A Unique Image Analysis Technique for the Determination of the Wicking Properties In Paper Produced for Inkjet Application

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Abstract

A new method for the determination of inkjet wicking and intercolor bleed is introduced. The method is based on the thresholding concept of image analysis. The spread of a printed dot is determined through the standard deviation of the mean pixel luminance. The larger the standard deviation the more wicking is taking place. A well-defined printed dot with not much variance in the pixel luminance will have a low standard deviation of the mean pixel luminance. The thresholding concept can also be used to determine intercolor bleed.

Known quality measures of paper topography and dot circularity were also used in conjunction with the newly introduced method to determine the quality of the printed dot and how the substrate surface influences these quality parameters.

Introduction

Inkjet print technologies have become common in our lives. Beginning with the original home and office applications, today they are used in the production of many printed pieces ranging from direct mail and banners to large wide-format posters. Inkjet printing is used increasingly together with offset print technology. At DRUPA 2012 printing machine manufacturers displayed inkjet heads mounted on an offset press producing personalized printed pieces in a single step.

Due to inkjet's speed and rapid set-up, application growth is certain. The inkjet print process is non-contact, and as such it differs from most other printing processes; to create the image, inks are propelled through the air as fine droplets to strike the medium. The electronic pump creating these droplets requires them to be

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very low in viscosity, and as such, the droplets are at least partially absorbed by the paper. Ink absorption directly affects the image sharpness or visual clarity, which is often referred to as wicking or raggedness. Wicking occurs between printed characters, lines, and in half-tone images between the dots.

In the case of inkjet print, dot sharpness and internal uniformity are affected not only by the formulation of the ink but also the properties of the paper; its surface treatment and the internal size, both of which affect the absorptive properties of the paper. A requirement for glossy inkjet paper coating is limiting the spread of the ink, i.e. to fix the inkjet colorants to the coating. In this study papers that have been specifically made for inkjet printing will be tested with water-based and UV inkjet inks.

Although the differences between two papers may be minimal in terms of wicking (i.e. raggedness and feathering), it can make the difference between a sharp, crisp looking print and a fuzzy looking print. This applies to text appearing fuzzy or too bold, and half-tone areas will darken as more wicking occurs.

The common test inkjet pattern contains lines but because scanners were used to acquire the test images, the authors chose to use dots as the primary test pattern, contrary to common practice. Using dots minimizes the possibility of the Moiré effect in the analysis: e. g. misalignment of the rectilinear printed line with the rectilinear scanner camera and the subsequent rectilinear image analysis. In addition, dots are the basis half-tone images, and the analysis program used in these tests was initially developed to analyze the quality of the offset/flexographic/gravure half-tone print; it was enhanced somewhat to handle non-contact inkjet tests as well. Practice has determined there is no difference between the perimeter wicking of a line and a dot. In this analysis the authors have chosen to use dots with a diameter of 2mm printed in a range of colors.

Theory

Inkjet ink is, for the most part, solvent followed by the pigment or dye. There are a few other components in the inkjet ink as well, that control the evaporation rate of the ink as well as the inhibited growth of the microorganisms. An exemplary inkjet ink formulation can be found in Table 1.

After knowing the general composition of an inkjet ink, it is important to know how well the inkjet ink agrees with the print media; what it will look like, not only from the layers present that form the substrate, but also how the substrates looks under a microscope. The following figure shows the general composition of three inkjet type media. The figure was adapted from Svandholm (Svandholm, 2007).

It can be seen from these images that all papers need an image receptor layer that helps to fixate the printed inkjet dot onto the paper. The next layer in all three substrates is there to absorb the liquid (water or monomers).

Ink Component	Component Amount (%)	Ink Function
Water	50 - 90	Solvent
Colorant	1 - 15	Color
Co-solvent / Humectant	2 - 20	Ink Vehicle, Inhibits Evaporation
Fixative / Penetrant	0 - 10	Fix Ink to Substrate
Surfactant	0.1 - 6	Adjust Surface Tension and Wetting
Resin	0.2 - 10	Durability, Adhesion
Biocide	0.02 - 0.4	Prevent Bacterial Growth
Fungicide	0.05 - 1	Prevent Fungal Growth
Buffer	0.05 - 1	Control pH
Other	0.01 - 1	Corrosion, Contamination, etc

