EJSDR
European Journal of Sustainable Development Research
e-ISSN : 2458-8091

# Recycling of aged inkjet prints with nano technology based inks

*Ivana Bolanča Mirković[1]*[1], Marina Vukoje[1], Zdenka Bolanča[2], Filip Vučković[1]*

[1] *University of Zagreb Faculty of Graphic Arts, Getaldićeva 2, 10000 Zagreb, Croatia.*

[2]*Croatian Academy of Engineering, Kaciceva 28, 10000 Zagreb, Croatia*

**Corresponding Author email: ibolanca@grf.hr*

## Abstract

Paper recycling has become an imperative at the end of the life cycle of all paper products. The development of technological processes in printing technology is usually associated with innovations in printing presses, but significant contributions also occur in the use of new graphic materials. In this research special attention was given to new formulation of printing ink which is based on nanotechnology. The samples were printed on a digital inkjet printing press Kodak Prosper 6000C. The mentioned printing press is using Adaphos NIR® technology for drying inkjet prints. The significance of this method is important because it provides the possibility of printing newspapers, but due to the reduction of energy use, which contributes to the reduction of the carbon footprint and the greenhouse effect. Another notable reason to use the selected printing press is in the use of new inks formulation which is based on nanotechnology. Nano-sized inks particles provide important properties to the prints obtained, for example enabling higher optical densities, as well as volume of gamut. Due to the stated property, as well as due to a good comparison with the real conditions of recycling the printed samples were subjected to a process of accelerated aging. The process of accelerated aging was conducted at several different intervals in order to study the effect of accelerated aging on the properties of recycled laboratory paper sheets. The process of accelerated aging was simulated in a climate chamber under conditions of elevated temperature and humidity and without the influence of solar radiation. By changing the printing technique, using nanotechnology-based inks, the changes in the qualitative properties of recycled sheets of laboratory paper occur. Changes in qualitative properties are manifested in the changes in the optical properties of laboratory sheets of paper, which are studied in this scientific paper.

## Key words

accelerate ageing, inkjet prints, nanotechnology inks, optical properties, recycling

## 1. INTRODUCTION

Environmentally sustainable production includes: innovative materials, clean technologies, closed loop systems, energy and material flows [1]. Generally, sustainability is significant for the development and except the concept of environment; it includes economic and social factors, implementation of society values and quality. Fortunati and O'Sullivan investigated the social sustainability of print newspaper versus digital media, and how the media system is an important factor of social participation and sustainable social change, as well as compared their economic model [2].

Cleaner production in graphic industry is a term for conservation of raw materials and energy, pollution prevention and emissions reduction. For graphic products, it means reducing their environmental impact during their entire life cycle. Life cycle assessment of the product has to be considered and included in product planning, starting from graphic design in early stage of product creation [3, 4].

The ecological footprint largely depends upon the printing techniques, the chemical composition of the ink, the type of printing substrate, and the characteristic of the prints, such as size and shape.

In the past, digital printing machines, due to their capacity and technology, were tied only to small editions, but with the development of computer speed and RIP software, new graphic materials, especially inks, are also associated with large editions. With the advancement of technology, high-performance digital machines can make a print that follows the quality of conventional printing techniques. Contribution of the increasing use of the mentioned technologies are reduction of relative costs of digital printing techniques [5]. The digital printing contributes to sustainable development. These printing techniques, in regard to some printing techniques, have advantage in fewer influence on environment, mainly due to faster make ready and the absence of plate making which is related to chemicals, materials, emissions and wastes [6].

