Establishing of thresholds

The ink distribution

To establish the threshold level of the PIXE measurements the following procedures has been used. In figure 1 the number of pixels with values greater than a certain threshold is plotted on the y-axis. On the x-axis the threshold level is varied. All 8 examined screen dots exhibit the same characteristic sharp edge near the threshold level of 0.005, a numerical figure proportional to the amount of copper. The first edge defines the minimum detectable level, i.e. one recorded Cu x-ray photon. The other edges are equal to two photons, three photons, etc.

To illustrate the relevance of this behavior a screen dot is plotted with three different threshold levels, figure 2. The positions of the threshold levels are chosen on the plateau between two edges. A 0.0025 threshold gives a large amount of responses from the non-printed background. These responses in the background are caused by the statistical nature of the detection method. The noise disappears if the threshold level is increased to 0.006. Increasing the threshold to 0.0125 corresponding to two photons the screen dot becomes smaller. This is obviously a too high threshold because it influences the size of the dot.

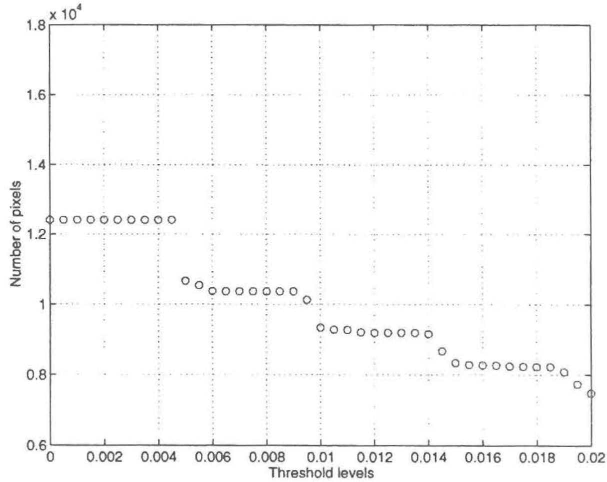


Figure 1: A typical threshold diagram from a screen dot.

Threshold level 0.0025 Threshold level 0.006 Threshold level 0.0125

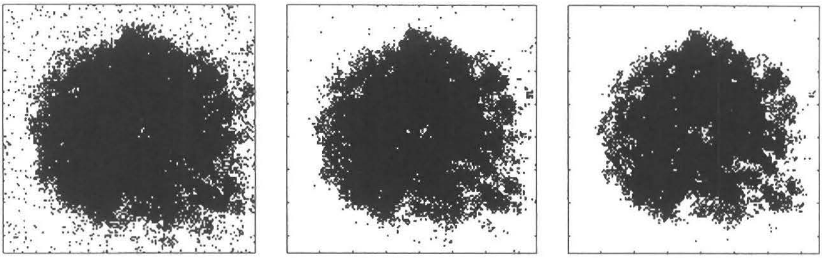


Figure 2: The lateral pigment distribution with different threshold levels.

The optical response

The optical response of the screen dots was measured with a three-chip color CCD camera and transformed into the HSI-color system. The optical parameters outside the border of pixels which contain ink is of special interest. An algorithm has been developed to calculate the shortest distance from a pixel with no pigment to the nearest pixel containing pigment. Taking the mean value of all such combinations for a certain distance, a "distance map" of the optical parameters can be constructed as shown in figure 3a-c. The distance is measured in μm and the vertical axis is expressed in percent of the mean value inside the screen dot for each parameter.

Figure 3a shows that the hue value decreases in proportion to the distance from the screen dot. If one describes the hue variations as a spectral change it will range from cyan at distance 0 to light green at a distance of 50μm. At a distance of approximately 50μm and beyond, a background appears which represents the unprinted paper.

The saturation parameter decreases rapidly with increasing distance from the printing dot. At a distance of only 4μm the saturation value has been reduced to less than 30% of the mean value inside the screen dot. Plotted in a log-log diagram, figure 3d, it appears that the transition from the dot border to the unprinted paper consists of two separated zones.