***Table 1:** Exemplary inkjet ink formulation (Stephenson)*

***Table 1** lists all the components and their function in inkjet ink. UV-inkjet inks contain monomers and oligomers for the solvent portion and there are also photo initiators present, which ensure proper curing of the ink and they absorb the UV-radiation based on the type of lamp (Hg-vapour or LED) that is used a source of UV light.*

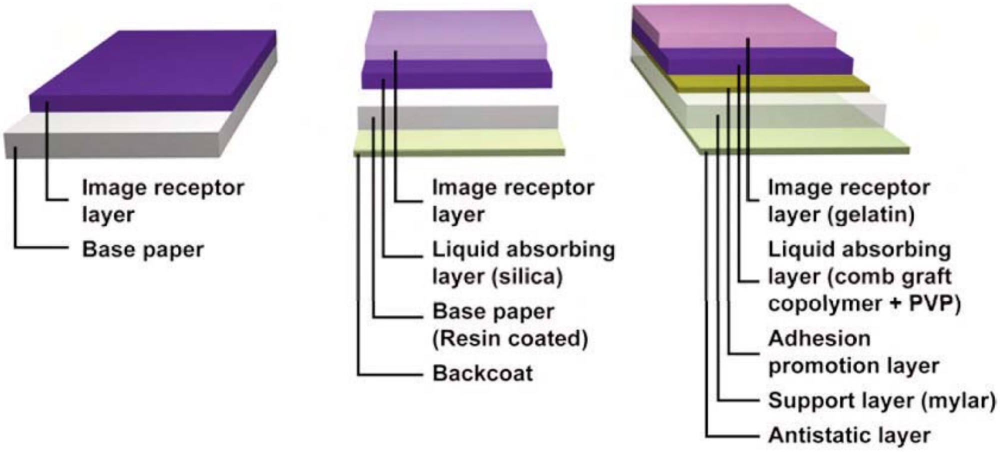


***Figure 1** shows the substrate composition of inkjet media. From left to right: basic paper, photographic paper, transparent inkjet medium.*

The images of the different surface structures help to understand why certain types of inkjet papers show more inkjet wicking and intercolor bleed than others. Before these images are shown it is necessary to see what is meant by wicking and intercolor bleed. The following figure is from Briggs (Briggs, 2002).

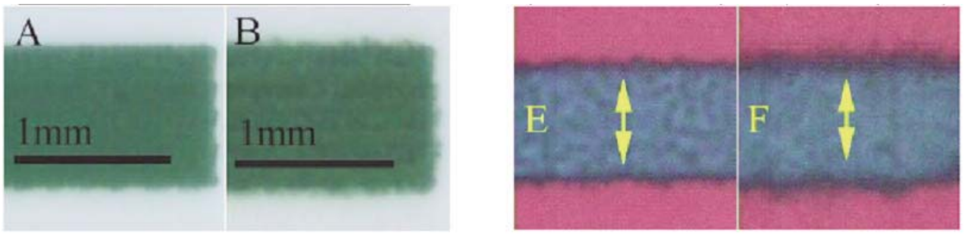
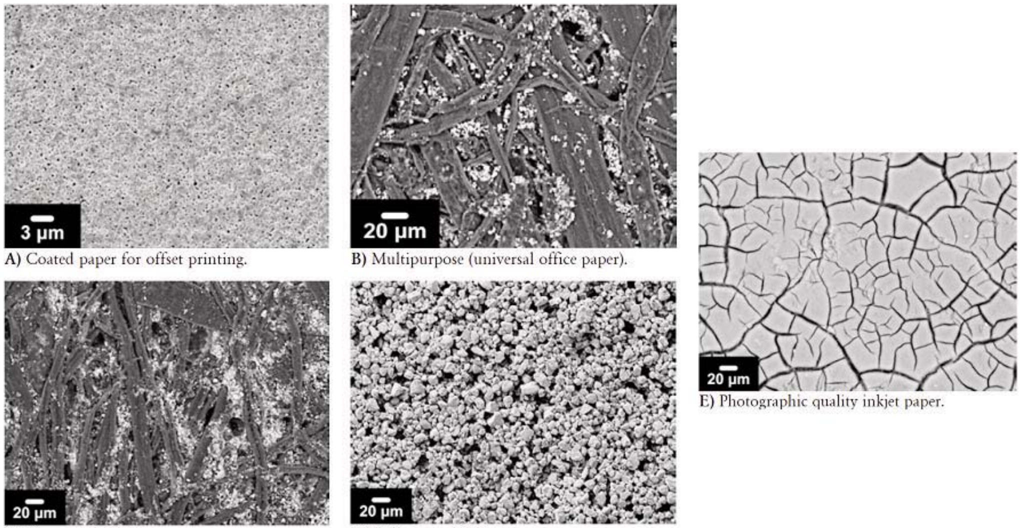


