EFFECTS OF INK CONSUMPTION ON PRINT QUALITY ON COATED CELLULOSE-BASED PAPER SURFACES

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Paper – ink interaction is extremely important in printing. Ideal printing outputs should be achieved with minimal ink consumption. It should not be supposed that visual printing quality will increase as the amount of ink increases. The effects of excessive ink consumption during the printing process on process sustainability, economy and environment should not be ignored. In this study, the effects of ink consumption during the printing process on printing quality parameters were mainly examined. Paper samples were printed with different amounts of ink, and the density and CIE *L*a*b** values of the solid ink films were measured. The lightfastness test was applied to determine the resistance of the printed ink films to light, and the changes in their color were examined. Ideal ink amounts to reach ideal color *L*a*b** values were determined and the effects of ink amount on the printing quality parameters were highlighted. Then, ink consumption was evaluated in terms of recycling, sustainability, environmental and economic effects, and recommendations were made to reduce the use of ink.

Keywords: ink amount, ink consumption, print quality, environmental, CIE *L*a*b**, color change

INTRODUCTION

In offset printing, an inked image from a printing plate is printed on a rubber blanket cylinder and then transferred to paper or another material.[1,2] Color printing uses yellow, magenta and cyan inks to produce various colors by subtractive mixing to give red, blue and green. The printing substrate is then layered with the colors cyan, magenta, yellow and black (CMYK), one after another, so that the complete printed image is created.[3]

The main task in multicolor printing is to produce printed CMYK ink color images that are identical in color and shape to the given part of the original.[4] However, CMYK colors should be also printed in the correct CIE *L*a*b** color values in order to produce images correctly. These correct color values may vary depending on the amount and density of the printing ink. For the same amount of ink, more productive inks give a higher optical density than less productive ones. On the other hand, less ink is required to achieve the same optical density when the ink is more productive.[5]

The formation of an ink film with the desired optical density is important for printing quality and the result. The amount of ink used in the printing process affects the total ink or total area coverage of CMYK colors. Ink coverage is expressed in grams per square meter or, taking into account the mass density of the ink, by the ink layer thickness in micrometers.[6] The measurements of ink mileage and transfer curves on paper are necessary for adequate evaluation of the interaction between ink and paper.[7]

Achieving optimum ink consumption in the printing process is important for its potential effect on image quality, increased production efficiency and actual ink saving.[8]

Ink consumption is important due to its potential effect on printing quality, as well as its adverse environmental effects, and thus it should not be ignored. With the optimum ink consumption meeting technically ideal printability criteria, both economic and environmental benefits are acquired. As the ink film thickness increases, the amount of energy required for drying the ink film increases as well and a greater amount of volatile organic compounds is released into the atmosphere. These volatile organic compounds (VOCs) affect the ozone layer and are associated with global warming because of their contribution to the greenhouse effect.[9]

In recent years, the number of studies focusing on the reduction of VOCs content produced by inks has boosted due to increased environmental awareness.[10,11] Nevertheless, there is no environmental study on the reduction of ink consumption in the printing industry. In this study, a series of printing processes have been performed with different amounts of ink, and the effects of ink amount on printing density, *CIE L*a*b** values, color change and lightfastness were examined. Also, the environmental effects of unnecessary ink consumption were discussed.

EXPERIMENTAL

The investigation was performed using RAPIDA Magenta 7000 49 mineral oil-based offset printing inks (Michael Huber, Germany) for the standard offset sheet printing.

In test prints, glossy coated paper was used, and the properties of this paper are listed in Table 1.

In this study, an IGT C1 (IGT, Netherlands) printability tester was used to print on the coated papers with different ink amounts. This printability tester allows homogeneous inking of a printing cylinder and the transfer of a certain amount of ink to the test papers under certain conditions.

The amount of ink transferred to the substrate was determined by weighing (g) the printing cylinder just before and after printing.

After the printed area was determined by measuring the printing length and width, the amount of ink applied to this area (in g/m^2) was calculated according to Equation 1 and the data are provided in Table 2:

$$C = \frac{m_1 - m_2}{A} \tag{1}$$

where C is ink coverage; m_1 is the mass of the inked printing cylinder before printing; m_2 is the mass of the printing cylinder after printing; A is the printed area.

The ink printed in this defined quantity (in g/m^2) was the starting point of the physical tests to be performed. The ink amount values obtained were a prerequisite for determining the applied ink volume and other relevant printability characteristics, such as color intensity and print gloss.

