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The influence of physico-chemical parameters of fountain solution on print quality

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ABSTRACT: *The influence of pH, conductivity and Ca^{2+} ion concentrations of fountain solutions on the quality of tone, dot, line and text was investigated. Physico-chemical parameters of fountain solutions were analyzed by standard methods. Image quality assessment (IQA) was carried out using the ISO methodology and ImageJ software. The obtained data of the mechanical and optical tone value, dot circularity, line and text raggedness were compared and correlated with the physico-chemical parameters of fountain solutions. The results of tone and dot quality indicated the great influence of pH, conductivity and Ca^{2+} ion concentrations of fountain solutions on the formation and circularity of magenta dots. The highest mechanical and optical tone value increases were observed in the mid tones of magenta color. The mutual nonlinear dependence, described by second-order polynomial, was existed between magenta dot circularity and the printed sheets. The results of line and text raggedness indicated that magenta lines and text and analyzed physico-chemical parameters of fountain solution were not in the mutual dependence.*

Keywords: *Ca^{2+} ion, conductivity, fountain solution, pH, print quality, sheet-fed offset*

I. INTRODUCTION

Offset lithography relies on the numerous key parameters, and among them the fountain solution plays an important role. Indeed, its main tasks are to:

- wet and desensitize the non-image areas of the printing form;
- maintain hydrophilic character of the non-image areas;
- prevent the acceptance of ink on the non-image areas;
- maintain the working properties of ink;
- aid in proper blanket release, which reduce piling on the blanket [1-3].

The fountain solution, as one of the major component of the offset lithographic process, contains water, wetting agent (isopropyl alcohol), buffer, desensitizing agent (gum arabic), corrosion inhibitor, biocide and additives. Fountain solution effectiveness depends on properly mixing and maintenance of all fountain solution components. Accurately-measured pH value and conductivity of fountain solution are both essential for quality printing. While these two parameters are basically independent, each one provides vital information about the used water and the prepared fountain solution in the fountain solution dosing system. Fountain solutions are normally buffered at specific pH value, which means that pH of fountain solution decreases as the buffer concentration increases. When the certain pH value of fountain solution is reached the additional amount of buffer does not affect its changes. pH value increases when the buffer capacity weakens and then fountain solution becomes more alkaline. Conductivity, as other important parameters of the fountain solution, accurately determines the initial fountain solution strength and indicates its contamination during the printing. The ink and paper, as a primarily alkaline-based matter, contaminate the fountain solution by changing its pH value to alkaline and weakening the buffer capacity. This fountain solution affects the final print quality and leads to scumming, toning, tinting, etc. [2, 4-6].

Also, many printing problems could be directly traced to the increased presence of calcium in the fountain solution. The common sources of calcium are:

(i) water - most calcium compounds present in water are insoluble in acid-based fountain solution. Calcium carbonate slowly reacts with the acid-based fountain solution by releasing calcium ions, which can combine with citrate and phosphate ions from buffer, and precipitate out on rollers in the fountain system as a white haze or as hard, rock-like deposits. Also, carbonates increasing pH value of the fountain solution and reducing buffer capacity. Conductivity usually, but not always, increases with increasing of water hardness and alkalinity;
(ii) ink - calcium-based red pigments are mostly used in the formulation of magenta inks. The constant mixing of fountain solution and magenta ink during the printing causes calcium to be absorbed into the fountain solution. Once there, it is free to react with other present ions, and can form deposit, insoluble compounds. Fountain solutions in press units with magenta ink may also experience sharp upward rises in pH and conductivity within a short period of time [7, 8]; and
(iii) paper - in recent years most paper manufacturing has switched from an acid to an alkaline paper production process [7, 8]. Alkaline paper is made under slightly alkaline (pH 7.5 to 8.5) conditions, uses an organic sizing, and accommodates higher amounts of filler - usually 15 to 25% calcium carbonate [9, 10]. Improper or insufficient sizing or poor coating can lead to piling and the release of calcium carbonate onto the blankets. Then, it can build-in into the ink and dampening roller trains via the printing forms in the fountain solution [7, 8].

Therefore, the prevention of the negative effects of pH, conductivity and calcium concentration on the final print quality, as essential, implies the monitoring of these parameters during the printing and requires the application of the image quality assessment.

A common way to analyze the print quality is to objective assess the tone and color with light-reflection measuring device. Although the tone and color, as the quality parameters, are easily perceptible, they are not sufficient to determine the print quality. Therefore, the analysis of print quality must include and parameters of line and dot quality. The International Standards Organization was developed the ISO 13660 standard [11], which in accordance with ISO 19751 [12] provides definitions of 14 different printed image's attributes that help analyze the print quality. The attributes are categorized in two groups [13]:

1. Area attributes: darkness, background haze, graininess, mottle, extraneous marks, and background voids.
2. Character and line attributes: blurriness, raggedness, line width, darkness, character contrast, fill, extraneous marks, character field, and background haze.

