NON DESTRUCTION METHOD FOR EVALUATION OPTICAL INHOMOGENEITIES IN RECYCLED PAPER

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ABSTRACT

The image processing and analysis is interesting non destructive method for determining the number of the residual dirt specks within the defined size classes and the area they occupy in handsheets produced from fibers in different phases of the prints recycling process or produced on the paper. Dirt speck include the ink particles in the deinked pulp.
The justification of the image analysis application of handsheet made from the fibers during the different paper recycling phases in dependence to the technique which was used in printing. In results interpretation, the measuring results of the relevant optical factors of the recycled fibers were used and discussed in relation to the division of the size and number of particles obtainer by image analysis. A comparison between the two image analysis software tools is given.
Statistical techniques such as factorial design and analysis of variance (ANOVA) were used to interpret the findings.

Key words: non destructive method, image analysis, brightness, paper, recycling, printing techniques

1. INTRODUCTION

For monitoring the effectiveness of the recycling process and removing the ink from the cellulose fibers, the following optical parameters can be used: brightness, whiteness, lightness, three stimulus values X,Y, Z, CIE L*a*b* colour space and the colorimetric colour difference ΔE[1]. Except that, the dye removal index and the colour stripping index can be used [2].

The parameter frequently used to evaluate the optical quality of the recycled pulp and the effectiveness of ink removal is the spectral reflectance factor R_{457} used as a measure of brightness. Usefulness of brightness has certain limitations as well as that the measurement includes only the blue area of the visible spectrum between wavelengths of 400 and 510 nanometers [3]. It is the reason that this parameter does not always relate well with visual assessment [4]. In addition, this parameter is not only affected by the quantity of residual ink, but also by the size of the ink particles [5,6].

The more effective means of quantifying residual ink particles, when they are invisible and less than 10µm is obtained by the measurement of light absorption in the near infrared part of the spectrum-800-1300 nm. The development of the effective residual ink concentration –ERIC by Jordan and Popson has provided a tool to determine how much the ink population is impacting brightness of the pulp [7]. The ERIC value is based on the absorption of infrared light at 950 nm as measured by reflectance and depends on the amount of light scattering due to the sample fiber. Measurements at 950 nm are interesting, because at that wave length there is almost no influence of bleaching, dyes and lignin chromophores. Infrared residual ink measurements are useful in understanding the relationship between the deinking phase and the need of using the additional operations in the recycling process.

Ink particles, whose diameters are between micro and macro area, as well as the visible ones, have less influence on brightness of the recycled fibers than the ones with the size under 10 micrometer [8]. It is important to monitor the transition from the invisible into the visible area and to understand the mechanisms of influences of the process conditions on product properties. In the determined conditions in the process and the agents for removal the ink, the agglomerations can be formed which will less influence the brightness and which will increase the effectiveness of the particle removal; but only those which are within the sizes 50 – 150 µm, which is the optimum for flotation [9,10].

Many authors have studies the image analysis technique (Heimonen J. Oksanen T. 1995, Trepanier et al. 1995, Göttsching L et al.1999). Image analyzers are divided into dedicated and research instruments. Research instruments are coupled to computer software with an optical microscope and a CCD camera. These instruments are producing results for allowing smaller particles to be analyzed.

Except the mentioned, the application of the image analysis on stickies concentration was monitored [14]. Rosenberger and Houtman use the system of the image analysis for measuring in 24 bit colour. They classify the contaminants on the basis of the colour as the residual ink, coloured contaminants and dyed particles [15]. In the colour of the image analysis the contaminants that have adsorbed the hydrophobic dye can be distinguished from the inks and dirts. In this case two scans are necessary, the scan handsheet before dying to determine the dirt and a scan of the dyed handsheet to determine hydrophobic contaminants and dirt.

The investigation results of the digital printing technique with the liquid and the stiff toner are presented in this work, as well as the conventional printing techniques with regard to the dirt specks including the ink particles in handsheet, made from the fibers from different recycling phases and with this the possibility of the application of the image analysis on their identification. The influence of the essential factors of the described system has been determined and discussed. Statistical techniques such as factorial design and analysis of variance were used to interpret the findings. In addition, the comparison between the two image analysis software tools is given.

