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INVESTIGATION OF FACTORS INFLUENCING TONE REPRODUCTION ON RECYCLED PAPER PRINTED BY DIGITAL TECHNOLOGIES

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Abstract:
In the second part of the 20th century the production and use of recycled papers became more and more popular, the range of recycled products was becoming wider as well. Today recovered paper is an important raw material of paper production besides virgin pulp. The mechanical processing of recycled pulp reduces energy costs, on the other hand the high concentration of contaminants (eg. pigments, and other inorganic materials) requires the incorporation of sorting and extraction stages in the processing chain. Digital printing technologies are emerging since their appearance, constantly gaining new market segments from traditional technologies. Print quality of different digital technologies is heavily influenced by the applied substrates and inks, ink transfer and fixation processes. Accurate prediction of print quality requires the information on the performance of the technology with a recycled substrate.
Our research focuses on the print quality on recycled paper substrates. A test chart was printed in Canon Pixma iX7000 inkjet and Canon imagePRESS C1 electrophotographic presses. We investigated 9 different types of substrates: surface smoothness, and optical characteristics (optical density, tone values increase, colour difference) of the prints were determined. We compared our results with conventional papers' properties.

Keywords: *recycled paper, inkjet printing, electrophotograpy, TVI, colour gamut*

1 INTRODUCTION

The global climate change is probably the most debated environmental problem of these days. It is a fashionable, yet considerably simplifying approach to attribute most of the related responsibilities to industrial activities. Approximately half of the fibers used by the European paper industry comes from forests, where the remaining half originates from recovered waste paper. Since the early 1990s, the European paper industry has been adopting practical measures to support sustainable forest management. One of these measures allows only wood from permitted logging to be used for the purposes of paper industry. Obviously, wood is a renewable raw material whose overall volume – in contrast with the general belief – is not dropping owing to sustainable forest management. In the past more than ten years, the total expanse of forests in Europe has been growing by the ten-fold area of a Paris-sized city each year. In Hungary, the current annual growth rate of the 356 million cc m living tree stock in forests is 13.1 million cc m annually, which means that we produce more wood than the volume hat is logged [1]. One of the key endeavors of the European paper industry is to use recycled fibers to the farthest possible extent. A key issue of climate change is the reduction of the volume of carbon dioxide entering the atmosphere. The cellulose and paper industry can be regarded to be uniquely neutral in terms of the loading of the environment with carbon dioxide. Wood used as a raw material removes the air-borne carbon dioxide for decades, and turns it into its own, integrated

substance via photosynthesis. When turned into first cellulose and then paper, wood ensures the retention of the bound carbon dioxide for its entire lifecycle [2].
Concurrently, one of the main directions of the development of paper industry is the improvement of the efficiency of energy use, the enhancement of the consumption of energy from renewable resources. At the present, the cellulose and paper industry generates 25% of the energy originating from biomass in Europe. The European paper industry confirms the possibility of environmentally friendly industrial activities with the support of sustainable forest management, the increasing efficiency of the use of recovered fibers, developments targeted at sparing energy consumption, the intensified involvement of renewable energy resources, as well as the radical reduction of the emission of wastewater and gases polluting the air [3]. Today, there are more and more people with focus on the safeguarding of the environment, yet there are just a few to know that paper is one of the materials that are recycled in the largest percentage rates, which substantially contributes to the protection of the environment. Furthermore, there are papers that are affixed with various certificates, such as the FSC certificate: the FSC logo can be found on products whose wood materials come from responsible managed forests.
Nowadays, recycled paper is one of the most important sources for paper-milling. Instead of the primary fibers, mostly cellulose, the manufacturing of recycled papers relies on fibers recovered from paper wastes. The quality of the manufactured recycled paper is determined by the composition of the recycled paper wastes. Waste papers, especially those recovered from the households, can feature highly varied compositions, while the most valuable raw material is constituted by the selected, pure, homogeneous paper wastes, which is the result of organized industrial recoveries in most cases. To manufacture recycled paper, 75% less water and 60% less energy is necessary, not to mention the large number of trees that do not need to be logged. These environmentally favourable characteristics are somewhat deteriorated by the extra costs expended on recovery, sorting, cleaning, transportation and the more complicated manufacturing technologies [4].
Digital printing technologies have been used to an ever-increasing extent in the field of printed media. The quality of the prints made by the digital devices that apply different printing technologies is materially influenced by the structure and surface properties of the applied substrates. It is important to know in what quality prints can be made on the recycled papers the use of the given digital printing technology [5] [6]. Electrophotography and injet are the main method of digital printing today. In electrophotographic printing the toner particles are charged electrostatically in the developing unit and are attracted to the drum by the oppositely charged image portions of the photoconductor. The transfer form the photoconductor onto the substrate take place via electrostatic forces. Toners usually consist of fine solid particles. To improve adhesion of the particles to the paper, fusing which is analogous to drying, follows the transfer step [7]. The ink jet process is a computer to print technology in which ink is sprayed from nozzles, which means that no image carrier is needed. Imaging is done directly onto the substrate. The type of ink to be used is also substantially determined by the properties of the substrate (absorbency, coating, foil, etc.), the surrounding conditions of use of the print media (light resistance, weather resistance, resistance to wear), and the drying process required during printing with different printing systems (productivity, multicolor printing, further processing, etc.). The ink used and its interaction with the substrate determine the thickness of the ink layer on the paper and thereby the quality of the printed image, especially in multicolor printing [8].
The printing characteristics of substrates are differentiated according to the printability and pressroom runnability. Runnability means the ability of the paper to get through the output device (press, inkjet machine, digital press). It covers all the paper properties which have to do with the ability of sheet to go through a printing press [9] [10]. Printability of paper is contribution of paper related factors that contribute to the achievment of a desired quality level. Printability is a group of paper properties which have an influence on the way an ink interact with a printed substrate to deliver a correct reproduction of text and images. Among these properties, we may find surface properties like smoothnes or permeability, optical properties like whiteness, opacity, brightness, and other