Solid density values and colorimetric coordinates of the test inks were measured *via* a Gretag Macbeth SpectroEye Spectrophotometer (CIE standard illuminant D50, CIE standard observer 2°, 0°/45° instrument geometry, and white backing) and recorded. The print gloss values of magenta ink films were measured at 60° geometry using a BYK Gardner Gloss Meter (Sheen Instruments, U.K.), in accordance with ISO 2813:2014.

Table 1
Features of used print paper

Properties	Standard	Glossy coated paper
Grammage (g/m^2)	ISO 536	115.0
Bulk (cm^3/g)	ISO 534:1995	0.77
Whiteness CIE D65/10 (%)	ISO 11475	122
Brightness D65/10 (%)	ISO 2470-2	99
Opacity with D65/10 (%)	ISO 2471	94.0
Gloss TAPPI 75 (%)	TAPPI T480 om-92	70
Surface roughness (PPS 1.0)	ISO 8791-4	0.7
Surface roughness Bendtsen (µm/Pas)	ISO 8791-2	-
Surface energy (mJ/m^2)	ASTM D5946	50.6

Table 2
Transferred amount of printing ink on paper

Series	1	2	3	4	5	6	7	8
Ink, g/m^2	0.459	0.515	0.543	0.585	0.627	0.655	0.752	0.864
Series	9	10	11	12	13	14	15	16
Ink, g/m^2	0.905	0.975	1.045	1.114	1.142	1.254	1.268	1.365

RESULTS AND DISCUSSION

The optimum ink amount in accordance with ISO 12647-2 printing parameters was determined in the test prints on matte coated papers, and the effects of ideal and different ink amounts on print density, CIE *L*a*b** values, color change and lightfastness were examined.[12]

Printability properties

Ink amount and density

Ink is structurally a dispersion system consisting of pigment, binder and solvent.[14] The physicochemical interaction between paper and printing ink is related to the spreading, setting and drying of wet ink.[15,16] The horizontal and vertical movement of the liquid ink within the paper is theoretically a good example to the liquid flow in the porous platform.[17] Print density is the color depth of a printed image.[13] In the study, the print densities of different amounts of ink (ink films) on the paper surfaces were measured and the density values obtained were shown graphically as a function of the amount of ink applied (Fig. 1).

The test prints were made in accordance with ISO 12647: 2 standard CIE *L*a*b** values (*L** 48, *a** 74, *b** -3, white backing). The ideal ink amount and density values were determined to be 0.752 g/m^2 and 1.40, respectively (Fig. 1).

In the study, it was determined that the density value increases proportionally with the ink amount used in printing. As the ink amount on unit area increased, the amount of pigment in the ink film also increased. Since the paper absorbed the liquid phase of the ink, more pigment was fixed per unit area on the paper surface. It is believed that the increase in the print density value due to the rising use of ink is related to the increase in the pigment ratio per unit area.

Ink amount and CIE lightness

The perception of color changes varies from person to person, the degree of illumination of the place, and many other factors. *L*a*b** is a system designed by CIE to eliminate these perception differences, by turning colors into mathematical expressions.[18] The CIE 1976 CIELAB color space is still most frequently used for measuring the colors of printing inks.[19] The CIE coordinates, *L** (lightness), *a** (red-green) and *b** (blue-yellow) can be obtained by mathematical transformation and computation of the X, Y and Z tristimulus values.[20,21]

The luminous intensity of a color – *i.e.*, its degree of lightness – is called its value. Colors can be classified as light or dark, when comparing their value.[22] In the color space, the CIE *L** (lightness) value describes the lightness.[19]

This study shows that as the amount of ink used for printing increases, the lightness value of magenta color decreases spectrophotometrically. In the three-dimension color space, a decrease in the lightness value of the stated color means that the color shifts towards the center (Fig. 2). In other words, the higher the amount of ink used, the darker the color is.

Ink amount and color

In the CIE *L*a*b** measurements performed for the purpose of examining the effect of ink amount on color value, it was observed that, as the ink amount was increased, the magenta color changed in '+' direction on axes a and b of the coordinate plane. This means that, as the ink amount rises, the magenta color becomes yellower and redder (Fig. 3).