***Figure 2:** Images of inkjet wicking (left) and intercolor bleed (right) (Briggs, 2002)*

From Figure 2 seen above, it can be seen that wicking leads to the spread of inkjet ink into the surrounding area of the printed image. The edges become ragged and less defined with more wicking. The edges become more ragged when more wicking occurs.. Intercolor bleed is in regards to the interaction of two inkjet inks neighboring onto each other. Depending on the ink composition and the wicking properties of the paper the intercolor bleed, this can be less or more severe.

In the following figure SEM (scanning electron microscope) images of five different substrates are shown.



A) Coated paper for offset printing.
B) Multipurpose (universal office paper).
C) Pigmented inkjet paper.
D) Fully coated inkjet paper.
E) Photographic quality inkjet paper.

Figure 3: *SEM images of different papers according to Svandholm (Svandholm, 2007)*

The paper surfaces in Figure 3 show clearly how smooth the surface of a coated offset printing paper is. The paper fibres of a universal, uncoated office paper are also clearly visible. The most interesting image is the surface of a photographic inkjet paper. Based on the great printed results that are achievable with this type of substrate one is astonished to see how many cracks and voids are in this paper.

Experimental & Results

To measure ink wicking, the authors have chosen this pattern of dots, which is shown in Figure 4.

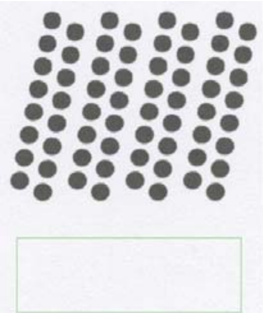


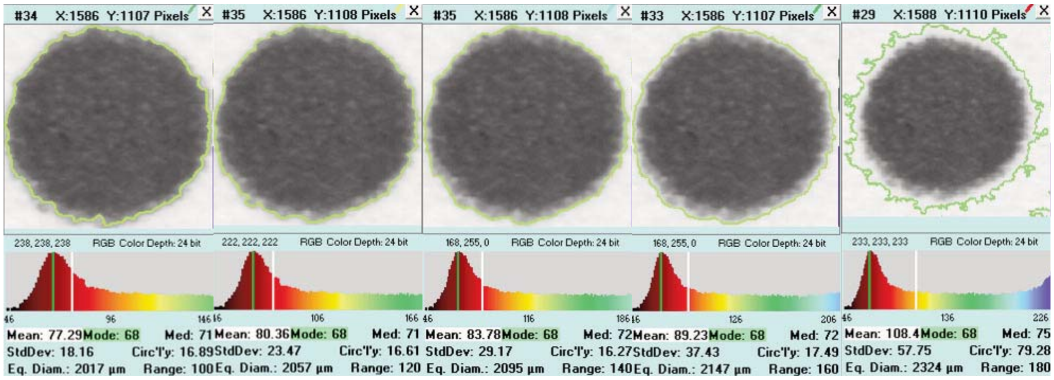
Figure 4: *Test pattern used to determine inkjet wicking*

These dots are uniformly 2 mm in diameter and may be printed in any color, within fields of any color. Dots offer many advantages to the image analyst, using as we have, a high quality scanner, because even at a low resolution of 600 ppi, dots cannot be misaligned.

Immediately below the dots is an unprinted area outlined in green. To prevent any contamination from ink over-spray on the original print, this area, with the dots above, is the final image on the page. In this unprinted area, defined by the green box, the analysis system measures the paper reflectivity and topography as shown to the right. The panel shows the actual topographic surface image of the paper on which the dots were printed. This area was imaged, and then measured for background reflectivity and topography before the dots were measured.

To measure the dots the software uses a concept known as "Thresholding". To understand the workings of a threshold one must first understand the image in which the measurement will be made is an 8-bit derivative of a full color 24- bit image. In an 8-bit image the pixel luminance (brightness) can have a value between 0, (pure black), to 255 (pure white). To see and to measure an object within the image it must contrast with its immediate surroundings. The degree of contrast is determined by the pixel luminance value (i e. pixel or picture element brightness). The program extracts or identifies the object of interest based upon the threshold value; those pixels having a value less than or equal to the threshold value are identified as being of interest. The program measurement algorithm then associates the identified pixels to form the objects that are then measured and reported. The associated pixels forming the object of interest, in our case a dot image, are further analyzed to compute the mean luminance value of all the pixels within its perimeter, i.e. its brightness. The series of dots shown below illustrate how the software computes the mean luminance at five (5) progressively higher threshold values. These multiple thresholds are set using a rigid mathematic progression that measures the dot from its core or darkest value through to its fully wicked condition.

