Effects of Paper Manufacturing Factors on Inkjet Print Quality and Lightfastness

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Abstract

Digital Imaging has introduced Color Printers as proofing device. On demand printing and Low volume Printing is generally supported by color digital printing method. Color Inkjet Printing is one of the digital color printing processes. Here the ink is in form of a liquid. The ink and substrate interaction determines the quality of print and the durability of the image.

In this paper, the PAPER properties and relationship with inkjet printability are studied. Inkjet Print Quality can be affected by modifying the paper characteristics, ink composition and the printer, and by improving the interactions between these variables. For light fastness properties, the interactions between the ink and the paper are the important factors. The experimental samples used in this study were produced on a pilot paper machine at three different levels of refining, filler, internal sizing and surface sizing.

*The optical, surface and absorption properties of paper were analyzed. The samples were then printed with inkjet printer. The solid ink density (SID) and colorimetric analysis on printed samples were performed. Color gamuts and ICC profiles for each of the paper sample were compared. In addition, the accuracy of printer color profile was investigated. The results of the profile accuracy measurements were expressed in terms of CIE La*b* coordinates and Root Mean Square (RMS) ΔE. Results of accelerated light fastness tests for the selected paper samples were interpreted in terms of change of profile and color gamut. The results show that inkjet printability and image permanence are greatly influenced by paper properties.*

Introduction

An inkjet imaging technique involves placing extremely small droplets of ink onto media to create an image [1-2]. The droplets are directed onto the surface of a moving sheet or web and controlled to form print characters and graphics. The inkjet print quality is highly dependent on the print head, media and ink properties and software [3-5]. Advancements in inkjet technology have also place new demands on the media due to faster printing rates, greater resolution through reduced drop volumes, and colorants added to the ink. To meet these requirements, papermakers are developing new paper grades.

The paper media for inkjet printing can be divided into two major categories; plain and photo paper [2]. The plain paper is mainly targeted at the largest volume applications and composed of cellulosic fibers and fillers [6-8]. Sizing chemicals, such as AKD (Alkyl Ketene Dimer) and ASA (Alkenyl Succinic Anhydride) [6,7] are used to impart hydrophobicity to prevent ink spread and strikethrough. Highly sized papers provide good optical density by retaining the ink at the paper surface, but have a high tendency to set-off (transfer of the ink from the paper to sheet handling rollers). Film formers such as starches [8], alginate, CMC (CarboxyMethyl Cellulose) and synthetic polymers are used to further modify the media surface. The size press is probably the most common method for applying a surface coating “on machine”. Natural polymers such as starch absorb water into the paper. A balance is needed between internal and surface sizing to control the rate of penetration and lateral spreading of ink. Surface size can have a large influence on color-to-color bleed.

High impression pressures are necessary in conventional presses to create uniform physical contact over the printing area [2]. Propelling a series of ink drops avoids such a requirement. The process is less dependent on the flatness of the substrate. Like most non-impact systems, ink jet printers were developed to provide hard copy devices and not to compete with conventional printing. Although ink jet printers have speeded up significantly since their introduction, they have not yet reached the speed of printing presses. However, the print quality achieved with high-resolution ink jet devices is approaching that of conventional printing. The key to creating quality images with ink jet is to generate a controlled stream of droplets. It requires control of droplets in their path to the printing medium or a method of turning the droplet stream on or off, as the nozzle moves along the substrate.

All ink jet printers work on digital raster image input [2]. Thus, the development of ink jet systems has closely paralleled that of digital image processing. The ink drop is in one to one correspondence with a bit of data. Thus, droplet formation and control always takes place in response to high frequency digital electronic signals. The differences among ink jet printers relate mostly to method of jet formation and method of jet control. Other differences are dithering methods and the way the droplet stream reaches the media. A characteristic of all modern ink jet systems lies in their utilization of micro-manufacture of electronic, thermoelectric and electro-acoustic elements.