The easiest way to reduce the environmental impact of printing is to use eco-friendly inks: water based, plant based and nanoparticles based inks. New formulated inks emit very few organic compounds while they dry resulting in better air quality in working area. In the water-based ink, higher alcohols or glycols act as moisteners and are probably the oldest eco-friendly ink available. Algae based inks are relative innovation [7]. These inks use renewable algae cells as the basis of their black pigment. Vegetable based inks from algae and other plant-based materials for inkjet printing are going to be developed in the future [8]. Steward and co- authors investigated the innovation of nanoparticle with application for printing on paper. They used network mapping method and three types of nano-innovation, which includes in research: nano-inks, nano-fiber and nano-coating [9]. Authors concluded that the emergent contribution tendency is to the performance goals of printability rather than deinkability.

Sustainable production of the raw materials for papers can be obtained from any virgin fibers which is FSC certified, but the mentioned raw materials are not often used in the production of newsprint printing substrate because newspaper printing substrate doesn’t require such optical and mechanical properties. Raw materials with a large amount of recycled fibers are commonly used [10]. Recycled fibers are even more environmentally friendly than FSC certified fibers, because recycled fibers require less bleaching than virgin fibers obtained from trees. Moreover, recycling facilitates in the reduction of methane production from landfills. Due to climate change concerns related to the environment, climate change and the optimal utilization of natural resources, much attention has increasingly been paid to shifting waste management up the waste hierarchy. The researcher from University College London found that greenhouse gas emissions would increase by 2050 if more paper were going to be recycled as current methods and the use of fossil fuels and electricity from grid [11].

In this paper, the influence of printing techniques, ink and substrate formulation as well as the influence of moist heat accelerated ageing on the ink detachment in paper recycling process was studied. Deinkability is expla0ined in the terms of ISO brightness and effective residual ink concentration (ERIC). The color coordinates $L^*$, $a^*$, $b^*$ were used to determine the effects of residual ink, respectively a coloration due to inks solubility. The results are important for the obtained quality of secondary raw material as well as in production of new formulation of graphic materials.

## 2. EXPERIMENTAL PART

### *2.1. Materials*

The Kodak water- based pigmented process color inkjet inks are used in the experimental work. The earlier color pigmented inkjet inks were causing nozzle clogging and have poor color gamut. The advantage of Kodak for Stream inkjet technology lies in a propriety micro –milling process that de-aggregates and fractures primary particles, resulting in smaller ones. By connecting nanoparticle pigment and knowledge of pigment dispersant chemistry, it is ideal for a wide range of processes and applications. Kodak's inkjet inks with nanoparticle pigments enabling higher optical densities, higher volume gamut, has superior print durability including lightfastness and water fastness.

A wide range of commercially available inkjet compatible printing substrate can be printed on Kodak Prosper 6000 C presses at full press speeds. These include industry standard uncoated, coated and glossy paper from 42-270 g/m$^2$. In this research, a commercial printing substrate was used for printing of a magazine. Coated paper has a special coating applied to the surface at one paper side. This coating allows the ink to be evenly absorbed into to paper. The Kodak Prosper 6000 C press was used for the printing of samples. The press incorporates a number of smart components that optimize print quality [12]. This press uses technical innovation in press design, drying, print speed and Kodak's Intelligent Prints innovation System (IPS). It is an advanced press management process, which constantly monitors system operation to ensure color quality and imaging performance. The imaging system combine to delivering, there are significant ink saving compared to thermal inkjet presses. Prosper press is able to deliver print quality that is comparable to offset printing.

### 2.2. Methods

#### 2.2.1. Ageing of samples

Accelerated ageing is the exposure of the object to a higher level of energy, mostly heat, but also to the influence of light or radiation, and aggressive pollutants. Deinkability behavior depends on different factors, and one of them is the ageing of the prints. Colored inkjet prints with nanotechnology inks were exposed to moist-heat accelerated ageing at 80ºC and 65% relative humidity without the influence of light during 1, 2, 3, 6 and 12 days in Kottermann 2306 conditional chamber [13].