The pictures below show the same single black inkjet dot printed on uncoated white paper measured by the software using the progressive threshold. It is the same dot in all the pictures taken from the system in an actual test.



Mean: 77.29 Mode: 68 Med: 71
StdDev: 18.16 Circ'ty: 16.89
Eq. Diam.: 2017 µm Range: 100

Mean: 80.36 Mode: 68 Med: 71
StdDev: 23.47 Circ'ty: 16.61
Eq. Diam.: 2057 µm Range: 120

Mean: 83.78 Mode: 68 Med: 72
StdDev: 29.17 Circ'ty: 16.27
Eq. Diam.: 2095 µm Range: 140

Mean: 89.23 Mode: 68 Med: 72
StdDev: 37.43 Circ'ty: 17.49
Eq. Diam.: 2147 µm Range: 160

Mean: 108.4 Mode: 68 Med: 75
StdDev: 57.75 Circ'ty: 79.28
Eq. Diam.: 2324 µm Range: 180

(1) (2) (3) (4) (5)

Figure 5: *Example images showing the thresholding process.*

Below each of the images are data and the pixel luminance histogram derived from the application of progressively higher thresholds. The green line traces the perimeter of the dot.

With the lowest threshold in Figure 5, the core or darkest portion of the dot is measured, as indicated by the equivalent diameter (Eq. Diam) measurement of 2.017 mm. As the threshold is changed the measured equivalent diameter becomes larger and the other property measurements change as well. Of primary interest is the variation in the pixel luminance value within the perimeter of the dot. The degree of variance in the dot mean pixel luminance measurement from low (core) to high threshold (maximum wicking) is the prime determinant of inkjet wicking. By computing the standard deviation of the mean pixel luminance value within each dot perimeter the IA program presents us a measure of ink wicking and image quality. In the pictures above:

The mean pixel luminance within the perimeter:

1. 77.29 (The minimum or core of the dot)
2. 80.26
3. 83.78
4. 89.23
5. 108.4 (The maximum wicking into the inter-space)

The Mean Pixel Luminance Standard Deviation: ---- = 12.35

The Mean Pixel Luminance Standard Deviation is proposed as the basis of comparative measurement of substrate quality for inkjet print.

Inter-color bleed is also an inkjet quality problem that is similar to wicking. This inter-color bleed depends on the colors that are being printed and can have an adverse effect on small colored text printed on a colored background. Line width and raggedness are defined in ISO 13660 and parts of this method will be used to evaluate the printed samples by substituting dots for lines.

For this research the following hard- and software was used to evaluate the printed samples:

- VerityIA MicroDot V 1.1 (now called Inkjet lines and dots)
- Epson Scanner, Model #
- Windows7 PC with 2GB RAM
- ImageJ V1.45s
- Interactive 3D surface plot plug-in

Prints made with large format printers from Océ, Epson and Fuji. Inkjet prints were made with water-based inkjet inks and UV-curable inkjet inks. There was also one UV-LED system tested. The other UV-curable prints were made with a mercury-vapor lamp as a source for the UV radiation. The following figure shows the scanner together with the sample weight to ensure that the sample is lying absolutely flat against the platen and that all samples have the same white background for measuring.

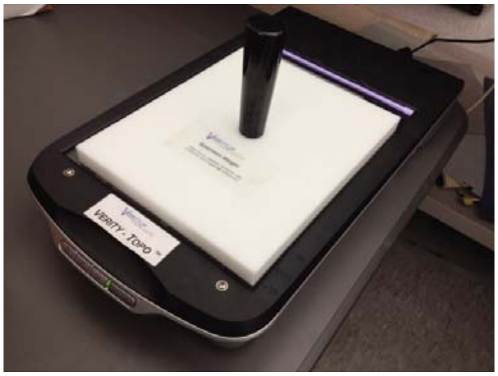


Figure 6: *Epson scanner with sample weight*

The following figure shows the test pattern that was included in the testform, so all samples will be evaluated similarly.