The objective of this investigation was to monitor the parameters of the fountain solution quality (pH, conductivity and Ca^{2+} ion concentration) during the printing of 24,000 sheets and to determine their possible correlation with the print quality parameters (mechanical and optical tone value increase, dot circularity, line and text raggedness).

II. Materials and Methods

2.1 Offset printing process

A four-color offset printing press Heidelberg SM HD102VP, which is installed in printing facility Forum, Novi Sad, and printed color in the sequences MCYK, was used in the printing process. Also, printing forms (KODAK, Germany) with CMYK color strips including the patches of 0, 2, 4, 6, 8, 10, 20 30, 40, 50, 60, 70, 80, 90, 92, 94, 96, 98 and 100% tone value, horizontal and vertical lines (1, 1,5 and 2pt) and Times and Arial text (4, 5, 6, 7, 8, 9, 10, 11 and 12pt font size) was used, Fig. 1.

For this investigation thirteen printed sheets (samples 1-13) were collected from the delivery unit during the printing of 24,000 sheets. Samples 1 and 13 were taken at the beginning and at the end of a print run, respectively. Samples 2-12 were every 2,000 printed sheet during a print run. Sample 7 was taken at the half of a print run, i.e. when 12,000 sheet was printed and it is used as a reference.

2.2 Fountain solution

Fresh fountain solution was prepared in printing facility Forum by mixing of 2% buffer (P56 Alkopufer, Cinkarna Celje, Slovenia), 12% isopropyl alcohol (P43 ISO fount, Cinkarna Celja, Slovenia) and 86% tap (untreated) water. Thirteen samples of fountain solution (samples 1-13) were taken for the monitoring of pH, conductivity, total dissolved solids and Ca^{2+} ion concentrations during the printing of 24,000 sheets. Each sample was followed by the sample of printed sheets. Sample 7 of fountain solution is used as a reference.

2.2.1 Analysis of tap water and fountain solution

The preparation of fountain solution was included the monitoring of pH, conductivity and total dissolved solids of tap water in printing facility Forum using HI 98129 instrument (USA) with accuracy of measurement: ± 0.05 pH, conductivity ± 0.02 μS/cm and total dissolved solids ± 0.02 ppm. The same instrument was used for measurement of the mentioned parameters in fountain solution samples. The Ca^{2+} ion concentration in samples of tap water and fountain solution was determined by Inductively Coupled Plasma with Mass Spectrometry (ICP-MS), using a PerkinElmer Elan 5000 mass spectrometer.

Water hardness is determined by complexometric titration of water samples with a solution of complexone III and Eriochrome Black T indicator.

Surface tension of fountain solution is measured by using stalagmometer. The density of fountain solution samples was firstly measured by pycnometer, and then the number of drops of each fountain solution sample, which flows from the constant volume of stalagmometer, was determined. Surface tension of fountain solution is calculated by the following formula (1):

$$\gamma_i = \gamma_0 \frac{n_0 \rho_i}{n_i \rho_0} \quad (1)$$

where is: γ_i - surface tension of fountain solution, γ_0 - surface tension of water, n_i - number of fountain solution drops, n_0 - number of water drops, ρ_i - density of fountain solution and ρ_0 - density of water [14].

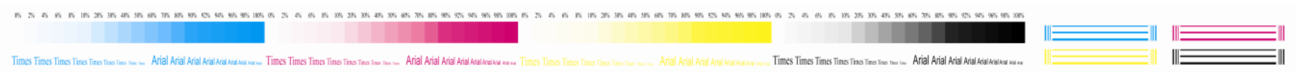

Fig. 1 Color strip with CMYK tone values, lines and text

2.3 Paper and ink

A glossy coated paper (BIOGLOSS, B&B Papirnica, Vevče) with the characteristics presented in Table 1, defined as Type I in ISO 12647-2: 2004 [15] were printed with sheet-fed offset ink set (Inkredible RAPIDA F 10 RP, Huber group, Germany) with general chemical composition presented in Table 2.

Table 1 Characteristics of Biogloss paper [16]

Property	Value	Unit	Method	Tolerance
Grammage	90	g/m^2	ISO 536	+/- 4%
Caliper	65	μm	ISO 534, single sheet measurement	+/- 5%
Brightness	95	%	ISO 2470, R457 D65	+/- 2%
Opacity dry	91	%	ISO 2471	+/- 2%
Gloss Lehmann	72	%	TappiT 480, 75°	+/- 5%
Picking resistance dry (IGT)	60	cm/sec	ISO 3783 IGT, L3803	min.
Relative humidity	45	%	Hygromer Rotronic	+/- 5% at 23 °C
pH value	7	-	ISO 6588	+ 1%

Table 2 General chemical composition of Inkredible RAPIDA sheet-fed offset ink [17]

Component	mass %
Pigment (organic)	10 - 35
Carbon black	0 - 20
Resin	20 - 35
Vegetable oil	15 - 20
Mineral oil	15 - 20
Additives	>10

Literature data [18-20] indicated that the commonly used pigments in the production of CMYK sheet-fed offset inks are copper phthalocyanine or cyan (CI Pigment Blue 15:3), lithol rubine or magenta (CI Pigment Red 57:1), diarylide yellow or yellow (CI Pigment Yellow 13) and carbon black or black pigment (CI Pigment Black 7), respectively.

