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Ecological Sustainability and Waste Paper Recycling

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Abstract

In accordance with environmental sustainability and in order to optimize the recycling process of prints from indirect electrophotography with liquid toner the results of investigating the effects of changes in printing conditions on the characteristics of recycled fibres is presented. Changing of printing machine conditions, respecting of voltage variations, comprises of the reverse rollers and intermediate cylinder.

Based on the results it can be concluded that the change in the voltage of the reverse rollers more affect the recycling efficiency with respect to the voltage change of the intermediate cylinder. Brightness gain is higher when the print for recycling is made on uncoated paper compared to coated, and dependent on the voltage changes. Effective residual ink concentration decreases far more on handsheets obtained from recycled samples on uncoated paper in relation to both sides coated paper. Increasing the positive voltage of intermediate cylinder and increasing the negative charge of reverse rollers increases the 3 D gamut CIE L*a*b* color cubic units. Guidelines for the size of the voltage in order to obtain optimal print reproduction are provided.

The further research will include the development in area of clean technologies, advanced materials, closed loop systems; therefore the significant terms in the area of environmental sustainability.

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Keywords: Electrophotography; Liquid toner; Reverse rollers; Intermediate cylinder; Recycling

1. Introduction

Environmentally more sustainable product system and demands of sustainable conditions will result in production and consumption that are in the system of contemporarily industrial society and sustainability. The term of sustainability is significant for the development, and it includes energy and material flows, closed loop systems,

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clean technologies, economic and social factors, implementation of society values and quality[1].

The waste and the influence on environment depend on the printing technique and the used materials. Significance of making the right choice is in the field of printing substrates (substrates with high content of secondary raw material, substrates made from total chlorine-free process), inks (lower solvent content level biodegradable inks, formulation with more renewable raw material), printing (clean technologies, preparation of printing forms with no wastewater which contains chemicals from the process, cleaning agents for machine elements which are based on renewable resource) and post-press finishing, binding process can be specified to enable full recycling of paper content without glue contamination[2,3].

The digital press based on electrophotography generates less paper and chemical waste than conventional printing press. Digital electrophotography Indigo press produces paper waste 5-20%, and chemical waste 0.2-1.1g per impression [4].

Sheet- fed offset press produces 35-75% paper waste and 3.2-7.3g chemical waste per impression [4] The VOC emission was 74 mg/m^3 in the breathing area of digital press and 484 mg/m^3 above the conventional press (VOC emissions expressed as the concentration of n-hexane) [4].Water footprint of the HP Indigo 7000 press option is 59% lower than that of the sheet fed offset press [5].

As the volume of the digitally printed products increases, recyclability of the waste paper becomes important, because materials can be reused accepting cradle-to-cradle concept [6].

Poorly deinkable digital prints made in the technique of indirect electrophotography with liquid toner ElectroInk were proved by the investigations [7-9]. ElectroInk appears to produce big specks after pulping, which is difficult to eliminate in a flotation deinking plant.

The digital printing equipment manufacturers and INGEDE have different opinions on the deinkability of digital prints. During DRUPA 2008, HP claimed that the version of ElectroInk 4.0 is as deinkable as dry toners. INGEDE issued a press release starting that the claims were incorrect [10]. Digital printing equipment manufacturers also question the relevance of the single-step laboratory test of the INGEDE 11 method, claiming that it does not reflect the industrial conditions of two-loop deinking [11].

The new generation of Electro Ink produces smaller specks after pulping. Specks which are effectively broken up by dispersion are floatable in a second flotation loop [12, 13].

Zang and co-others describe the design of a laboratory scale two-loop deinking process with inclusion of a low-speed high shear kneading step in between two flotation steps [14]. The samples for recycling were mixed office waste and mixtures of mixed office waste with various amounts of liquid electrophotography prints. The two –loop process successfully brings the dirt area for mixed office waste with liquid electrophotography prints (5% and20%) to a satisfactory level.