EXPERIMENTAL DESIGN

This work is divided into three phases: (1) to manufacture paper on a pilot machine with different conditions, (2) to print paper using an inkjet printer, and (3) to characterize the paper sample’s optical, print and permanence properties.

Materials

The different samples investigated during this study are shown in Table 1. A 60:40 hardwood to softwood ratio was used for furnish. The internal starch addition was kept constant to 15 lb/T. Three different levels of refining, filler (PCC), internal sizing (12.5% solid AKD) and surface sizing (Penford Gum 290) were used.

Paper Testing Procedure

All the paper samples were conditioned for 24 hrs at 50% RH and 23°C before any measurements were made. The samples were then tested for physical, optical, and surface properties. The brightness, opacity, roughness, and porosity were measured as per TAPPI standards. The brightness of the samples was measured using a Technidyne Brightness meter, TAPPI procedure T 452. The surface roughness and air permeability (from PPS porosity) of the samples were measured using a Parker Print Surf (PP) tester (T 555) at 1000 kPa. Thicknesses of the samples were measured using a Micrometer (T 411).

Table 1: Sample IDs of Different Substrates

Sample ID		Refining	Filler	Int. Sizing	Surface Sizing (PG 290)	
		CSF (mL)	PCC (lb/T)	AKD (lb/T)	Sol'n (%)	Pickups (lb/T)
1	500 CSF	500	0	1	0	0.0
2	400 CSF	400	0	1	0	0.0
3	300 CSF	300	0	1	0	0.0
4	100 lb	400	100	1	0	0.0
5	200 lb	400	200	1	0	0.0
6	300 lb	400	300	1	0	0.0
7	2 lb@ 0%	400	200	2	0	0.0
8	2 lb@ 6%	400	200	2	6	61.0
9	2 lb@ 8%	400	200	2	8	84.1
10	2 lb@10%	400	200	2	10	121.6
11	3 lb@ 0%	400	200	3	0	0.0
12	3 lb@ 6%	400	200	3	6	60.2
13	3 lb@ 8%	400	200	3	8	84.7
14	3 lb@10%	400	200	3	10	107.0
15	3 lb@8% w/AKD*	400	200	3	8	76.0
16	4 lb@ 0%	400	200	4	0	0.0
17	4 lb@ 6%	400	200	4	6	44.0
18	4 lb@ 8%	400	200	4	8	76.7
19	4 lb@10%	400	200	4	10	99.1

* w/AKD = with 1% AKD by dry weight of starch.

Printing Procedure

An HP DesignJet 20PS color printer was chosen to perform inkjet-printing tests on the selected samples of paper. For the given 19 samples of paper an 'ECI2002R [9] CMYK print test chart' was printed on the HP inkjet printer with the HP recommended RIP. To know the exact capacity of the printer to reproduce colors, it is required to turn off the built-in color correction options for the RIP and the printer. The test chart was converted to an EPS file through Adobe Photoshop. All color management settings were turned off and conversion was Absolute colorimetric to find out the true color output of the printer [10].

Having set the RIP and Printer for this paper we printed the test chart on all 19 samples. Using each test chart, we measured the output values of colors from the test chart and then used these values to build color profiles for each of these samples. In the software, GretagMacbeth ProfileMaker, we modified the color separations by choosing maximum black usage for the GCR (gray component replacement). Figure 1 shows the settings that we chose for profile building.