characteristics like porosity or surface energy. Thermal or electrical properties are also to consider [11].
In electrophotographic process, the quality of print depends on paper dimensional stability, tendency to curling under monsture or temperature variations and to linting at the finishing stage of printing. A critical parameeter is the value of surface electrical resistivity. A suitable value of this parameter is located in the 10^{10} to 10^{12} Wm range. The dielectric constant of paper is also to consider [12]. The smoothness of the surface of the printed substrate is also important, specially in the case of high quality color printing. On ather hand, as the toner is submitted to fusion under pressure, a minimum roughness is required to avoid spreading. A good compromise must be found between these two requirements. It is also important that paper can reach a high temperature in the fusing nip and then cool down quickly to avoid set-off on back side [13] [14]. In inkjet process is characterised by the use of liquid inks. After an ink drop hits the paper surface, several phenomena govern its behavior: adhesion, penetration, spreading and evaporation. paper surface energy has to be adated and roughness becomes a critical parameter to reach a good printing results. Inkjet papers must be smooth so that drops impacting on the paper spread evently] [15]. Penetration is important for drying the surface, but the paper has to retain colorants at its surface to insure a suitable optical density. This is difficult in case of dye inks: such a feature explains the tendency towards the use of pigment inks, specially for high quality color printing. Pigment particles must be as small as possible, to allow ink ejection by the nozzle. Thus, in all cases, the pore structure and distribution has to be adapted. For coated papers, high specific surface coatings seem to be an efficient solution] [16].
In the course of the research work, we have examined the quality of prints made on recycled papers with the use of digital printing technologies, measured the optical properties of the prints (density, tone value increase, reproducible colour range).

2 EXPERIMENTAL

In the course of our research, the printability of recycled papers was studied (Table 1). All the nine paper types are recommended for use in digital (electrophotographic and inkjet) printing by the respective manufacturers.

Table1:Properties of paper substrates

No.	Type	g/sq m	Property
1	Recycled	80	Recycled
2	Recycled Pure	80	Recycled
3	Recycled Plus	80	Recycled
4	Nautilus Universal	80	Recycled
5	Nautilus Superwight	80	Recycled
6	IQ Triotec unique	80	Environmentally friendly
7	Mondi Premium	80	Non-recycled
8	Cyclus Print	80	Recycled
9	Cyclus Offset	80	Recycled

From among the paper samples, IQ Triotec Unique is a paper described as environmentally friendly. As its main property, it is a composite paper containing both recycled and non-recycled paper fibers (Figure 1).

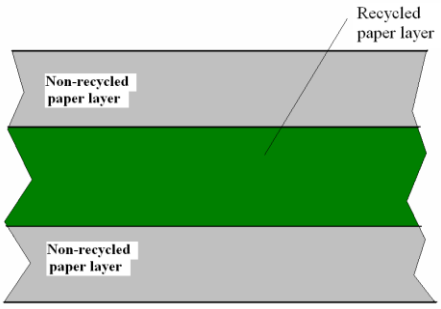

Figure 1: Cross-sectional structure of IQ Triotec Unique environmentally friendly paper

The test image includes visual, densitometric and spectrophotometric test elements. It has been printed on an A4-sized substrates (Figure 2).