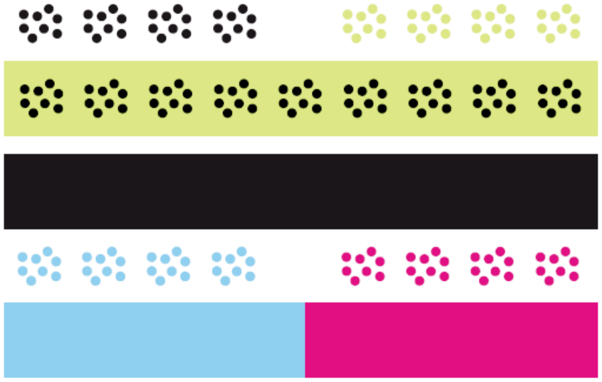


Figure 7: *Test pattern used for the determination of the inkjet wicking properties*

Besides the determination of the "Mean Pixel Luminance Standard Deviation" for the inkjet wicking properties of the samples the topography of the tested samples and the dot circularity were also determined so comparisons can be made to say how these two parameters correspond with the mean pixel luminance standard deviation.

The tested materials ranged from very smooth to quite rough. This is illustrated in the topography values that were obtained in this study. They ranged from 38.05 (very smooth) to over 3000 (quite rough). The following figure shows exemplary 3D-plots of some of the tested materials.

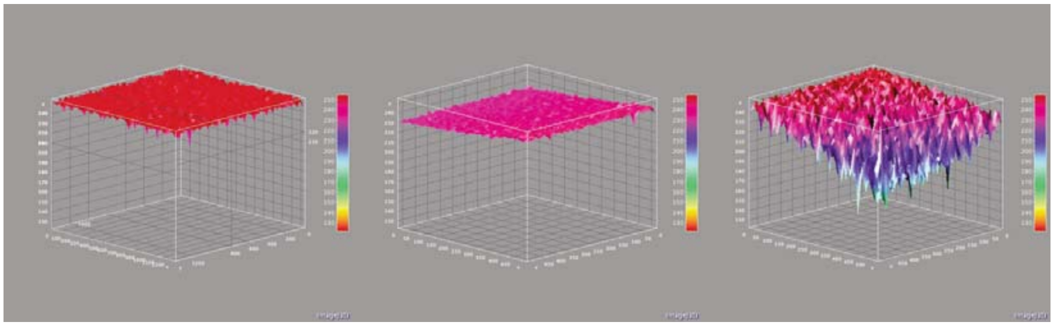


Figure 8: *Exemplary 3D topography plots. Topography values were 38.05, 399.1 and 2561 from left to right*

In the first analysis the obtained circularity values were plotted against the topography values of the tested substrates.

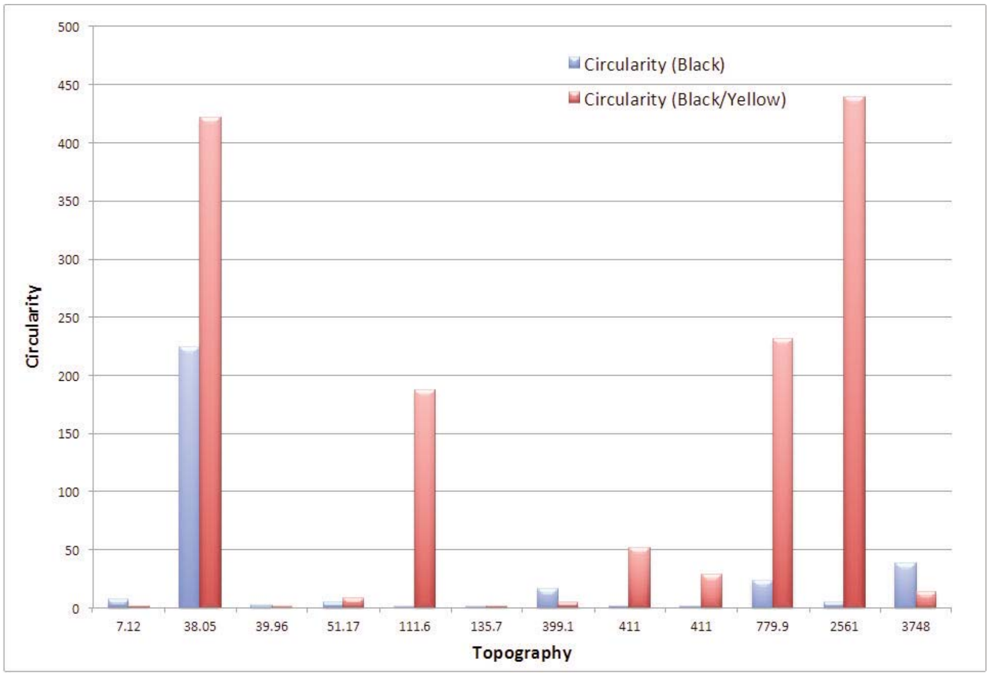


Figure 9: *Circularity results of the tested substrates vs. the topography of the tested substrates*