Ng and co-authors demonstrated that good deinkability of HP commercial prints (liquid electrophotography, dry electrophotography and ink jet) can be achieved with neutral deinking chemistry [15]. They found a direct correlation of the chemical effects to the ink-particle speck contamination and its particle size distributions.

The aim of our extensive research was to determine the influence of the conditions in indirect electrophotography with liquid toner (scorotrone voltage, laser strength, voltage of reverse roller, voltage of intermediate cylinder, concentration of the liquid toner etc.) on effectiveness of the prints recycling [16-19].

In this paper the impact of changes in the voltage of the reverse rollers and voltage variation of intermediate cylinder in indirect electrophotography with liquid toner on the efficiency of the deinking flotation process is presented.

The efficiency is determined by the effective residual ink concentration and specks number and area on handsheets made from pulped and recycled fibers. In order to determine the reproduction quality the same samples were used, overall extend color information as color 3D gamut and ΔE CIE Lab_{2000} were investigated.

Research results are the contribution to the explanation of the printing process conditions on prints deinkability, possibility of the application in the area of reused materials accepting cradle-to-cradle concept and in the design of graphic products taking into consideration the postulates of ecological sustainable development.

2. Experimental

The samples were made on digital machine Turbo Stream HP Indigo, based on electrophotography. The test form contained different printing elements: standard CMYK step wedge in the range from 10-100% tone value, standard ISO illustration and the standard wedge with 378 patches for production of ICC profiles and 3D gamut.

ElectroInk of the third generation and double sided coated paper were used for printing. Paper brightness was

95% and basis weight was 115g/m^2 [20, 21].

One series of indirect electrophotography samples was prepared so that the voltage of reverse rollers was changed as follows: 0V, -50V, -125V, -200V and -250V. In the other series the change of the intermediate cylinder voltage was: 500V, 550V, 600V, 650V and 700V.

During the experiment, only one stage in the printing process is varied, while all other parameters remained constant defined by the initial calibration of the printing machine [22].

The method of alkaline chemical deinking flotation was used for recycling prints. In the previous article it was described in details [23]. Laboratory handsheets are made with the use of standard sheet former Rapid- Köthen, according to ISO 5269-2 [24]. On this handsheets using spectrophotometer Technidyne Color Touch 2, brightness and effective residual ink concentration before and after flotation are measured [25].

According to the recycling process phase image analysis is made with the use of SpecScan® Apogee System software in accordance with TAPPI standard method [26]. This system is utilizing scanner to digitize image. Threshold value (100), white level (75) and black level (65) were chosen after comparing computer images to handsheet.

The spectrophotometer X Rite DTP 41 and the application ColorShop X were used for calculating output results such as: L*a*b*, c*, H*, x, y, Y. All values were measured three times and average values were used for further analysis. The colour difference ΔE^*_{2000} was calculated using the equation described by Luo and co- author and Johnson and Green [27, 28]. The X-Rite DTP 41 device is suitable for measuring a large number of patches (in this case the test chart with 378 colour patches). The measurements were used to create the ICC profiles using the program MonacoProfiler Platinum v 4.8. From the generated ICC profiles space the colour gamut was formed and gamut volumes were detected in the program Gamut Works v.1.0.

3. Results and discussion

In accordance with environmental sustainability and in order to optimize the recycling process of prints from indirect electrophotography with liquid toner the results of investigating the effects of changes in printing conditions on the characteristics of recycled fibers is presented. Changing of printing conditions, respecting of voltage variations, comprises the third phase, in which is the development with reverse rollers. In addition, the study includes the fourth stage in indirect electrophotography, which includes a first transfer of ink. In this transfer toner particles from photoconductor surface are transmitted to the intermediate cylinder.

The impact of voltage changes in the described phases of an electrophotography printing with liquid toner to specks number is shown in fig 1.