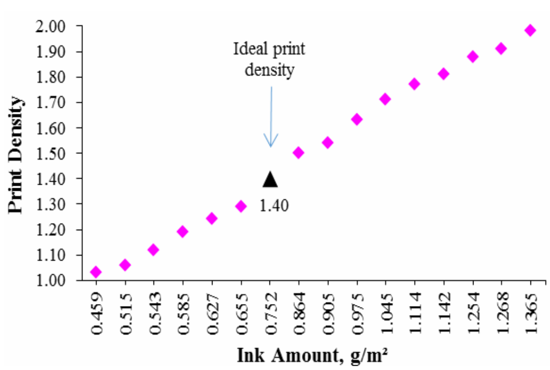

Figure 1: Ink amount and print density

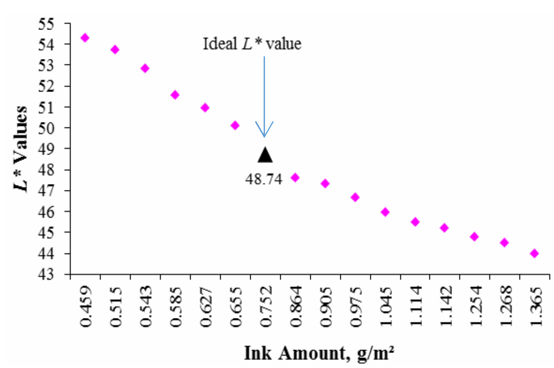

Figure 2: Color CIE *L** value *vs*. ink amount

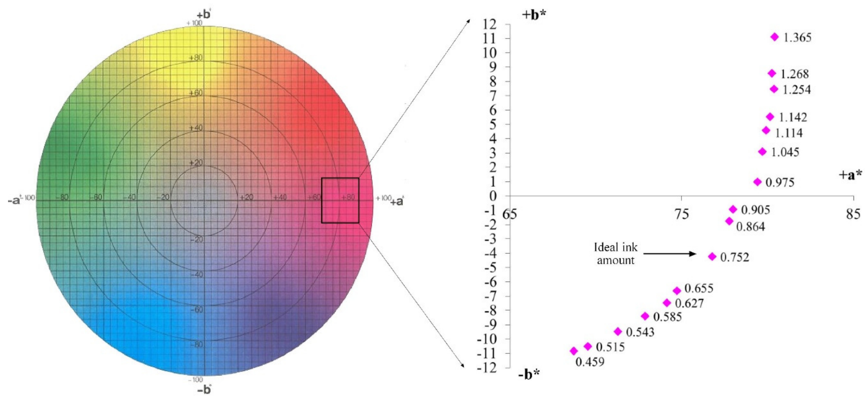

Figure 3: Color deviation in CIE $L^*a^*b^*$ color space depending on ink amount

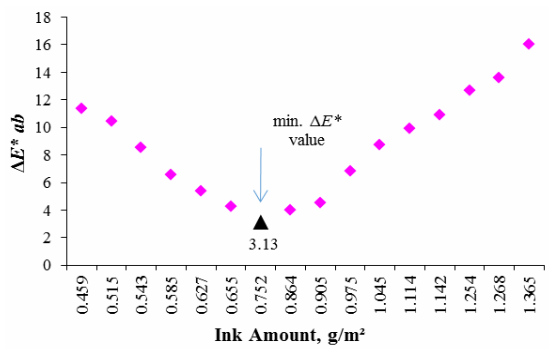

Figure 4: Color difference (ΔE^*_{ab}) as a function of ink amount

The changes in ink amount caused color deviation from the ideal CIE $L^*a^*b^*$ value (Fig. 3). As can be observed in Figure 4, color values change depending on increasing or decreasing the amount of ink used.

Effect of ink amount on lightfastness

The lightfastness measurements of the printing test samples were made according to ISO 12040: 1997(R2016). The lightfastness of the printed ink films was compared with standardized blue wool samples and the changes in colorimetric appearance were expressed as CIE L^* a^* b^* and ΔE^*ab. After the lightfastness testing, it was observed that the CIE L^* value of the magenta color ink film increased, compared to that recorded in the printing moment for all the ink amounts used. This CIE L^* value increased with a narrower margin, as the ink consumption increases. This indicates that the lightness of the color is less affected by light, due to the increase in ink consumption and density (Fig. 5a).

It was observed that the CIE a^* (+red) value of the color did not change significantly in the measurements, following the lightfastness test (Fig. 5b). In particular, it was found that the CIE a^* (+red) value was minimally affected by light in the range of the ideal ink amount.

Also, after the lightfastness test, it was observed that the CIE b^* value of the magenta color equally decreased for all the ink amounts (Fig. 5c). The yellowness (+yellow) of the sample decreased and the sample became predominantly blue (-blue). Accordingly, it could be noted that the amount of ink used had no effect on the changes of the CIE b^* value of the color under the influence of light.

