EFFECTS OF PULPING TEMPERATURE AND ACCELERATED AGEING ON OPTICAL PROPERTIES OF DIGITAL DUPLICATOR PRINT HANDSHEETS

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Deinking efficiency and optical stability of digital duplicator print handsheets have been examined. During chemical deinking through washing, fatty alcohol ethoxylate C 13-15 with 7 EO groups has been used as a surfactant. The pulping temperatures were changed, while the other washing process conditions, including surfactant concentration, pulping and homogenization time, were carefully chosen and kept constant. Deinking efficiency was monitored through the optical properties of the laboratory handsheets in the visible part of the electromagnetic radiation. The best optical performance of a handsheet was achieved at the lowest disintegration temperature. The optical stability of the handsheets obtained at different disintegration temperatures was tested by accelerated ageing. The changes in the values of relative reflectance and scattering and absorption coefficients, due to the interaction of UV and visible electromagnetic radiation with the samples, were monitored.

The results obtained point out that optimal deinking efficiency and optical stability are achieved under energy-saving (low disintegration temperature, which is unusual for common deinking) and environmentally friendly (only surfactant – without other deinking chemicals – has been used) process conditions.

Keywords: digital duplicator prints, chemical deinking by washing, washing temperature, ageing, optical characteristics

INTRODUCTION

In recent years, we all have become victims of the advertising market. Every day new shopping centres open and each of them wants to get through to consumers. The easiest way to introduce fresh information about current events is to print commercial brochures. Consequently, each day we find a number of commercial materials on our doorsteps and in our mailboxes. In this way, the commercial waste contributes with about 60% to global landfills, so that its recycling is essential.[1] Numerous brochures are printed on recycled paper, since they are evanescent and do not need high-quality paper, even though the mechanical and optical characteristics of the paper made from recycled pulp are inferior to those of office paper. However, while there is an increasing demand to reduce the amount of paper waste, thus reducing landfilling, the requirements for paper manufacturing from recycled fibers are extremely high.[2]

Apart from the origin of the paper used for printing commercial materials, it is also worth noting that the printing houses use various printing technologies. Thus, digital printing technologies are gaining an increasingly larger market share, being preferred for printing commercial materials.[3] The main benefits of digital duplicating include its high reliability and low costs, particularly for users who need to make many copies of a single document, since the cost of a master is relatively high. Digital duplicators operate differently from digital photocopiers and network printers, which use a reusable photo-receptive drum, toner and a fuser unit that melts the toner onto the paper. They work by creating a stencil, called ‘master’, from the original, either scanned or electronic. The master is a thin sheet with tiny micropores (holes) created by imaging laser. The holes form the image of the original, like a stencil. The master is wrapped around a drum, which outputs ink. Pressure is exerted on the ink, pushing it through the holes of the master onto the paper fed over the master drum surface. Each new image requires a new master. The longer a print run is, the more cost-effective it is to output it on a digital duplicator. Printing takes place at a high speed, using special fast drying ink.[4]

As paper can be recycled several times, the present study explores the additional recycling possibilities of office papers made from recycled fibers. Based on previous results,[5] the deinking conditions assuring the highest deinking efficiency (chemical deinking by washing without flotation) were selected: the energy-saving (lower disintegration temperature) and environmentally friendly conditions. Namely, during disintegration, only fatty alcohol ethoxylate C 13-15 with 7 EO groups has been used as a surface active agent, no other chemical being added. The handsheets formed under the selected conditions were exposed to UV and visible electromagnetic radiation over the defined time interval. Their optical stabilities were monitored before and after accelerated ageing. To this end, optical parameters, such as reflectance, scattering and absorption coefficients, have been determined.

EXPERIMENTAL

The paper samples for deinking through washing represented original office paper made from recycled fibres (the unprinted sample) and original office paper printed by a Ricoh JP8500 digital duplicator (the printed sample).

The ink used for printing was Ricoh HD ink, composed of petroleum solvent, sorbitan oleate, ethylene glycol, black pigment and water.