Increasing negative voltage of reverse roller in a range from 0V to - 250V leads to decrease in the number of specks on handsheets made from the fibers before flotation as follows: N_{0V}/N_{-50V} 4.4%, N_{0V}/N_{-125V} 18,5%, N_{0V}/N_{-200V} 24,8% and N_{0V}/N_{-250V} 34,1%. Total number of specks with flotation decreases from 5% -15% depending on the voltage of reverse rollers. To lower negative voltage of revers rollers higher efficiency of removing specks with flotation within the above-indicated values is associated.

With changing the voltage of intermediate cylinder in the range from 500V to 700V there were no major impacts on the number of specks on handsheet. Depending on the voltage total number of specks ranges from 894 to 999, which is no more than 25% more compared to the total number of specks obtained by varying the voltage of reverse rollers. Separation of specks with flotation in the described experimental conditions is somewhat lower than those obtained by varying the voltage of reverse roller and ranges from 3.8 to 5.6% depending on the voltage of the intermediate cylinder.

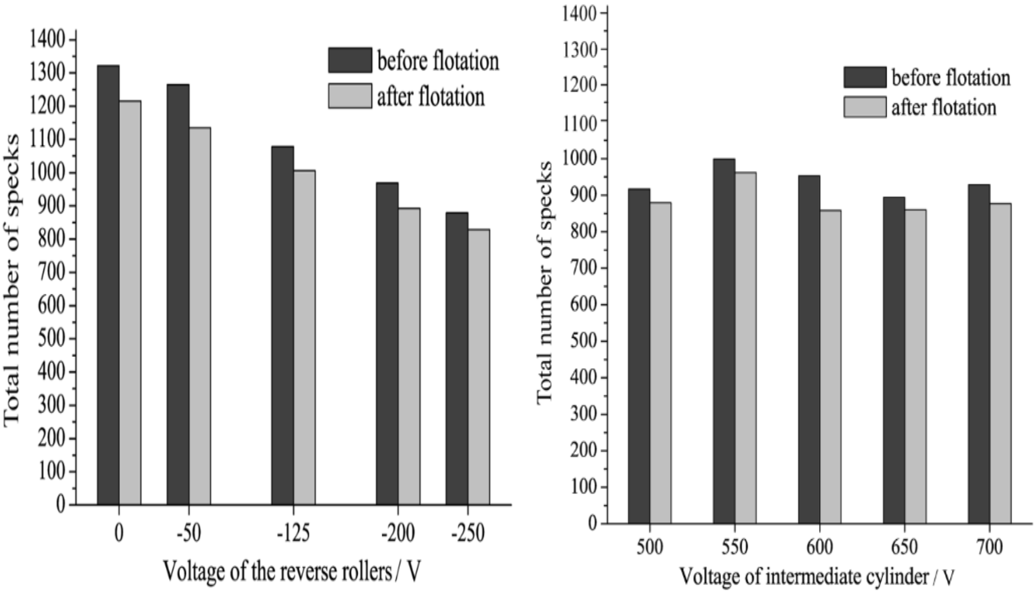


Fig. 1. (a) Total specks number on handsheet versus voltage of reverse rollers in printing; (b) total specks number on handsheet versus voltage of intermediate cylinder in printing.

Area of specks on handsheets in relation to voltage of reverse rollers and intermediate cylinder is shown in Figure 2.