#### 2.2.2. Paper recycling process

Printed paper samples were recycled by means of chemical deinking flotation under laboratory conditions defined by standard procedures described in ISO 21993:2020 [14]. The ISO method is based on INGEDE Method 11 [15]. Non-aged and aged samples were used in recycling process. Printed paper samples with the addition of all defined chemicals, were disintegrated using Enrico Toniolo disintegrator. A certain amount of pulp suspension was separated after disintegration process before flotation (marked UP) and used for production of laboratory paper handsheets. Remained pulp suspension was transferred to laboratory flotation cell. During flotation process, froth was collected and removed from pulp suspension. Residual pulp suspension was used for production of deinked laboratory paper handsheets (marked DP). UP and DP laboratory paper handsheets of 45g/m$^2$ were made using automatic sheet-forming device Rapid-Köthen Sheet, PTI [16].

#### 2.2.3. Deinkability evaluation

The efficiency of recycling process was evaluated by measuring optical properties of laboratory handsheets made from un-deinked pulp (UP) and deinked pulp (DP) obtained from unaged and aged inkjet prints. Evaluation of optical parameters was conducted according to spectrophotometric standard methods. The spectrophotometer Technidyne ColorTouch was used to measure the *L*a*b** chromatic values (under following condition: D50 illumination and 2°)[17], and determination of diffuse blue reflectance factor as ISO brightness [18] and Effective Residual Ink Concentration (ERIC number) by infrared reflectance [19].

## 3. RESULTS AND DISCUSSION

Flotation is the most used technology for ink removal in the paper recycling process. The deinkability of printed paper products can be assessed by the quality factor of the deinked pulp: color shade, dirt specks, while the efficiency of the process itself can be monitored by ink elimination, ERIC number and filtrate darkening.

Deinkability behavior depends upon the ageing of the prints. The efficiency of deinking process (Figure 1) is further clarified by brightness gain (ΔB= brightness of handsheets made from DP pulp - brightness of handsheets made from UP pulp. The results show that the highest brightness gain is 11.3 points for 12 days aged inkjet prints, 10.11 points for 6 days aged prints, 9.00 points for 3 days aged prints, 9.00 points for 2 days aged prints, 6.02 points for 1 day aged prints and 2.10 points for non- aged prints (Figure 1). These results show the efficiency of the recycling process in relation to the ageing days of the prints.

In addition brightness gain should be observed as ΔB= brightness of UP handsheet made from aged prints – brightness of UP handsheets made from non-aged prints. The results show: $UP_{1\ day}$-$UP_{0\ day}$ =12.10 points, $UP_{2\ days}$-$UP_{0\ day}$ =10.05 points, $UP_{3\ days}$-$UP_{0\ day}$ =7.30 points, $UP_{6\ days}$-$UP_{0\ day}$ =8.02 points and $UP_{12\ days}$-$UP_{0\ day}$ =6.03 points.

Brightness after pulping illustrates variation in ink fragmentation, and depends on the type of ink. Typical water based inkjet inks disintegrate into very small particles during pulping. These particles are very difficult to remove by flotation deinking and remain in the pulp suspension, and consequently can reattach to the fibers. In general, the ink removal by deinking flotation process is based on the difference between hydrophobic inks and hydrophilic paper fibers, which is not the case here.

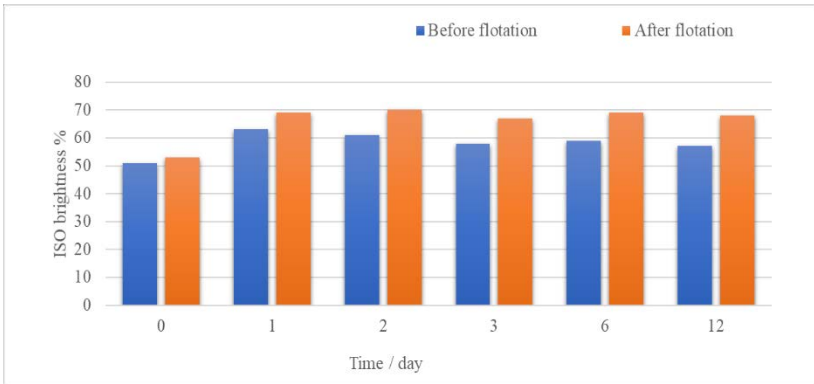


*Figure 1. ISO brightness of the undeinked (UP) and deinked pulp (DP) handsheets made from the non-aged and aged inkjet prints*

