Evaluation of Ink Particles in Deinked Pulp with Non-Destructive Method

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Abstract. The image processing and analysis are interesting methods 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 paper recycling process or produced on the paper. Dirt specks include the ink particles in the deinked pulp. In this study, prints from digital offset printing technique based on Indigo electrophotography were used for recycling. In printing process the voltage levels on the photoreceptor drum were 300V and 600V respectively. Printing substrate was the mat fine art paper of different basis weights. Effects of artificial ageing, flotation process and paper side were also studied. Residual ink size, number and area of ink particles were assessed with two image analysis systems – Spec*Scan, Apogee System and Proton. Results of a full factorial 25 experimental design from measurements obtained by Spec*Scan are presented with a special emphasis on influential factors that affect residual dirt particles distribution in deinked pulp. In addition, a comparison between the two image analysis software tools is given.

1. Introduction

For evaluation of the quality of the recycled pulp and the effectiveness of ink removal, optical parameters, such as brightness, luminance and color can be applied [10]. Frequently encountered parameter to determine the optical quality is the spectral reflectance factor R457 used as a measure of brightness. However, this procedure has certain limitations, e.g. the measurement includes only the blue area of the visible spectrum between the wavelengths of 400 and 510 nm. That is why this parameter does not always relate well with visual assessment [3,11]. In addition, spectral reflectance factor is not only affected by the number of residual ink specks, but also by their size [2,8].

A more effective means of quantifying residual ink is by measuring the light absorption in the near-infrared part of the spectrum (800 to 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 specks population is impacting brightness of the pulp [7,11]. 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. This method is used when the particles are invisible to the naked eye, i.e. when their size is smaller than 10 μm.

The particles whose diameter is between micro and macro area and the invisible ones, have smaller influence on brightness of the recycled fibers compared to those being smaller than 10 µm [6]. It is important to study the transition from the invisible area into the visible one and to understand the underlying mechanisms as the process conditions influence the product properties. In the determined conditions in the process and agents for the removal of ink, the agglomerations can be formed which will have smaller influence on brightness and which will increase the effectiveness of the particle removal [5,12].

Image analysis systems are useful for recording optical inhomogeneities. These are dirt specks including ink particles in lab handsheets or in paper producing an optical contrast to the sheet background. With this method, the number, diameter and area of the residual dirt particles in visible, macroscopic area can be determined. Many authors have studied the techniques of the image analysis [4,13].

In this paper, results of investigation of dirt particles size distribution in lab handsheets before and after deinking flotation process of digital offset prints using two image analysis software systems are presented. Statistical techniques such as factorial design and analysis of variance (ANOVA) were used to interpret the findings.

Experimental

The digital offset printing machine Indigo E-Print 1000+ was used for printing. The voltage levels on the photoreceptor drum were 300 V and 600 V. The test form used in printing contained areas of tonal values ranging from 0 to 100% coverage in steps of 10% for CMYK colours.

Printing substrates were the mat fine art papers of 200, 250 and 280 g/m^2 (gsm) basis weight. The corresponding thickness values were 0,185 mm, 0,235 mm and 0,260 mm, respectively. The printed samples underwent the alkaline deinking flotation process [1]. The handsheets were made using a laboratory sheet former, according to standard TAPPI method T 205.

Optical unhomogeneity 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 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 to 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 (value 0). The image analysis ends in measuring the dirt particles and in producing the data output.

Dirt particle analysis procedure is presented in Figure 1.

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

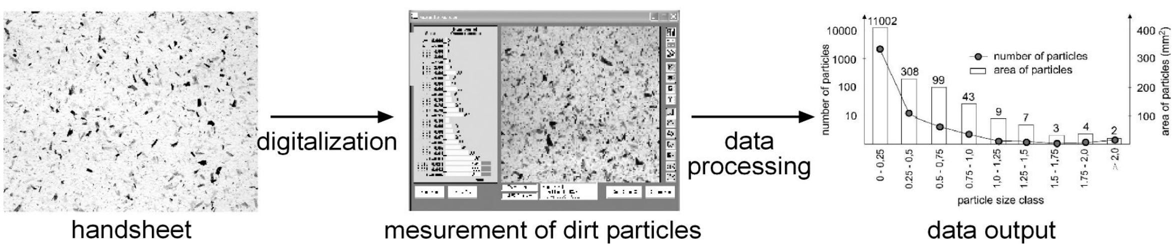

Figure 1. Dirt particle image analysis procedure.

