# Color shifts in waterless offset, - trapping or dot gain in halftones?

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## Abstract

Trapping effects in waterless offset were studied with two inks, two halftone types of screening and two coated fine papers as variables to determine which contribute most to color shifts. A scientific test-form was used giving independency on the type/construction of the waterless offset printing press. Color gamut shifts were measured from 2229 patches by running the waterless printing process optimal to press contruction, with linearly adjusted ink keys, printing the test-form at similar fulltone print densities. Thus, the ink coverage was kept as equal as possible in all process inks and ink key positions, with an observed thermal process stability.

Determining the relationship for halftone trapping through color gamut measurements by spectrophotometric means revealed that halftone screening and ink composition dominated over effects from coated fine paper properties.

Differentiating dot gain effects and trapping effects for halftones is difficult while using only densitometry and spectrophotometry. Through spectral measurements we may still determine how different variables induce color shifts, however we can not clearly determine the actual reason. For waterless offset, using no dampening solution, color shifts in halftones seem to arise mainly from dot gain. This means that correct pre-press adjustment is crucial to control accurately, i.e. through compensations in each process inks separately, or by using color management profiling, to maintain highest possible print quality in the chosen production based printing configuration with locked consumables.

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# Introduction

Thermal process stability is crucial to maintain during the calibration phase of a waterless offset printing process. Waterless offset has been less investigated with regard to trapping, but high temperature differences on the rollers and cylinders has been reported by Chou *et al.* (1996). Chung *et al.* (1994, 1995) investigated differences between waterless and conventional offset, where the focus was more on basic quality parameter differences such as print density, dot gain and process solid ink density during production related runs. It is pointed out that it is important to control the process temperature. Wong *et al.* (1995) targetted color space, dot gain and print contrast in web fed waterless offset, however with relatively little data on the actual gamut, and limited only to control-strip information related to process ink consumption on a known area coverage on plates. Thus information on color shifts in the whole reproduction range of colors during printing trials has not been revealed in detail. A printer, Anon. (1994), declares that ink intensity, e.g. pigment content in ink, clearly improved sharpness and ink-trap efficiency for high resolution screen waterless offset, where the ink consumption at the same time is probably maintained at a relatively low level. And note that in waterless offset there is no dampening solution diluting the inks through emulsification.

Traber (1995) reports that proper temperature control is crucial to obtain accurate reproduction of color hues in conventional offset containing dampening solution, where ink rheology and ink/dampening emulgation is highly influenced by temperature variations. This may also influence ink trapping, i.e. wet ink applied upon a previously printed wet ink layers, which still prevails in offset printing processes of today because there is no drying present between the inking stations in multi-color offset ink transfer.

Ink trapping can be investigated in the laboratory, e.g. as done by Truffi *et al.* (1995). Laboratory measurements are made usually as two-color printing using only fulltone area coverage without any properly emulsified dampening solution, or dampening prevailing on the surfaces, to create secondary colors. The time elapsed after printing the first ink in laboratory is usually long, or the first ink is down is probably let to dry, prior to application of the second ink. The difference between laboratory conditions and a real offset press, additionally studies without dampening, means that this may not give the right answers towards reality, and information on how halftone areas respond is in practice not yet revealed at all. On the laboratory level, it is however possible in the waterless offset field to study halftones, although results have so far been reported on single colors. Nordström and Alm (1997) have shown that such data can be correlated to a sheet-fed waterless printing press.

Trapping determinations have generally been made using fulltone (100% coverage) ink layers, measured from either well-defined analog strips on film, or as digital postscript/encapsulated postscript on lay-out software being used in color separation, digital sheet pagination and/or plate setter level. These control strips, as developed and explained by Schmitt (1997), do not take into consideration the whole layout and its ink consumption, nor printing press ink delivery capacity/stability related to a printing job. Thus we have undefined ink coverages of process inks upon the whole area of rotation in an offset press, and the layout may affect the results gained when these excellent digital strips are used. Solutions and measuring methods have been developed over the years by Brunner (1989), Dolezalek and Besson (1990), Löffler (1991) and Pfeiffer (1992) which all basically work in a similar way measuring a part of the layout, without taking issues mentioned above into consideration.

Davidson (1969), Schläpfer and Keretho (1979) underlined the importance of trapping, especially in multicolor printing to avoid set-off and aid ink drying. Hamilton (1985, 1986), Field (1985), Holub *et al* (1986) and Seaton (1991) have all seen trapping as important, especially while going further from the area of print density characterisation to spectrophotometric determinations. More work is still required, especially characterisations within the present waterless offset printing process.

Trapping determinations and explanations have been made in several ways over the years. Several equations have been proposed to calculate ink trap, mainly for fulltone coverage where the trapping effects are clearly dominant. Preucil (1958) defined apparent ink trap as

$$T_P = \frac{D_{OP} - D_1}{D_2} * 100 \qquad (1)$$

where $D_{OP}$ is the print density of the overprint , $D_1$ the print density of the first down ink, $D_2$ the print density of the second down ink. Trapping in equation (1) is thus defined as 100 times the ratio of the observed ink-layer density of the second ink to the expected ink-layer density. This equation responds in a linear manner to the changes in ink film thickness and has been criticised because ratios of logarithms (densities) are used rather than antilogarithms. Childers (1980) proposed the following equation

$$T_C = 10^{(D_{OP}-D_1-D_2)} * 100 \qquad (2)$$

, where the letters have the same meaning as those in the Preucil equation. Trapping is defined as 100 times the ratio of the expected reflectance (according to the additivity rule) to the observed reflectance of the two-color overprint. This equation predicts the direction of the trapping change, but overestimates the amount of overtrapping and undertrapping due to its non-linear characteristics.

Brunner (1984) suggested an alternative trap equation

$$T_B = \frac{1-10^{-D_{OP}}}{1-10^{-(D_1+D_2)}} * 100 \qquad (3)$$

with the usual meaning for the letters. Trapping is in this case defined as 100 times the ratio of the observed absorption to the expected absorption of the two color patches. This equation, like the Childers equation, predicts the direction of the trapping change, but is not accurate in predicting the magnitude of the change. The Brunner equation underestimates the amount of overtrapping and undertrapping. Ritz's (1994) suggests that the overprint with the second ink takes the appearance of a halftone pattern, Figure 1., and his definition of ink trapping is given by the equation

$$T_R = \frac{1-10^{-(D_{OP}-D_1)}}{1-10^{-D_2}} * 100 \ . \qquad (4)$$

This trap equation looks thus at the tint of the second printed ink layer as a halftone and uses the Murray –Davies equation for the second printed ink.

**Figure 1.** Ink trapping; when printed directly on paper, both the first-down (D1) and second-down ink (D2) form a uniform film. When they are overprinted (Dop) though, the second down ink film resembles a halftoned image.

Although the proposed equations of Childers (1980), Brunner (1984) and Ritz (1994) none of these have been found to be important in the present work, and thus only Preucil´s (1958) equation is used.