From Figure 9 it can be seen that the circularity results vary drastically, independent of the topography values of the tested substrates. The red column shows any inter color bleed that is occurring between the black dots and the yellow solid shown in Figure 7. The relatively smooth paper with a topography values 38.05 shows quite an irregular dot and a lot of inter color bleed, while the roughest substrate with a topography value of 3748 shows quite a round dot and very little inter color bleed. It needs to be seen how this comparison works in relation to the proposed mean pixel luminance standard deviation. This can be seen in the next figure.

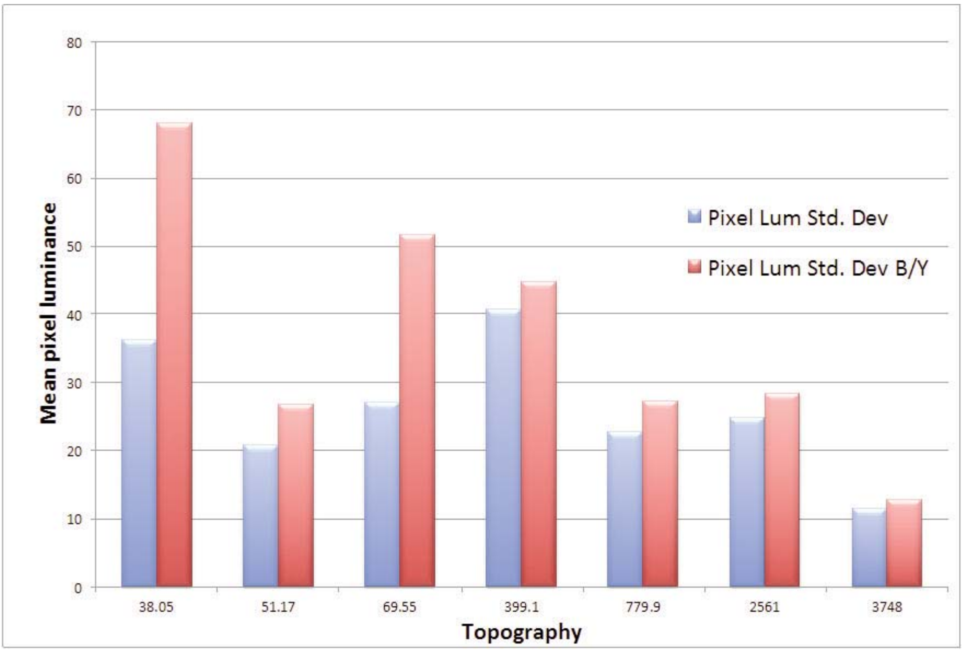


Figure 10: *Mean pixel luminance standard deviation vs. topography of the tested substrates*

Figure 10 shows a much clearer picture. All tested substrates show some inter color bleed, but the results are not as drastic as they were shown in figure 4. It is now possible to compare substrates over a wide range of surface topography values for their properties in regards to inkjet wicking and inter color bleed. The substrate with a topography value of 38.05 shows more inkjet wicking than the papers with a rougher topography. The last three substrates in Figure 10 show less ink wicking and less inter color bleed than the substrates with smoother surfaces. A smooth substrate surface is not a guarantee for a superior print quality as revealed in the roundness of the tested dots.

The next two figures show the results in regards to circularity and topography.