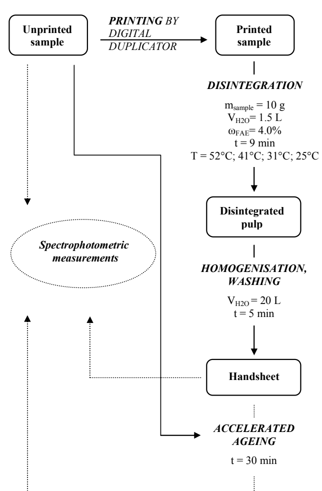

Figure 1: Experimental flow chart

Deinking by washing

Disintegrated pulp of original office paper printed by digital duplicator (the printed sample) was obtained in an Enrico Toniolo disintegrator under the following conditions: water content V = 1.5 L, mass of printed sample – 10 g, fatty alcohol ethoxylate – 4% and disintegration time – 9 min. The only parameter that was modified during disintegration was temperature (Fig. 1). Consequently, four tests were performed at different temperatures (52, 41, 31 and 25 °C). The disintegrated pulp obtained at a particular disintegration temperature was homogenized over the defined time interval (5 min). Homogenizations were provided by a laboratory handsheet former for 340 mm x 250 mm handsheets, consisting of two parts separated by a screen. In the upper part, the suspension and water were repelled, while the bottom part was filled with water. During the homogenization of the disintegrated pulp, the suspension and tap water (20 L) were uniformly mixed by a special mixer, in a direction perpendicular to the screen.

After 5 min of homogenization, the water was released from the upper to the bottom part of the laboratory handsheet former, so that the impurities from the suspension were removed and the printed sample handsheet formed. The impurities were so small that they were flushed with water through the screen. Four handsheets made at different disintegration temperatures were exposed to electromagnetic radiation.

Handsheet spectrophotometric measurements were performed before and after accelerated ageing.

Accelerated ageing

Accelerated ageing of the unprinted sample and handsheets involved their exposure to UV and visible electromagnetic radiation for 30 min, while the radiation source was at the distance of 20 cm from the sample.

Evaluation of optical characteristics

Handsheet reflectance measurements were made on an X-rite Spectrophotometer, Digital Swatchbook. Measurements were made on a Color Shop 2.0 software and the results were calculated by MathCAD 2002 and by Data Analysis and Technical Graphics Origin 6.0. The diffuse reflection measured in the area from 410 to 700 nm, at 10 nm intervals, served as basis for evaluating the optical properties of papers. To measure reflectivity, the present study employed $d/0^0$ geometry (the test sheet was illuminated by a diffuse light source, while the reflected light was measured at a 0^0 viewing angle), an illuminant D65 set to measure CIEY, 2^o standard observers. During spectrophotometric measurements, the relative atmospheric humidity was of 60 ± 1% and the temperature – of 21± 1 ºC.

High light scattering affects positively paper properties, since paper becomes whiter and more opaque. Light scattering occurs when the light is reflected and refracted from the fibre surfaces and filler particles, as well as from the cracks and cavities inside the fibres. Fillers and coatings increase the light scattering of paper; to achieve a higher effect, makers of fine papers may also add mechanical pulp. Light absorption is directly related to the amount of coloured matter in the paper. The removal of coloured substances is therefore absolutely vital for reaching a high level of pulp brightness.

The brightness (R_{457}) method was developed to monitor pulp bleaching, because the change in reflectivity is the highest at these short wavelengths (from 400 to 500 nm) during bleaching. With the introduction of modern spectrophotometers, it has been convenient to use[6] reflectance at 460 nm. It practically makes no difference whether reflectance is used at a wavelength of 457 nm or of 460 nm.

One of the most famous and useful theories defining the basic properties of light scattering and light absorption is the two-flux approximation presented by Kubelka and Munk.[7]