The chemical structures of these pigments, Fig. 2, show that only lithol rubine or magenta pigment in its structure contains calcium. Therefore, only the magenta ink samples (two samples) were taken in order to determine the presence of calcium.

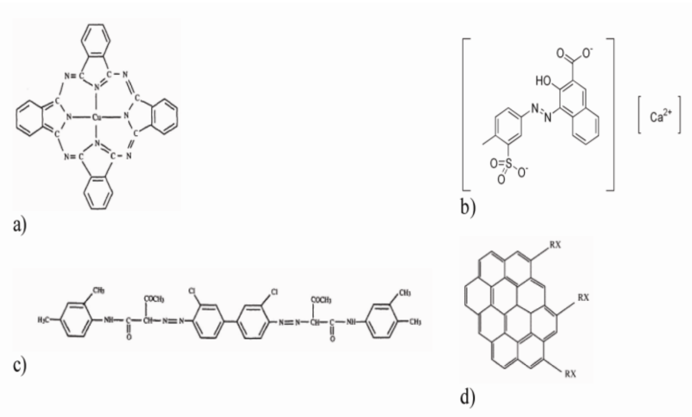

Fig. 2 Chemical structure of pigments for CMYK process inks: a) copper phthalocyanine - cyan, b) lithol rubine - magenta, c) diarylide yellow - yellow and d) carbon black - black [19, 20]

Sample 1 was the reference magenta ink sample, taken from the original ink packaging prior the printing process, while magenta ink sample 2 was taken from the ink unit at the half of a print run, i.e. when 12,000 sheet was printed. Sample 2 of magenta ink was taken with the sample 7 of fountain solution.

Also, the sample of coated paper was taken for the analysis of calcium presence.

2.4 Image quality assessment (IQA)

The IQA was carried out using the ISO 12647, ISO 13660 and ISO 19751 methodology in order to analyze the quality of tone, dot, horizontal and vertical line, serif and sans-serif text style on thirteen printed sheets (samples) during the changes in fountain solutions quality. For this purpose the device: Spectrophotometer SpectroPlate (TECHKON GmbH, Germany), Spectrophotometer SpectroDens (TECHKON GmbH, Germany), flat-bed scanner CanoScan 5600F (Canon Inc., Canada), and software Adobe Photoshop CS3 and ImageJ (version IJ 1.45m) were used.

2.4.1 Analysis of tone value

As the final print quality is the most important, it was necessary to evaluate how the changes of the fountain solution quality (pH, conductivity and Ca^{2+} ion concentration) influence on the dot formation and tone value increase. Therefore, the mechanical tone value increase was firstly measured after the printing in order to establish a reference point for the evaluation of the optical tone value increase on the printed sheets. Both, the mechanical and optical tone values were generated from the spectrophotometric measurements using the spectrophotometers SpectroPlate and SpectroDens on the above mentioned patches.

2.4.2 Analysis of dot, line and text

For achieving the quality of the continuous tone the printing of the smallest elements (screen dot, line and text) is essential. Attributes such as line and text raggedness and dot circularity were of interest for this investigation, since they have an obvious and major influence on the quality of any print. The analysis required the usage of 'reference prints' which were visually and by software compared to the actual samples in order to get the significant quantitative data. As the actual samples it was used:
(i) the microscopic images of 30% CMYK tone value recorded by the spectrophotometer SpectroPlate for the analysis of dot circularity; and
(ii) the samples scanned by using scanner CanoScan and software Adobe Photoshop CS3 (1200 dpi scanning resolution) for the analysis of line and text raggedness.

After this procedure, the print defects are easily detected and quantified by the ImageJ software.

III. Results and Discussion

3.1 Analysis of tap water and fountain solution

In order to obtain the high-quality results during the offset printing process it is essential to accurate control the physico-chemical parameters of tap water and fountain solution. The values of conductivity and total dissolved solids (TDS) (Table 3) indicated that used tap water contains the significant amounts of dissolved ions, which is confirmed by hardness of 11 °dH. Although the used water is hard, it is suitable for the offset printing process.

Table 3 Physico-chemical parameters of tap water

Parameter	Value	Unit
pH	7.49	-
Conductivity	497	µS/cm
Hardness	11	°dH
	196.9	mg/l $CaCO_3$
TDS	249	ppm
Ca^{2+} ion concentration	155.2	mg/l

The investigation showed that the values of pH, conductivity, total dissolved solids and Ca^{2+} ion concentrations of fountain solution samples significantly varied during the printing (Figs. 3-7) with the increasing tendency of all parameters in sample 7 (when 12,000 sheet was printed). The explanation for those phenomena is the fact that conductivity and total dissolved solids rises as the press runs due to increased contamination of fountain solution by inks, paper dust, metals particles from printing form and atmospheric gases. Whereas, increasing of pH value of fountain solution is caused by buffer capacity weakening during the interaction of fountain solution with paper, ink, plate coatings or printing form. Exactly higher print speed and interaction between the used materials during the reproduction process gradually increase the fountain solution contamination in Baldwin system by causing weakening of buffer capacity which was reflected through the slightly increasing of pH, conductivity, total dissolved solids and Ca^{2+} ion concentrations in samples 1 to 6. Significantly increasing of all mentioned parameters are observed at the half of a print run (12,000 sheets), sample 7, when buffer totally disappear from fountain solution. After that, the decreasing trend of pH, conductivity, total dissolved solids and Ca^{2+} ion concentrations is observed in samples 8 to 13 due to the new quantities of buffer and tap water was dosed in Baldwin system, which significantly diluted the contaminated fountain solution and allowed its further usage in the printing process.