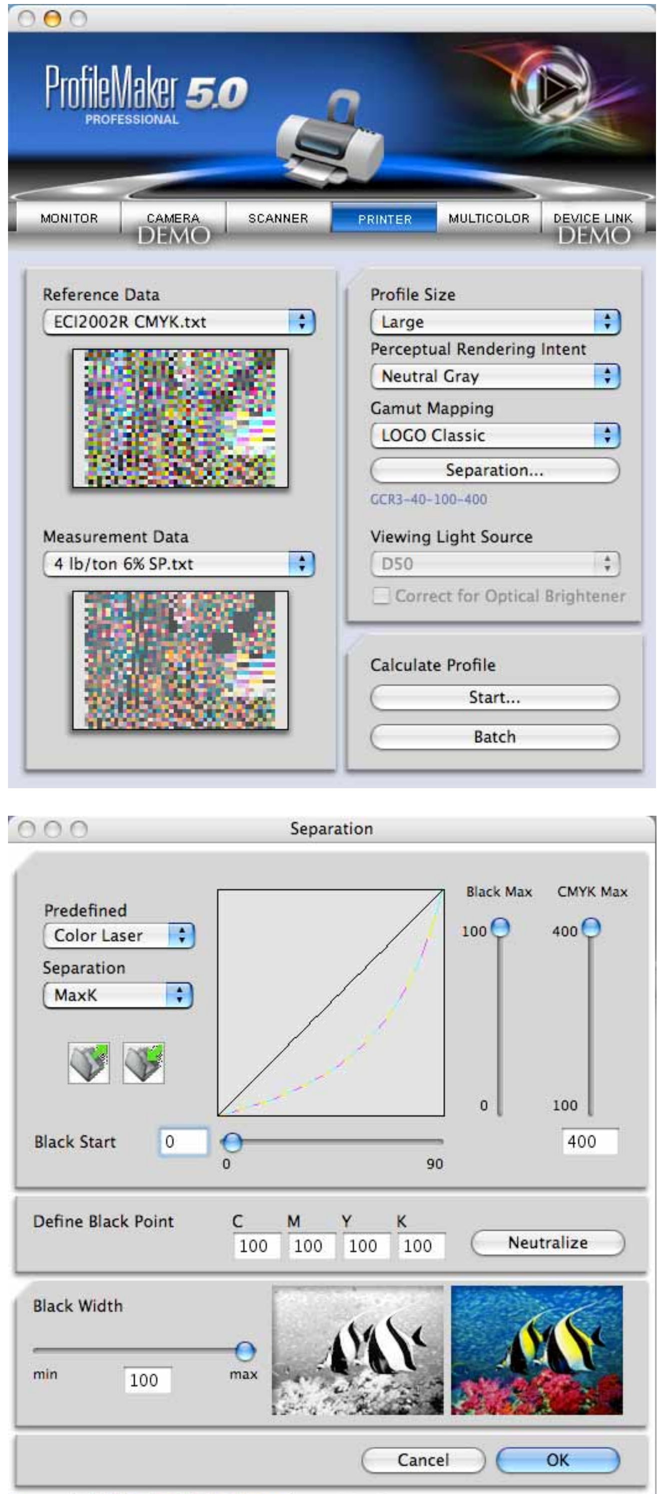

Figure1. Setting for ICC Profile Using ProfileMaker 5.0

The final goal of these tests was to compare the gamut volumes for each sample of paper and to perform lightfastness tests on them [11,12]. To calculate the gamut volume of the color profiles, we used 'Color Think Pro'. 3-D color spaces were built in La*b* system to compare different profiles and their color gamut. Depending on the printer profile built for each paper sample, the Macbeth ColorChecker was printed along with Cyan, Magenta, Yellow and Black color solid patches. The file was generated in Adobe InDesign. A similar procedure that was used for printing the test chart was used. The modifications were done in the working color space and profile application before converting to EPS files. The color settings are similar to those seen in the Figure 2 given below. The only difference will be in the CMYK profile, which depends upon the paper used.