Light scattering can be determined by measuring reflectivity (the maximum reflectance of a layer, which cannot be enhanced by any further increase in thickness) R_∞, and reflectance, R, when the sheet is placed over the background. An alternative method,[8] especially when the amount of material is limited, is to measure reflectance over two different backgrounds, white and black, presented in Equations (1) to (4):

$$a_i = \frac{1}{2}\cdot\frac{(R_{gwi}-R_{gbi})(1+R_{wi}R_{bi})-(R_{wi}-R_{bi})(1+R_{gwi}R_{gbi})}{R_{bi}R_{gwi}-R_{wi}R_{gbi}} \quad (1)$$

$$R_{\infty i} = a_i - \sqrt{a_i^2-1} \quad (2)$$

$$s_i = \frac{1}{w\left(\frac{1}{R_{\infty i}}-R_{\infty i}\right)}\cdot\ln\frac{(1-R_{bi}R_{\infty i})(R_{\infty i}-R_{gbi})}{(1-R_{\infty i}R_{gbi})(R_{\infty i}-R_{bi})} \quad (3)$$

$$k_i = \frac{s_i(1-R_{\infty i})^2}{2R_{\infty i}} \quad (4)$$

where:

R_{gwi} = reflectance factor of paper over a white background of reflectance R_{wi};
R_{gbi} = reflectance factor of paper over a black background of reflectance R_{bi} (commonly a black background is used with R < 0.5 %);
w = paper sample grammage; kg m^{-2}
s = scattering coefficient; m^2 kg^{-1}
k = absorption coefficient; m^2 kg^{-1}.

Subscript i = 0-28 from these measurements corresponds to a wavelength interval from 410 to 700 nm for every 10 nm. Consequently, R_{gwi}, R_{gbi}, R_{bi}, R_{wi}, represent a one-column matrix consisting of 29 members, each of them representing reflection experimental data.

The reflectance spectra of all examined handsheets over black and white backgrounds were recorded 10 times, and the mean values of R_0 and R_∞ were used to calculate the scattering and absorption coefficients from the Kubelka–Munk expressions – Eqs. (3) and (4).

RESULTS AND DISCUSSION

The reflectance of the unprinted samples was measured over the 410-700 nm interval, before and after accelerated ageing (Fig. 2).

The unprinted unaged and aged samples show lower reflectance in the area of shorter wavelengths, which means that the basic unprinted substrates were obtained by recycling. After ageing, relative reflectance changes, $\Delta R = (R_{aged} - R_{unaged})/R_{unaged}$, by approximately -2% in the area of shorter wavelengths, while negligible increases, of ~1%, are recorded at longer wavelengths. This result demonstrates the stability of unprinted paper upon electromagnetic radiation.

The printing substrate was printed by digital duplicator and recycled under conditions of deinking washing. The reflectance of the samples obtained at different disintegration temperatures, 52, 41, 31 and 25 ºC, before and after accelerated ageing, was measured. The measured reflection spectra show the lowest reflectance values for recycled unaged samples, at a disintegration temperature of 52 ºC, in the 0.57-0.66 interval (R_{460} = 0.61). By decreasing the disintegration temperature to 41 and 31 ºC, reflectance is increased within interval values from 0.60 to 0.70 (R_{460} = 0.64). A further decrease in the disintegration temperature to 25 ºC increased reflectance from 0.60 to 0.70 (R_{460} = 0.67), which denotes successful deinking (Fig. 3).

By accelerated ageing of the handsheets, the reflectance values are insignificantly increased at lower disintegration temperatures, 41 and 31 ºC, while, at the temperature of 52 ºC, the reflectance increase was significantly higher, the most interesting being the increase of reflectance in the blue part of the spectrum, at the temperature of 25 ºC.

The relative changes in reflectance, presented in Figure 4, occur over the -1-0.7% range, for lower temperatures, and from 2 to 4%, at the highest temperature – 52 ºC.

From the reflection spectra, scattering *s* and absorption coefficients *k*, before and after handsheet ageing at different disintegration temperatures, are calculated, with Equations (1) to (4). The scattering coefficients of the handsheets, as well as their relative changes, before and after ageing, are presented in Figures 5 and 6 as a function of the disintegration temperatures. The sample disintegrated at the temperature of 52 ºC before ageing shows the lowest value of the scattering coefficients, ~40 m^2/kg. After ageing, the scattering coefficient increases to a value of ~43 m^2/kg. The relative changes of the scattering coefficients over that temperature range are between 3 and 15% (Fig. 6).