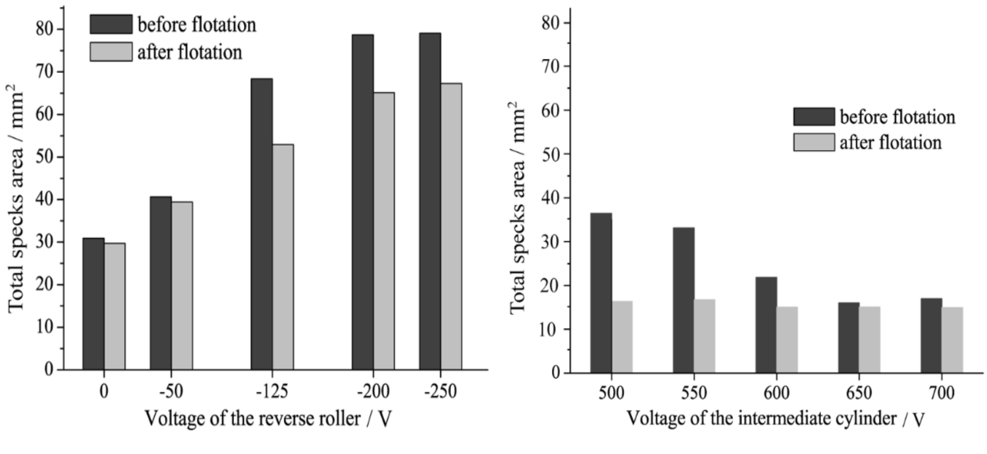


Fig. 2. (a) specks area on handsheets versus voltage of reverse roller; (b) specks area on handsheets versus voltage of intermediate cylinder.

The results show the opposite relationship between the areas of total specks (0V 29,71mm^2, 50V 39,41mm^2, -125V 52,91mm^2, -200V 65,09mm^2, -250V 67,20mm^2) in relation to the number of specks (0V 1216, -50V 1135, -125 1005, -200V 893, -250V 829) on handsheets made from recycled fibers prints obtained by changing the voltage of reverse rollers. By increasing the negative voltage of reverse roller in the printing specks area on handsheets expands as follows: A_{0V}/A_{-50V} 24,2%, A_{0V}/A_{-125V} 54,8%, A_{0V}/A_{-200V} 60,7% and A_{0V}/A_{-250V} 61,1%. Due to the fact that increasing negative voltage of reverse rollers reduces the number of specks after pulping and increases specks area, it actually means that the particles have a larger surface.

By increasing the voltage of intermediate cylinder in the printing the total specks area reduces as follows: A_{500V}/A_{550V} 7,3%, A_{500V}/A_{600V} 40,1%, A_{500V}/A_{650V} 48,3% and A_{500V}/A_{700V} 48,3%. Reduce of the total specks area for voltage of 500V of the intermediate cylinder is 51.1%, and then decreases as follows: V_{550} 45,9%, V_{600} 23,6%, V_{650} 1,6%, V_{700} 6,6%.

More precise monitoring and interpretation of the deinking flotation mechanism in the described conditions is possible with the use of image analysis and specks spot size from 0.001-0.006 mm^2 to >=5mm^2, which includes 26 spot sizes. The research results show that the increase in negative voltage of the reverse rollers formed larger flat specks, sometimes larger than 5 mm^2 (Table 1).

Table 1. Specks area in spot size >= 5mm^2 after pulping and after flotation versus voltage of the reverse rollers.

Sample	0 (*V*)	-50 (*V*)	-125(*V*)	-200(*V*)	-250(*V*)
Total area of specks after pulping (mm^2)	5,68	6,58	18,11	31,09	30,93
Total area of specks after flotation (mm^2)	0	0	6,59	14,09	12,44

Described characteristic is not recognized when varying the voltage of the intermediate cylinder (Table 2).

Table 2. Distribution of large specks after pulping and after flotation versus the voltage of the intermediate cylinder.

Sample	500 (*V*)	550 (*V*)	600(*V*)	650(*V*)	700(*V*)
Total number of specks after pulping in spot size >= 5mm^2	1	0	1	1	0
Total number of specks after flotation in spot size >= 5mm^2	0	0	0	0	0
The biggest spot size (mm^2) with specks after flotation	1,00-1,50	1,50 2,00	1,00-1,50	1,00-1,50	1,00-1,50
Number of specks in the biggest spot size with specks after flotation	1	1	1	1	1

Table 3. Distribution of specks after pulping and after flotation versus the voltage of the intermediate cylinder.