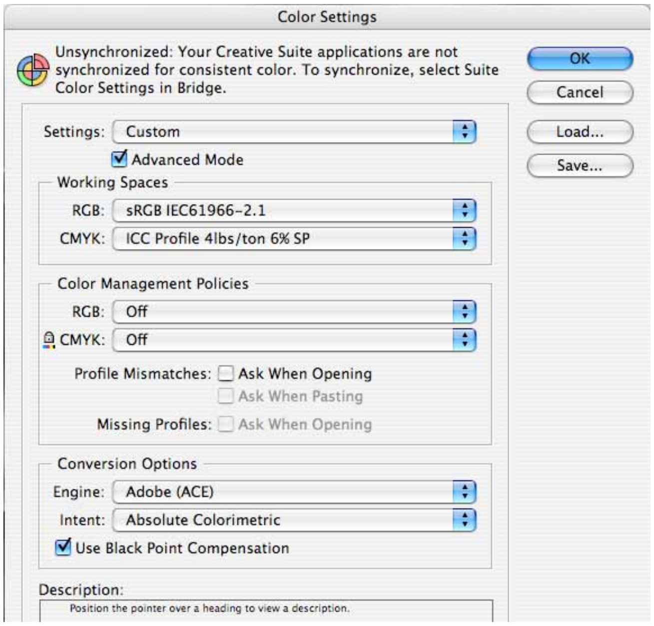

Figure 2. *Color Settings for Printing*

EPS file conversion was done through export option in Adobe InDesign. The level of Post Script was selected to be 3 with TIFF preview and Best quality output. The printed Macbeth ColorChecker was used to measure the actual color output of the Printer-paper combination. Different papers might give different outputs for the same printer. The variation in the colors of print with respect to the expected output can be found by measuring the actual color value of printed patches and the expected color value according to Adobe Photoshop when the particular profile is applied to the color patch. ΔE values calculated for these patches help in finding the accuracy of the printer-paper combination in reproducing the color.

Finding the color gamut of a printer profile is to find the theoretical number of colors those can be printed with a given set of inks on the given paper within a ΔE tolerance of √3, while measuring the color variation leads to accurate knowledge of reproducible colors. We can compare the ΔE values for different papers at different color patches. Formula for ΔE is [9,13]:

$$\Delta E = ((L^*_1 - L^*_2)^2 + (a^*_1 - a^*_2)^2 + (b^*_1 - b^*_2)^2)^{.5} \qquad (1)$$

RESULTS AND DISCUSSION

Physical, Surface and Optical Properties

The Brightness, Opacity, PPS Roughness, Air Permeability, Solid Ink Density (SID) are compared for all the samples in graphical format. The Air Permeability was calculated from the PPS Porosity, using the Pal equation [14]. The graphs comparing each of these properties are shown in Figures 3-7.

The results show that the reduction in freeness (more refining) results in reduction in Brightness, opacity, roughness and permeability. Increase in roughness with increase in surface sizing level may be due to cracking of the starch film on the surface. The increased filler level causes an increase in brightness, while the freeness reduction results in brightness reduction due to loss of air pockets. This air gap loss is due to increased fiber bonding. Opacity tends to increase with increasing amount of fillers. In the 2lb/ton internal sizing of paper, the brightness is reducing with surface sizing. The common trend in Opacity is that there is loss of opacity with increasing surface sizing. The same trend is followed in the permeability of papers. A drastic reduction in permeability is observed with decrease in freeness of paper fibers.

The graph of absorption shows that there is the tendency of reduction in absorbency with increasing levels of internal sizing. The first 6 readings for absorbency are not recorded because of too low HST and too high Cobb values. Reduction in absorbency should increase the gamut volume and ink density, due to reduction in ink penetration [5].