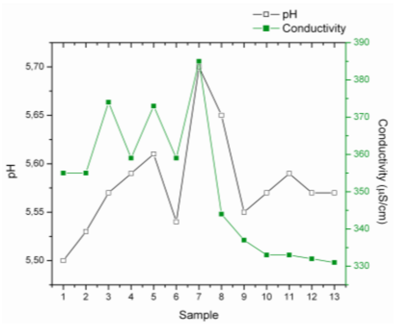

Fig. 3 A correlation between pH and conductivity

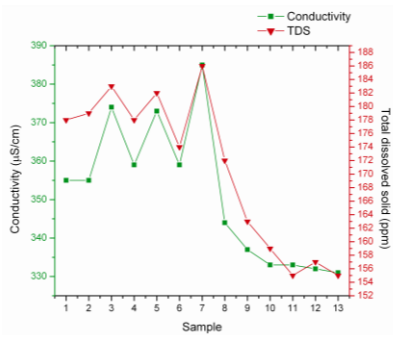

Fig. 4 A correlation between conductivity and TDS

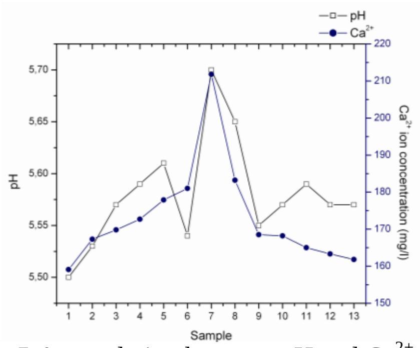

Fig. 5 A correlation between pH and Ca^{2+} ion

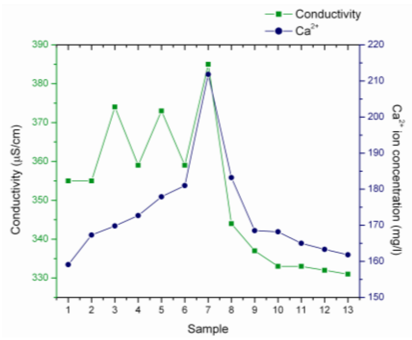

Fig. 6 A correlation between conductivity and Ca^{2+} ion

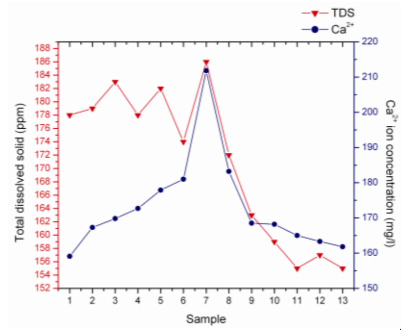

Fig. 7 A correlation between TDS and Ca^{2+} ion

The surface tension (Fig. 8) has the similar trend, and its value was relative constant in range from 38.4 to 41.6 mN/m, before and after sample 8. Sample 8 indicates that an alcohol control (Balcontrol) system, which is installed on Baldwin dosing system, dosed the new quantities of isopropyl alcohol which currently decreases the surface tension in fountain solution.

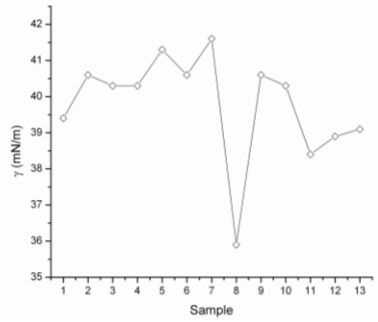

Fig. 8 A surface tension of fountain solution

As calcium carbonate can affect the quality of fountain solution, it was necessary to examine the reasons of pH, conductivity, total dissolved solids and Ca^{2+} ion concentrations changing in the fountain solution samples by the analysis of used paper and magenta ink.

3.2 Analysis of paper and magenta ink

The investigation primarily involved the characterization of used paper in order to examine the filler type and the possible presence of calcium carbonate.

SEM analysis of used Biogloss paper (Fig. 9) by including the paper surface shown that inorganic filler stands out as bright sparsely distributed particles against the pulverized background of paper, i.e. it was not observed the network-like structure of paper with fiber-fiber bond and crossing.