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 (see below) 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.

The other software – Proton – applied the same image acquisition procedure using the Microtek ScanMaker 5900 scanner and resolution of 300 dpi, however, no adjustment of the system to TAPPI standard methods was made.

Factorial design

We wanted to examine effects of several variables on efficiency of floatation deinking so we performed experiments according to a standard 2^5 factorial design scheme with randomized runs varying each of the factors at two levels. Factors studied were as follows:

1. Artificial ageing (AGEING): without (S0) / with (S1)
2. Printing drum voltage (VOLTAGE): 300 V (N0) / 600 V (N1)
3. Basis weight (BASISWT): 200 gsm (G0) / 280 gsm (G1)
4. Floatation deinking process (DEINK): before (F0) / after (F1)
5. Handsheet side (PAPSIDE): bottom (P0) / top (P1)

Data on the following eight parameters related to number and size of dirt particles as obtained by image analysis software were recorded:

6. Total number of specks (NOS_T)
7. Number of specks larger than 0,04 mm^2 (NOS_L4)
8. Number of specks smaller than 0,04 mm^2 (NOS_S4)
9. Total area of specks (TSA_T)
10. Average area of specks (ASA_T)
11. Area of specks larger than 0,04 mm^2 (SA_L4)
12. Area of specks smaller than 0,04 mm^2 (SA_S4)
13. Grayscale brightness (GSB)

Results and discussion

Due to the large quantity of data produced, only some of the results are presented below. Analysis of variance (ANOVA) tables for NOS_T, ASA_T and GSB are shown in Tables 1 to 3. Statistically significant ($p<0,05$) effects of factors and their combinations, i.e. two-factor interactions are displayed in green. From the corresponding F values it is clear that the printing drum voltage (VOLTAGE) is by far the most influential factor with respect to both the number (NOS_T) and the average size (ASA_T) of dirt particles present in the handsheets. Apart from that, in case of the ink specks number (NOS_T), BASISWT, AGEING and DEINK also seem to be important (apart from some two-factor interactions), while PAPSIDE has some effect on average specks area (ASA_T). On the other hand, the only statistically important effect on grayscale brightness (GSB) is that of basis weight (BASISWT).

Table 1. ANOVA table for total number of specks (NOS_T).

ANOVA table; Var.: NOS_T; R-sqr = 0,97741; Adj: 0,95624					
	SS	df	MS	F	p
(1)AGEING	138381,8	1	138381,8	43,2867	0,0000
(2)VOLTAGE	1572207,8	1	1572207,8	491,7965	0,0000
(3)BASISWT	281937,9	1	281937,9	88,192	0,0000
(4)DEINK	104996,5	1	104996,5	32,8436	0,0000
(5)PAPSIDE	12285,3	1	12285,3	3,8429	0,0680
1 by 2	28143,8	1	28143,8	8,8036	0,0090
1 by 3	25821,3	1	25821,3	8,0771	0,0120
1 by 4	4991,7	1	4991,7	1,5614	0,2290
1 by 5	124	1	124	0,0388	0,8460
2 by 3	33131,7	1	33131,7	10,3638	0,0050
2 by 4	255	1	255	0,0798	0,7810
2 by 5	1906,5	1	1906,5	0,5964	0,4510
3 by 4	4178,5	1	4178,5	1,3071	0,2700
3 by 5	5159,6	1	5159,6	1,614	0,2220
4 by 5	4,3	1	4,3	0,0013	0,9710
Error	51149,9	16	3196,9		
Total SS	2264675,5	31			

Table 2. ANOVA table for average specks area (ASA_T).

