konica Minolta TN321 4 Colour Toner Cartridge Multipack which contains A33K150, A33K450, A33K350 and A33K250 toners. The third printing machine (Xerox WorkCentre 7228) uses Xerox 6R1176 (cyan), 6R1177 (magenta), 6R1178 (yellow) and 6R1175 (black) toners. Efi Fiery® RIP software was used with selected profiles generated for the machines themselves. The print resolution is set to the maximum values of the machines, which is 2400 × 2400 dpi for Xerox DocuColor 250, 1800 × 600 dpi for Konica Minolta Bizhub C224e and 1200 × 1200 dpi for Xerox WorkCentre 7228.

Eight uncoated printing papers with different surface structure and grammage were tested, i.e. used in the printing process (paper 1 - 80 g/m^2, paper 2 - 100 g/m^2, paper 3 - 130 g/m^2, paper 4 - 160 g/m^2, paper 5 - 170 g/m^2, paper 6 - 200 g/m^2, paper 7 - 240 g/m^2, and paper 8 - 300 g/m^2).

The paper surface roughness was characterized by AutoProbe CP-Research SPM (TM Microscopes-Bruker), on surface 5 × 5 µm^2. AFM measurements were performed using non-contact mode and Bruker Phosphorus (n) doped silicon Tap300 metrology probes, model MPP-11123-10 with Al reflective coating and symmetric tip. The nominal resonance frequency of these cantilevers is 300 kHz, while the nominal value of spring constant is 40 N/m. AFM images were analyzed using Image Processing and Data Analysis Version 2.1.15 and SPMLab Analysis software from VEECO DI SPMLab NT Ver. 6.0.2.

Paper optical properties were measured using spectrophotometer Eye-One (i1) along with the software Babel ColorCT&A (Whiteness Tool). The measurement of whiteness was carried out in accordance with the standard CIE-GANZ 82, and brightness and opacity were measured according to the standards TAPPI T452/ASTM D985 and CGATS.5/ISO 2471 (D50). Appropriate white and black substrates were used for the measurement. The measurement was performed ten times, at different positions of the substrate, while the results show the average values obtained for each paper.

Optical density of reproduced color was measured on the four primary colors (cyan, magenta, yellow and black) at the patch of 100 % tone value. Test chart was printed in a controlled environment (20°C, 50% relative humidity - RH). At the beginning of the printing process, all the printing machines were calibrated according to the user guide. For the measurement, we used the SpectroDensspectrodensitometer (Techkon, Germany) with the following parameters: directional 0°/45° measurement geometry, D50 standard illuminant and 2° standard observer.

3 RESULTS AND DISCUSSION

Roughness of the nanostructures on the paper fibers was studied using AFM. Surface roughness parameters (S_q and S_a) and 3D topographic images for all samples are shown in Tab. 1 and Fig. 1, respectively. Based on the visual assessment of the 3D topography shown in Fig. 1 it can be observed that the smallest difference between peaks and valleys is obtained for samples b) and g), which also have the smallest roughness value. In other samples, this difference is much less pronounced. Sample e) does not have pronounced peaks and valleys, but has a very steep surface, which led to a rather high values for surface roughness parameters.

The surface roughness of the samples was in the range of 64,3 - 193,1 µm (*Sa* parameter). The biggest average surface roughness has the paper 3 (130 g/m^2), while the lowest average roughness has the paper 7 (240 g/m^2), regarding both considered surface roughness parameters (S_q and S_a). Coefficient of correlation between these two parameters was measured using CORREL function in Excel. Result showed very strong correlation between S_q and S_a parameter (0,99).

Table 1 Surface roughness parameters for all papers

Paper	RMS Roughness, S_q / nm	Average Roughness, S_a / nm
1	172	148,7
2	87	68,2
3	231,4	193,1
4	168,2	124,7
5	223,5	180,3
6	178,9	145,2
7	80	64,3
8	172,8	145,4

Whiteness, brightness and opacity measurements of the papers are shown in Fig. 2. The whiteness of all uncoated papers was in the range of 119,7 - 135,8. The whitest paper is paper 7, and the lowest value has paper 3, which has the roughest surface.

After the whiteness was determined, the brightness of the same samples was measured. According to values from

Fig. 2 it can be concluded that all uncoated samples have very similar values. Obtained brightness values were in the range of 97 - 101,7. The largest brightness value has the paper 7 (which is the whitest), while the lowest brightness value has the paper 1.

