Measurement methods for controlling silver metallic ink film thickness

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Abstract:

In this research a number of measurement techniques for silver metallic inks are evaluated. As no specific instrumental method for the measurement of these inks exists, a glossmeter, a spectro-densitometers, and a conventional densitometer were evaluated for their ability to measure the output of a press run where the amount of silver metallic ink was varied gradually from miniscule to large amounts of ink metered by the ink feed system of an offset lithographic press.

A regression analysis was made to determine which of the metrics used in the study correlates best with physical amounts of metallic ink. Results will be presented to show the correlation between ink amount and gloss at 20^0, 60^0 and 75^0, density via spectral data, density via a conventional densitometer, and CIE L*a*b* measurements by a spectrophotometer. Data will be presented to show that gloss measurements have a poor correlation between varying amounts of silver metallic ink, whereas the L value of the CIE L*a*b* color space and all four filter channels of densitometers as well as densities convolved mathematically with status filter densitometry yielded good correlations with varying amounts of silver metallic inks.

Introduction

A major application for inks containing metallic particles is for the creation of metallic effects, as the realistic reproduction of metallic surfaces is not possible by means of standard printing inks. Metallic inks are an economic alternative to foil stamping or metallized substrates, which require both, expensive materials, and additional manufacturing processes subsequent to printing the regular image content of a printed matter. Conversely, metallic inks can be printed simultaneously with the other standard inks in a single pass from a regular offset

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press printing unit, as was done for this study, or for still better results, from a coating unit.

Metallic gold and silver inks contain fine metallic powders made from varying copper/zinc proportions and 99.5% pure aluminum respectively (Kippan, 2001). These pigments must be fairly large to produce a brilliant metallic effect, which causes runability problems with the highly pigmented inks that are used in the offset lithographic printing process. Average metallic pigment sizes range from 3.5 µm for offset inks to 8-9 µm for gravure and flexography inks, as opposed to conventional printing ink pigments, which are no larger than 0.1 to 3 µm (Kippan, 2001). The logical consequence of large pigment sizes is therefore, that metallic inks require a considerably thicker ink film than normal printing inks.

For these reasons, the preferred printing processes to create metallic effects have always been gravure and flexography, because the large pigments contained in metallic inks are compatible with the rheology requirements of the relatively fluid flexographic and gravure printing inks (dynamic viscosity $\eta = 0.05 - 0.2$ Pa· s) (Kippan, 2001). Gravure in particular, aided by the large volume of ink that is transferred from the depth of image carrier cells, produces excellent metallic effects.

Pigment research and technology development has to date resulted in metallic pigments that can be up to ten times thinner than conventional metallic pigments by a process know as Physical Vapor Deposition (PVD), where pigments are manufactured from almost pure aluminum by way of high pressure and evaporation (Seubert, 2003). These pigments, by virtue of being thinner, but not smaller in surface area than conventional aluminum pigments, are also lighter, which conforms more nearly with the rheology requirements of the much more viscous offset inks (dynamic viscosity $\eta = 40\text{-}100$ Pa · s) (Kippan, 2001).

PVD pigments take on flake-like shapes, which come to rest relatively flat on a paper surface, thus producing exceedingly high gloss and consequently produce brilliant metallic effects. Used on offset presses, PVD pigments, suspended in water-dilutable dispersion varnishes, create metallic effects that approach those of gravure and flexography. The silver metallic effect of these inks can be reproduced particularly effective if they are dispensed from dedicated double coating units with chambered doctor blades (Seubert, (2003).

Generally, the best metallic effect is achieved with so called leafing metallic pigments, but if a product has to be coated or laminated subsequent to printing the metallic image area, non-leafing metallic pigments retain their metallic luster better (Schwab et. al., 2006).

As no generally accepted quantitative method to measure metallic appearance exists, the most common approach to monitoring the quality of metallic ink reproductions is by visual comparisons between a production sample and an approved OK sheet (Schwab et. al., (2006). Because densitometers are intrinsically designed to measure process colors, they are ostensibly not suitable for other colors, including metallic inks. While spectrophotometers could measure any color, spectrophotometrically derived CIE L*a*b* values supply more information than an operator needs to control a single color metallic ink film thickness, which unlike multi-color reproductions is not dependent on a controllable balance between color constituents.

The problems associated with visual assessments of color are well documented, but with regard to metallic inks they are further compounded by their specular reflection characteristics, which make their appearance highly dependent on the viewing angle.

While this study was designed and conducted with the expressed purpose of investigating the measurability of silver metallic inks, two other types of printing inks, scratch-off and conductive inks, have somewhat similar pigment characteristics.