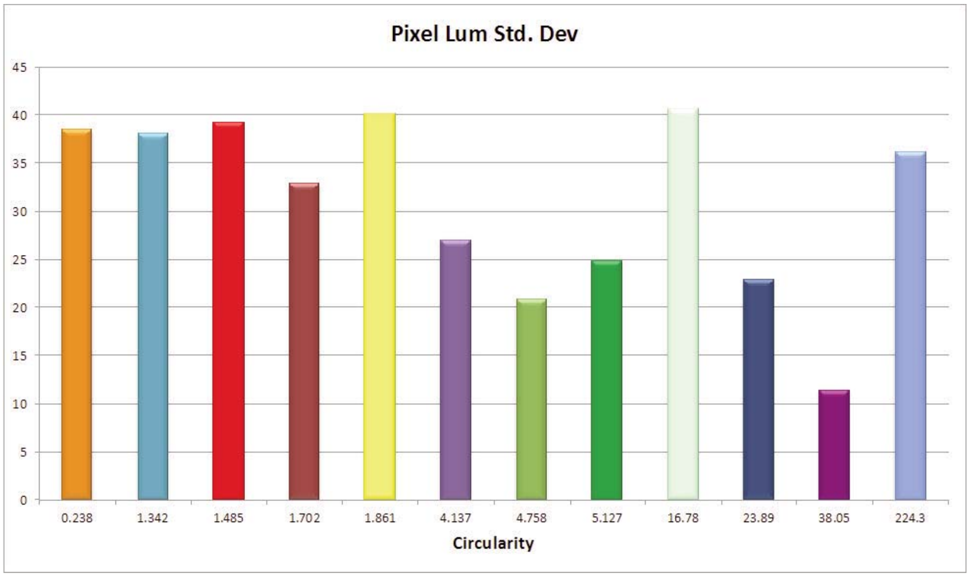


Figure 11: *Mean pixel luminance standard deviation vs. dot circularity.*

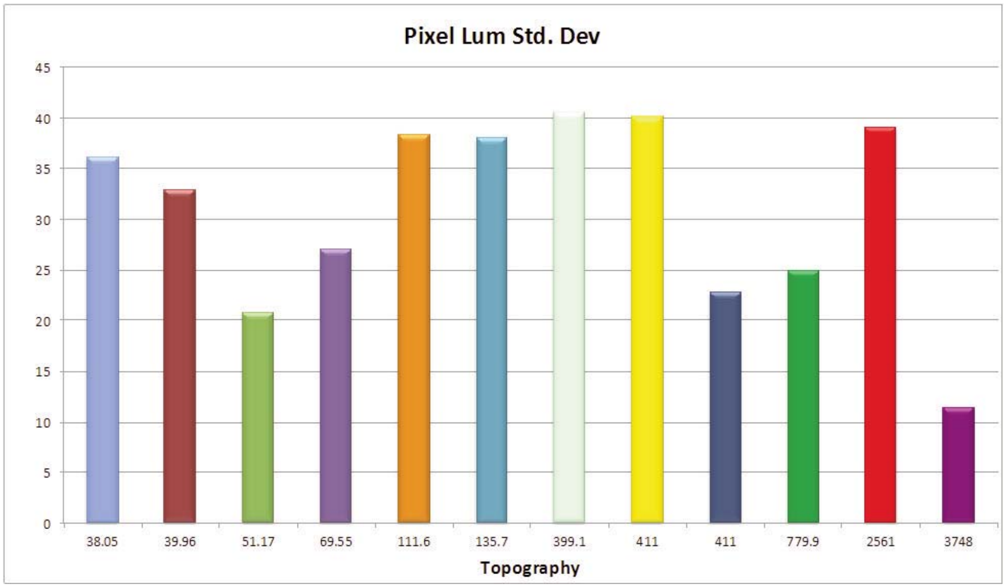


Figure 12: *Mean pixel luminance standard deviation vs. topography.*

Figure 11 and Figure 12 contain the results from all the tested prints on different substrates. The columns have been color coded to show how the order of the tested systems changes. For example the light blue colored system in figure 11 has the highest dot circularity number, which means that the dot is not very round on a quite smooth substrate as can be seen in figure 12. The results from these two figures for this system mean, that the dots themselves are not very round, yet the paper shows a decent amount of ink wicking. There are substrates with a rougher surface, meaning higher topography values, yet the paper shows less ink wicking than a smoother substrate. This example can be seen in the olive green column in Figures 11 and 12.

In the next figure the values for the black dots and the inter color bleed for black and yellow are shown.