ANOVA table; Var.: ASA_T; R-sqr = 0,94104; Adj: 0,88576					
	SS	df	MS	F	p
(1)AGEING	0,000192	1	0,000192	0,4917	0,4932
(2)VOLTAGE	0,091143	1	0,091143	233,7246	0,0000
(3)BASISWT	0,000076	1	0,000076	0,194	0,6655
(4)DEINK	0,000024	1	0,000024	0,0619	0,8066
(5)PAPSIDE	0,002803	1	0,002803	7,1867	0,0164
1 by 2	0,00077	1	0,00077	1,9753	0,1790
1 by 3	0,001561	1	0,001561	4,0018	0,0627
1 by 4	0,000336	1	0,000336	0,8612	0,3672
1 by 5	0,000086	1	0,000086	0,22	0,6453
2 by 3	0,000073	1	0,000073	0,1867	0,6715
2 by 4	0,000233	1	0,000233	0,5973	0,4509
2 by 5	0,001162	1	0,001162	2,9788	0,1036
3 by 4	0,001094	1	0,001094	2,8043	0,1134
3 by 5	0,000015	1	0,000015	0,0386	0,8468
4 by 5	0,000013	1	0,000013	0,0325	0,8592
Error	0,006239	16	0,00039		
Total SS	0,105818	31			

Table 3. ANOVA table for grayscale brightness (GSB).

ANOVA table; Var.: GSB; R-sqr = 0,59116; Adj: 0,20787					
	SS	df	MS	F	p
(1)AGEING	1,0513	1	1,05125	0,215626	0,6486
(2)VOLTAGE	6,5401	1	6,54014	1,341471	0,2638
(3)BASISWT	38,4272	1	38,42722	7,881946	0,0126
(4)DEINK	3,4672	1	3,46722	0,711174	0,4115
(5)PAPSIDE	3,9668	1	3,96681	0,813646	0,3804
1 by 2	1,9013	1	1,90125	0,389972	0,5411
1 by 3	2,645	1	2,645	0,542525	0,4721
1 by 4	3,2939	1	3,29389	0,675621	0,4232
1 by 5	0,0613	1	0,06125	0,012563	0,9122
2 by 3	1,3889	1	1,38889	0,28488	0,6009
2 by 4	18,8089	1	18,80889	3,857959	0,0671
2 by 5	8,6113	1	8,61125	1,766284	0,2025
3 by 4	1,3613	1	1,36125	0,279211	0,6045
3 by 5	17,8006	1	17,80056	3,651136	0,0741
4 by 5	3,4672	1	3,46722	0,711174	0,4115
Error	78,0056	16	4,87535		
Total SS	190,7976	31			

Similar information is contained in Pareto charts of standardized effects for the three above mentioned parameters (Figures 2 to 4): effects with bars crossing the p=0,05 demarcation line are statistically significant at 95% confidence level. Sign of an individual effect estimate is an indication of its positive or negative influence on the particular parameter: higher voltage (600 V), higher basis weight (280 gsm), non-aged handsheets and deinking process – all lead to lower NOS_T (Figure 2). Again it has to be emphasized that, compared to the drum voltage, all other effects are very small. With a lower voltage (300 V) significantly smaller (ASA_T) dirt specks are produced (Figure 3). Pareto chart for grayscale brightness (Figure 4) shows that higher basis weight (280 gsm) is accompanied by higher brightness.

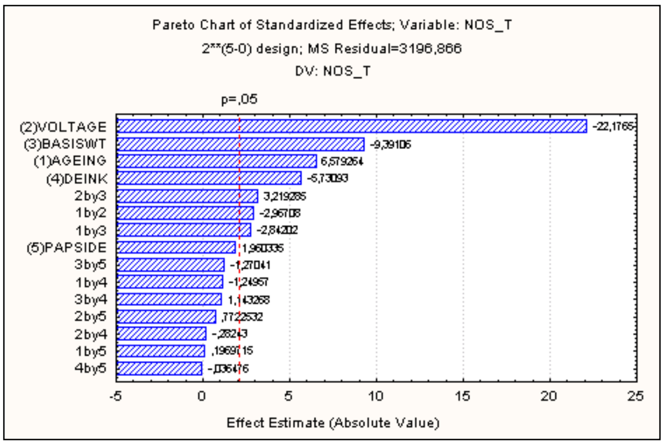

Figure 2. Pareto chart of effects for total number of specks (NOS_T).