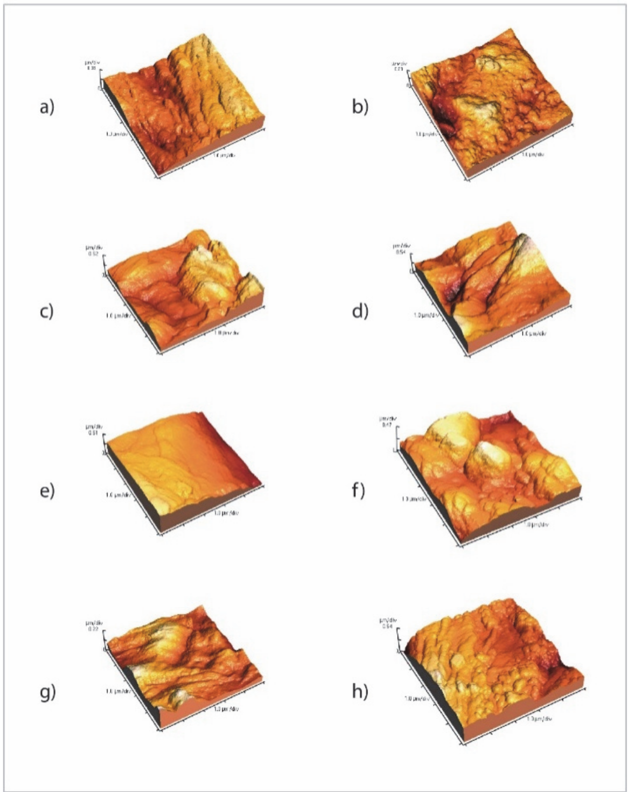

Figure 1 3D topographic images for all papers: a) paper 1, b) paper 2, c) paper 3, d) paper 4, e) paper 5, f) paper 6, g) paper 7 and h) paper 8

Fig. 2 also presents the opacity values for all eight samples. The opacity differences between the samples are minimal, like in case of the brightness parameter. The largest opacity value also has the paper 7 (which is the whitest and brightest), while the lowest opacity value has the paper 3, which has the roughest surface. Opacity goes over 94%, which indicates very opaque papers.

When the results of the optical properties between the papers are compared, a strong correlation is obtained. The correlation coefficient between the values of whiteness and brightness and between whiteness and opacity is 0,9, while by comparing the brightness and opacity of the paper, a slightly lower value of the coefficient was obtained, which is 0,8. By comparing the roughness values with the values of the optical properties, very low correlation was found. The correlation coefficient is negative, and below 0,5. Thus, based on these results, it can be confirmed that the mechanical properties of the paper affect the optical properties, but may not be completely correlated.

Density values for all papers printed on three different machines are shown in Fig. 3 to Fig. 6. Fig. 3 illustrates the density values for all samples for cyan; Fig. 4 presents the density values for all samples for magenta; Fig. 5 shows the density values for all samples for yellow and Fig. 6 presents the density value for the last processed color black.

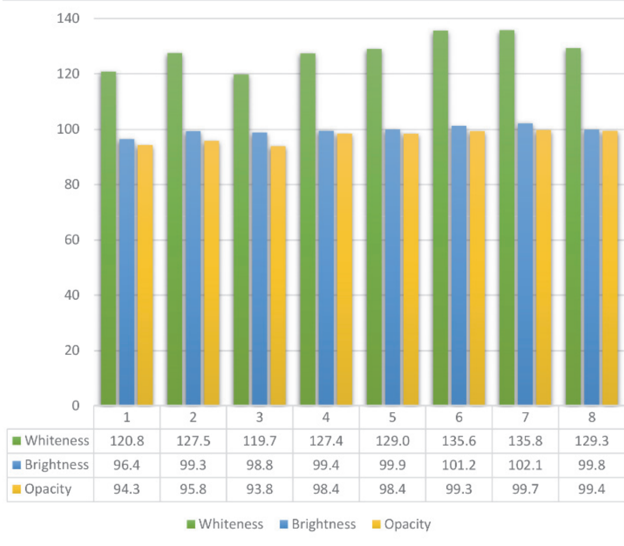

Figure 2 Results of optical parameters for all samples

From the presented figures, we can see that all obtained results per color in the case of one machine are similar. Standard deviation values for all colors (printed on same machine) are very low. The highest standard deviation value was 0,15, for samples printed with black ink on Xerox WorkCentre 7228 printing machine. The lowest standard deviations were calculated for samples printed on Konica Bizhub C224e printing machine, bellow 0,08. What can be concluded is that with rougher papers, a lower value of optical density was obtained, which can be explained by the higher absorbency of these papers. But this is not the case for all papers with similar roughness values. In addition to roughness, other properties of paper affect the print quality.