The samples obtained at lower disintegration temperatures, of 41 and 31 ºC, have medium values of the scattering coefficient – ~41 m^2/kg – which change insignificantly after ageing, indicating the higher stability of the samples disintegrated at lower temperatures. Over the 460-625 nm interval, the relative change of the scattering coefficient almost disappears at disintegration temperatures of 41 and 31 ºC. At the lowest disintegration temperature, 25 ºC, the relative change of the scattering coefficient increases after ageing, especially in the blue and red part of the spectrum.

The scattering coefficients of the handsheets, as well as their relative changes, before and after ageing, are presented in Figures 7 and 8, as a function of the disintegration temperatures. The lowest absorption coefficient over the whole measured spectra is achieved by the samples disintegrated at 25 ºC, which is in correlation with the highest deinking efficiency.

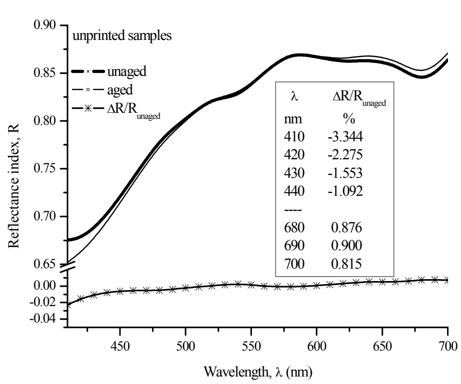

Figure 2: Reflectance of unprinted samples; the framed part evidences the relative reflectance changes after ageing

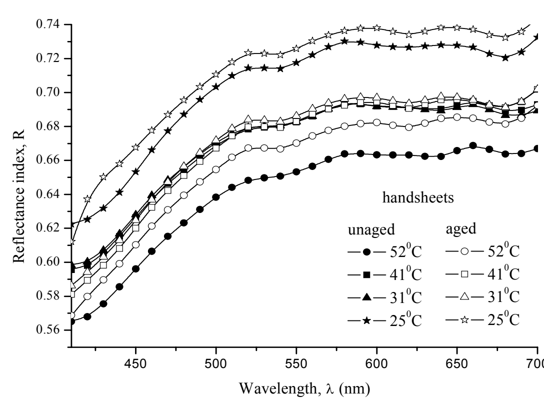

Figure 3: Reflectance of unaged and aged handsheets, as a function of disintegration temperature

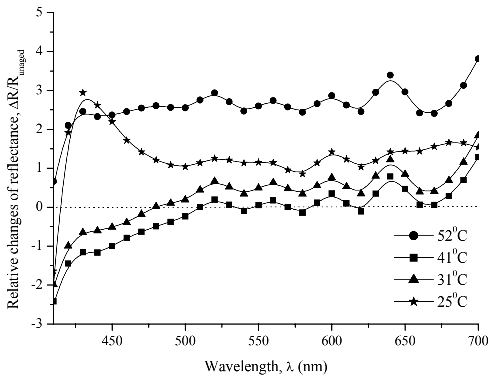

Figure 4: Changes in relative reflectance of handsheets after ageing, as a function of disintegration temperature

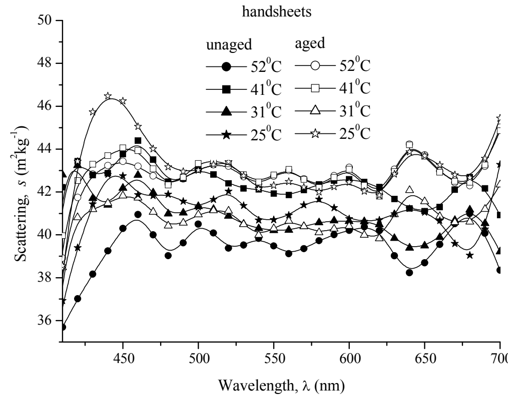

Figure 5: Changes in scattering coefficients of unaged and aged handsheets, as a function of disintegration temperature

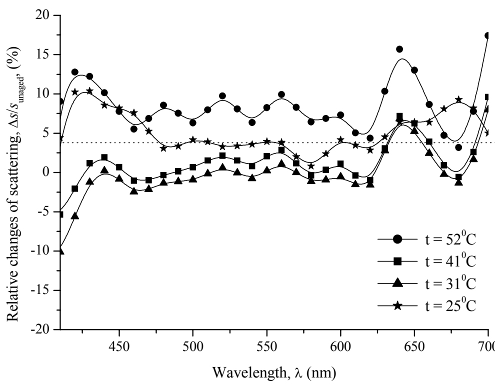

Figure 6: Changes in relative scattering coefficients of handsheets after ageing, as a function of disintegration temperature