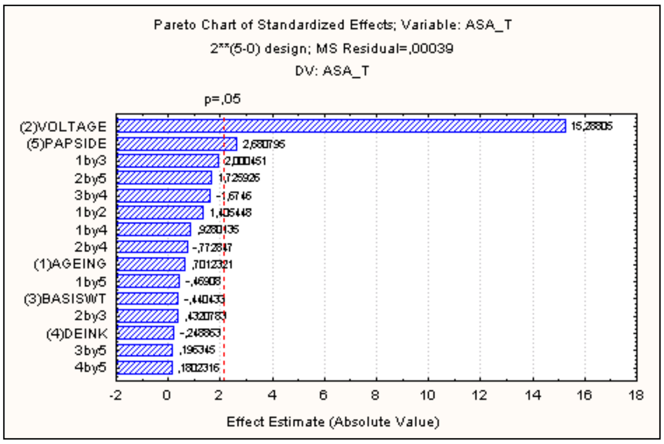

Figure 3. Pareto chart of effects for average specks area (ASA_T).

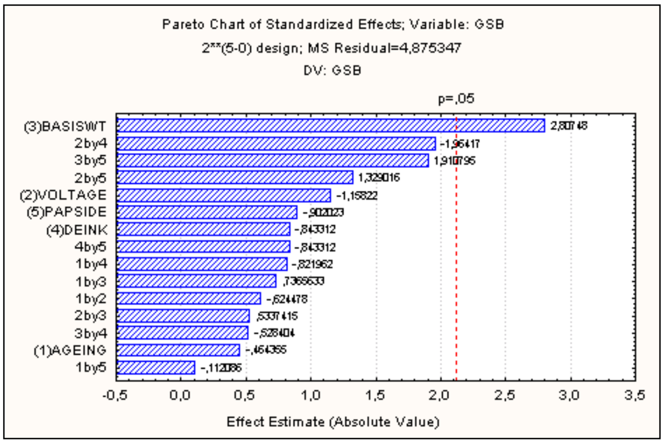

Figure 4. Pareto chart of effects for grayscale brightness (GSB).

On the basis of the created statistical models that include all main effects and two-factor interactions it is possible to predict values of corresponding measured parameters. Cube diagrams (Figures 5 to 7) show what are the predicted means of a particular parameter when taking into account the three most influential factors only. In case of NOS_T (Figure 5) it can be noted, that the lowest predicted value (i.e. 384,4) can be obtained by using higher voltage (600 V), higher basis weight (280 gsm) and handsheet sample that did not undergo an artificial ageing process.

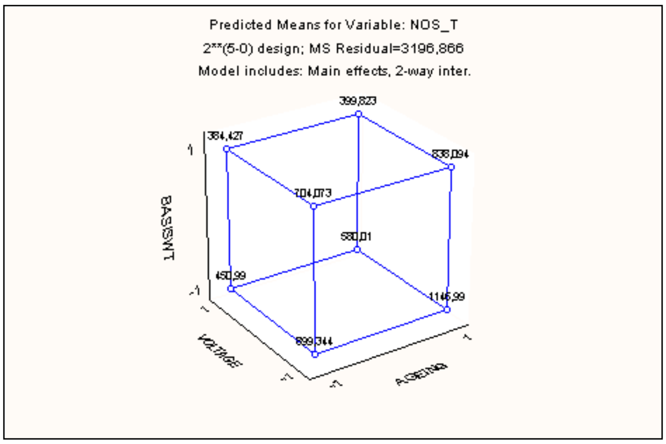

Figure 5. Cube plot for total number of specks (NOS_T).