ISO brightness can be affacted by the presence not only of ink, but also upon the presence of other light absorbing material in the blue part of the spectrum such as lignin, cromophores and dyestuffs. The Effective Residual Ink Concertation (ERIC) method mesaurents in the infrared part of the spectrum and the light absorption coeficient of the ink are greater than the asorption coeficient of the fibre and other components, thus can provide sensitiv estimation of the ink concentration, which is mostly effective for submicron particles.

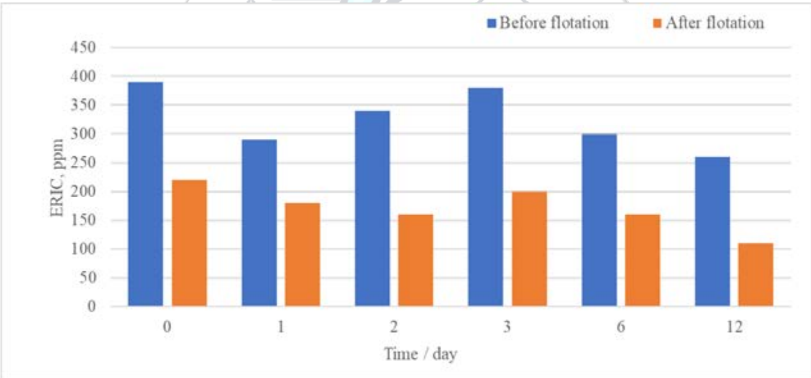


*Figure 1. The value of the ERIC for undeinked (UP) and deinked pulp (DP) handsheets made from non-aged and aged inkjet prints*

The obtained results show an inversely proportional relelationship betwen the results of brightness and ERIC, i.e. increasing the brightness, decreaes the ERIC value. The results for UP handsheets show: $UP_{1\ day}$-$UP_{0\ day}$ =- 100 points, $UP_{2\ days}$-$UP_{0\ day}$ =-50 points, $UP_{3\ days}$-$UP_{0\ day}$ =-10 points, $UP_{6\ days}$-$UP_{0\ day}$ =-91 points and $UP_{12\ days}$-$UP_{0\ day}$ =-130 points, and for handsheets DP show: $UP_{1\ day}$-$UP_{0\ day}$ = -40 points, $UP_{2\ days}$-$UP_{0\ day}$ =-60 points, $UP_{3\ days}$-$UP_{0\ day}$ =-20 points, $UP_{6\ days}$-$UP_{0\ day}$ =-40 points and $UP_{12\ days}$-$UP_{0\ day}$ =-110 points (Fig.2). Based on the results, it could be concluded that in some cases when the ink particles have detached from the fibers and dispersed into the aqueous phase, they are redeposited on the fiber surfaces.

Figure 3 shows the $L^*$ chromatic coefficient which presents the lightness of the UP and DP handsheets color made from unaged and aged inkjet prints. The results obtained are as follows: $L^*_{UP\ non\ aged\ prints}$-$L^*_{DP\ non\ aged}$=-2.21 points, $L^*_{UP\ 1\ day\ aged\ prints}$-$L^*_{DP\ 1\ day\ aged}$=-2.69 points, $L^*_{UP\ 2\ days\ aged\ prints}$-$L^*_{DP\ 2\ days\ aged\ prints}$=-5.31 points, $L^*_{UP\ 3\ days\ aged\ prints}$-$L^*_{DP\ 3\ days\ aged\ prints}$=-6,30 points, $L^*_{UP\ 6\ days\ aged\ prints}$-$L^*_{DP\ 6\ days\ aged\ prints}$=-5,39 points, $L^*_{UP\ 12\ days\ aged\ prints}$-$L^*_{DP\ 4,00\ days\ aged\ prints}$=-4.00 points.