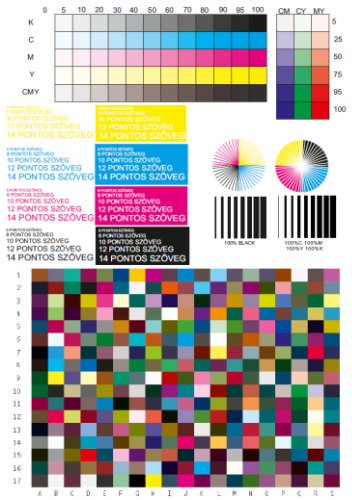

Figure 2: Test image

A test image was printed in A4 size, on nine paper substrates of different properties. Each test print was made in one copy, with the use of electrophotographic and inkjet peresses, under identical circumstances and conditions.
Test printing was performed under normal operating conditions as follows:

- printing machines: Canon imagePRESS C1 electrophotographic press and Canon Pixma iX7000 inkjet press
  t=21 ºC, RH 39–44%

To measure density and tone value increase, an X-rite SpectroEye spectrophotometer was used. Measurements were performed 5 days after printing. The circumstances of the measurements were as follows: D50/2°/Abs/ black backing.

3 RESULTS

3.1 Tone value increase

Images containing more than two tones are known as continuous tone images in printing industry. This category includes photos, graphics, painting reproductions that are to be transformed into autotype tones for reproduction purposes by way of splitting the tones into halftone dots. A characteristic of digital technologies is the application of FM halftones, projections of dots of permanent size, but varied densities. The tone value is the quantification of the tones in the halftone system, and expresses the ratio of the parts of the unit area covered with halftone dots in percentages, from 0% to 100%. In practice, however, the size of the halftone dots may change, ink may become spread on the print carrier, and result in closing, while dots featuring any tone value under 5% are difficult to print. The end result is invariably the growth of the halftone dots, meaning that the print will be darker. This phenomenon is called the dot gain (tone value increase – TVI).

On the IMAGEPRESS C1 printing machine has produced prints of higher toner coverage than the Canon Pixma iX7000 inkjet press on all the papers (Table 2).

Table 2: Measured optical density values of CMYK process colors

Printing machine	Print carrier	Density			
		Cyan	Magenta	Yellow	Black
Canon Pixma iX7000 inkjet	Recycled	1.29	1.04	1.03	1.67
	Recycled Pure	1.28	1.01	1.01	1.68
	Recycled Plus	1.24	1.02	1.02	1.59
	Nautilus Universal	1.21	0.99	1.02	1.66
	Nautilus Superwight	1.17	0.97	1.02	1.57
	IQ Triotec unique	1.28	1.04	1.09	1.72
	Mondi Premium	1.30	1.07	1.09	1.76
	Cyclus Print	1.57	1.23	1.15	1.94
	Cyclus Offset	1.20	1.01	1.05	1.68
Canon imagePRESS C1 electrophotographic	Recycled	0.69	0.84	0.68	1.46
	Recycled Pure	0.77	0.89	0.72	1.53
	Recycled Plus	0.77	0.88	0.68	1.47
	Nautilus Universal	0.68	0.82	0.66	1.26
	Nautilus Superwight	0.69	0.81	0.65	1.17
	IQ Triotec unique	0.67	0.80	0.66	1.39
	Mondi Premium	0.64	0.82	0.65	1.28
	Cyclus Print	0.74	0.86	0.69	1.59
	Cyclus Offset	0.73	0.86	0.68	1.42

Curves of tone value increase (TVI, %) were measured on the 10-100% process color tone patches of the test chart. On all the papers, for both inkjet and electrophotographic printing, the largest tone value increase has been measured for the cyan colour. Figure 3–4 demonstrate the average value and variation of the tone value increase for all the papers printed with inkjet and electrophotographic technology.