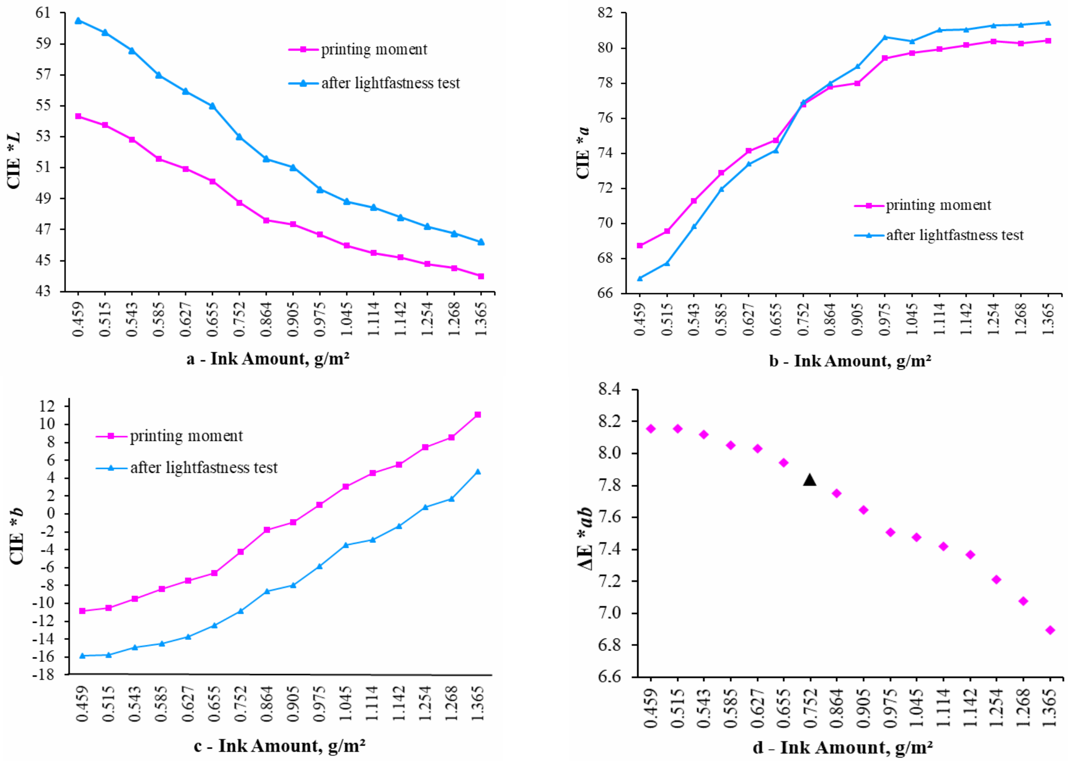

Figure 5: Changes of CIE $L^*a^*b^*$ and ΔE^*_{ab} value of color as a function of ink amount

The lower the pigmentation concentration of the ink, the lower the lightfastness.[23] In the present study, the color change decreased as the ink amount increased following the lightfastness testing, compared to the recordings taken in the first printing moment (Fig. 5d). This is considered to be caused by the increased density and pigment concentration of the ink film. Thus, the ink film was less affected by light when a higher amount of ink was used in printing.

CONCLUSION

Varying the amount of ink used in printing has caused printing parameters to change. Using an excessive or a lower ink amount in the printing process diverted especially the print density and color from the CIE $L^*a^*b^*$ values stated in ISO 12647-2 standard. Particularly in multi-color printing, this would cause final printing results to deviate from the original image. Therefore, the ideal ink amount and ink density should be determined according to the paper and ink structure selected for printing.

On the other hand, using excessive ink in the printing process makes the drying of the ink film difficult, prolonging the drying process, increases the energy consumption, delays overprint varnish applications and post-print finishing processes. Thus, using excessive ink in the printing process should be avoided.

In addition, excessive ink consumption will certainly have adverse effects, especially, on the economy of the printing process and on the environment, because of higher consumption of energy resources. Therefore, environmental sustainability of printing can be achieved by keeping ink consumption at an optimum level in the printing production process.