The influence of the inkjet prints accelerated ageing on the UP handsheet chromatic coefficient $L^*$ made was determined as follows: $L^*_{UP1\ day\ aged\ prints}$-$L^*_{UP\ non\ aged\ prints}$ =5.51, $L^*_{UP\ 2\ days\ aged\ prints}$- $L^*_{UP\ non\ aged\ prints}$ = 4.20,

$L^*_{UP\ 3\ days\ aged\ prints}$-$L^*_{UP\ non\ aged\ prints}$ = 3.80, $L^*_{UP\ 6\ days\ aged\ prints}$ $L^*_{UP\ non\ aged\ prints}$ = 4.11, $L^*_{UP12\ days\ aged\ prints}$-$L^*_{UP\ non\ aged\ prints}$ =3.40.

In addition, the results of the accellerted ageing influence on the DP handsheets chromatic coeficient $L^*$ are presented: $L^*_{DP1\ day\ aged\ prints}$-$L^*_{DP\ non\ aged\ prints}$ =6.09, $L^*_{DP2\ days\ aged\ prints}$-$L^*_{DP\ non\ aged\ prints}$ = 7.40, $L^*_{DP3\ days\ aged\ prints}$-$L^*_{DP\ non\ aged\ prints}$ = 5.99, $L^*_{DP6\ days\ aged\ prints}$ $L^*_{DP\ non\ aged\ prints}$ = 7,56, $L^*_{DP12\ days\ aged\ prints}$-$L^*_{DP\ non\ aged\ prints}$ = 6,09.

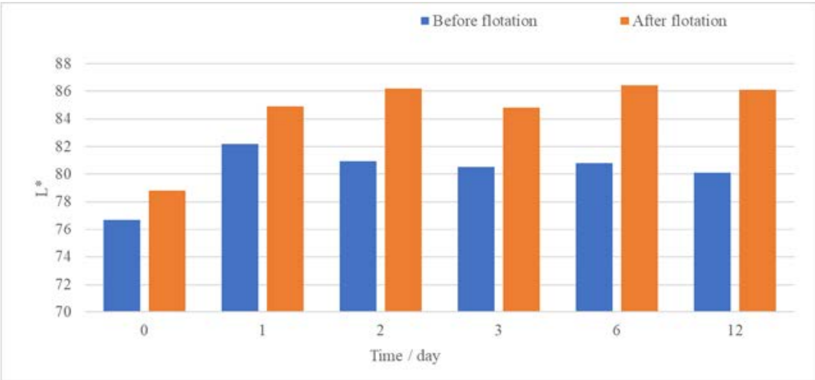


*Figure 2. The value of the chromatic coefficient L* for undeinked (UP) and deinked pulp (DP) handsheets made from non-aged and aged inkjet prints*

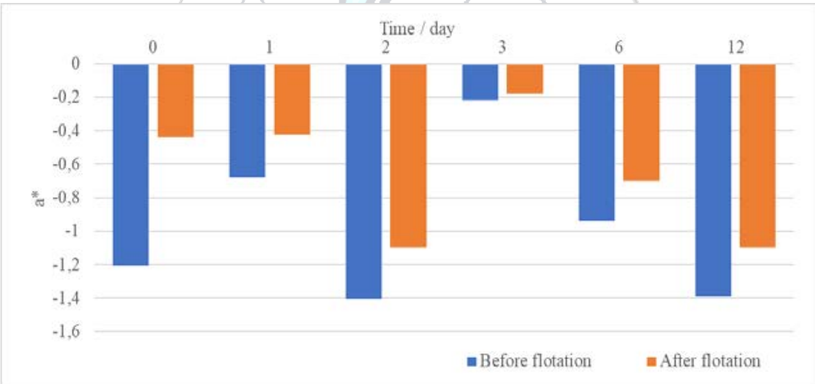


*Figure 3. The value of the chromatic coefficient a* for undeinked (UP) and deinked pulp (DP) handsheets made from non-aged and aged inkjet prints*