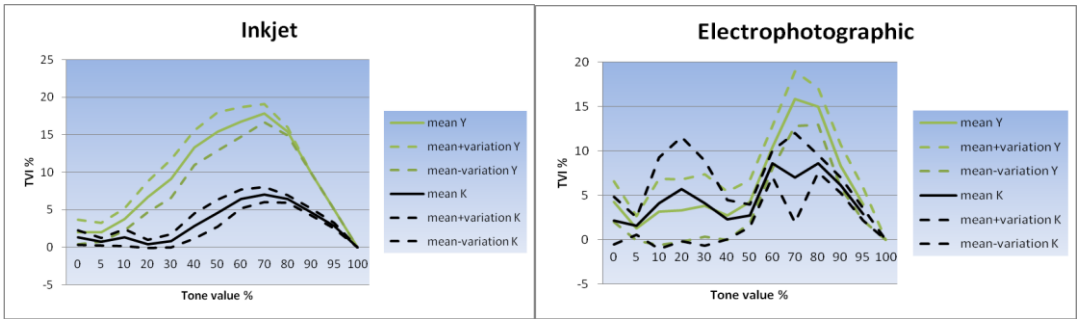

Figure 3: Average value (continuous line) and variation (broken line) of the tone value increase curves for all the printing media printed with inkjet (left) and electrophotographic (right) technology, for yellow and black colours

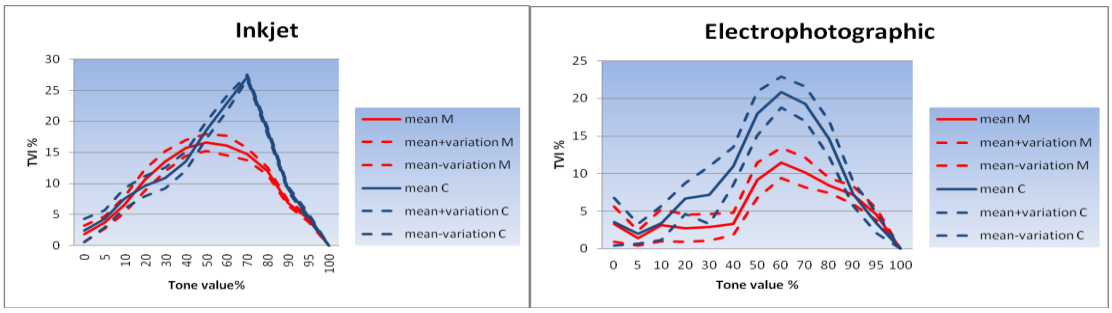

Figure 4: Average value (continuous line) and variation (broken line) of the tone value increase curves for all the printing media printed with inkjet (left) and electrophotographic (right) technology, for yellow and black colours

3.2 Reproducible color gamut

The range of reproducible colours is dependent on the given device, material and system. It means the collectivity of colours that can be created with the use of the given equipment. In addition to the toner, the print carrier is also largely responsible for the size of the reproducible colour range. System dependence is influenced by the applied profiles, under colour removal procedures and the form scanning properties of certain technologies.

For the measurements, X-RITE EYE-ONE IO spectrophotometer and the associated X-Rite i1 Match software was used. For the test images printed on nine types of print carriers with the use of two digital appliances, 18 ICC profiles have been obtained, and used for the preparation of the colour bodies. The GamutVision 1.3.7 software application has been applied to present the colour bodies, and calculate their volumes that have been expressed in CIELAB units (Table 3).

Table3: Volumes of the colour ranges presented in the profile analysis software in absolute and relative units, in comparison with the maximum values (1)

Paper	Volumes of the colour ranges			
	Inkjet	Electrophotographic	Inkjet (rel.)	Electrophotographic (rel.)
Recycled	215856	180713	0,95	0,79
Recycled Pure	221899	195270	0,97	0,85
Recycled Plus	195600	196808	0,86	0,86
Nautilus Universal	216650	178780	0,95	0,78
Nautilus Superwight	214412	183313	0,94	0,80
IQ Triotec unique	220876	191326	0,97	0,84
Mondi Premium	228417	192795	1,00	0,84
Cyclus Offset	211880	189689	0,93	0,83

The colour ranges reproduced in the prints that have been made with the Canon imagePRESS C1 printing machine are significantly (by approx. 12%) larger than the colour ranges reproduced with the Canon PIXMA iX7000 printing appliance. Considerable differences (approx. 22%) can be observed in between the smallest and largest gamut volumes in the case of both printing machines (Figure 5-6).