REFERENCES

[1] C. Aydemir and C. Özakhun, in “Matbaa Malzeme Bilimi” [What the Printer Should Know about Ink, in Turkish], edited by Dr. Nelson R. Eldred, Marmara University Publications, 2019, pp. 28-30, http://bt.ubyo.marmara.edu.tr/en/our-published-books/

[2] Ž. Pavlović, S. Dedijer, S. Draganov, I, Karlović and I. Jurič, in “Printing on Polymers, Fundamentals and Applications”, edited by J. Izdebska and S. Thomas, Elsevier, USA, 2016, Chapter 13 Offset Printing, pp. 217-229, https://doi.org/10.1016/B978-0-323-37468-2.00013-0

[3] P. Bajpai, in “Biermann’s Handbook of Pulp and Paper”, edited by P. Bajpai, 3rd edition, Elsevier, 2018, vol. 2: Paper and Board Making, pp. 237-271, https://doi.org/10.1016/B978-0-12-814238-7.00011-8

[4] H. Kipphan, “Handbook of Print Media: Technologies and Production Methods”, Springer, Berlin, 2014, Chapter 3 Digital Prepress, pp. 561-562
[5] Fogra Research Institute for Media Technologies, Ink Mileage, https://www.fogra.org/index.php?menuid=536&reporeid=339&getlang=en
[6] ISO 2834-1 First edition 2006-06-01: Graphic Technology – Laboratory preparation of test prints – Part 1: Paste inks, International Standards Organization, Geneva, Switzerland, https://www.iso.org/standard/41292.html
[7] B. Havlínová, L. Horňáková, V. Brezová, Z. Liptáková, J. Kindernaya *et al*., *Colloid*. *Surface A*, **168**, 251 (2000), https://doi.org/10.1016/S0927-7757(00)00489-1
[8] J. Zhou, Master’s Thesis, Rochester Institute of Technology, USA, 2012, pp. 1-4, http://scholarworks.rit.edu/theses
[9] C. Aydemir, S. Yenidoğan, A. Karademir and E. A. Kandırmaz, *J. Appl. Biomater. Funct*., **16**, 3 (2018), https://doi.org/10.1177/2280800018764761
[10] EuPIA, in “Environmental impact of printing inks”, Information Note, March, 2013, https://www.eupia.org/fileadmin/FilesAndTradExtx_edm/2013-03-05_EuPIA_Environmental_Impact_of_Printing_Inks_01.pdf
[11] A. M. Che, Master’s Thesis, Swedish University of Agricultural Sciences, Sweden, 2011, pp. 8-10, https://stud.epsilon.slu.se/3284/1/michael_a_110928.pdf
[12] ISO 12647-2:2013: Graphic technology – Process control for the production of half-tone colour separations, proof and production prints – Part 2: Offset lithographic processes, International Standards Organization, Geneva, Switzerland, https://www.iso.org/standard/57833.html
[13] C. Aydemir, S. Yenidoğan, A. Karademir and E. Arman, *Mater. Manuf. Process*., **32**, 1310 (2017), https://doi.org/10.1080/10426914.2017.1279323
[14] C. Aydemir, *Sci. Eng. Compos. Mater*., **23**, 565 (2016), https://doi.org/10.1515/secm-2013-0266
[15] C. Aydemir, Z. Özomay, A. Karademir and E. A. Kandırmaz, *Sci. Eng. Compos. Mater*., **20**, 141 (2013), https://doi.org/10.1515/secm-2012-0070
[16] S. Yenidoğan, *Asian J. Chem*., **22**, 7865 (2010), http://www.asianjournalofchemistry.co.in/User/ViewFreeArticle.aspx?ArticleID=22_10_54
[17] J. Håkans, Study of Ink Mileage and Print Through. Graphic Technology, Borlänge, Switzerland, 2002, pp. 7-10, http://www.diva-portal.org/smash/get/diva2:518517/FULLTEXT01.pdf
[18] S. Yenidoğan, C. Aydemir, A. Karademir and E. A. Kandırmaz, *Cellulose Chem. Technol*., **53**, 325 (2019), https://doi.org/10.35812/cellulosechemtechnol.2019.53.32
[19] B. Thompson, “Printing Materials, Science and Technology”, 2nd ed., Pira International, U.K., 2004, pp. 429-431
[20] R. Anayath and A. Pandey, *Acta Graphica*, **26**, 38 (2015), http://www.actagraphica.hr/index.php/actagraphica/article/view/20/18
[21] Brancher, “The description of colour”, Technical Info, http://www.brancher.com/-La-description-de-la-couleur-.html?lang=en
[22] X-rite, “A Guide to Understanding Color Communication”, 2007, pp. 1-24, http://tqmsystems.nl/uploads/Understand_Color_en.pdf
[23] C. Aydemir and S. Yenidoğan, *J. Graph. Eng. Des*., **9**, 37 (2018), http://doi.org/10.24867/JGED-2018-1-037