Sample	500 (*V*)	550 (*V*)	600(*V*)	650(*V*)	700(*V*)
Total number of specks after pulping in spot size >=0.04mm^2	79	78	89	56	74
Total number of specks after pulping in spot size <0.04mm^2	838	875	833	837	859
Total area of specks after pulping in spot size >=0.04mm^2	29,27	21,09	25,38	14,77	11,54
Total area of specks after pulping in spot size <0.04mm^2	6,94	7,14	7,73	6,64	7,09

Within the experimental conditions and the results displayed in Table 2 could be concluded that increasing the voltage of the intermediate cylinder in the printing, is not particularly characteristic for specks number in spot size >= 5mm^2 on handsheet made from the fibers after pulping, as is the case with increasing the voltage of the reverse rollers.

Presented results can be explained trough the principle of the electrophotography with liquid toner, as follows. During the printing process the ElectroInk is transferred to the blanket that is heated to 100^0C. This causes the toner particle to melt and fuse together, forming hot adhesive liquid plastic. When the ink contacts relatively cool substrate it solidifies, it sticks to it and is stripped off the blanket, leaving no residue behind.

Table 4 shows the brightness gain and effective residual ink concentration difference of the handsheets after pulping and after flotation.

Table 4. Brightness gain and difference of the effective residual ink concentration handshets after pulping and after flotation in dependence of the type of the paper and the voltage of the reverse rollers in printing.

Voltage of the intermediate cylinder	500 (*V*)	550 (*V*)	600(*V*)	650(*V*)	700(*V*)
Brightness gain, uncoated paper	9,6	10,4	12,3	10,4	11,4
Brightness gain, coated paper	1.3	0,9	0,1	2,0	0,3
Δ ERIC, uncoated paper	43,1	41,4	49,4	48,5	54,6
Δ ERIC, coated paper	5,2	0,5	12,3	0,9	2,1
Voltage of reverse rollers	0(*V*)	-50(*V*)	-125(*V*)	-200(*V*)	-250(*V*)
Δ ERIC, coated paper	1,42	4,09	1,43	2,76	2,10

Results presented in Table 4 have good matching and confirm the results presented before, distribution of dirt count and area, depending on the voltage of the intermediate cylinder and the type of printing substrate.

Flotation of prints on uncoated paper in relation to the voltage of the intermediate cylinder increases handsheet brightness gain from 9.6 to 12.3, while on the print on both sides coated paper maximum values are 2.0. Difference of the effective residual ink concentration decreases far more on handsheets obtained from floated fibres on uncoated paper prints in relation to both sides coated paper prints.

One of the reasons for the poorer efficiency of the flotation is that ElectroInk heat fused into the paper, they tend to form continuous film they are strongly across their area and when detached from paper fibres they were formed the large plate-like structures.

The coating process assists in dispersing the fillers in the coating. In recycling process dispersants are surface active and together with alkali can lead to acceptable ink detachment from the coated paper. These species can hydrophilise ink containing agglomerates and hinder flotation efficiency as well as contribute to unwanted foam stability.

As for sustainability implementation of quality is significant, Figure 3 shows a 3D gamut for prints depending on the voltage of the reverse rollers and intermediate cylinder.

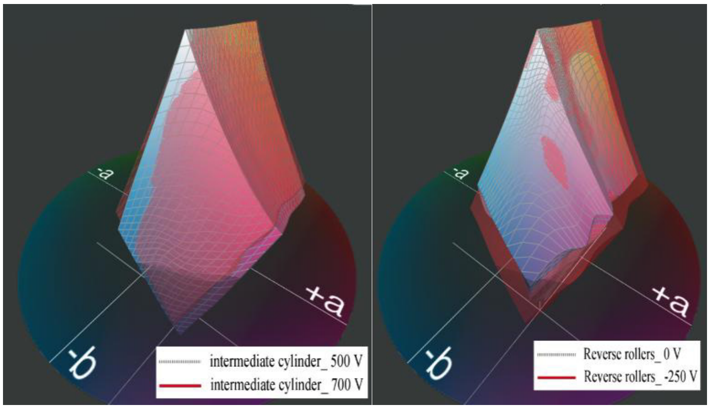


Fig. 3. (a) 3D gamut of the prints depending on the voltage of the reverse rollers; (b) 3D gamut of the prints depending on the voltage of the intermediate cylinder.