Chromatic coefficient $a^*$ represents the colour position on red-green axis. The results obtained from the measuring the chromatic coeficient $a^*$ for all tested samples are in the negative part of the red –green axis, so they are in the green area (Figure 4). The highest negative value have UP handsheets made from unaged and samples aged for 2 and 12 days, as folows: handsheet $_{UD,\ non\ aged}$ = $a^*$-1.21, handsheet $_{UD,\ aged\ 2days}$ = $a^*$-1.41, handsheet $_{UD,\ 12\ days}$ = $a^*$-1.39. After deinking flotation, decrease in the negative value of the chromatic coeficient $a^*$ was found in all cases, and the largest for DP handsheet made from non aged inkjet prints, handsheet $_{UD,\ non\ aged}$ - handsheet $_{PP,\ non\ aged}$ = $a^*$-0.77.

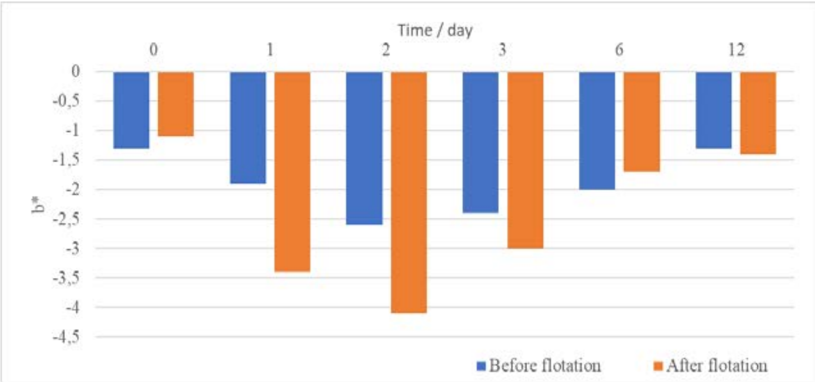


*Figure 4. The value of the chromatic coefficient b* for undeinked (UP) and deinked pulp (DP) handsheets made from non-aged and aged inkjet prints*

Chromatic coefficient $b^*$ represents the color position on yellow-blue axis. The results obtained from the measuring the chromatic coefficient $b^*$ for all tested samples, are in the negative part of the yellow-blue axis, so they are in the blue area. The best results are achieved by deinking flotation of the non-aged sample: handsheet $_{\text{UD, non-aged}} = b^*$-1.31 and handsheet $_{\text{PD, non-aged}} = b^*$-1.10. The exposure of the ink jet prints to moist heat ageing without the influence of light, no dependence on the value of the chromatic coefficient $b^*$ is observed.

## 4. CONCLUSIONS

Digital printing in recent years has developed on a large scale. Electrophotography and inkjet printing have proven to be the best solutions, and solutions in which development has been mostly invested in recently. Trends in the printing industry, such as a high degree of print personalization, small editions, and a short printing time, favor digital printing techniques. In addition, another promising advantages of such technologies derive from their environmental aspect; there are no adverse processes of film and plate making, and thus no problems related to wastewater discharge and treatment. The printing processes themselves require less energy consumption, and the production of machines is more environmentally friendly. With the development of awareness about environmental pollution, more and more importance is attached to paper recycling globally. In this paper, the influence of moist heat aging on ink jet prints recycling process was examined. The result showed that aging of ink jet samples affects the optical characteristics of produced recycled papers (laboratory handsheets). From the results, it can be seen that samples aged for three days have the highest value of the ERIC, the lowest values of ISO brightness and $L^*$ chromatic coefficient. After prolonged exposure to aging, there is a decrease in the tendency to form inks particles during disintegration of the prints. From the results, it can be concluded that obtained recycled paper sheets have good quality and can be used for commercial purposes.