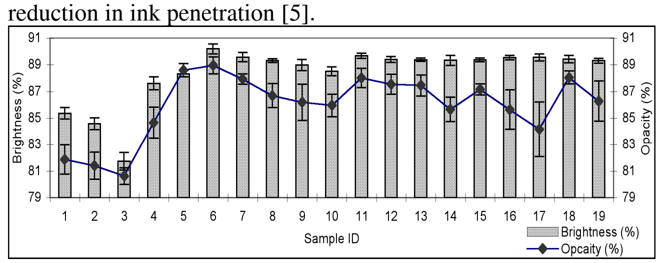

Figure 3: *Comparison for Brightness and Opacity*

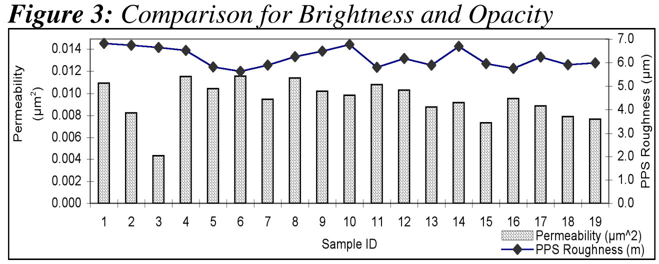

Figure 4: *Comparison for Permeability and PPS Roughness*

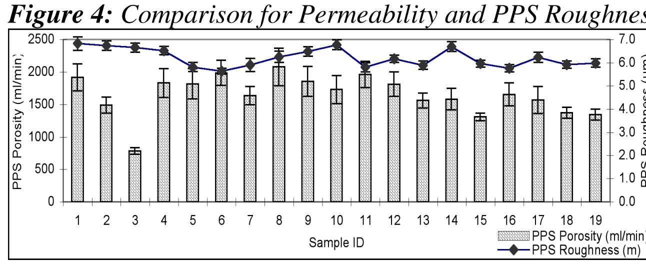

Figure 5: *Comparison for PPS Porosity and PPS Roughness.*

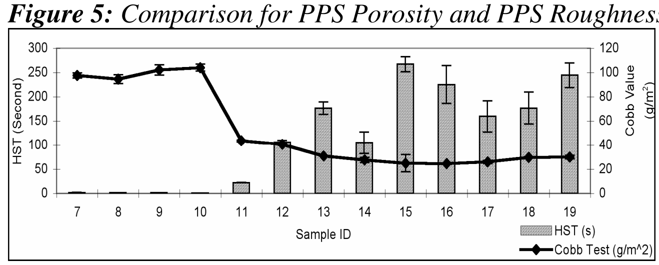

Figure 6: *Comparison for Absorption*

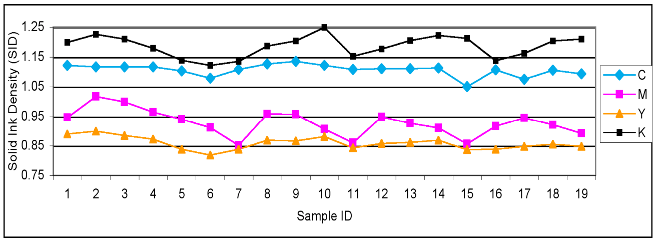

Figure 7: *Comparison for SID*

Solid Ink Density and Color Gamut Comparison

The solid ink densities (Figure 7) of different inks vary on different surfaces. However, the common trend for papers with fillers is that an increase in PCC content has a negative effect on the solid ink density for any of the four C, M, Y, K inks. However surface sizing has improved the ink density of all inks except the Magenta.

The ink density of magenta was reduced with increase in surface sizing. In AKD introduction for surface sizing, all the ink densities were reduced except Black. So overall, the AKD usage in surface size has produced a negative impact on the ink densities.

Table 2 summarizes the gamut volume and lightfastness data for the different paper samples. These show significant dependence of color gamut on papermaking variables. Indeed, Color Gamut has been proposed as a tool for papermakers to characterize their paper for a target print process [15]. Color Gamut has been seen to be very sensitive to paper, ink and print device [11,12,15,16]. As seen in the Table, the image permanence is strongly dependant on paper properties, even when the same ink and printer are used. This is consistent with results given elsewhere [11,12,17]. Figure 8 shows the color gamut and fading data along with the permeability obtained from the Pal equation [14].