Gamut volume at a reverse roller voltage of 0V is 551.702 CIE L*a*b* CCU, and at a voltage of -250V is 762.139 CIE L*a*b* CCU. By increasing the voltage from 0V to -125V a greater increase occurs in the gamut $\Delta V_{125V\text{-}0V}$ 178.472 CIE L*a*b* CCU, compared with $\Delta V_{-250V\text{-}-125}$ 31,965 CIE L*a*b* CCU. Central part of the gamut body at a voltage of 0V has the best reproduction for blue and green tones. Voltage of -250V will affect only the tones that have high value at + b coordinate.

By changing the voltage of the intermediate cylinder largest 3D color gamut is obtained for a voltage of 700V (V_{700} 781,947 CIE L*a*b* CCU), and the smallest 3D gamut is at 500V (V_{500} 744.224 CIE L*a*b* CCU).

For an accurate analysis of the impact of printing conditions at the reproduction quality is necessary to measure 100% and 50% of raster fields of basic color of the subtractive and additive synthesis. The results of these measurements in relation to the observed printing conditions are shown in Figures 4 and 5.

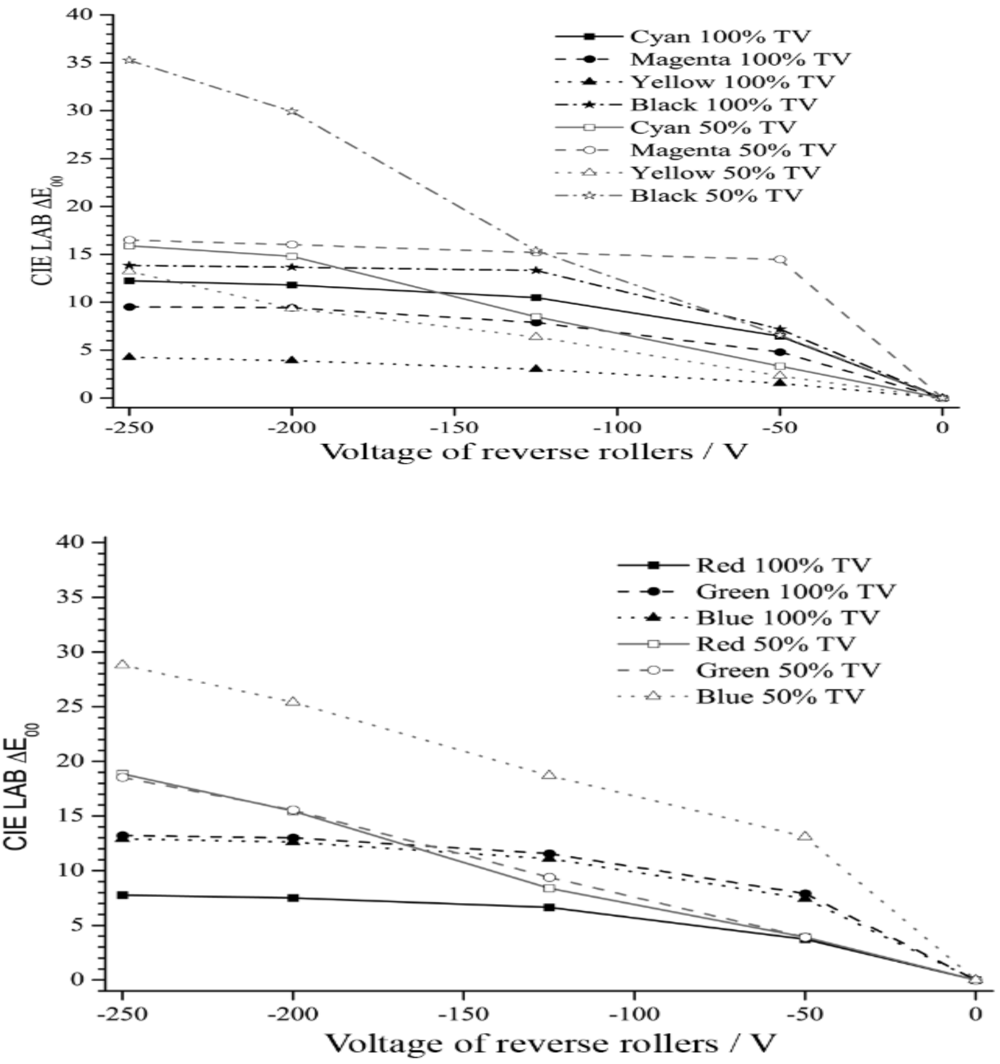
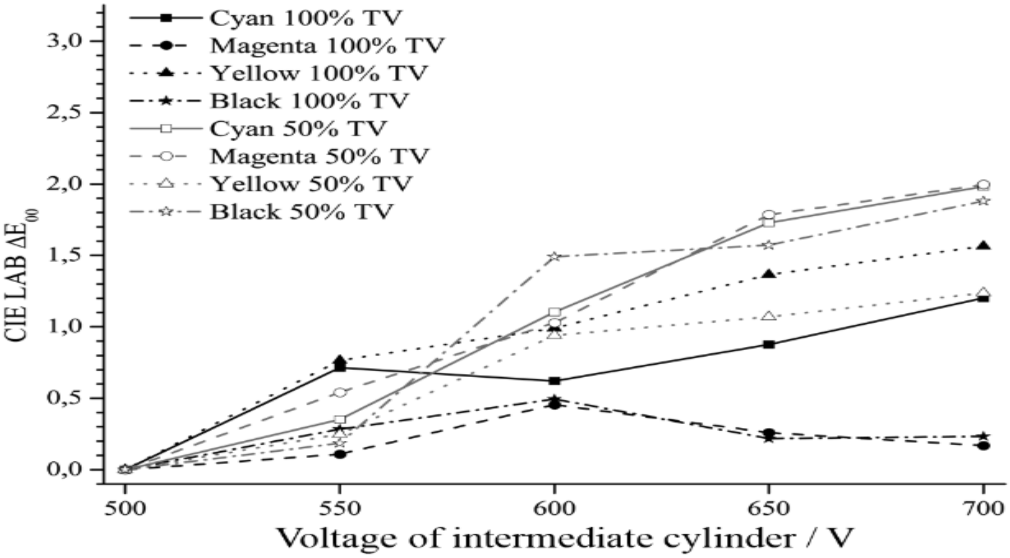


Fig. 4. (a) The dependence of the voltage reverse rollers on the CMYK color difference of the prints made by 100% and 50% of the raster tone values; (b) The dependence of the reverse roller on the RGB color difference of the prints made by 100% and 50% of the raster tone values.

Prints obtained by variation of the voltage of reverse rollers with full tones have an average deviation of tints ΔE_{max} - ΔE_{min} 27,3 while 50% raster prints have ΔE_{max} - ΔE_{min} 33,4. The resulting deviations are as follows: $\Delta E_{100\%\ red}$ 32,1 (maximum value), $\Delta E_{100\%\ cyan}$ 19,7 (minimum value), and 50% raster prints: $\Delta E_{50\%\ yellow}$ 31,5 and $\Delta E_{50\%\ red}$ 46,9. To gain optimum print the -190V for yellow, -130V for magenta and 0V for cyan should be used.