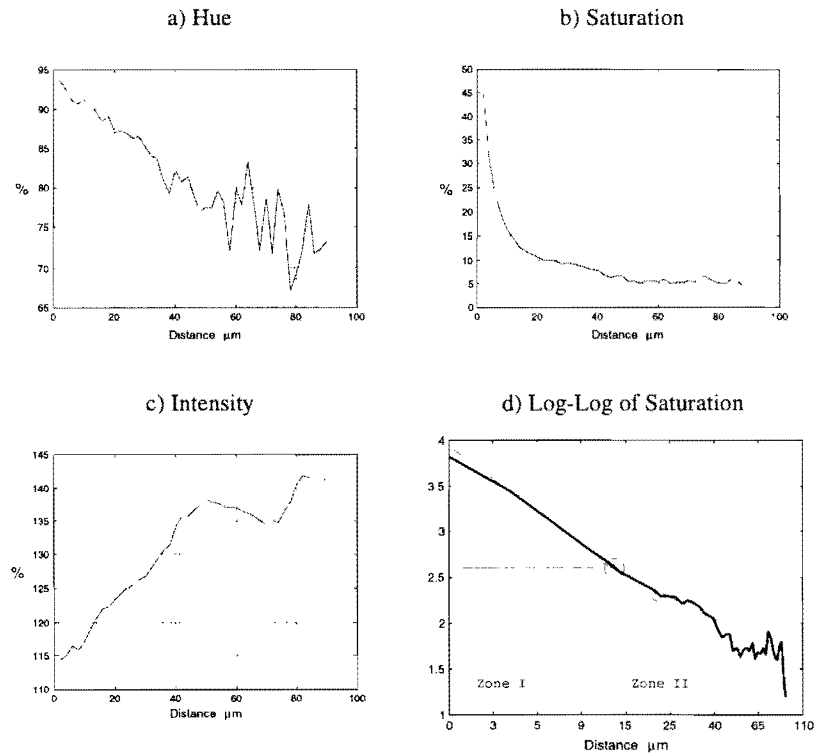


Figure 3: The optical parameters as a function of distance from a cyan pigment for screen dot A.

The two zones probably represent two different mechanisms dominating the optical response. We interpret the first zone as dominated by optical dot gain caused by light scattering in the paper structure and light absorption from pigments in the dots. The second zone can be interpreted as dominated by paper darkening due to oil penetration in the paper structure and thus less light scattering. We choose the intersection between the two lines as the limit for the pigment influenced dot gain.

According to the discussion above the threshold level for dot A were determined to 15% of the mean value inside the screen dot for the saturation value and for dot B 14%. This corresponds to a distance of 12µm for the A and 8µm for the B screen dots. In figure 4 the two dots A and B are illustrated with their respective threshold levels.