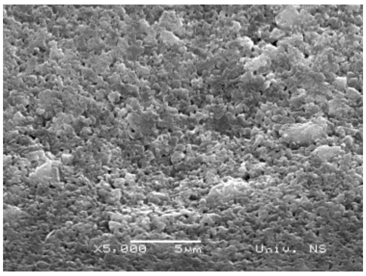

Fig. 9 SEM image of used Biogloss paper (magnification 5,000 x)

As can be seen from Fig. 9 the particles of kaolin (which tend to be platy) and coarsely ground natural calcium carbonate (GCC) (which has irregular edges) are present in Biogloss paper.

In order to accurately determine the elemental chemical composition of the paper sample, i.e. which fillers are presented in Biogloss paper, the analysis by the energy dispersive spectroscopy (EDS) was carried out. Obtained EDS spectra (Fig. 10) shows that calcium carbonate is dominant in Biogloss paper. Magnesium with aluminum, silicon and iron suggests that kaolin is present. While calcium alone (or with carbon and oxygen) suggests that calcium carbonate is present. Thus, the EDS analysis confirmed the presence of kaolin and calcium carbonate as the fillers in Biogloss paper. Proportions of all inorganic elements in Biogloss paper sample are given in Table 4.

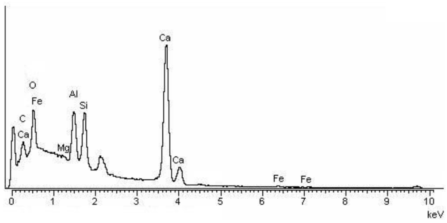

Fig. 10 EDS elemental spectra of Biogloss paper

Table 4 Chemical composition of Biogloss paper

Element	mass %
C	21.25
O	47.27
Mg	0.33
Al	4.99
Si	5.27
Ca	20.30
Fe	0.38

Also, magenta ink samples were examined using EDS in order to control the concentration of calcium ions in magenta ink during the printing as well as to confirm the increased Ca^{2+} ion concentrations in sample 7 of fountain solution (when 12,000 sheet was printed).

The obtained EDS spectra of the magenta ink samples, Figs. 11 and 12, confirmed the dominant content of calcium in magenta ink formulation. Proportions of all inorganic elements in magenta ink samples, given in Tables 4 and 5, indicated that the amount of calcium decreased in magenta ink sample 2 because the higher interaction between magenta ink and fountain solution causing absorption of calcium ions into the fountain solution. This is the reason why pH, conductivity, total dissolved solids and Ca^{2+} ion concentrations in fountain solution dramatically increases in sample 7.

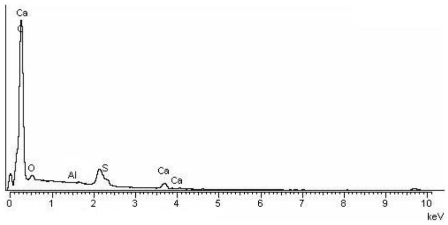

Fig. 11 EDS elemental spectra of reference magenta ink sample (sample 1)

Table 5 Chemical composition of reference magenta ink sample (sample 1)

Element	mass %
C	88.66
O	9.49
Al	0.09
S	0.84
Ca	0.92

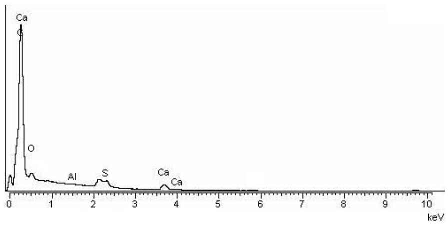

Fig. 12 EDS elemental spectra of magenta ink sample 2, when 12,000 sheet was printed

Table 6 Chemical composition of magenta ink sample 2

Element	mass %
C	85.68
O	12.35
Al	0.09
S	0.80
Ca	0.87

3.3 Image quality assessment

The investigation have shown that changes in the fountain solution quality during the printing process had no influence on the quality of tone, dot, line and text of cyan, yellow and black process color, therefore, the paper represents only the results of influence the examined physical-chemical parameters of fountain solution on the quality of magenta prints and their mutual correlations.

3.3.1 Tone quality

Although, there are many variables that influence tone value increase (TVI) it was of great importance for this investigation to examine how the changes in the fountain solutions quality during the printing of 24,000 sheets impact on the mechanical and optical tone value increase of magenta color. The changes of TVI of magenta color during the printing 24,000 sheets are presented in Fig. 13a-m. The measured TVI on the printed sheets (1-13), Fig. 13a-m, indicated the significant differences in the mid tones of magenta color. The TVI of samples 1-6 is gradually increased with increasing pH, conductivity and Ca^{2+} ion concentrations. In samples 7 and 8 TVIs were more than 40% for 50% tone value. The possible reasons for that are: the quality of fountain solution, improperly water/ink balance, incompatible the fountain solution component and magenta ink and color order during the printing (MCYK). As can be seen from Figs. 13g and 13h (samples 7 and 8) optical TVI was the same as mechanical. After sample 8 TVI began to decrease by following the trend of the examined physico-chemical parameters up to sample 13 when the value of TVI again increased.