## CONFLICT OF INTEREST STATEMENT

"The authors declare that there is no conflict of interest".

## REFERENCES

[1]. I. Bolanča Mirković, I. Majnarić, Z. Bolanča,"Ecological sustainability and waste paper recycling *Procedia Engenering*,Vol.100, pp 177-186, 2014.

[2] L. Fortunati, and J. O'Sullivan, "Situating the social sustainability of print media in a word of digital alternatives", *Telematics and Informatics,* Vol .37, pp137-145, 2019

[3] I. Bolanča Mirković, I. Majnarić, S. Mustač, and Z. Bolanča, "Printing and sustainability", IARIGAI, 38, Eds. E. Nils, M. Lovrecek, Advances in Printing and Media Technology, Vol.37, pp. 361-368, 2012

[4] Y.V. Fan, H.H. Chin, J.J. Klenas, P.S. Vorbanov, and X. Liu, "Optimization and process design tools for cleaner production", *Journal for Cleaning Production*, Vol.247, pp 119-181, 2019

[5] M. Karinieme, M.Nors, and H. Pihkola, "Evaluating environmental sustainability of digital

printing," in Proc. NIP 26, 2010, pp. 92-96
[6] P. Viluksela, M. Kariniemi, M. Nors, "Environmental performance of digital printing", Research Centre of Finland, Research Note 2538, 2010.
[7] M. Shall (2021.) Water and plant-based inks gaining popularity with environmental consciousness on the rise [Online], Available http://www.bigpicture com/sustainable-digital-printers-should-know-these.eco-friendly-inks
[8] (2020.) EcoEnclose web site [Online] What is the most sustainable ink? https://www.ecoenclose.com
[9] F.Steward, J. C.S. Tsio, A.M. Coles, A comparison of nanoparticle and deinking niches as emergent sociotechnical networks, Journal of Cleaner Production, 2008., 16 (8-9), 957-966
[10] P. Bajpai, Environmentally Friendly Production of Pulp and Paper, New Jersey, Jon Wiley & Sons, 2010
[11] Stijn van Ewijk, Julia A. Stegemann, Paul Ekins. Limited climate benefits of global recycling of pulp and paper. Nature Sustainability, 4, 180–187, 2021. https://doi.org/10.1038/s41893-020-00624-z
[12] (2018) Presses [Online], Available, printing.org/intertech-entries/Kodak-prosper-6000-presses
[13] ISO 5630-3:2012, 2012 Paper and board-Accelerated ageing-Part 3: Moist heated treatment at $80^0$C and 65% relative humidity, [Online], Available: https://www. iso.org.> standard
[14] ISO 21993:2020, 2020 Paper and pulp — Deinkability test for printed paper products [Online], Available: https://www. iso.org.> standard
[15] INGEDE e. V., 2012. INGEDE Method 11- Assessment of Print Product Recyclability (Deinkability Test). Bietigheim-Bissingen. [Online], Available: https://www. Ingede.org
[16] ISO 5269 - 2, 2004. Pulps — Preparation of laboratory sheets for physical testing — Part 2: Rapid-Köthen method.
[17] ISO 5631-3:2015, 2015, Paper and board-Determination of color by diffuse reflectance-Part 3: indoor illumination condition (D $50/2^0$)
[18] ISO 2470-1:2016. 2016. Paper, board and pulps — Measurement of diffuse blue reflectance factor — Part 1: Indoor daylight conditions (ISO brightness).
[19] ISO 22754:2008. 2008. Pulp and paper — Determination of the effective residual ink concentration (ERIC number) by infrared reflectance measurement.