Scratch-off inks used for such products as lottery tickets, telephone cards or concealed PINs, must for obvious reasons be extremely opaque, which is achieved by water based rubber latex inks, loaded with highly opaque pigments such as aluminum powder. The water based nature of these inks render them unsuitable for the offset lithographic process. To facilitate the removal of scratch-off inks by fingernails, coins or other sharp-edged objects, the substrate is usually coated before the scratch off ink is printed (Scarlett, et al., 1984).

The printing of electronic circuits on synthetic and coated papers by the offset lithographic process has been shown to be possible, and offers the prospect of reducing printed circuit manufacturing cost, by virtue of relatively high offset lithographic press productivity rates. One recent study of conductive inks with 80% (by weight) silver particulate loading (1µ mean size) has shown to produce ± 2.5% variation in resistance over short print runs, as well as from lead edge to trailing edge of a press sheet, while resistance variations across the width of the press sheet were ± 15% (Ramsey et. al., (2007).

The similar spectral responses, which these inks share with silver metallic inks, indicates that the findings made in this study could possibly be applied to the process control of concealment of images by scratch-off inks and the acceptability of electric conductivity produced by conductive inks.

Experimental method

A Heidelberg Printmaster 52 offset press was used to print a conventional silver metallic ink (Silver PSS27606 by Colmar Corporation) on coated paper (Euro Art Gloss, 100 lb. basis weight, 148 g/m^2). The ink is specifically formulated to match the silver metallic hue 877c of the Pantone Matching System, on coated paper.

The intent was to produce progressively higher ink film thicknesses. The press run commenced with minuscule amounts of ink that did not produce an acceptable metallic effect, and was continued until such time that an excessive amounts of ink caused scumming in the non-image areas.

To this end, the ink fountain keys were opened to about 50% of their ink delivery capacity and the fountain roller sweep was adjusted to its maximum. Without stopping the press, the first sheet was sampled after a few dabs of ink were transferred to the ink free inking system, which produced a faint hue of gray. Thereafter, samples were pulled from the press delivery at 50 impression intervals, without interrupting the running of the press. Since after the 10th sampling cycle (500th sheet) the amount of ink supplied by the ink feed system was still not sufficient to match the PMS standard, it was decided to open the ink keys to their maximum. This again was done while the press was running. The press run was terminated when the 18th sample showed clear signs of the dampening system's inability to keep the non-image areas clean, because of excessive amounts of ink.

Because the uniformity of the mechanically induced ink film thickness increases were interrupted by human intervention, two distinctly different sets of data before and after the intervention were generated. Therefore samples 1-10 and 11-18 were analyzed separately.

Measurements of the samples were made by a glossmeter (Novo-Gloss by Rhopoint Instruments Ltd) at 20º, 60º, and 75º incident angles, a conventional reflection densitometer (Ihara R710 with Status T filter response), and a spectrodensitometer (530 X-Rite with a Status T filter response).

To ensure that the measured ink film thickness variations were not caused by factors other than the uniformly increasing amounts of ink supplied by the ink feed system, the measuring area was confined to the exact same 1 cm^2 area in the X and Y directions of the press sheets sampled.

Given that the ink feed system of a modern offset press meters the exact same amount of ink with every oscillation cycle of the ductor roller and the regular sampling intervals, it can be reasonably surmised that the inter-interval ink film increases are approximately equal.

Results and discussions

The aim of this study is to find practical means of measuring metallic appearances produced specifically by silver metallic inks for the purpose of repeatability, rather than to seek absolute values of metallic luster or brilliance, which has eluded researchers for the longest time. Given that absolute standards or measuring methods for metallic luster do not exist, it would therefore be desirable to determine, which of the extant optical measurement instrumentations currently used in the graphic arts responds best to varying metallic ink film thicknesses, hereafter abbreviated IFT.

Glossmeter: The rational for using a gloss meter to measure the degree of metallic luster is based on the assumption that metallic effects are to a great extent created by specular reflection, which gloss meters are designed to measure, and the observable fact that metallic effects are clearly more pronounced with rather thick as opposed to very thin ink film thicknesses. For example the first sample with the least amount of silver metallic ink appears visually to be a light gray and progressively changes to a more metallic silver appearance as IFT increases, although arguably, the precise point were the most realistic metallic silver appearance is achieved can not be determined with certainty and is therefore in praxis a matter of subjective choice. This being the case, it would be desirable to find a metric that corresponds with the process related ink film thicknesses that produces an acceptable metallic luster.