2. EXPERIMENTAL

The prints of the digital printing techniques are used, based on the electrophotography which used the liquid and the stiff toner (printing machines HP Indigo and Xerox). The following conditions were used in printing. The voltage levels on the studied photoreceptor drum were -600 V. The voltage of corotrone on the back side of the paper was 212V. One sample series was printed in the conventional offset technique on the printing machine Heidelberg.

The test form was designed by using the standard ISO and ECI templates and it was created in the application Adobe Photoshop. Except that, the test contained the standard CMYK step -like wedges in the range from 10 to 100% screen value.

Printing substrates were the mat fine art papers of 200 g/m2 (gsm) basis weight. The corresponding thickness values were 0,185 mm respectively.

The printed samples underwent the alkaline deinking flotation process. In the process of the chemical deinking, the following chemicals were used: 2% sodium silicate, 1% sodium hydroxide, 1 % hydrogen peroxide, 0,3% DTPA and 0,3% non-ionic surfactant. Percentages are on dry weight fibres. The handsheets were made using a laboratory sheet former, according to standard TAPPI method T 205. The brightness of the handsheet was measured according to ISO standard method.

Optical inhomogeneities was assessed by means of image analysis. In general, the principle of this method is the usage of the difference in contrast between the particles of dirt specks and the substrate. The image obtained by a flat-bed scanner (or, alternatively, camera) is digitally converted into pixels whose size depends on the visibility field and the image depends on the scanner resolution. Identification of the dirt specks is based on the differences in gray values. The value between 0 and 255 is given to each pixel in accordance with its reflectance.

The image segmentation converts the digitalized gray value image of the camera to a binary, black-and-white, image. In this way all the pixels with the gray value above the determined threshold value are identified as the dirt specks and they get the value 1 in the binary image. Pixels with gray values below the threshold are considered as background. The image analysis ends in measuring the dirt particles and in producing the data output.
Dirt specks analysis procedure is presented in figure 1.

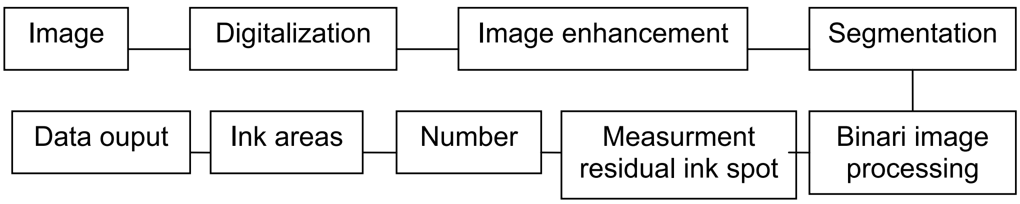


Figure 1: Dirt specks image analysis procedure

Residual ink particles size (area) and number were assessed with image analysis-based software systems: Spec*Scan (Apogee System). Spec*Scan system utilizes a flat-bed scanner Epson Perfection 2400 Photo to digitize image, its resolution was set to 600 dpi. Three lab handsheet samples for each combination of settings were scanned on both sides. Size intervals were defined according to TAPPI methods T 213 and T 437. Threshold value (100), white level (75) and black level (65) were chosen after comparing computer images to handsheets.

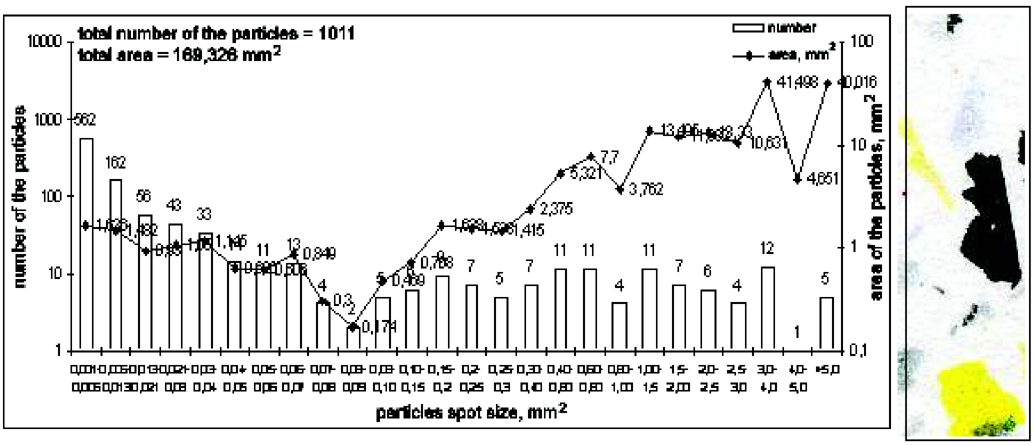
Residual ink particles size (area) and number were assessed with two image analysis-based software systems: Spec*Scan (Apogee System) and Proton (local manufacturer).