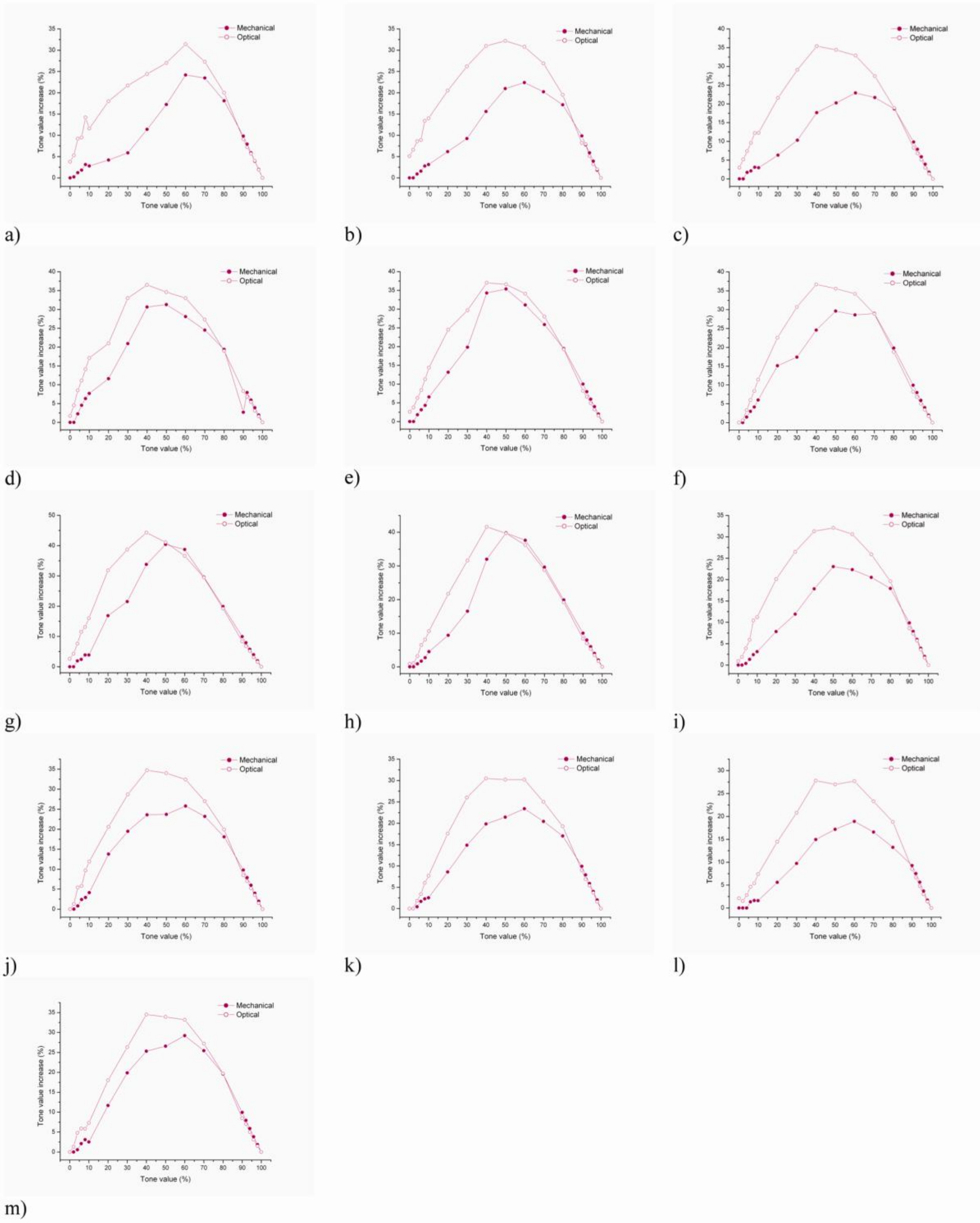

Fig. 13 Mechanical and optical tone value increase of magenta color during the printing of 24,000 sheets

By comparing the measured values of the physico-chemical parameters of fountain solution (Figs. 5 and 6) with the measured tone value increase (Fig. 13a-m) it can be concluded that the changes of pH value, conductivity and Ca^{2+} ion concentrations in fountain solution samples had the significant influence on the formation of magenta dots. The reason for the observed correlation is greater absorption of calcium ions from the magenta ink in the fountain solution during the printing.

3.3.2 Dot quality

One important factor for print quality is the sharpness and contrast of halftone dots that are used to print continuous-tone images. The sizes of the dots on the prints must not be significantly modified, i.e. they must not change either the size or their geometrical shape (circularity).

The results obtained in ImageJ software showed the deviations from the ideal value of circularity (value 1) of magenta dots during the printing of 24,000 sheets (Fig. 14). Magenta dots were ragged and had irregular, distort shape with the least circularity value of 0.36. Also, the significant decreasing and increasing of magenta dot circularity was observed between the analyzed printed sheets.