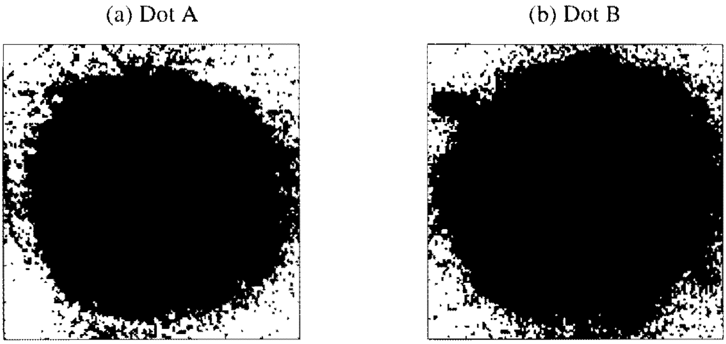


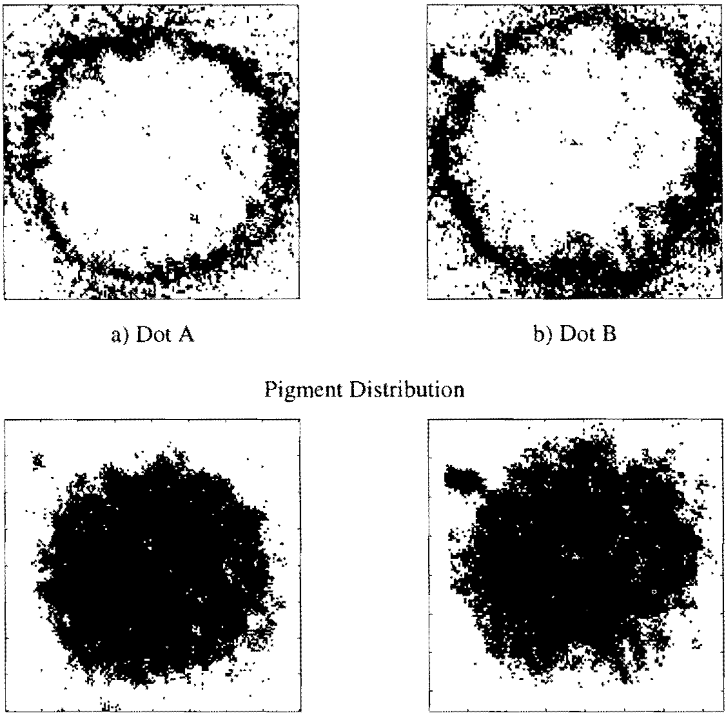
Figure 4: The lateral distribution of the optical response for dot A and dot B.

Scattering of light around the printed dot

To illustrate how the light interaction between the screen dot and the underlying paper structure takes place, a picture is created with all pixels that do not have any measured pigments but have an accepted saturation above the threshold. In figure 5a-b this is shown for dat A and B. Such a picture expresses the area where an optical response has taken place without any presence of pigments. In figure 5c-d the lateral pigment distribution are shown.

From a comparison between the two dots an obvious difference in character and in extension of light interaction outside the screen dot can be observed. In spite of the large distance between the screen dots the optical response tends to bridge the distance between the dots.

Optical dot gain



a) Dot A b) Dot B

Pigment Distribution

c) Dot A d) Dot B

Figure 5: (a-b) The optical dot gain for dot A and B. (c-d) The lateral pigment distribution of dot A and B

Calculation of dot gain ratio

The area covered with pigment and the area without pigment but with an optical response can be calculated by counting the number of pixels belonging to each category. The number of pixels belonging to the dot has been denoted n_0 and the number of pixels without pigment but with an accepted optical response caused by the dot is denoted n. The results are given in table 1.

	n_0	N	ratio
Dot A	11 652	2 408	0,207
Dot B	10 809	3 140	0,290

Table 1: Number of pixels from the true screen dot and from the halo area.

Since the pixel size is 2×2 μm^2 these numbers can be converted to an area and a diameter of a corresponding perfect circular dot.

	Area n_0 (μm^2)	Area n (μm^2)	∅ (n_o)	∅ (n_0+n)
Dot A	46 608	9 632	244	267
Dot B	43 236	12 560	234	267

Table 2: The geometrical properties of the two idealized dots.

The average increase in diameter can be calculated to 23μm for dot A and 33μm for dot B. This difference is surprisingly large for the two closely positioned dots on the same paper.

When plotting the screen dot area as a function of optical dot gain for the eight investigated dots a negative correlation was found, i.e. smaller screen dots shows a larger relative optical dot gain, measured as a percentage of the screen dot area. If the optical halo have a constant width independent of the true dot area, variations in the true dot area means a variation in calculated percentage relative optical dot gain according to,

$$ODG(\%) = \left[\frac{\left(\sqrt{A/\pi} + \Delta r\right)^2}{A/\pi} - 1 \right] \times 100 .$$

Where A is the true dot area and Δr is the width of the optical halo.

This relation, with the width of the optical halo, Δr, being constant, is plotted in figure 7 as a solid line. Plotting the experimental results from the 8 dots in the same diagram reveal a difference between the model and the behavior of the eight measured screen dots. The difference in slope shows that the width of the optical halo is bigger for smaller screen dots. The size difference among the dots are, however, small.

The creation of a too small screen dot as well as the accompanying larger optical gain most probably have an origin in a common cause related to the paper structure.