In order to determine the influence of different variables such as the printing techniques, phases of the recycling process, software types, the multifactor experimental design was used.

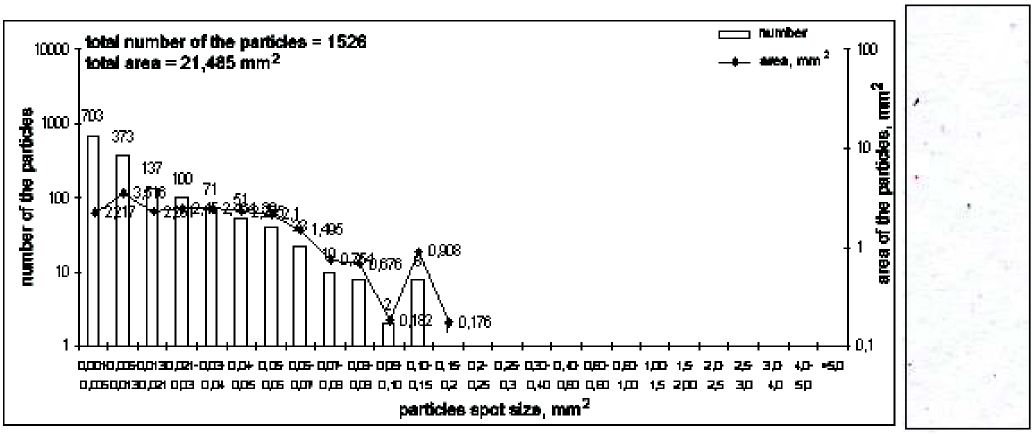
Data on the following seven parameters related to number and size of dirt particles as obtained by image analysis software were recorded: total number of specks (NOS_T), number of specks larger than 0,04 mm^2 (NOS_L4), number of specks smaller than 0,04 mm^2 (NOS_S4), total area of specks (TSA_T), average area of specks (ASA_T), area of specks larger than 0,04 mm^2 (SA_L4) and area of specks smaller than 0,04 mm^2 (SA_S4).

3. RESULTS AND DISCUSION

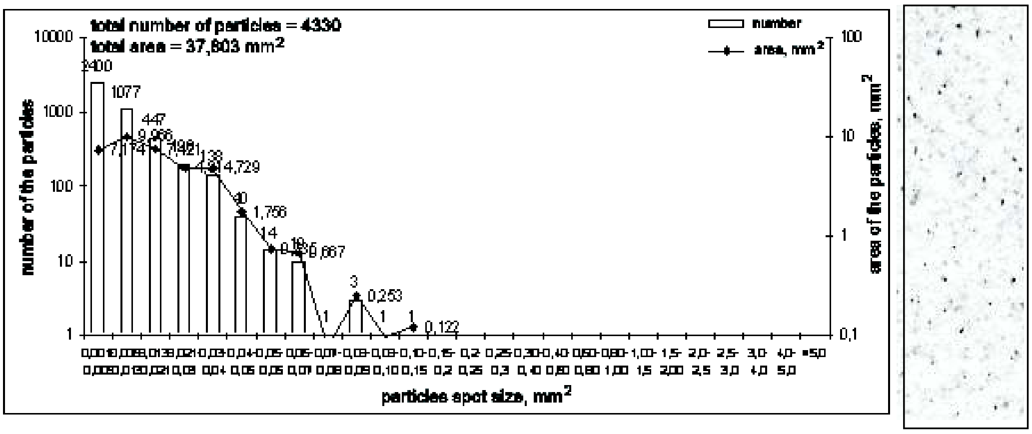
As the digital printing techniques as well as those based on the electrophotography are more and more present in the graphic reproduction, the problems of the used prints disposal in the contests of obtaining the secondary raw materials suitable for the production of fine graphic papers are interesting. In the described segment, there exists a series of system variables which were presented earlier, while in this work, in figure 1, the influence of the printing technique in the defined printing conditions on the distribution of toner particles and ink has been presented by the application of the non destruction method of the image analysis [16].