Based on the graphs shown in Fig. 3 to Fig. 6 and based on the values of standard deviations, it can be concluded that the smallest variations of optical densities on different papers appear when printing with a Konica Bizhub C224e.

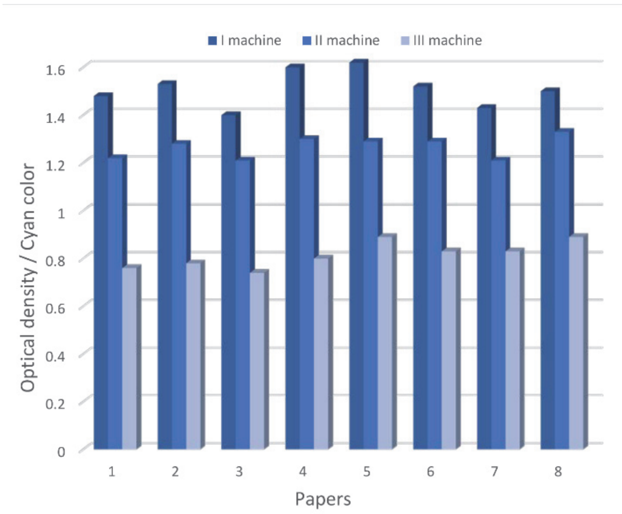

Figure 3 Optical density values for cyan for all machines and papers

When comparing the optical density with the paper characteristics measured in this experiment, no constant correlation was found. For some colors and some machines, a medium correlation was obtained, while for others it was very weak. Therefore, it is impossible to draw a global conclusion. Based on the results, it can be concluded that minimal variations exist in the measured optical densities for all primary colors on different papers. A much larger difference in optical density is observed when different machines are used, so it can be concluded that in this case the printing machine properties have a much greater effect on color reproduction compared to the substrate used, which does not agree with the results obtained in the previous papers [8-10].