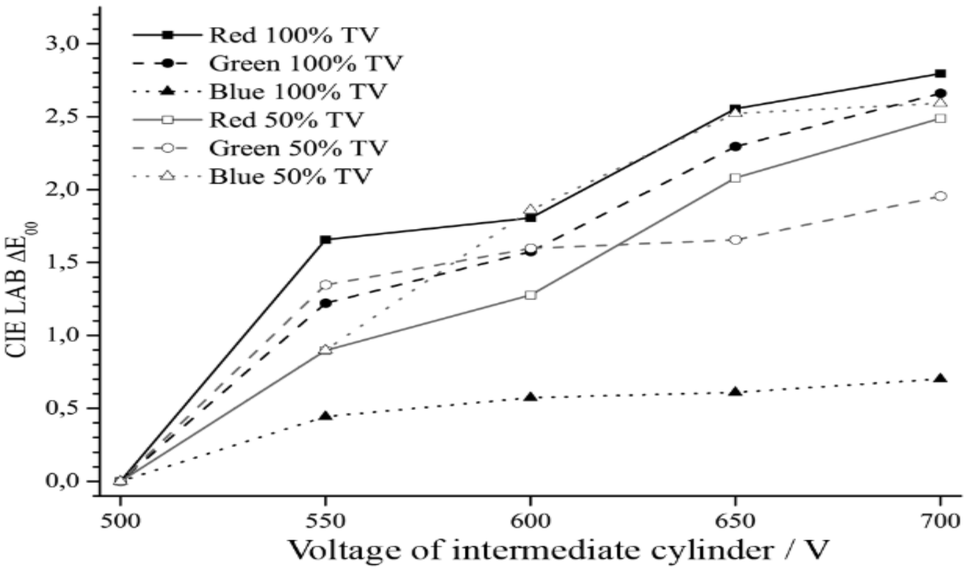


Fig. 5. (a) The dependence of the intermediate cylinder voltage on the CMYK color difference of the prints made by 100% and 50% of the raster tone values; (b) The dependence of the intermediate cylinder voltage on the RGB color difference of the prints made by 100% and 50% of the raster tone values.

By variation of the voltage of intermediate cylinder average deviation of tints ΔE_{max}-ΔE_{min} 2,95 is achieved. The smallest deviation of color is achieved for 100% raster cyan ($\Delta E_{100\%\ cyan}$ 0,3) and the highest at 100% raster yellow ($\Delta E_{100\%\ yellow}$ 7,7). Raster prints 50% tone value have a slightly larger average color deviation (ΔE_{max}-ΔE_{min} 3.5). Between 50% raster colors magenta ($\Delta E_{50\%magenta}$ 3,9) and yellow ($\Delta E_{50\%\ yellow}$ 3,9) change the most. To gain optimum print the voltage of intermediate cylinder of 600V for yellow, magenta, cyan, and blue and voltage of 650V for the red and green should be used.

Conclusion

The basic stages in the indirect electrophotography process with liquid toner differently affect the print quality as well as the deinking flotation, and characteristics of recycled fibers.

Based on the results it can be concluded that the change in the voltage of the reverse rollers (0V, -50V, -125V, -200V and -250V) at the stage of developing more affect the recycling efficiency with respect to the voltage change of the intermediate cylinder (500V, 550V, 600V, 650V and 700V) during transfer of ink from the photoconductor to transfer media. Increasing of the positive voltage of the intermediate cylinder in the printing is not particularly characteristic of speck number in spot size >= $5mm^2$ on handsheet made from the fibers after pulping, as is the case with increasing of the negative voltage of reverse rollers. Brightness gain is higher when the print for recycling is made on uncoated paper compared to coated, and is dependent on the voltage changes. Effective residual ink concentration decreases far more on handsheets obtained from floated fibers on uncoated paper prints in relation to both sides coated paper. Increasing the positive voltage of intermediate cylinder and increasing the negative charge of reverse roller increases the color gamut volume. Guidelines for the size of the voltage in order to obtain optimal prints are provided.

The further research will include the development of material flows, recycling, reuse, closed loop systems; therefore the significant terms in the area of environmental sustainability.

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