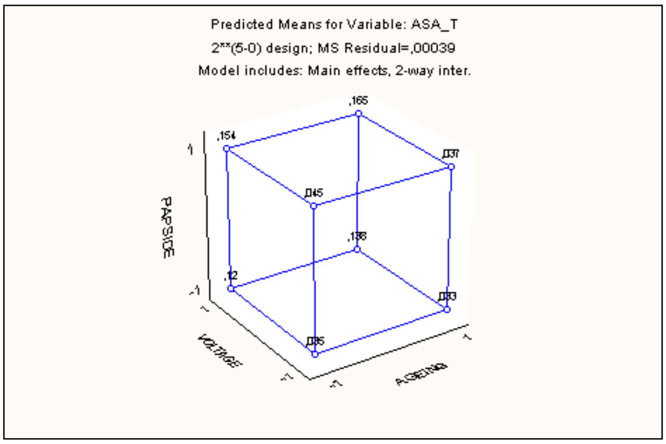

Figure 6. Cube plot for average specks area (ASA_T).

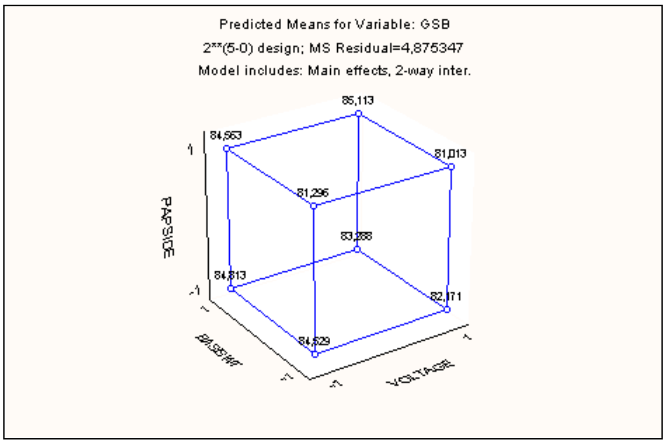

Figure 7. Cube plot for grayscale brightness (GSB).

Finally, we measured the same eight handsheet parameters using another image analysis software Proton. Only top paper side (P1) was analysed. Results for number of specks – all (NOS_T) and those smaller than 0,04 mm^2 (NOS_S4) – and specks size – of all (TSA_T) and of those particles which are smaller than 0,04 mm^2 (SA_S4) for both image analysis systems are presented in Figures 8 to 11. It can be seen that, although Proton values (P; primary y-axis) are always higher than those obtained by Apogee (A; secondary y-axis) software, trends are very similar. In case of particles number (Figures 8 and 9) there is no significant difference in factor effects between the number of total (NOS_T) and smaller (SA_S4) particles. For the specks area (Figures 10 and 11), however, differences are obvious: prints produced with higher drum voltage (600 V) yield overall bigger particles (TSA_T), but ink specks smaller than 0,04 mm^2 (SA_S4) occupy with these settings much smaller area compared to those obtained by low voltage (300 V). It can generally be stated, that higher voltage leads to production of a lower number of ink particles, which are bigger in size compared to high-voltage specimens.

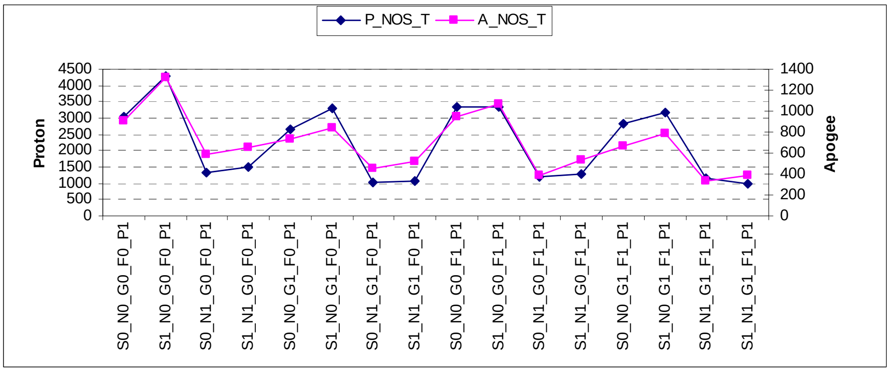

Figure 8. Comparison of image analysis tools for total number of specks (NOS_T).