a) the print made in digital offset technique used for recycling, based on the electrophotography with the liquid toner



b) the print made in digital offset technique used for recycling, based on the electrophotography with the stiff toner



c) the print of the conventional offset printing used for recycling

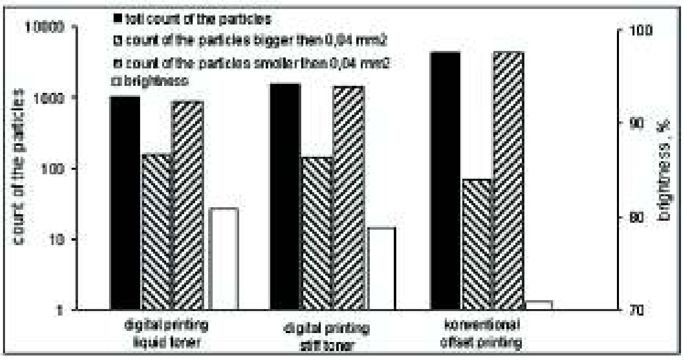
Figure 1. The results of the image analysis of handsheet made from the fibers after the disintegration process

The investigation results point at the influence of the technique on the shape, size and the number of particles of the residual toner on handsheet after disintegration process. The total smallest number of flat particles in this case is present on handsheet during the print recycling made by the indirect electrophotography with the liquid toner in relation to the two other observed prints. The characteristic of this handsheet is that the particles were arranged in all classes from 0,001 – 0,006 to the class >5,0 mm^2. In the class with the sizes >5,0 mm^2 there were 8 particles with the surface of 56,109 mm^2.

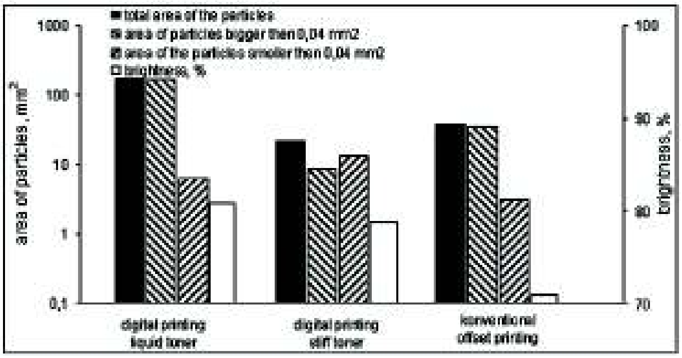
On the other hand, the greatest number of particles which essentially differed in their shape from the earlier mentioned ones was obtained in the case of the print recycling made by the conventional offset printing. The characteristic of the particle distribution in that case was the greatest number of particles in the lowest class size (in the class

0,001 – 0,006 mm^2 there were 2400 particles). In the classes with the sizes from 0,15 – 0,2 to >5,0 mm^2 there were no particles found. The residual particles of the stiff toner on handsheet made from the fibers after the disintegration process were sorted in the classes similar to those obtained for the classical offset print (0,001-0,006 do 0,15-0,2 mm ^{2}). The obtained results could be explained by the work principals of the used printing techniques.

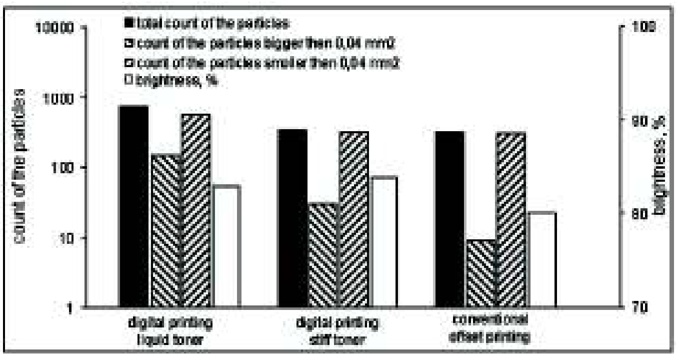
For monitoring and determining the relation of the particle size and the handsheet brightness, the following results are presented in figure 2 as follows.