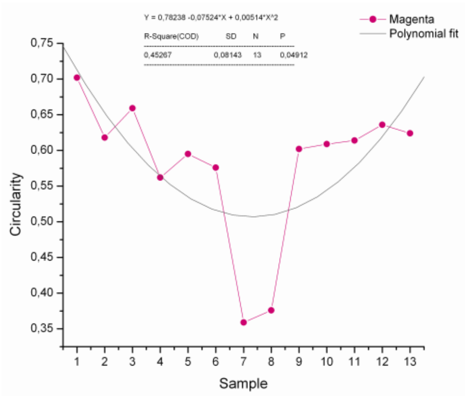

Fig. 14 Dependence of magenta dot circularity on the printed sheets (1-13)

As can be seen from Fig. 14 between magenta dot circularity and samples of printed sheets exist the nonlinear dependence, described by second-order polynomial with the equation curve: $y = 0.00514x^2 - 0.07524x + 0.78238$. This correlation is weak due to the correlation coefficient $R^2 = 0.4527$ and standard deviation SD = 0.08.

Comparison of the curves from Figs. 5, 6 and 14 suggested that magenta dot circularity is in the correlation with pH, conductivity and Ca^{2+} ion concentrations during the printing of 24,000 sheets, i.e. increasing of pH, conductivity and Ca^{2+} ion concentrations in fountain solutions caused decreasing of magenta dot circularity, and vice versa. The reason for those correlations is the presence of calcium ions in the contaminated fountain solution and changes of their concentration in magenta ink during the printing. Generally, the results of magenta dot circularity indicated that the dot reproduction was not consistent during the printing of 24,000 sheets due to the high standard deviation (up to 0.08) and the dissimilarity of dot shape.

3.3.3 Line and text quality

It is known that an image quality must not be judged based on a single entity such as dot circularity, but the reproduced line and text, as the important elements of each image, must also be considered. Line and text analysis is easier since line and text primarily depend on the value of ‘raggedness’ (the geometric distortion of the edges of the line and text). Since ISO 13660 standards [11] defines only the minimum length of line (1.25 mm) this investigation included the analysis of horizontal and vertical lines that were longer than the minimum defined length. A good quality line and text is described as the one having the least raggedness and sharp edges. The value of line raggedness is expressed in the function of the area (P = ab) and the perimeter (O = 2(a+b)). The results of line area (Figs. 15a and 16a) indicated that vertical 1.5pt line printed with magenta color (with 1.9 to 5.4% area increase) and horizontal 1.5pt line printed with magenta color (with 6.4 to 10.5% area increase) had the most raggedly edges.

Line raggedness as a function of line perimeter, Figs. 15b and 16b, showed also that vertical 1.5pt line printed with magenta color (with 2.2 to 8.2% perimeter increase) and horizontal 1.5pt line printed with magenta color (with 1.0 to 7.5% perimeter increase) had the most raggedly edges. In the both cases, the least raggedly edges are obtained on the tiny horizontal and vertical lines (1pt). The results indicated that the area and perimeter of analyzed lines increased during the printing due to the ink smearing on the line edges (Figs. 15 and 16).

All the prints with a text value up to 12 units showed no eye visible difference when they was visually checked, but by scanning with the resolution of 1200 dpi text look raggedness.

For the serif font, Fig. 17a, the least raggedness is observed with 10pt font size (up to 7.5% area increase); whereas 5pt font size had the most raggedly edges (up to 41.2% area increase). The sans-serif font (Fig. 17b) showed significantly better results in comparison with the serif font. The least raggedness is observed with 9pt font size (up to 5.4% area increase); whereas 4pt font size had the most raggedly edges (up to 12.3% area increase). The text analysis also showed that the text area increased during the printing due to the ink smearing on the text edges (Fig. 17a and b).

The analysis showed that there was no mutual dependence between the physico-chemical parameters of fountain solution (Figs. 5 and 6) and the line and text raggedness (Figs. 15-17).

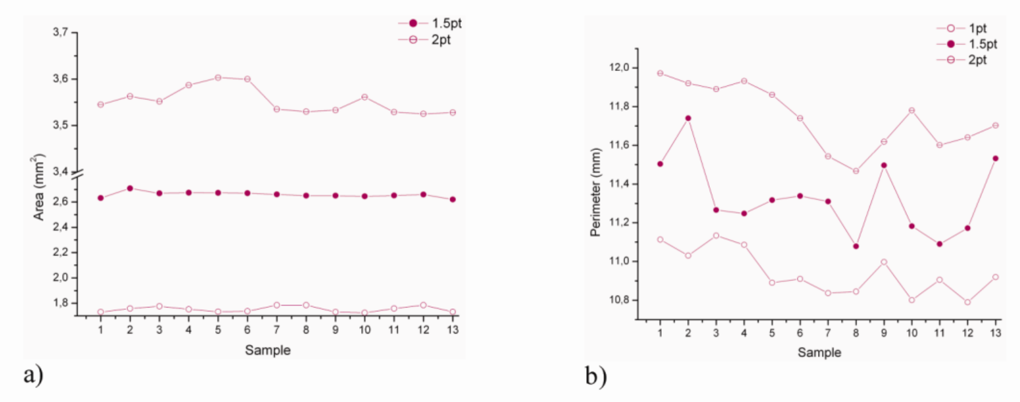

Fig. 15 Vertical line raggedness as a function of: a) line area and b) line perimeter