Cerný and Kaplanová (1998) have measured fulltone trapping on different papers from a control strip, whereas trapping values based on Preucil were significantly lower for uncoated papers. In KCMY printing order, measured green trapping (C+Y) is very high, probably because the non-image areas of the magenta inking station blanket backtraps the cyan and sets the cyan ink into the substrate structure and thus enables a higher trap level for following yellow ink printed last. Ink coverage upon the printing plate, the look of the actual layout and compatibility for these inks to the used printing press has not been revealed in detail. Only one single four color set of inks was used in the study, although in practice, different papers are printed with various types of inks, usually configured to be run beneficially in a specific construction of the inking station/press. These inks used were intensive inks, containing probably a high level of pigments, giving a thin ink film thickness upon the substrate. This maximises the effects arising from the substrate, in a combination with effects from inking of the plate, quality issues for the plate (smoothness, evenness) and blanket characteristics (ink release, compressiblity, evenness, impression holdout, resistance to wear). Ink film thickness, or gravimetric amount of ink per area on substrate related to a well defined print density, has not been discussed.

Ruokosuo (1994) also estimated changes between different parameters and different inking characteristics (anilox versus conventional) from control patches in a strip for newsprint, whereas the layout in the production can have a huge influence on the results, i.e. layout effects are not reported in detail, e.g. what the other ink transferring areas look like, which were close to the control patch and strip.

Paul (1998) has studied extensively color fluctuations in offset printing and defines new ways to determine secondary colors in the midtonal range, which is seen as a sensitive area to the human response while viewing a reproduced image. The model explained is very interesting, although the data to support it may have some minor questionmarks in connection to the actual layout printed and its runnability on a offset press using dampening solution, because no clear explanation is given on the layout. Thus more reproducible data is needed from a well-defined layout principle, having more variables in inks, halftones and substrates, to find out which of these parameters are the most dominant for color fluctuation, and how they suit the proposed model.

## Main aim in this work

When an image is processed from RGB scanned data to a CMYK system some of the colors present in the original image are lost as the color gamut shrinks, mainly because of the way secondary colors are created, i.e. RGB in additive and CMYK in subtractive way. Part of the shrinkage in the color gamut is generally attributed to the fact that ink trapping in CMYK case is not perfect in offset. The amount of ink transferred on a previously wet printed ink film is smaller than the amount of ink that would be transferred to the paper alone under the same press conditions, i.e. we lose e.g. 20% to 50% of the second ink printed. In addition to this, light has to pass through the layers of ink applied in the subtractive way to create the color wanted, thus transparency/intensity of ink is limited to accept a show through. Thus also inking order can have effects both for physical as well as for optical reasons, especially in halftones. Trapping is usually measured on fulltone areas of the inks used, and measuring trapping in halftoned areas is a new task to determine in detail. Both mechanical and optical dot-gain influences the optical measurements of the halftoned areas and additionally trapping effect may induce some deviations. Paul (1998) has made an approach into determinations for halftones both in theory and in practice.

The objective of this work was to try and separate the effects of trapping from the effects in dot gain, and to study in realistic printing how the color gamut is affected by paper/ink/screen as variables within waterless offset printing. This work was also done to verify that a newly created and carefully defined layout is beneficial, e.g. to determine the color gamut in a more objective way. Eight different combinations were studied, as shown in Table 1.

**Table 1.** Eight different runs by changing the three original variables (screen, ink and paper).

| [redacted] | [redacted] | [redacted] |
|---|---|---|
| Glossy | Yes | 133 |
| Glossy | Yes | 175 |
| Glossy | No | 133 |
| Glossy | No | 175 |
| Silk | Yes | 133 |
| Silk | Yes | 175 |
| Silk | No | 133 |
| Silk | No | 175 |

Color charts printed with all these combinations of variables were measured and the differences in color gamuts were evaluated (looking at the gamut as a three-dimensional volume, i.e. 3D-object). Great attention was made to ensure that parameters such as optical print density, press temperature and press speed remained as constant as possible in a realistic printing facility. In addition, the use of a scientific layout STFI-JEP™, STFI - Justified and Enhanced Print *(pat.pend.)*, established by Nordström (2001), was used to diminish effects of the offset press construction. The method enables printing with linear ink key setting, minimising control stages for impositioning (register control) and inking adjustment, making it possible to control and evaluate the whole printed area objectively with high repeatability with a connection and concern to the printing equipment used (press capacity and capability). STFI-JEP™ makes it possible to minimize the amount of consumables used during the chosen type of a print run, in this case optimal for the chosen waterless offset press.

## Materials and methods

The materials used in the offset printing process count for a major part of the parameters involved. It is thus crucial to define the materials in detail. In this study, only paper and inks have been changed. Films were taken from the same batch of a film roll; plates from the same batch, all process chemicals were used in a defined way, all trials were performed in a narrow time-span with a well-controlled, relatively new and properly adjusted/temperature controlled machinery. The complete pre-press, press and post-press equipment are located at a commercial print house and are used in daily production, running waterless offset only.

## Substrate

Two different kinds of paper were tested as substrate, one matte silk and one glossy. Table 2 summarises the main properties of the two papers as printing substrates. Both base papers were made from chemical pulp and were double coated and calendered off-line. These coated papers were chosen since they reproduce well the chosen screen rulings. The papers were chosen to give good press run, i.e. feeding of the sheets without a process stop, and excluding problems as picking and piling, which could occur due to a high tack of too cold waterless inks run at high speed in the press. The two papers had the same grammage, brightness and opacity, while the glossy paper was slightly thinner (i.e. higher in gravimetric density, or lower in bulk) and had a smoother surface than the matte silk one. The paper sheets had a size of 420*650 mm (which yields A2 printed sheets), with the paper fibres oriented mainly in the short direction of the sheets. Thus paper was printed in the cross direction (CD).

**Table 2:** Properties of the two analysed substrate qualities.

| Paper type | Grammage (g/m$^2$) | Thichness (um) | Roughness (um PPS10) | Brightness (ISO %) | Opacity (%) | Gloss (Hunter 75) |
|---|---|---|---|---|---|---|
| Glossy | 130 | 100 | 0.6 | 91 | 96 | 77 |
| Matte Silk | 130 | 113 | 1.3 | 91 | 97 | 33 |

## Inks

Two different four-color ink series were used. Both ink series were developed for waterless printing only and were based mainly on vegetabile oils. Mineral oils were according to the manufacturer replaced by fatty acid monoesters obtained from a vegetabile source.

Compared to common waterless offset inks, the tested ones had, according to their manufacturer, lower viscosity, lower tack, better oxidative drying and better gloss. Unfortunately the exact compositions of the inks were not available from the ink manufacturer, who however guaranteed that the only difference in the composition of the inks was the presence of a small amount of polydimethylsiloxane (approx. 2 %) in one of the four color ink sets. The additive was according to the manufacturer added to all inks in the four-color set. In the future more openly discussed ink fomulations would aid tremendeously the general understanding. Ink manufacturers are suggested to step forward and reveal more details aiding the whole printing community to be more united against the digital printing trends being the main fear to small sized offset print transferred information.