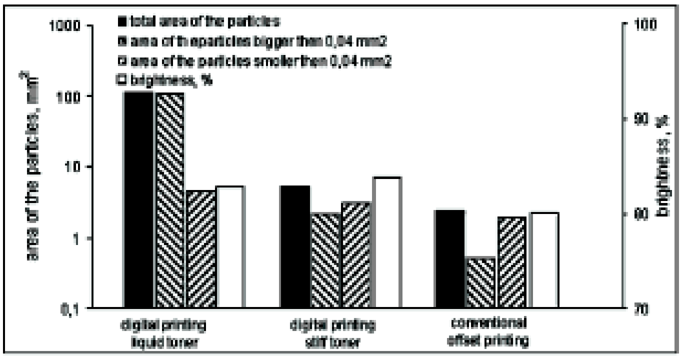
a) handsheets made from fibers after disintegration



b) handsheets made from fibers after disintegration



c) handsheets made from fibers after flotation



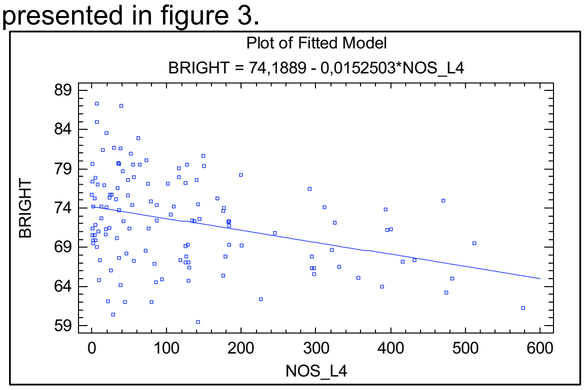
d) handsheets made from fibers after flotation

Figure 2. Results of the image analysis and the spectrophotometric measurements of brightness

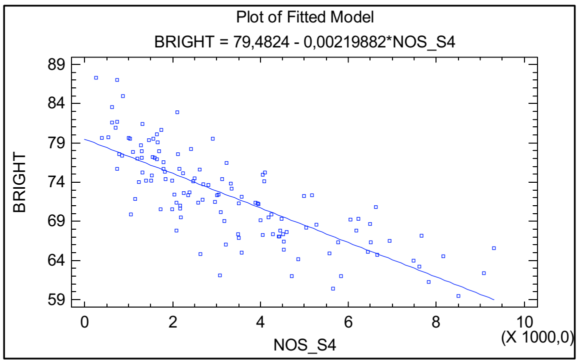
The investigation results point at the non linearity of the relations of particle sizes of the residual ink and handsheet brightness. In processing the prints made by the indirect electrophotography with the liquid toner on handsheet, great particles were noticed, which occupy the surface greater for 87,3 % and have 8,6 greater brightness in relation to those obtained in processing the prints of the conventional offset printing. The prints also made on the principle of electrophotography but made with the stiff toner behave somewhat different. In this case the particle number of the lowest class increases and the brightness decreases, which is more expressed in processing the prints from the conventional offset printing.

Observing the obtained results after flotation, one can notice that by processing the prints made by electrophotography and the liquid toner, smaller brightness increase was achieved (difference before and after flotation was 2,1) in relation to other prints (electrophotography of stiff toner – the difference before and after flotation was 5,0, and in the case of the conventional offset printing process it was 9,7). These results answer the question of effectiveness of the recycling process for the determined kind of prints.

The relation of the results obtained by using the Spectrophotometric method for brightness measurements and the particle sizes obtained by the image analysis is presented in figure 3.



a) particles >0.04mm^2



b) particles <0.04mm^2

Figure 3. Correlation between the brightness and the number of particles on handsheet

In figure 3, the investigation results of the correlation between the brightness and the number of particles of the residual ink on handsheet are presented. The handsheet was made from the fibers obtained by the recycling the prints of the conventional offset printing.