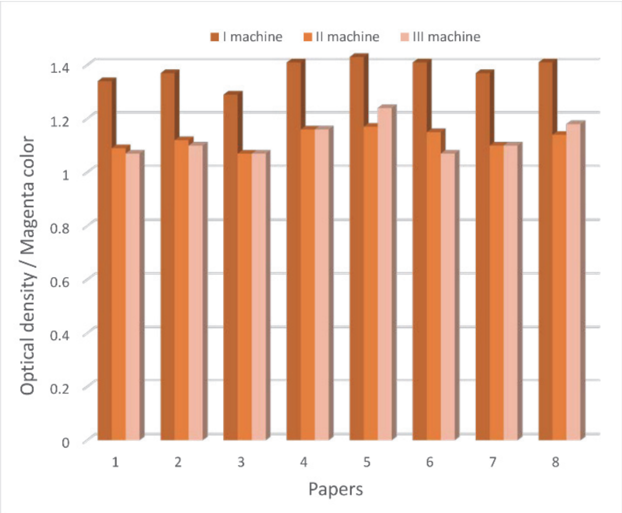

Figure 4 Optical density values for magenta for all machines and papers

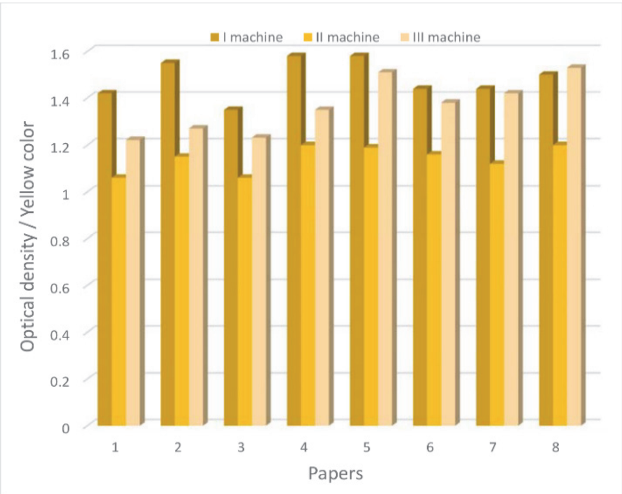

Figure 5 Optical density values for yellow for all machines and papers

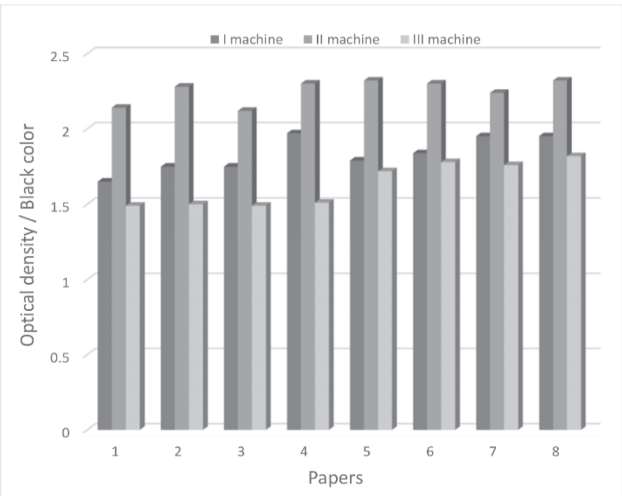

Figure 6 Optical density values for black for all machines and papers

4 CONCLUSION

This study investigates the influence of printing substrates with different characteristics (basis weight, surface roughness, whiteness, brightness and opacity) and three types of electrophotographic printing machines on optical density (print quality).

Obtained results of the research show that the printing machine had a profound impact on the reproduced optical density. The Xerox DocuColor 250 enabled significantly higher density values, especially regarding cyan, magenta and yellow ink prints, compared to other two used printing machines: Konica Bizhub C224e and Xerox WorkCentre 7228. On the other hand, Konica Bizhub C224e achieved the most stable optical density values when changing paper.

The surface roughness is quite different between the samples; the measured values are in the range of 64,3 - 193,1 µm (S_a parameter) and 80 - 231,4 µm (S_q parameter). The measured values of the optical properties (whiteness, brightness and opacity) are similar between the samples.

Comparing the properties of paper with optical density, no model was found that would accurately define whether there is an influence between them. Based on the results, it can be concluded that the change in the printing machine properties has the most significant impact which is not consistent with previous research. The explanation for this is that in those previous studies, a smaller number of samples and a smaller number of printing machines were used.

Based on the results obtained in this work, it can be said that changing uncoated substrates does not make a big difference in optical density, so any substrate can be used and the color reproduction will be satisfactory. But if it is necessary to obtain a print with the same colors on different machines and on the same substrate, it is also necessary to adapt the operation of the machines to each other.

Acknowledgements

This research (paper) has been supported by the Ministry of Education, Science and Technological Development through project no. 451-03-68/2022-14/200156 "Innovative scientific and artistic research from the FTS (activity) domain", and a Grant Agreement with the Institute of Chemistry, Technology and Metallurgy, Grant No. 451-03-68/2022-14/200026.

5 REFERENCES

[1] Kašiković, N., Novaković, D., & Vladić, G. (2016). Trends in printing industry. *Proc. 8th Int. Symp. GRID*, Novi Sad, University of Novi Sad, Faculty of Technical Sciences, 19. https://doi.org/10.24867/JGED-2017-1-019
[2] Kašiković, N., Stančić, M., Novaković, D., Vladić, G., & Petrović, S. (2016). Analizadigitalneštampeitrendovi u njenomrazvoju. *Proc. 12th Int. Conf. Teslić*, University in Banja Luka, Faculty of Technology, 594.
[3] Schein, L. B. (1992). *Electrophotography and Development Physics*. Springer, Berlin, ISBN 978-3-642-77744-8. https://doi.org/10.1007/978-3-642-77744-8

[4] Kipphan, H. (2001). *Handbook of Print Media: Technologies and Production Method*. Springer, Berlin, ISBN 978-3-540-67326-2. https://doi.org/10.1007/978-3-540-29900-4

[5] Ohta, N. & Rosen, M. (2006). *Color Desktop Printer Technology*. Taylor & Francis Group, New York, ISBN 978-0-367-39112-6.

[6] Duke, C. B., Noolandi, J., & Thieret, T. (2002). The surface science of xerography. *Surf. Sci. 500*, Elsevier, 1005-1023. https://doi.org/10.1016/S0039-6028(01)01527-8

[7] Vogl, H. (2008). *A survey of digital press manufacturers: critical paper requirements visiting professor*. School of Print Media Rochester Institute of Technology, Rochester.