Polydimethylsiloxane is mainly used to decrease the tack of the ink and also to increase the critical toning temperature (CTT). As all silicones, polydimethylsiloxane can play an important role in the building of a thin weak fluid boundary layer upon the non-image area on the plate consisting of similar silicone based chemistry. Thus, there may exist a risk with inks containing polydimethylsiloxane to reduce the wet trap while creating secondary and tertiary colors because of silicone containing inks upon each other.

## Pre-press

The pre-press stage of the process was particularly time-consuming compared to the printing stage. This was because we wanted a fully controlled print job flow from original to make-ready. If the work (scanning, creating palettes, text, images etc.) in the layout end of pre-press is done in great detail, the work on the press and post-press goes rapidly without problems, once the right combination of consumables has been chosen and used correctly in the calibration runs.

### Page layout

An effort was made to minimise the variables involved in the process, mainly through controlling the print test-form layout. At the same time a shortest possible make-ready time could be reached and also process stability established (ink-flow through the press), thus saving expensive consumables (which usually prevails in reserach with model and pilot manufactured materials). In addition we get better reproducibility, i.e. running the same type of a trial with a defined layout, the variables investigated respond similarly in the previously found way.

The layout was planned in order to require a constant amount of every process ink per plate coverage on the press and a possibility to reach make-ready in a shortest possible time [2]. Effects such as uneven distribution of ink on the plate, or layout-induced deviation, is avoided (e.g. ghosting from defects in plate inking etc.). The data obtained in one area of the sheet can be related to other parts of the same sheet with the greatest possible process accuracy. The page layout in this work was divided in the PMD (printing machine direction) into two areas, upper half for gamut characterisation and lower half to fill the ink covered areas to reach a linear control for ink keys. The total area coverage of both areas was locked to the actual coverage and the capability for the chosen waterless offset printing press inking station construction. While coverage is known on plate, ink consumption is also easily gravimetric calculated during print runs from the difference of ink in/out from inking duct versus rotations made.

The gamut characterisation area in the layout was in this work based on a commercially available palette chart, which was created by mixing different amounts of the four process inks in KCMY printing order to obtain a uniform coverage of the printable color gamut. This means that once some parameters

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[2] The concept is called STFI-JEP™ (STFI - Justified and Enhanced Print). STFI ( http://www.stfi.se ) and Nordström (2001) has a patent pending upon the concept.

such as total dot coverage, UCR and black point were chosen, the used software created a digital sheet containing spots with suitable process color mixes. Table 3 shows the settings given for the palettes made and Figure 2 the visual look.

**Table 3.** Values for total dot and UCR parameters used in the used color palette. The chart was composed by 2200 color squares and additional 29 squares to measure grey balance.

| Total Dot Coverage | 320% | 280% |
|---|---|---|
| Black Weight | 7 out of 10 | 7 out of 10 |
| Black Start | 50 % | 50 % |
| Max Black | 100 | 100 |
| Color Squares | 2229 | 2229 |

- Size of the layout was A3. Since the sheets in printing were in A2 format, two layouts of the same kind were put beside each other on the same plate using two different screen resolutions (133 lpi and 175 lpi)
- An A4 with 2200 color spot palettes with 29 spots to determine a curve for grey balance was used to create a proper color gamut
- Four series of single process color shades, that enable curves to be drawn for dot gain based on 19 measured points per process color
- Spots where fulltone trapping can be determined for blue (C + M), green (C + Y) and red (M + Y) on several places in the layout
- Spots of 100% C, M, Y and K put on different places in the sheet to check that the ink density of the fulltone single inks is constant on the whole sheet
- An area to host 2 square 4-color images with a 8 cm side, whose ink consumption is compensated by placing negative images for each color just under the originals. Images can be a part of, or not in general connected to the layout. Images can also be replaced in similar manner to images with needed test areas for different interests
- Positioning crosses which can be replaced with digital microscale imposition marks used to control mark the process inks register control/deviation during a print run
- Compensation areas, where a mix of process colors has been calculated to buffer for the ink consumption along the PMD/PCD (printing machine/cross direction) of the sheet, so that the total dot coverage and ink consumption in the used waterless offset press is equal while looking on one rotation. In our case while using dot coverage 320% the layout coverage area was locked to 45% for C, M and Y and 25% for K, which suited the press construction and general ink coverage in products printed in the printing facility. For the dot coverage 280% all inks covered the layout at 25% of the printable area, i.e. best optimum for the cosen waterless offset press constructional need to tranfer properly the ink, where the press was reacting very fast and in a well defined manner on inking changes.

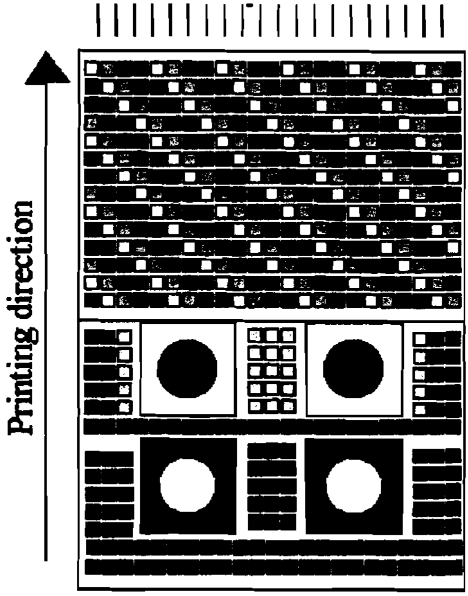

**Figure 2.** STFI-JEP™ concept was used. A schematic view of the A3 page layout using the concept. A commercial test-palette was placed in the top part of the A3 sheet. Image areas, negatives of the images, trapping and process color spots, dot gain spots and compensation areas to enable a run with linear ink keys are displayed in the lower part of the sheet. Press control strip is not located in the layout, they can be chosen according to the need/preferences in the press process control. The whole layout has an even and known ink consumtion in the process inks according to the rotational length, i.e. printing is run with linear inking keys in cross direction, suitable to the press construction.

## Printing press and printing trial

Once the layout was ready, A3 negative films were made. The films were mounted so that the same layout with different screens could be impressed on the same A2 waterless plate. Plates were exposed with an A1 sized frame to diminish distortions on plate edges from the exposure procedure, being careful to do maximal visual image positioning control between the four plates. After exposure the plates were developed with automatic plate processing and cleaning equipment, and thereafter taken to the press.

All the sheets were printed on a B2 sized (52 cm x 74 cm, or 20" x 28") four-color waterless offset press, one side only. The press has no dampening system installed and can only be run waterless. The press can print B2 sheets with a maximum speed of 15000 sheets per hour (approx. 2 m/s). Each inking station is equipped with three rollers that can both heat and cool the press, which allowed a defined printing process temperatures to be maintained during the experiments. Before running the press, sheet thickness was measured and the nip distances adjusted accordingly. The plate inking roller line width in each inking station was adjusted according to specifications, assuring uniform transfer of ink to the waterless plates without any excessive wear of the plates. The print order of ink series was KCMY.

The press was run in all trials at full speed (15000 sheets/hour) and plate temperature was held at 29°C in each inking station with an accuracy of 0,5°C. The thermo-camera used in the thermal test runs had an accuracy of 0.1 °C, Figure 3. Paper consumption was approximately 4000 sheets for each trial point.