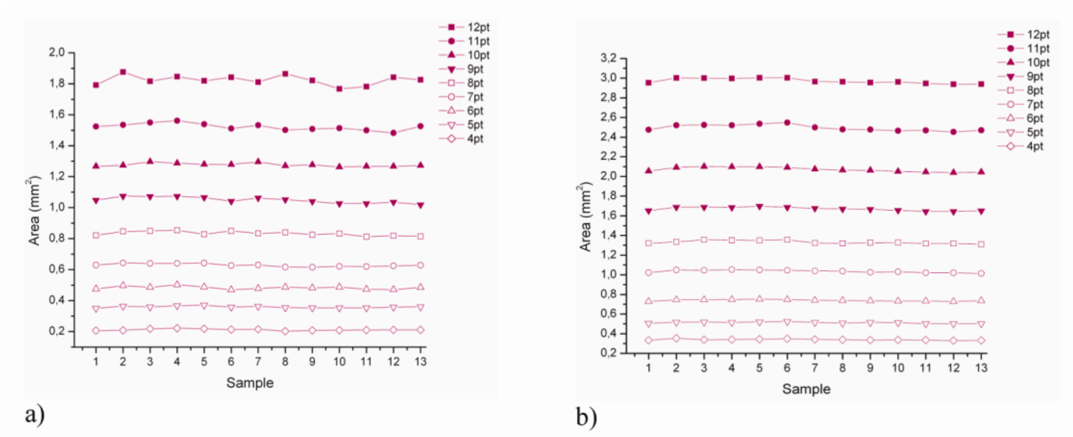

Fig. 16 Horizontal line raggedness as a function of: a) line area and b) line perimeter

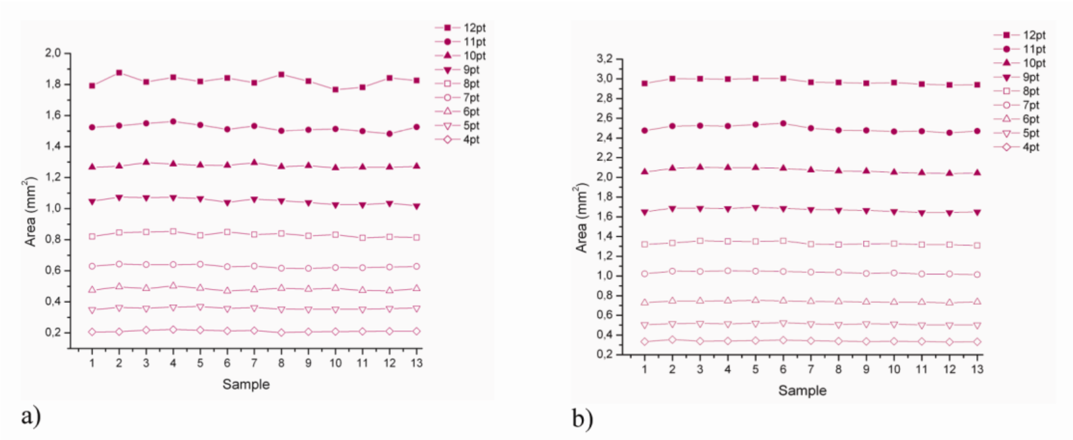

Fig. 17 Text raggedness: a) Times and b) Arial font

IV. CONCLUSION

The experimental data of the influence of physico-chemical parameters of fountain solution on the print quality indicated that the values of pH, conductivity and Ca^{2+} ion concentrations of fountain solution significantly varied during the printing 24,000 sheets with the increasing tendency of all parameters in sample 7, when 12,000 sheets was printed. The changes of pH value, conductivity and Ca^{2+} ion concentrations during the printing were confirmed by the EDS characterization of used printing materials (paper and magenta ink).

The highest mechanical and optical tone value increases were observed on samples 7 and 8 (when 12,000 and 14,000 sheets were printed) due to the changes in fountain solution quality, improperly water/ink balance, incompatible fountain solution component and magenta ink and color order (MCYK) during the printing. The measurements in ImageJ software showed the considerable deviation of magenta dot circularity. Between the magenta dot circularity and the printed sheets was existed the mutual nonlinear dependence, described by second-order polynomial with equation: $y = 0.00514x^2 - 0.07524x + 0.78238$. The analysis of geometric distortion of the line and text printed with magenta color showed that 1.5pt horizontal and vertical lines had the most raggedly edges, whereas the least raggedness was obtained with 1pt horizontal and vertical lines. The sans-serif font, Arial, showed the least raggedly edges in all range of font size (4-12pt), in comparison with Times.

The analysis shown that between the lines and text printed with magenta color and pH, conductivity and Ca^{2+} ion concentrations of fountain solution was not existed mutual dependence. However, the changes in pH, conductivity and Ca^{2+} ion concentrations had the significant impact on the quality of tone and circularity of magenta dots.

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