Gloss measurements of 18 silver metallic areas at 20º, 60º, and 75º incident angles (Figure 1) show that the highest correlation between gloss and IFT is achieved when the samples are measured with a 20º incident angle, which resulted in a correlation of determination value, as denoted by r^2, of 0.737925 for the first 10 readings, while in the higher IFT range $r^2 = 0.0252$ (see data in Appendix A). Gloss values will rise with increased IFT regardless of the type of printing ink that is used, because thicker ink films smooth the irregularities of a paper surface. To which extent IFT, or greater concentrations of metallic pigments contributed to gloss is however not determinable. From the 11th to the 18th measurement interval there is a markedly lower correlation between gloss and ink film thickness. While in the lower IFT range the gloss/IFT correlation is highest when measured with the 20º incident angles, the high IFT range shows exact opposite results.

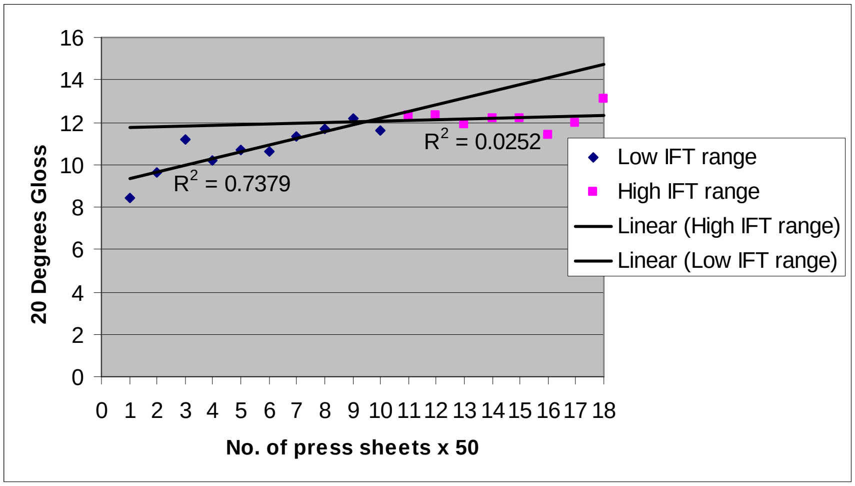


Figure 1: 20º Gloss correlation with silver metallic ink

Gloss readings taken at 75º incident angles (Figure 2) show no significant correlation between gloss and ink film thickness at both IFT ranges. This is particularly true for the lower IFT range, which unlike the 20º gloss results has a lower r^2 value than the higher IFT. The coefficient of determination values are 0.0874 and 0.3085 for the lower and higher density ranges respectively.

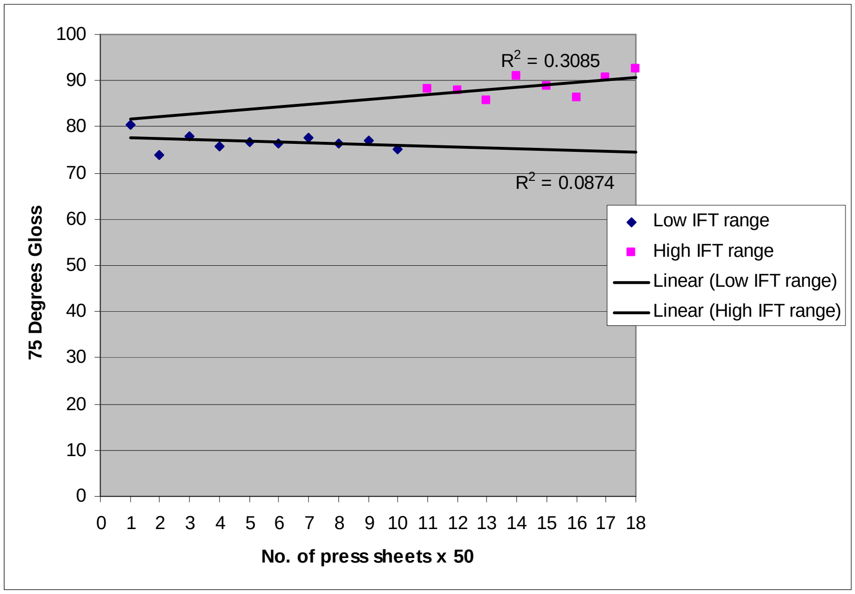


Figure 2: 75º Gloss correlations with silver metallic ink

Gloss readings taken at 60º show only a weak correlation between gloss values and ink film thickness, but at the same time 60º gloss readings display the least correlation difference between the high and the low ink film thickness ranges.