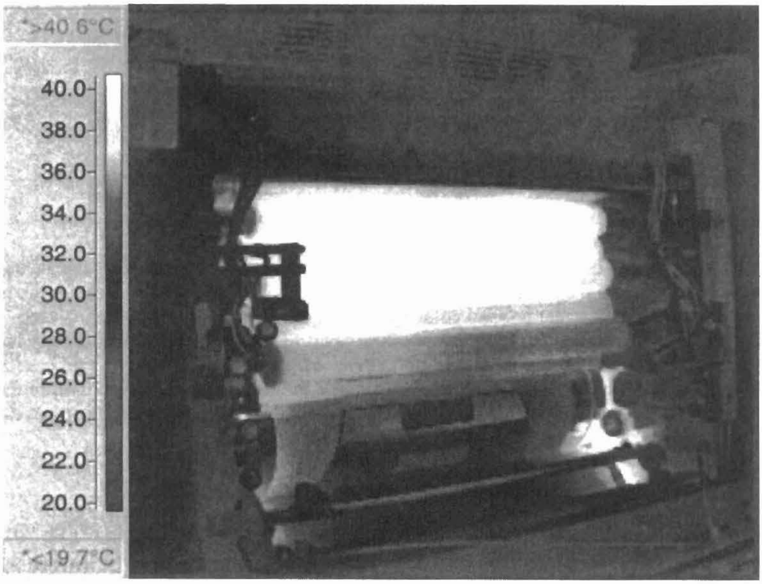

**Figure 3.** Printing press thermal stability during the printing trials.

### Measuring devices

The choice of the measuring devices was made according to their reliability from practice in a co-operation with the printing facility. Both a densitometer (Gretag D19c) and spectrophotometers (Gretag SPM100II and SpectroLino) were used. The data obtained by these devices was treated using different statistic softwares.

During the press run, the densitometer was used to check the ink densities of the four process colors on the commercial reference strip on the tailing edge of the sheets.

In laboratory the densitometer was used to determine print densities on series of sheets in order to check that the printing conditions were stable. Dot gain of the process colors (including both mechanical and optical dot-gain) was determined using the Murray-Davies equation in the densitometer.

The color gamut was measured using 10 nm intervals in wavelengths from 380 nm to 730 nm while measuring the 2229 color patches, controlled to perform a white calibration after every 40 measuring points. A white calibration tablet of barium sulphate was used as reference white. The measures were carried out in a room where no direct light reached the measuring table.

# Results

Ink densities of the different measured sheets are presented, followed by the results concerning fulltone trapping and dot gain. ΔE values between different variables are represented, and finally the parts of the color gamut within the secondary colors that were affected. The results here are pointed towards the needs of the printer arising from end-user interests, i.e. understanding the main effects on color gamut when using smaller screen rulings, and changing the ink and the substrate in specific directions.

## Ink print densities

Optical print densities were checked for each process color during the run and kept as constant as possible. Reference values were locked, suggested by the ink manufacturer specific for the substrates chosen. During the later measurements, randomly picked series of 15 sheets from the accepted stable print run were taken for each combination of variables, and the ink densities were measured again using 50 sheets of unprinted paper beneath. One representative sheet for each series was chosen in random and therafter measured to calculate trapping, dot gain, and to perform the measurements to determine the color gamuts, Figure 4. Time that elapsed between printing and later measurements was in a time-scale of days, i.e. the inks had properly set and dryed on the substrates as in a normally printed product from the printer.

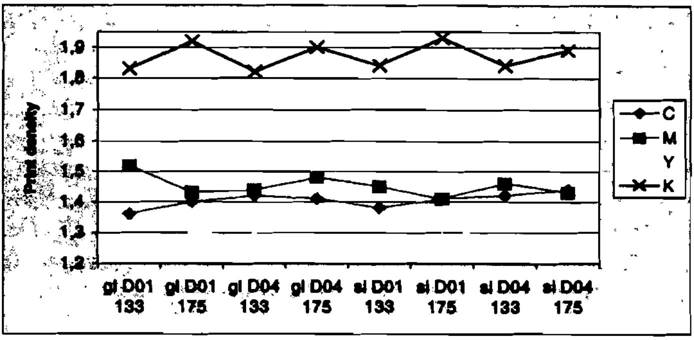

**Figure 4.** Optical print densities (using Gretag D19c) for the randomly chosen sheets for each process color and trial point. Inking order was KCMY.

## Dot gain

Patches with 50% dot on film were measured for every process color and dot gain was calculated using the Murray-Davies equation, Figure 5.

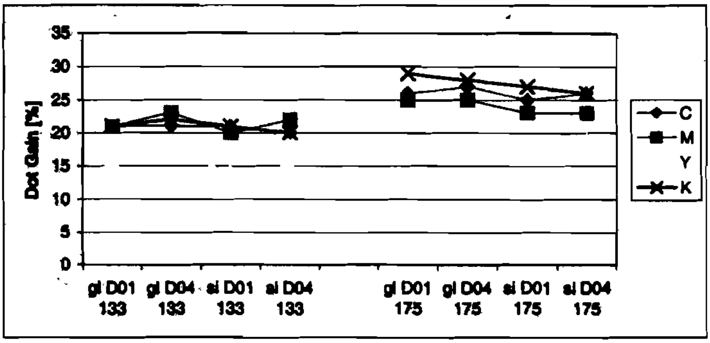

**Figure 5.** Total dot gain (Murray-Davis) measured for 50% film dot; the curves indicate the different process colors and the points indicate the different combinations of paper and ink (gl= glossy, si= silk, D01= ink with polydimethylsiloxane, D04= ink without polydimethylsiloxane). On the left dot gain for 133 lpi screening, on the right dot gain for 175 lpi screening. Printing order KCMY.

Total dot gain, which includes the film/plate exposure/processing dot gain (negative exposure), mechanical dot gain on press (inking/plate, plate/blanket, blanket/substrate) and optical dot gain upon the substrate, reveals that the difference in dot gain between different combinations of paper and inks is quite small. A difference can be noticed between the two different screenings. The 175 lpi screening leads to a slightly higher total dot gain. The value for the yellow dot gain is markedly lower than the ones for the other process inks.

## Fulltone trapping

Fulltone trapping (100% dot covered ink layer on a previously printed 100% dot covered ink layer) was calculated for the three combinations of C, M and Y inks, Figure 6. Trapping values are calculated according to Precuil (1958), equation (1), printed in KCMY sequence (BlacK, Cyan, Magenta, Yellow).