Table 2. Gamut Volumes Comparison

ID	Gamut Volume		
	Before Fading	After Fading	Apparent reduction (%)
1	283,728	Not Available	Not Available
2	**284,058**	66,399	76.62
3	282,141	79,962	71.66
4	276,060	76,507	72.29
5	252,027	42,083	*83.30*
6	**235,324**	56,016	76.20
7	249,729	62,160	75.11
8	258,550	Not Available	Not Available
9	265,749	70,182	73.59
10	272,054	77,203	71.62
11	252,465	72,504	71.28
12	257,700	62,477	75.76
13	263,061	74,295	71.76
14	265,825	78,264	70.56
15	242,689	64,644	73.36
16	250,889	67,930	72.92
17	252,869	56,635	77.60
18	254,220	66,823	73.71
19	261,521	76,507	70.74

Though the numbers obtained from gamut volume measurement (Table 2) give us the idea about which color gamut is larger, it does not provide us the information about the region of color space that is covered by the selected profile. The supplementary visual comparison using 3-D color space can give us the better idea about the profile.

We have compared profiles for all the samples of paper having only one variable and the color spaces for these samples were combined into one graphical representation to compare them visually. 'Color Think Pro' is the software that can build color spaces using the profiles and show them from all directions. For the convenience of this paper, only one view is captured. The nose of the color space is the +b* axis in La*b* space. These are shown in Figures 9-16.

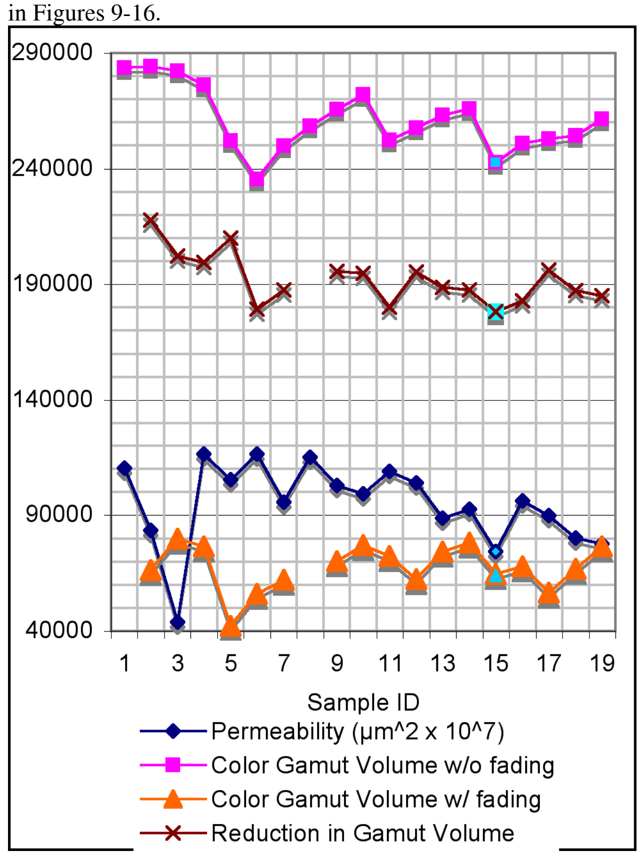

Figure 8: *Color Gamut Volume and Permeability*

From these images, we can find that which profile can reproduce the colors in selected regions. We compared the profiles for papers based on the following conditions:

- Freeness/Refining
- Fillers (PCC)
- Internal sizing (AKD)
- Surface sizing (Penford Gum 290)

Color spaces of profiles for the samples with no surface sizing (0%), 6% sizing, 8% sizing and 10% sizing are given below. Similar color spaces for the profiles of samples with varying freeness and varying filler (PCC) contents are given. The type of sizing is changed in samples 13 and 15 hence they are compared separately.

From these images, we can notice that although the color gamut for one profile is greater than the other two, it cannot wrap the other two gamuts completely. The color codes used for different spaces in the same image are as described below. The table given with each image explains the profiles.