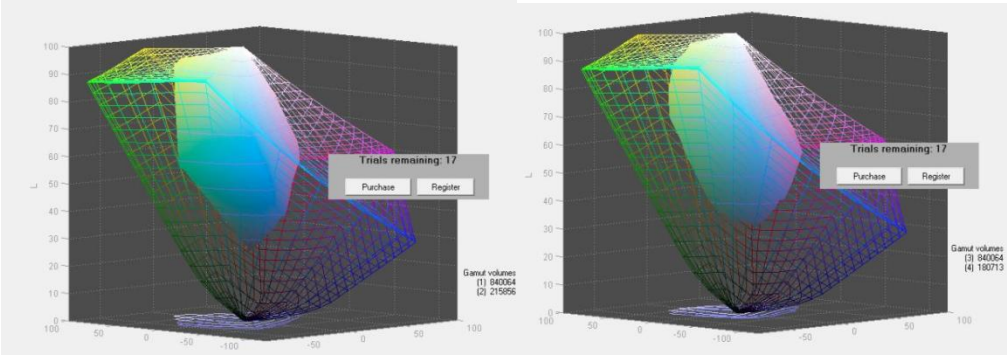

Figure 5: Maximum colour range that can be presented in the CIELAB colour space on Recycled type paper, wherein the spatial mesh body represents the standard sRGB colour space (left: inkjet; right: electrophotographic)

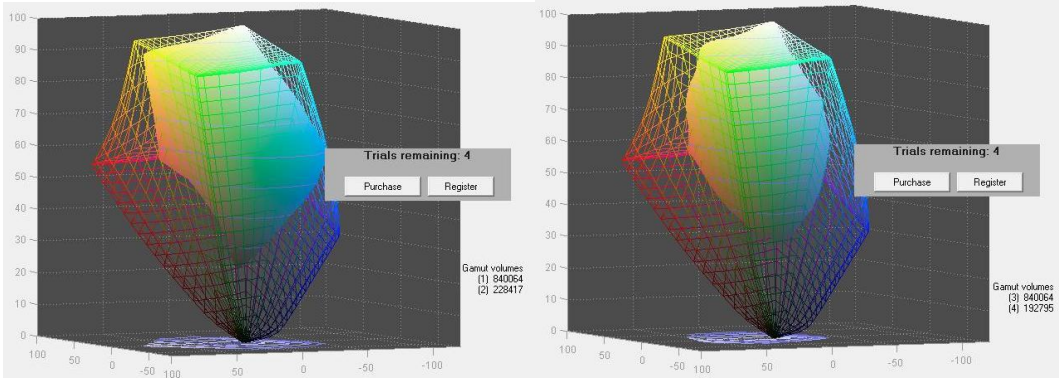

Figure 6: Maximum colour range that can be presented in the CIELAB colour space on Mondi Premium type paper, wherein the spatial mesh body represents the standard sRGB colour space (left: inkjet; right: electrophotographic)

4 CONCLUSIONS

Thus study describes the printability of recycled papers of varied quality with the use of the electrophotographic and inkjet technique. The summary of the associated literature focuses on the processing and manufacturing of recycled papers, as well as digital (non-impact) printing techniques. The test prints have been made on 9 types of recycled papers with the use of the electrophotographic Canon imagePRESS C1 and inkjet Canon PIXMA iX7000 printing machines. The optical properties of the test prints (tone value increase, and reproducible colour range) have been measured.

In the light of the results, it can be claimed that the IMAGEPRESS C1 printing machine has produced prints of higher density on all the print carriers. In these prints, the tone value increase is 10–15% larger on the average than on the prints produced by the Canon PIXMA iX7000 printing machine. The largest TVI value and most outstanding reproducible colour range have been fund for the Mondi Premium paper for both devices. In the case of the Recycled Plus paper, the inkjet technique has resulted in the smallest reproducible colour range, whereas the electrophotographic procedure has yielded the largest reproducible colour range. The average and variation of the tone transmission curves for the individual technologies show that the curves describing the inkjet procedure reflect smaller deviations on the specific types of print carriers.

The printability studies have suggested that there is some 10% deviation between the quality properties of the prints on the examined recycled and normal papers made from primary fibers.

5 REFERENCES

[1] ERDŐVAGYON, ERDŐ ÉS FAGAZDÁLKODÁS MAGYARORSZÁGON 2010 [ONLINE]. *AVAILABLE FROM* HTTP://WWW.AGRARKAMARA.HU *ACCESSED:* 03-12-2011

[2] EUROPEAN PAPER INDUSTRY CUTS CO2 EMISSIONS BY 42% SINCE 1990. *AVAILABLE FROM* HTTP://WWW.ENVIRONMENTALLEADER.COM/2009/11/20/EUROPEAN-PAPER-INDUSTRY-CUTS-CO2-EMISSIONS-BY-42-SINCE-1990/ ACCESSED: 03-12-2011