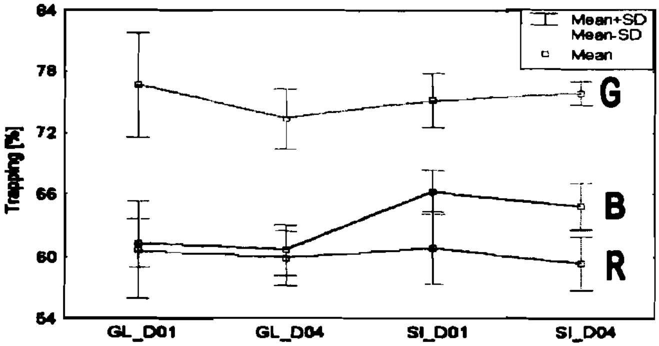

**Figure 6.** Fulltone trapping values for the KCMY inking order according to Preucil (1958) for Blue (M on C), Red (Y on M) and Green (Y on C). The x-axis displays the different combinations of paper and ink (gl=glossy, si=silk, D01=ink with polydimethylsiloxane, D04=ink without polydimethylsiloxane). Mean and 95% confidence intervals have been calculated from 6 measurements from 15 printed sheets in a row.

Trapping values (Preucil) were approx. 60% for red (Y on M), 60-65% for blue (M on C) and between 73% and 77% for green (Y on C) trapping. Trapping values are significantly higher for green (C+Y) than for red (M+Y) and blue (C+M). Blue (C+M) trapping is slightly higher than red (M+Y) on silk paper, while no clear distinction can be made in the case of glossy paper due to the high deviation.

The presence of silicone in the ink does not lead to any significant difference in fulltone trapping. Mean values are generally between 1% and 4% lower in the inks without silicone, and the deviations in the measurements are lower for the inks without silicone.

## ΔE

The spectrophotometer gave CIE L*, a* and b* values for every of the 2229 color squares printed in the palette for every set of variables studied. Three-dimensional CIEL*a*b* color spaces were created, Figure 7 shown as an example. These gamuts represent the range of hues that can be obtained at the chosen printing conditions by the process with a given set of paper, ink and screen ruling.

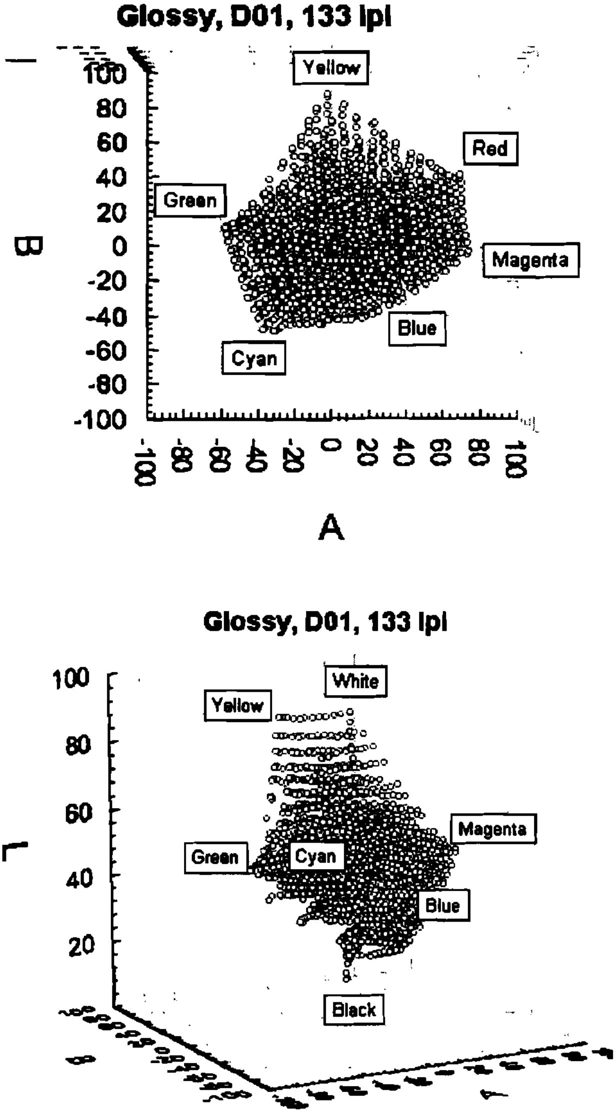

**Figure 7.** Three-dimensional representation in the CIE L*a*b* color space of all the reproducible colors was created for every combination of paper, ink and screening. In this example the color gamut for inks containing silicone, printed on glossy paper at 133 lpi is shown.

Eight color gamuts were obtained, as listed in Table 4 showing the maximum and minimum values for L*, a* and b* .

**Table 4.** Color gamut maximum and minimum L*, a* and b* values for the different variables.

| | | | | | | |
|---|---|---|---|---|---|---|
| Glossy, D01, 133 | 13.37 | -55.35 | -47.69 | 92.92 | 70.48 | 77.35 |
| Glossy, D01, 175 | 11.63 | -54.54 | -47.36 | 92.94 | 70.14 | 80.61 |
| Glossy, D04, 133 | 11.49 | -54.97 | -47.56 | 92.35 | 71.55 | 73.33 |
| Glossy, D04, 175 | 10.12 | -55.01 | -48.24 | 92.07 | 69.39 | 72.07 |
| Silk, D01, 133 | 12.05 | -55.04 | -47.66 | 93.29 | 70.52 | 76.36 |
| Silk, D01, 175 | 11.89 | -53.72 | -46.94 | 93.11 | 69.48 | 79.93 |
| Silk, D04, 133 | 10.52 | -53.89 | -47.20 | 92.50 | 71.35 | 74.60 |
| Silk, D04, 175 | 9.77 | -54.19 | -47.30 | 91.96 | 70.23 | 79.24 |

The deviations between these gamuts were evaluated by calculating ΔE between the gamuts in each printed and measured color square. For example, the value of ΔE marked in Figure 8 as GL_D01, indicates the difference in ΔE between the two screens printed on glossy paper with ink containing polydimethylsiloxane from 2229 color squares in the gamut. In the same way, the value marked as D04_133 indicates the difference in ΔE caused by the two different coated papers when printed with ink without polydimethylsiloxane using a 133 lpi screen.

ΔE alone does not tell the size of the color gamut, in which direction the difference occurs, or in which part of the gamut a color deviation prevails. ΔE indicates only the level of difference from L* a* b* data.

The three windows in Figure 8 refer to (from left to right) differences caused by screening (A), ink (B) and paper (C). Figure 8 contains layout settings where the 280% UCR (filled circles) is evaluated together with 320% UCR (open squares). Press speed was 7500 sheets per hour in the case for 280% UCR and the total layout ink coverages on the plates were 25% in all inking stations for the 280% UCR case.