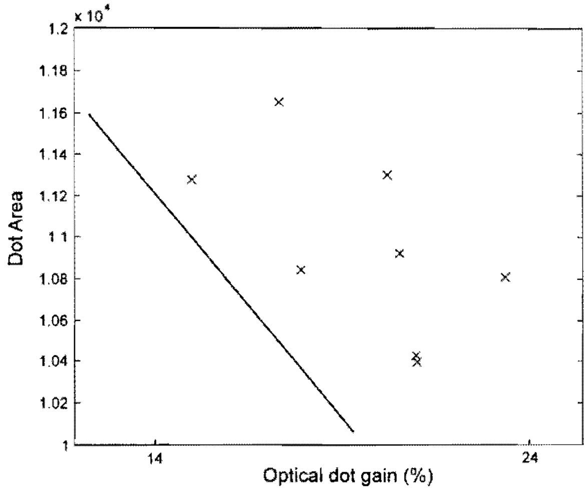


Figure 6: The dot area as a function of the relative optical dot gain for the model and the measured screen dots.

Ink-paper properties and the optical dot gain ratio

The analysis of the relative optical dot gain for the 8 measured screen dots reveal large differences in optical behavior. Therefore, it would be of interest to compare this with other properties of the ink - paper system recorded.

From the NMP measurements it is possible to calculate the average basis weight for each $2\times2\mu m^2$ pixel of the paper just behind the printed dot. In figure 7 the basis weight is plotted as a function of the relative optical dot gain were the screen dot is printed. The plot shows a positive correlation between optical dot gain and the basis weight, i.e. a thicker paper have a larger optical dot gain. The conclusion from this is that the local paper structure has an obviously influence on the optical response.

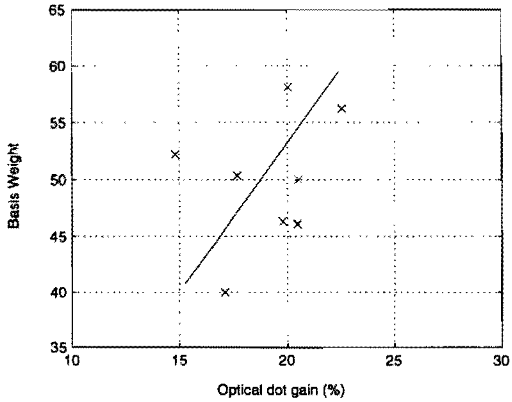


Figure 7: Correlation plot between the optical dot gain and the basis weight of the 8 measured screen dots.

Conclusions

The experimental studies of optical dot gain performed by a non-optical measurement as a reference opens up new possibilities to an insight in the mechanisms responsible for this phenomenon. This is not only of interest from the research point of view, but it also provides fundamental knowledge for the possibilities to manufacture a paper with better printing properties.

Is has been shown that the optical saturation image area is influenced by the paper properties. Furthermore, this interaction appears to be dependent on the local paper properties where the dot is printed.

This indicates a potential for the papermaker to improve the printability of their paper, especially for such grades that have the largest variations on the submillimeter scale of paper-light interaction properties. From the results reported here we conclude that the paper structure has an influence on the potential to make an excellent print on it and that attention from the papermaker should be given to the optimization of parameters like formation, submillimeter distribution of paper density, distribution of functional additives which all influence the scattering and absorption of light in the paper structure.

References

[1] Johansson, S.A.E. and Campbell J.L., PIXE - a novel technique for elemental analysis, John Wiley & Sons Ltd., 1988.

[2] P.Kristiansson, L.Malmqvist and G.Sunnerberg, *Proceedings of the 1994 International Printing and Graphic Art Conference*, pp.77, 1994.

[3] P.Kristiansson, L.Malmqvist, K.A.Sjöland and G.Sunnerberg, *The Lund nuclear microprobe in newsprint research*, Nucl.Instr. and Meth. B 104(1995)584.

[4] P.Kristiansson, K,Malmqvist, L.Malmqvist, C.M.Nilsson and W.Persson, *Procceedings of the 1996 International Printing and Graphics Arts Conference*, pp.39, 1996.