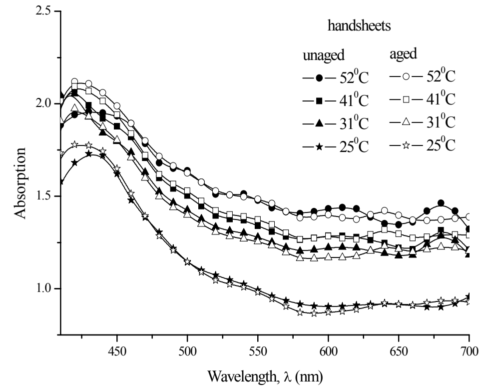

Figure 7: Changes in absorption coefficients of unaged and aged handsheets, as a function of disintegration temperature

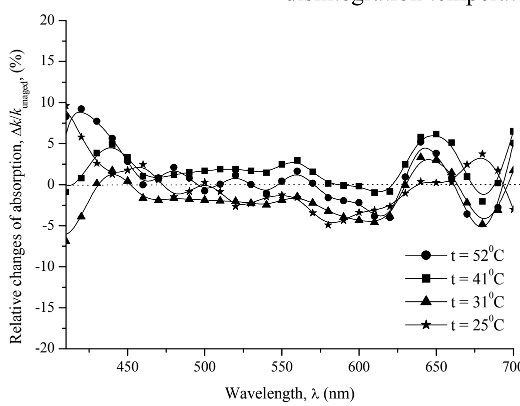

Figure 8: Changes in relative absorption coefficients of handsheets after ageing, as a function of disintegration temperature

The relative changes of the absorption coefficients occur between -5 and 3%, in the central part of the visible spectrum, significantly higher values, from -6 to 9%, being recorded in the blue and red part of the spectrum (Fig. 8). Accelerated ageing does not influence the absorption coefficients, regardless of the recycling process conditions.

CONCLUSIONS

The effects of disintegration temperature and accelerated ageing on the optical properties of deinked pulp from a digital duplicator were examined. The process applied was chemical deinking by washing without flotation – an environmentally friendly process. More precisely, during disintegration, only fatty alcohol ethoxylate has been used as a surface active agent, without other commonly used deinking chemicals.

The only parameter modified during deinking was the disintegration temperature. The best optical performance of deinked digital duplicator prints was achieved at the lowest disintegration temperature, which is an energy-saving process. The unprinted samples showed stability during exposure to ageing. The optical properties of the printed samples, depending on the disintegration temperature, were changed after being exposed to ageing. The samples deinked at the lowest disintegration temperature, 25 ºC, after accelerated ageing, indicate lower changes in the values of reflectance, scattering and absorption coefficients, as compared to those deinked at higher temperatures, which evidences the higher optical stability of the handsheets disintegrated at lower temperatures.

REFERENCES

[1] M. Misner, *Waste Age*, **33**, 86 (1992).
[2] S. Imamoglu, *J. Appl. Sci*., **6**, 9 (2006).
[3] B. Carre and L. Magnin, in *Procs. 7th Research Forum on Recycling*, Quebec, Canada, 2004, p. 27.
[4] K. M. Koppenhaver, in "Forensic Document Examination: Principles and Practice", edited by Melissa Caravella and Tara L. Bugg, Humana Press Inc., Totowa, New Jersey, 2007, pp. 221-227.
[5] Z. Barbaric-Mikocevic, V. Dzimbeg-Malcic and T. Muck, *Appita J*., **63**, 45 (2010).
[6] S. B. Lee, J. Bogaard and R. L. Feller, *J. Am. Inst. Conserv*., **28**, 1 (1989).
[7] D. B. Judd and G. Wyszecki, "Color in Business, Science and Industry", J. Wiley & Sons, Wiley-Interscience, 1975, p. 420.
[8] N. Pauler, in "Paper Optics", AB Lorentzen and Wettre, Tofters Tryckeri, 2001, p. 31.