The results point at greater correlation of brightness and the particle size in the case of particles <0,04mm^2, i.e. in the case of those which are not visible by bare eye in relation to the greater ones.

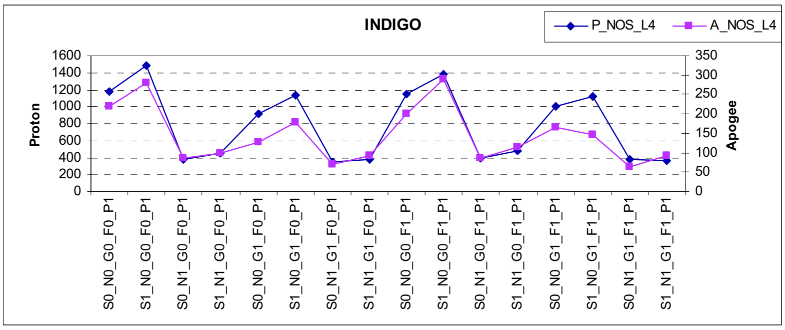
In the presentation 3b the particles greater than 0,04 mm^2 were comprised, but only within the classes sizes of 0,04 – 0,05 and 0,10 – 0,15 mm^2. By increasing the particles size the observed correlation becomes lost and in the case of handsheet obtained by the print recycling made on the base of electrophotography with the liquid toner with regard to the particle size, one can talk about the optical inhomogeneity of the handsheet.

In the investigations presented in this work it is important to choose the right methods of monitoring the chosen system variables. The results confirm that by monitoring the particle sizes on handsheet obtained from the fibers after the recycling of prints of the conventional offset printing it is not very suitable to use the image analysis in the presented experimental conditions.

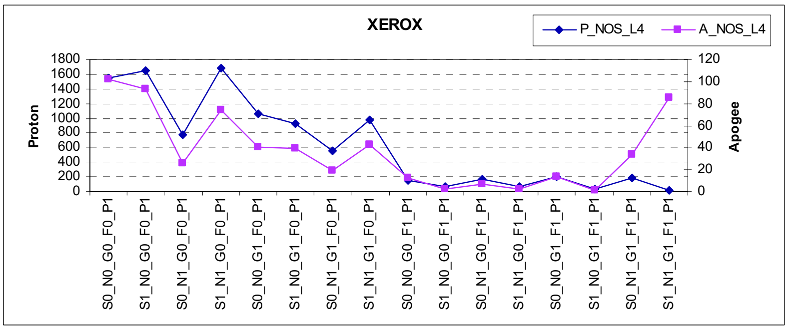
On the other hand, just that method proved to be good in the analysis of handsheet made from the recycled fibers of prints produced on the base of electrophotography by the liquid toner.

In figure 4, the results of the image analysis from two software tools (Apogee and Proton) were compared for handsheets made from the recycled fibers of prints obtained by the application of electrophotography and the liquid toner (a), as well as the application of the electrophotography and the stiff toner (b).

The difference between the prints in each series refers to the conditions of printing, the kind of the printing substrate and the processing before the recycling process itself.



a) comprises the number of particles in the classes from 0,04-0,05mm^2 to >5mm^2



b) comprises the number of particles in the classes from 0,04-0,05 mm^2 to 0,10-0,15 mm^2

Figure 4. Comparison between the two image analysis software tools

Regardless the variables of the print preparations, some of which are very significant, the results obtained by using the software Proton are somewhat higher in relation to those obtained by the software Apogee, but the trends are very similar. There are not essential differences in relation to the particle sizes in each of the observed series.

4. CONCLUSION

The investigation results show that the method non- destructive image analysis is necessary in studying the recycling process of prints based on electrophotography with the liquid and stiff toner. The application of the method in scientific sense is interesting in studying the mechanisms of detaching of toner particles from the fibers in the disintegration process in relation to the determining the laws of influences and the relation of the essential factors of the observed system.

In this way, with the support of the experimental design and creation of the statistical models, the relation of essential factors with the chosen characteristic of the experimental units can be determined, which, except the scientific importance, it has the determined applicative contribution.

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