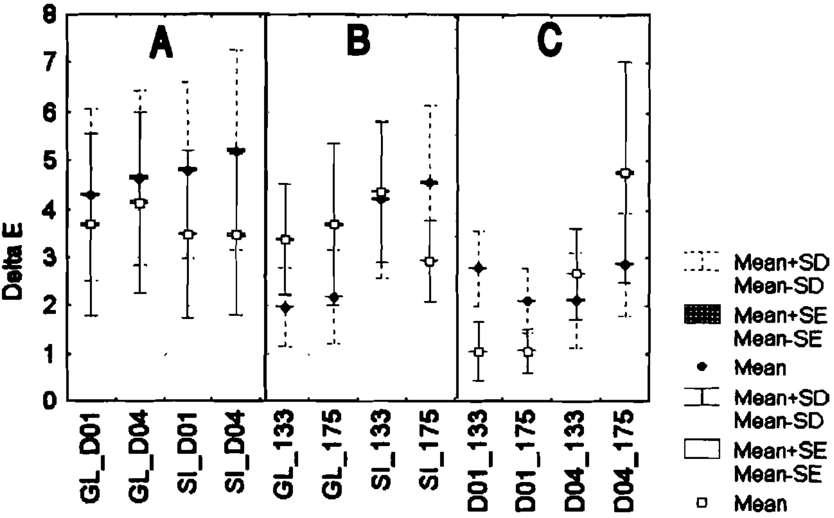

**Figure 8.** The three windows refer (from left to right) to differences caused by screening (A), ink (B) and paper (C). ΔE difference between different total dot coverage, i.e. 280% total dot coverage (filled circles) 320% total dot coverage (open squares). Gl = glossy paper, Si = silk paper, 133-175 = halftones in lpi, D01 = ink with polydimethylsiloxane, D04 = ink without polydimethylsiloxane.

Unfortunately the deviations are so high that no significant conclusion can be drawn for all cases. By looking at the mean values the following was observed:

- Difference in ΔE between halftone screens (window A in Figure 8): Halftone screen type is an important parameter to study, since the difference in ΔE is high (mean approx. between 3 and 5 ΔE). This difference is then almost the same for every combination of paper and ink, with glossy paper giving a slightly higher ΔE in 320% dot coverage. A higher UCR level (280% total dot) gives a slightly higher mean value for ΔE than 320%.
- Difference in ΔE between inks (window B in Figure 8): Different inks cause also a significant ΔE, no clear distinction between values obtained with different combinations of paper and screening can be made. When looking at UCR importance, ΔE diminishes with a higher UCR (280%) on glossy paper and silk paper at low screens.
- Difference in ΔE between paper qualities (window C in Figure 8): The difference in ΔE which is caused by the substrate is very small for the ink containing polydimethylsiloxane (≈1 ΔE), and becomes significant when using the ink not containing polydimethylsiloxane, especially at high screens. UCR level has a different influence depending on the ink used: the inks containing polydimethylsiloxane gives higher ΔE:s with higher UCR (280% total dot), while the ink series without polydimethylsiloxane gives

higher ΔE with lower UCR (320% total dot). 280% UCR (i.e. less C, M and Y and more K) leads generally to less influence from the ink formulation, whereas substrate influence increases.

### Halftone trapping shifts

Only secondary colors containing C, M and Y (blue C+M, green C+Y and red M+Y halftone hues) have been considered, reducing the large amount of data to approximately one fourth by removal of the tertiary hues. Three subsets were made each containing data on a single secondary color (blue, green or red); each set consisted of 170 values. Every subset of data was compared to a similar set of data from other gamuts. The comparisons were made by calculating the difference in L*, a* and b* values between subsets that differed in one variable only. A mean value of the differences obtained was calculated for every couple of subsets. For every secondary color, twelve values were obtained, and these indicated the following:

- A large shift caused by the change of screen from 133 lpi to 175 lpi
- A small shift caused by the difference in ink composition, in particular by removing polydimethylsiloxane from the ink formulation
- A measurable shift caused by the different substrates, changing from the glossy coated paper to the silk quality

These twelve values were finally reduced to three by calculating the mean of the four numbers indicating the difference in one variable (losing the influence of the other variables).

The final values are shown in the following sections, where measured differences caused by different screens, inks and papers are shown. Note that they indicate an average shift over the whole range of secondary colors, and the zero point (the black cross in the figures) corresponds to an arbitrary start position, i.e. no shift is assumed to occur in the zero point.

### Screening

The shift in L*, a* and b* values was calculated for every secondary color. Every value reported in Figure 9 is a mean value of the four values obtained for the four different combinations of ink and paper. The differences indicate the largest shift in this study takes places when "changing" the screen from 133 lpi to 175 lpi.

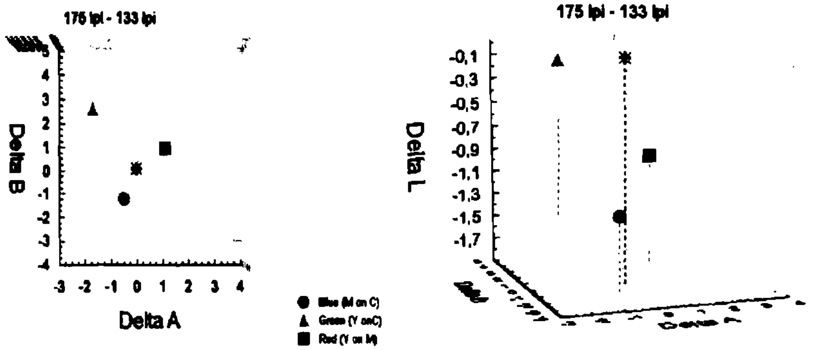

**Figure 9.** Average difference in L*, a* and b* values for the three secondary colors caused by a change in screen ruling for 175 lpi screen withdrawn from the values for 133 lpi screen. The black cross represents the zero, i.e. the point where there is no difference changing the screen from 133 lpi to 175 lpi.

The following trends can be observed for the secondary colors when changing screen from 133 lpi to 175 lpi: Blue hues tend to move towards cyan process color, and to become darker. The mean shift was about (-1.3; -0.5; -1.3) in the CIEL*a*b* units. Green hues tend to increase considerably in saturation while lightness remained virtually the same. The mean shift was (-0.1; -1.8; 2.5). Red hues increased in saturation, but not as strongly as the green, and became darker using a 175 lpi screen. Shift values were about (-0.8; 1.2; 1.0).

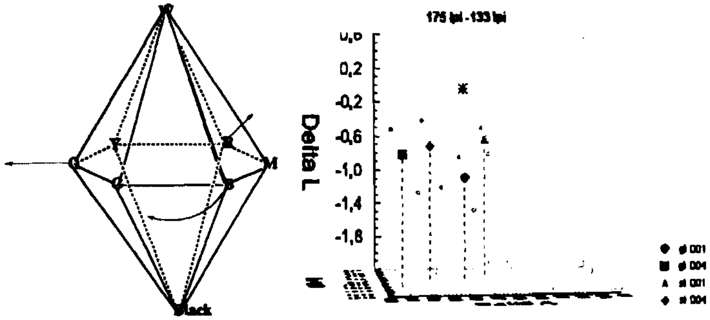

**Figure 10.** Color shifts due to a change in screening; the deformation of the color gamut with regard to hue and saturation (mean deformation for every combination of paper and ink); graph on right showing the difference in lightness. The small open dots represent the change in the lighter half and the filled smal dots the darker half of the gamut.

When changing screen from 133 lpi to 175 lpi the color gamut became darker. The shift in the lighter half of the gamut was more marked than the one in the darker half, leading to a shrink in the range of the reproducible lightness levels in the gamut.