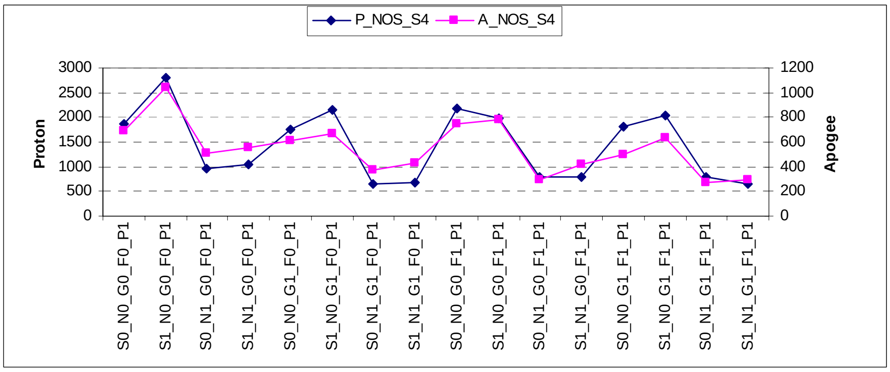

Figure 9. Comparison of image analysis tools for number of specks smaller than 0,04 mm^2 (NOS_S4).

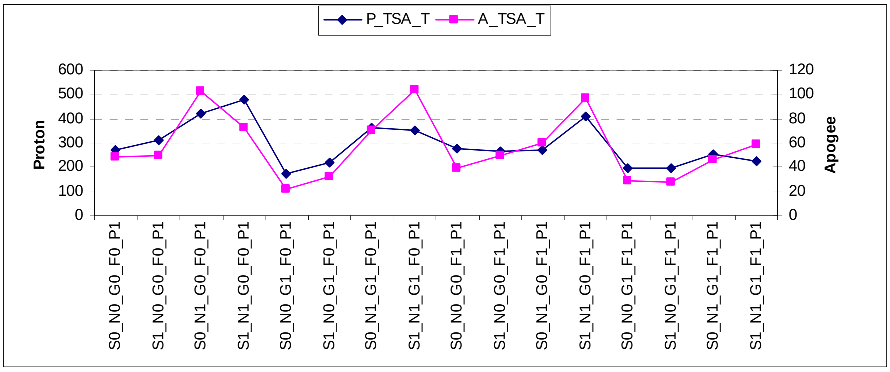

Figure 10. Comparison of image analysis tools for total specks area (TSA_T).

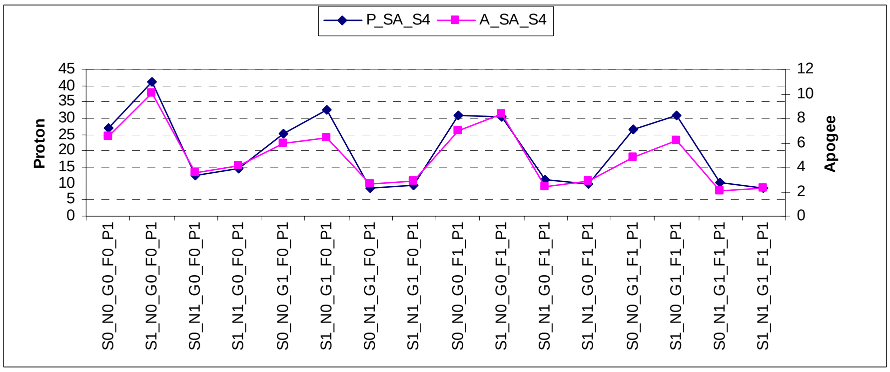

Figure 11. Comparison of image analysis tools for area of specks smaller than 0,04 mm^2 (SA_S4).

Conclusions

Our investigations confirmed that printing conditions as well as pulp deinking procedure have important impact on the size and number of residual ink in pulp. Printing drum voltage proved to be the most important factor influencing these parameters, although other factors, such as basis weight, presence or absence of artificial ageing and, naturally, deinking process itself also play their roles. Both image analysis systems show the same trends regarding the influence of individual factors on the dirt specks' number and size, although their values differ.

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