The images and the numbers in the gamut volumes clearly indicate that, the fading test has very significant impact on the colors of the print. The color gamut is drastically shrunk when compared with original volume, but the fading causes the ink to reduce its saturation in color. This is well known for dye based inks, such as those used in the DesignJet 20PS [11,17] and is generally less pronounced for pigmented inks. The result is increase in lightness values of the lightest colors. Hence a few colors in faded image can cover parts of the color space that are out of the scope of original profile. This can be seen in the Figure 16. The faded color gamut is coming out of the original color gamut. This effect is mainly observable in the column over the positive quadrant of a*-b* plane i.e. for the colors between magenta and yellow.

As we go on increasing the fillers in the paper, the color gamut is reducing (samples 4, 5, 6). The reason could be hydrophilic nature of the PCC. The effect could be the more and more absorption of the ink in the paper due to higher PCC contents. On the other hand, if we increase surface sizing, the water penetration is reduced and this could be the reason for increase in gamut volume with increase in the surface sizing. The results show that with same level of surface sizing we get reduction in the color gamut with increase in internal sizing.

The graph in Figure 8 shows that there is a relationship between surface sizing, permeability and lightfastness of colors. By increasing surface sizing we can see the reduction in permeability and also the improvement in lightfastness of inks.

Also, it has been noted that by increasing surface sizing, we can achieve lower and lower lightness in colors due to low penetration of inks (higher ink density).

Table 3: Color code for Color Gamut comparison

0% Surface sizing		6% Surface sizing	
Color	Sample ID	Color	Sample ID
Red	7	Red	8
Green	11	Green	12
Blue	16	Blue	17

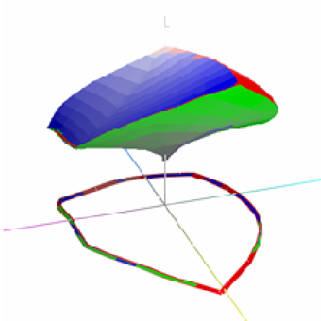

Figure 9: *0% Surface sizing.*

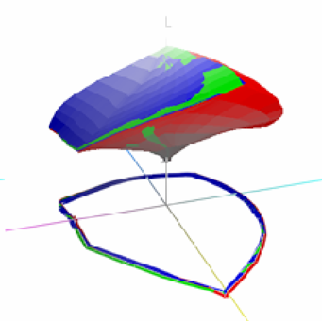

Figure 10: *6% Surface sizing.*

Table 4: Color code for Color Gamut comparison

8% Surface sizing		10% Surface sizing	
Color	Sample ID	Color	Sample ID
Red	9	Red	10
Green	13	Green	14
Blue	18	Blue	19

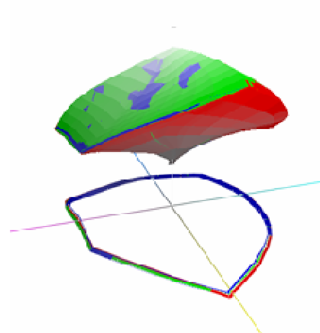

Figure 11: *8% Surface sizing.*

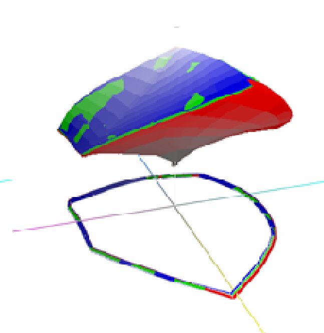

Figure 12: *10% Surface sizing.*

Table 5: Color code for Color Gamut comparison

8% Surface sizing w/AKD		Freeness	
Color	Sample ID	Color	Sample ID
Red	13	Red	1
Green	15	Green	2
		Blue	3