# Ink

Polydimethylsiloxane was the only component to make the difference between the two tested inks, D01 containing polydimethylsiloxane (approx. 2%), D04 without it. Every value reported in Figure 11 is a mean value of the four values obtained for the four different combinations of screen and paper. The differences thus indicate the shift that takes places when "taking away" the polydimethylsiloxane from the inks used.

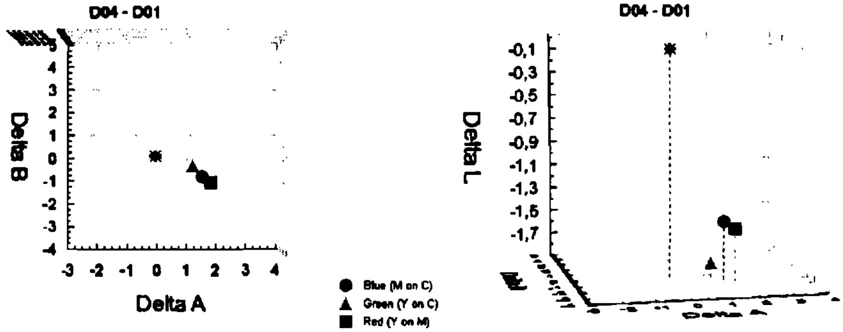

**Figure 11.** Average difference in L*, a* and b* values for the three secondary colors when removing the additive from the ink. The difference was calculated as the value for ink not containing polydimethylsiloxane minus the value for ink containing polydimethylsiloxane. The black cross represents the zero, i.e. the point where there was no difference in L*, a* and b* values when taking away polydimethylsiloxane in the ink composition.

The following trends were observed for the secondary colors when removing polydimethylsiloxane from the ink composition: Blue hues assume a higher saturation, as well as they become darker. The mean shift was about (-1.4; 1.5; -0.8) in CIE-L*a*b* units. Green hues became darker and diminished in saturation when changing ink composition. Mean shift values were in this case (-1.7; 1.2; -0.3). Red hues shifted to the hue of the magenta process ink, as well as they became darker. The shifts were (-1.5; 1.8; -1.1).

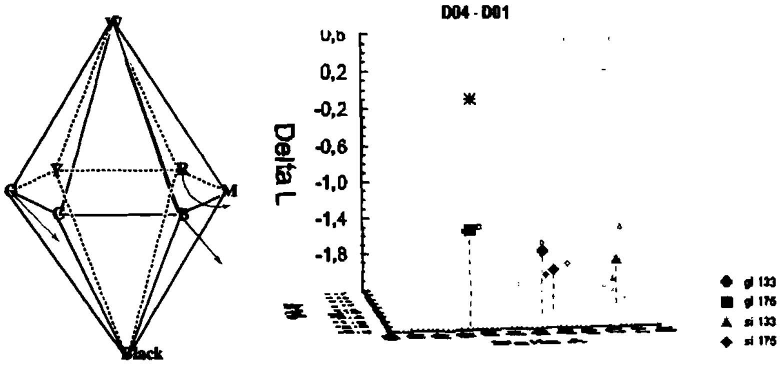

**Figure 12.** Color shifts due to a change in ink composition; on the left, the deformation of the color gamut with regard to hue and saturation (mean deformation for every paper/screen combination); on the right a graph showing the difference in lightness. The small open dots represent the changes in the lighter and the filled small dots the darker halves of the gamut.

The removal of polydimethylsiloxane from the ink composition gave a significantly darker gamut (1.5 delta L*). This shift was usually uniform in the gamut, shown in Figure 12, with the exception of silk paper printed with a 133 lpi screen.

## Substrate

Color shifts depending on the papers were calculated for every secondary color. Every value reported in Figure 13 is a mean value of the four values obtained for the four different combinations of screen and ink formulation. The differences thus indicate the shift that takes place when changing the paper from the glossy to the silk quality.

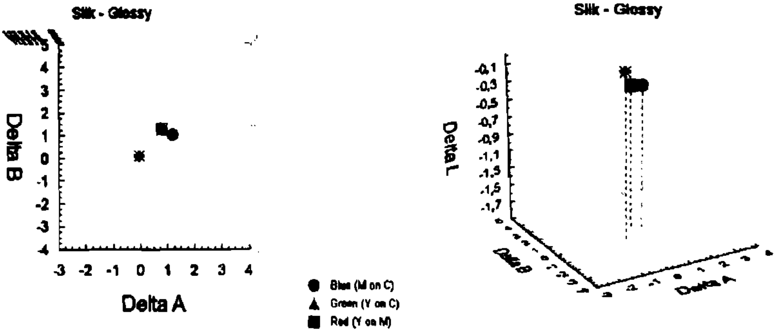

**Figure 13.** Average difference in L*, a* and b* values for the three secondary colors when changing substrate. The difference was calculated as the value for silk paper minus the value for glossy paper. The black cross represents the zero, i.e. the point where no difference caused by the substrates was detected.

When using silk instead of glossy paper, Figure 14, blue tints shift their hue to magenta, while their lightness was not strongly affected. Mean shift values were (-0.22; 1.2; 0.9). Green tones maintain also the same lightness, but the shift in hue was here in the direction of the process yellow. In this case shift values were (-0.25; 0.7; 1.2). Red shades increase their saturation when changing substrate. As the precedent two cases, lightness was not significantly affected. Shift values were here (-0.27; 0.8; 1.1).

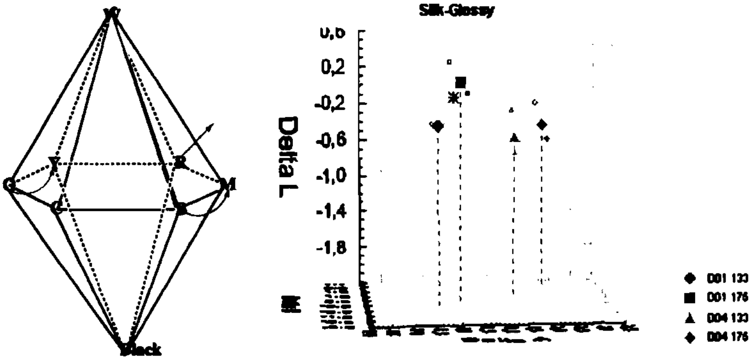

**Figure 14.** Color shifts due to a change in the substrate; on the left, the deformation of the color gamut with regard to hue and saturation (mean deformation for every combination of ink and screen); on the right, a graph showing the difference in lightness. The small open dots represent the changes in the lighter and the filled small dots the darker halves of the gamut.

The difference in hue, saturation and lightness when changing substrate from glossy to matt silk coated paper was measureable, however very small. Lightness increased slightly with matt silk substrate.

# Discussion

## Fulltone trapping

Three secondary fulltone trapping values for a given combination of paper and ink vary in a range of 10 to 15%, where green trapping (Cyan+Yellow) having by far the highest value followed by blue (Cyan+Magenta) and red (Magenta+Yellow). The process colors were run KCMY, Figure 15.