[8] Ataeefard, M. (2015). The influence of paper whiteness, roughness and gloss on the optical density of colour digital printing. *Pigment & Resin Technology*, *44*(4), 232-238. https://doi.org/10.1108/PRT-11-2014-0108

[9] Ataeefard, M. (2014) Investigating the effect of paper properties on color reproduction of digital printing. *Progress in Organic Coatings*, *77*(9), 1376-1381. https://doi.org/10.1016/j.porgcoat.2014.04.024

[10] Chen, S. S. (2009). *Effects of paper properties on Xerographic print quality*. Department of Chemical Engineering and Applied Chemistry, University of Toronto.

[11] Dawitz, A. (2004). *Paper for Digital Printing*, *Literature Review*. School of Print Media Rochester Institute of Technology, Rochester.

[12] Aksoy, B., Joyce, M., & Fleming, P. (2003). *Comparative study of brightness/whiteness using various analytical methods on coated papers containing colorants.* Department of Paper and Printing Science and Engineering.

[13] Norberg, O. (2007). *Paper whiteness and its effect on the reproduction of colors*. Proceeding Human Vision and Electronic Imaging XII;, *6492*. https://doi.org/10.1117/12.703013

[14] TAPPI (1998). T452 om-98 brightness of pulp, paper, and paperboard (directional reflectance at 457nm).

[15] Jurič, I., Karlović, I., & Tomić, I. (2013). Optical paper properties and their influence on colour reproduction and perceived print quality. *Nord Pulp Pap Res J*, *28*, 264. https://doi.org/10.3183/npprj-2013-28-02-p264-273

[16] TAPPI (2011). T 425 om-11 Opacity of paper (15/d geometry, illuminant A/2°, 89% reflectance backing and paper backing), Test Method.

[17] Norberg, O. & Andersson, M. (2009) *Perceived Image Quality of Printed Images and Their Relation to Paper Properties*. Final Program and Proceedings - IS and T/SID Color Imaging Conference, Mid Sweden University, Department of Information Technology and Media, ISBN: 978-089208288-9, 210-215.

[18] Coppel, L. G., Norberg, O., & Lindberg, S. (2010). *Paper whiteness and its effect on perceived image quality*. Eighteenth Color and Imaging Conference: Color Science and Engineering Systems, Technologies, and Applications, San Antonio, ISBN / ISSN: 978-0-89208-294-0, 62-67

[19] Wu, Y. J., Pekarovicova, A., & Fleming, P. D. (2007). How Paper Properties Influence Color Reproduction of Digital Proofs for Publication Gravure. *Journal TAGA*, ISSN 0082-2299, 54-55.

[20] Yang, L. (2003). *Ink-paper interaction*. Linkoping Studies in Science and Technology Dissertations No. 806, Department of Science and Technology Linkoping University, Sweden.

Contact information:

Nemanja KAŠIKOVIĆ, PhD
University of Novi Sad,
Faculty of Technical Sciences,
Department of Graphic Engineering and Design,
Trg Dositeja Obradovića 6, Novi Sad, Serbia
E-mail: knemanja@uns.ac.rs

Ivana JURIČ, PhD
(Corresponding author)
University of Novi Sad,
Faculty of Technical Sciences,
Department of Graphic Engineering and Design,
Trg Dositeja Obradovića 6, Novi Sad, Serbia
E-mail: rilovska@uns.ac.rs

Danijela RANDJELOVIĆ, PhD
Department of Microelectronic Technologies,
Institute of Chemistry, Technology and Metallurgy,
University of Belgrade, Njegoševa 12, 11000 Belgrade, Serbia
E-mail: danijela@nanosys.ihtm.bg.ac.rs

Iskren SPIRIDONOV, PhD
University of Chemical Technology and Metallurgy,
Department of Printing Arts,
Pulp and Paper,
Bulevard Sveti Kliment Ohridski, 8, Sofia, Bulgaria
E-mail: i_spiridonov@abv.bg

Zuzanna ŻOŁEK-TRYZNOWSKA, PhD
Warsaw University of Technology,
Faculty of Mechanical and Industrial Engineering,
Institute of Mechanics in Printing,
Narbutta 85, 02-524 Warsaw, Poland
E-mail: Zuzanna.Tryznowska@pw.edu.pl

Rumyana BOEVA, PhD
University of Chemical Technology and Metallurgy,
Department of Printing Arts,
Pulp and Paper
Bulevard Sveti Kliment Ohridski, 8, Sofia, Bulgaria
E-mail: r_boeva@abv.bg

Saša PETROVIĆ, PhD
University of Novi Sad,
Faculty of Technical Sciences,
Department of Graphic Engineering and Design,
Trg Dositeja Obradovića 6, Novi Sad, Serbia
E-mail: petrovic.sasa@uns.ac.rs