[3] "RECYCLING IN THE PAPER INDUSTRY" [ONLINE]. ROBERT C. WILLIAMS PAPER MUSEUM, GEORGIA INSTITUTE OF TECHNOLOGY. *AVAILABLE FROM* HTTP://WWW.IPST.GATECH.EDU/AMP/COLLECTION/MUSEUM_RECYCLING.HTM. *ACCESSED:* 03-12-2011

[4] K J Kramer at al: ENERGY EFFICIENCY IMPROVEMENT AND COST SAVING OPPORTUNITIES FOR THE PULP AND PAPER INDUSTRY. ERNEST ORLANDO LAWRENCE BERKELEY NATIONAL LABORATORY. SPONSORED BY THE U.S. ENVIRONMENTAL PROTECTION AGENCY OCTOBER 2009

[5] H. Lee at al: EFFECT OF DIFFERENT TYPES OF FINES ON THE PROPERTIES OF RECYCLED CHEMICAL PULP JOURNAL OF INDUSTRIAL AND ENGINEERING CHEMISTRY 17 (2011) [ONLINE]. *AVAILABLE FROM* HTTP://WWW.CHERIC.ORG/PDF/JIEC/IE17/IE17-1-0100.PDF 100–104 *ACCESSED:* 03-12-2011

[6] S. Grilj, T. Muck, D. Gregor Svetec: EVALUATION OF DIGITAL PRINT QUALITY RECYCLED PAPER. *PROCEEDINGS OF 5TH INTERNATIONAL SYMPOSIUM ON GRAPHIC ENGINEERING AND DESIGN*, PP. 91-98 NOVI SAD 11-12. NOVEMBER. 2010. SERBIA, ISBN 978-86-7892-294-7

[7] Oittinen, P. – Saarelma, H.: *PRINTING, PAPERMAKING SCIENCE AND TECHNOLOGY*, BOOK 13, FAPET OY, HELSINKI 1998

[8] Kipphan H.: *HANDBOOK OF PRINT MEDIA: TECHNOLOGIES AND PRODUCTION METHODS.* SPRINGER, 2001
[9] M. Debeljak; D. Gregor-Svetec; Szentgyörgyvölgyi R.: PRINTABILITY OF SYNTHETIC PAPERS BY ELECTROPHOTOGRAPHY. *ACTA GRAPHICA JOURNAL FOR PRINTING SCIENCE AND GRAPHIC COMMUNICATIONS,* VOL.21 NO.3-4 APRIL 2011. PP.17-24.
[10] ALL ABOUT PAPER [ONLINE]. *AVAILABLE FROM* HTTP://WWW.PINC.ORG/VAULT/ALL_ABOUT_PAPER_04.PDF *ACCESSED:*06-02-2012
[11] Lyne, M. B.: ON THE INTERACTION OF LIQUIDS WITH PAPER UNDER DINAMIC CONDITIONS. *OXFORD FUNDAMENTAL RESEARCH SYMPOSIUM*, PP. 885-911, LEATHERHEAD 1993. PIRA INTERNATIONAL
[12] Mensonen, M.: PAPER AND DIGITAL PRINTS. EXPRESSIS VERBIS 13:44 (2003)
[13] Baudin, G. [ONLINE]: DIGITAL PRINTING TECHNOLOGIES: RECENT EVOLUTIONS AND TRENDS. *AVAILABLE FROM* HTTP://WWW.E-WPP.COM/DOWNLOAD/PDF/K9.PDF *ACCESSED:*06-02-2012
[14] Sastri, B., Sankaran, V.. MEDIA/TONER INTERACTIONS IN LASER PRINTING. *PROCEEDINGS OF THE IS&T NIP19: 2003 INTERNATIONAL CONFERENCE ON DIGITAL PRINTING TECHNOLOGIES*, PP. 619–622 NEW ORLEANS, 2003 LA
[15] Renmei, et al: THE EFFECT OF INK JET PAPER ROUGHNESS ON PRINT GLOSS, *JOURNAL OF IMAGING SCIENCES AND TECHNOLOGIES,* VOL 49, NO 6. 2005 PP. 660-666.
[16] Macholdt, H. T.: PIGMENTS AND DYES FOR NON-IMPACT PRINTING APPLICATIONS. *NIP18: INTERNATIONAL CONFERENCE ON DIGITAL PRINTING TECHNOLOGIES. SAN DIEGO*, CALIFORNIA SEPTEMBER 2002, P. 6-6; ISBN / ISSN: 0-89208-240-2