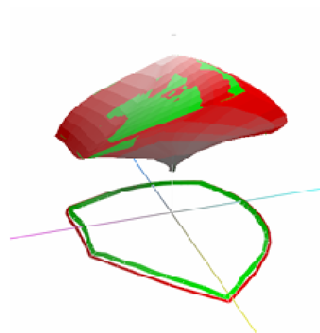

Figure 13: *8% Surface sizing.*

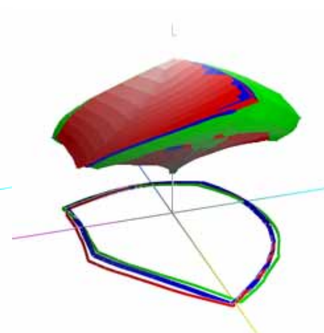

Figure 14: *Freeness w/AKD*

Table 6: Color code for Color Gamut comparison

Fillers		Faded Sample (ID 7)	
Color	Sample ID	Color	Sample
Red	4	Red Wireframe	w/o fading
Green	5	Blue Solid	faded
Blue	6		

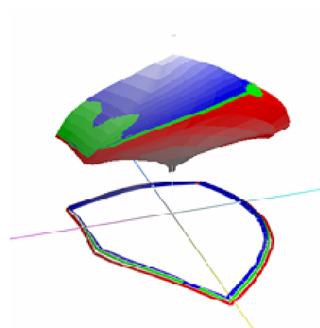

Figure 15: *Fillers.*

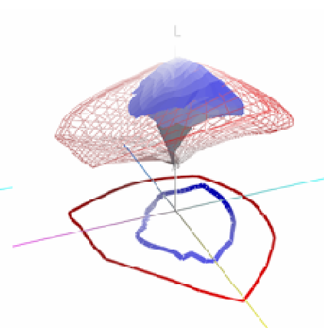

Figure 16: *Faded Sample (ID 7).*

Color Variation:

Color variation is expressed in terms of ΔE. The average ΔE value of all the samples is 5.93 (Predicted Color vs. Printed Color). The graph of the average ΔE values for each sample is shown below.

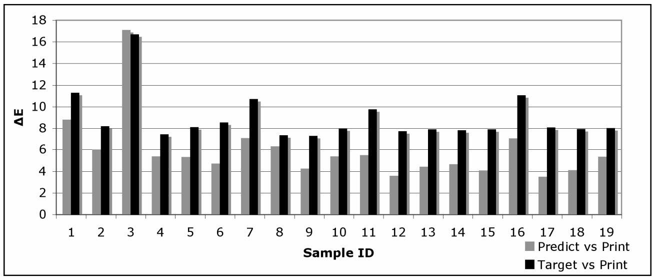

Figure 16: *Average ΔE for different samples*

The average ΔE value for each sample means the average variation of colors in the 'Macbeth ColorChecker' patches printed on those samples.

It was observed that there is high variation in color for a few patches of the printed sample. This high variation of ΔE could be due to a dirty printhead.

CONCLUSIONS

The print quality is highly influenced by paper properties. Higher refining has negative effect on the optical properties of paper, while addition of fillers improves optical properties of paper. Both refining and filler addition reduce the PPS roughness and permeability of the paper.

Internal sizing has negative effect on the optical properties of the paper. Surface sizing causes an increase in PPS roughness (or reduction in smoothness) and a decrease in permeability of the paper. Surface sizing has negative impact on optical properties of paper, though it is low.

As expected, the overall tendency of surface sizing is to reduce the absorbency of paper due to reduction in porosity. However, the increasing amount of absorbency is observed in the samples with 2 lb AKD internal sizing and increasing level of surface sizing.

A High color gamut is required to have high quality images with the color output near to the natural colors. However, the higher color gamut volume does not promise the coverage of all colors equally. The color gamut could be deformed in such a way that it could be excluding some portions those are covered under different gamuts; even though they have lower volume.

Also the increase in color gamut with decrease in absorbency is observed as expected.

The fillers reduce the gamut volume. AKD addition in the surface size caused the loss of color gamut volume and the color densities. The inconsistency in the printing, which is represented by color streaks and unreasonable ΔE in a few color patches, leads to the conclusions that the print head is not clean enough.

The lightfastness of inkjet colors is dependent on all of the paper manufacturing factors. With increased surface sizing we can observe increased lightfastness. We can achieve higher ink density by increasing surface sizing. Higher ink density lets us print the darker colors and hence the gamut volume increases.

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