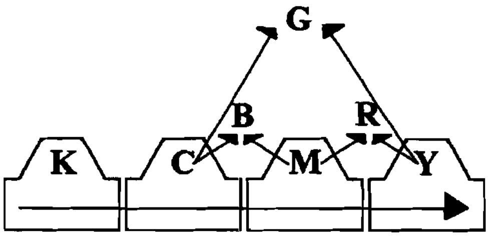

**Figure 15.** The position of the inking stations, showing which stations contribute in generating the secondary colors in fulltone coverage.

The higher values of green trapping (C+Y) was explained with the fact that the cyan ink was applied first, then cyan was given an additional nip and additional time to penetrate in the paper structure to set more while the sheet was passing in the magenta printing station nip. The yellow ink was then applied on an ink layer, which was more set and thus accepted more the secondary ink. High trapping is thus a high ability to print the intended color density on top of other inks already printed.

Red (M+Y) and blue (C+M) trapping have lower values since the two inks are applied in two consecutive inking stations, and the first ink down doesn't have so much time to set as the cyan ink in the green trapping case. Blue (C+M) trapping is though a bit higher than red (M+Y), depending on the fact that the substrate has to pass yellow inking station after both cyan and magenta have been printed, compared with none for the red case. Additionally, the inks penetrate more in the opener rougher structure of the silk paper, thus giving better trapping, as shown by the difference in trapping between blue and red on silk paper compared to glossy paper. Ink composition, i.e. the additive polydimethylsiloxan, does not have an influence on the same level in the fulltone trapping.

Press run conditions (i.e. press-speed and consequently time between nips, pressure in the nips, prevailing shear conditions etc.) probably play a role in determining the final trapping values. Those effects were not studied here, however these effects are suggested to be less dominant in waterless offset, if compared to a conventional dampening solution containing offset process.

The removal of polydimethylsiloxane from the ink composition leads to slightly lower trapping values in fulltone areas, however not on a significant level. This can exist due to the increased tack and viscosity of the ink without the polydimethylsiloxan that leads to a more uneven distribution of the second ink layer due to adhesive differencies in the ink layers. An other reason would be that the removal of the ink additive already caused differences in inking of the plate, prior to ink transfer to the substrate, which was not possible to study in this investigation.

Glossy paper gives lower trapping due to the difficulty for the first ink to penetrate in the paper structure, leaving a thicker and "wetter" substrate to which the second ink can less effectively adhere. Thus silk paper may have an advantage to glossy due to a higher trap. Generally seen the trapping should be as stable as possible and maintain its level during a print job with minimal deviation.

### Screening effect on the color gamut

The color gamut is affected by a change in the screen. Higher screen rulings lead into more saturated colors, while the range of lightness becomes smaller. These deformations in the gamut were caused by the difference in dot gain. Dot gain increases while increasing the screen ruling. Printed colors increase their saturation and become darker. The difference in $\Delta L^*$ is however greater for the lighter colors in the gamut (where dots do not touch each other and thus have the higher circumference/area ratio that gives higher dot gain), and the gamut shrinks in its $L^*$ direction. Only blue trapping (C + M) in halftones seems to be affected by the change in screen, with 175 lpi screen leading to a shift to the cyan tone of the blue shades, i.e. better trapping, probably because smaller dots transfer a thinner ink film. Othervise trapping effects seems minor when comparing to dot gain effects, and thus dot gain may be the main reason.

### Ink composition effect on the color gamut

The removal of polydimethylsiloxane leads to a slightly higher dot gain and slightly lower fulltone trapping. The results do not allow saying which of the two phenomena, which lead to opposite effects, is prevailing. The aspect on changes in waterless plate inking characteristics may be one reason, which was unfortionaltely not characterised in this work. The gamut becomes generally darker when surface chemical additives were removed, but the gamut does not shrink in its $L^*$ direction as it did when changing the screen. The shifts in hue indicate worse red trapping and significant increase in dot gain in the blue shades.

### Substrate effects on the color gamut

Silk coated paper has an open and rougher surface structure than glossy paper. The ink may penetrate easier into the paper structure and leave a more beneficial wet ink layer for the second ink to adhere to. Trapping values should thus be higher, as found also in this study. Different substrates showed very small differences, when compared to the other variables. Fulltone trapping (at least blue trapping) had slightly higher values for silk paper than for glossy paper, while dot gain is slightly smaller for silk paper than for glossy paper. The former phenomenon should lead to a more saturated and darker color gamut, while the latter should lead to lighter and less saturated colors. Trapping effects seem in this case to be more important, since the gamut becomes slightly darker ($\Delta L^*$ is negative) and secondary colors shift to shades of the process inks which are printed as second down inks.

Our goal was to obtain a process where the number of variables was minimised. The waterless technique offers in this way great advantages compared with the conventional offset technique, simply because all effects arising from the dampening was not present at all. Every step in our process has been checked to be sure of the reliability of the final results in real printing trials in practice. Less steps in prior to applying the printing plate in the press could have been beneficial, diminishing the number of steps in the plate making process. Using computer to plate technique instead of negative film and plate developing (elimination of general information loss and deviation, e.g. mechanical dot gain during film and plate exposure) could be beneficial. A complete knowledge of the ink chemical composition, formulation and manufacturing would also make it easier to analyse the results, as changes in gamuts can be caused by other differences in the ink formulation.

It sees impossible to clearly separate the effects of dot gain and trapping in halftones when using densitometric and spectrophotometric measurements. General trends can be observed if comparing the data for color shifts with the data for fulltone trapping and dot gain, and comparing the same data for different combinations of variables (as shown in this work). Numerical values can though be obtained only with the help of microscopy, or determination of a chemical tracer within the ink, which are expensive and time-consuming measuring methods. Mutual work with ink manufacturers to solve these issues is seen as crucial.

Fulltone trapping is based on densitometric measurements, while the color gamut is drawn using spectrophotometric measurements. It is thus hard to relate these two measurements by a simple number with a shift in a three-dimensional space, determining the amount of shift in the $a^*$, $b^*$ and $L^*$ directions.

## Conclusions

Color gamut difference was studied while changing variables in waterless offset sheet-fed printing. Three variables were evaluated: substrate (two coated fine paper types: silk and glossy paper), ink composition (four-color sets with and without polydimethylsiloxane) and halftoning (133 lpi and 175 lpi screen). Studied variables were important in determining the final quality of the print, where main effect arised from the halftone types and the ink properties. The coated substrate affected very little in comparison to halftone and ink variables.

Mean $\Delta E$ between 1.1 and 4.8 have been measured from 2229 patches in a color gamut. A trained pair of human eyes may detect differences of $\Delta E=1.5$ , and the $\Delta E$ between glossy and silk paper printed with the ink containing polydimethylsiloxane was below this value.

High fulltone trapping, i.e. more second ink upon a previously printed wet ink layer, was obtained when using silk paper instead of glossy paper. Ink containing polydimethylsiloxane gave better fulltone trapping, but trapping in the halftoned shades was clearly better only in the red zone of the color gamut.

Trapping differences in halftones were difficult to determine, if halftone trapping exists at all in high line screenings, because dot gain effects dominates in general. Correct pre-press control towards the chosen waterless offset printing process is thus crucial to master, either as simple dot gain characterisation for each process color separately, or by color management profiling through enough color patches in the measurements.

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