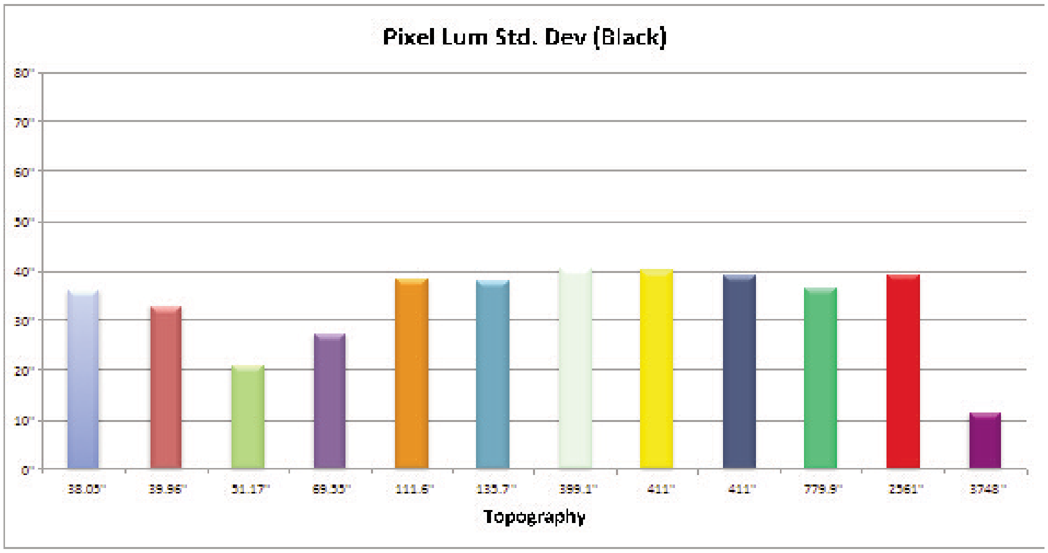


Figure 13

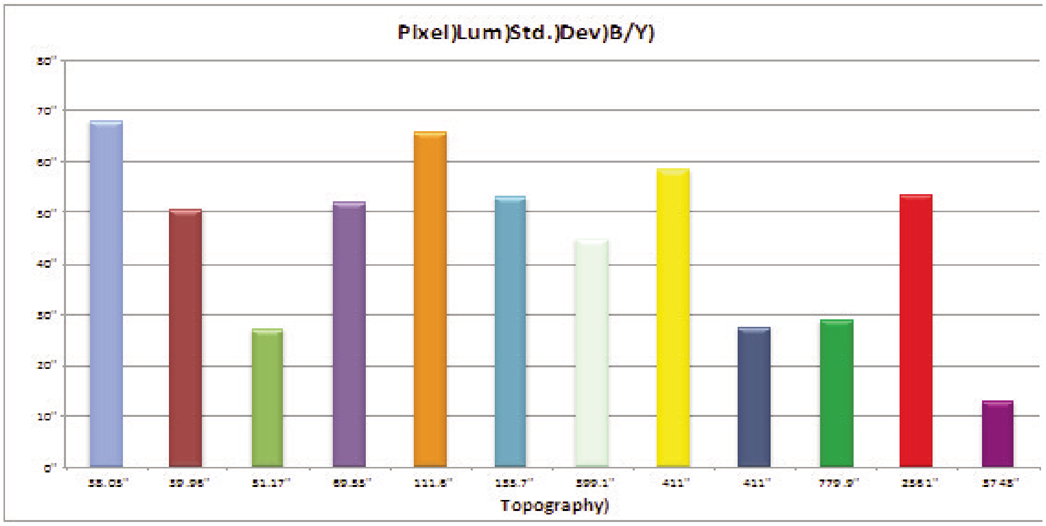


Figure 14

Figure 13 and Figure 14: Mean pixel luminance standard deviation for black and black-yellow intercolor bleed

From the top part of Figure 13 it can be seen that although the tested substrates get rougher and rougher the wicking properties remain quite stable. This is an interesting find, since it means that these substrates are capable of holding an inkjet dot quite well even though the printed surface gets quite rough. The last of the tested systems, symbolized by the purple column was quite fascinating. The paper was of a bond type quality and the print was made with gelled water-based inkjet inks. The inkjet printer is geared towards the architectural market, so CAD-type drawing can be printed quickly and with very good quality, meaning a sharp dot and little or no inter color bleed. The results shown above demonstrate this.

Conclusions

Topography and circularity alone do not give a clear picture if one paper shows more wicking and/or feathering than another. The standard deviation of the pixel luminance shows that a paper with a rough surface can still have less wicking than a smooth paper. A combination of circularity, topography and standard deviation of pixel luminance is needed to assess the wicking properties of a paper and the inter color bleed that can take place between two colors.

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