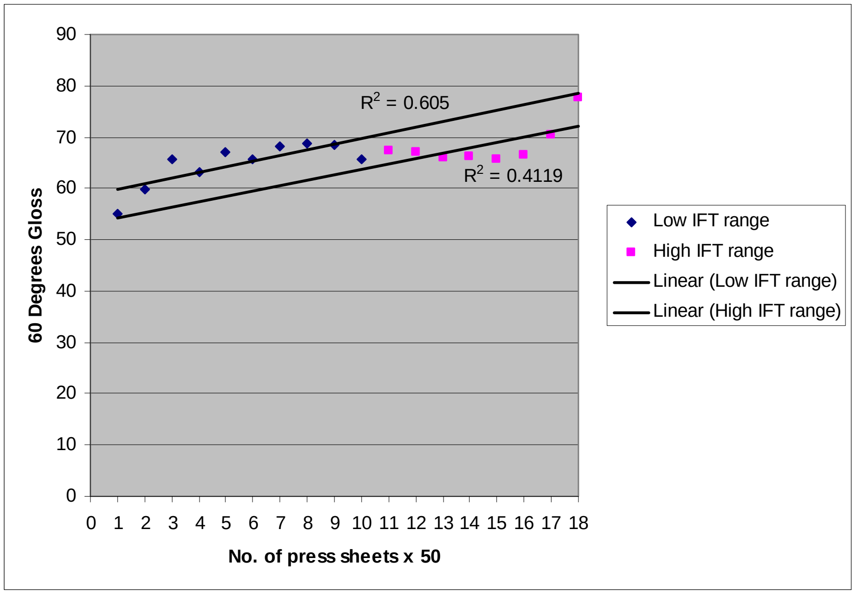


Figure 3: 60º Gloss correlations with silver metallic ink

Overall, gloss values show no consistent patterns. Depending on the gloss meter incident angles, low or high IFT ranges could have reversed relationships, while correlation of determination values could be as low as 0.025 and are never higher than 0.739.

Densitometer: Relatively equal visual, red, green and blue filter responses agree with the neutral gray visual appearance of silver metallic ink. The first and lightest sample measured, showed 0.17, 018, 0.18 and 0.15 for the visual, red, green and blue filter responses respectively. Still in the same filter order, this changed to 1.04, 1.07, 1.06 and 0.89 for the 18th and darkest sample measured. The correlation of determination values for the first ten lighter measurements are 0.975314, 0.969989, 0.974484 and 0.97583 for the visual, red, green and blue filters responses respectively. For the last eight darker readings the correlation of determination values decline to 0.893235, 0.899144, 0.884188, and 0.911053 for the visual, red, green and blue filter responses respectively.

Regardless of the densitometer channel used, very close to 97% of all filter responses are thus related to an increase in IFT in the lower IFT range, while in the higher IFT range the correlation is very close to 90% ± 1% (see data in Appendix B).

The correlation between IFT increases and densitometer filter responses is marginally better in the blue filter channel and is generally better for all filter channels in the lower as opposed to the higher IFT range (see Figure 4).

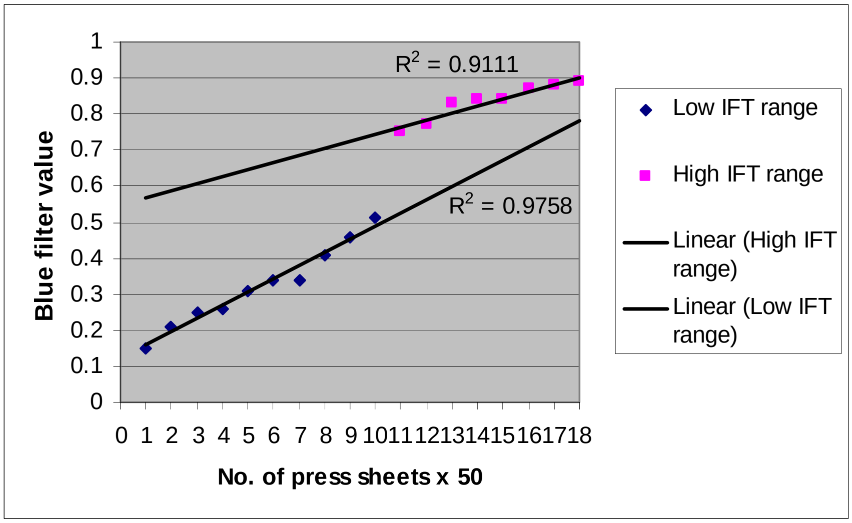


Figure 4: Blue filter densitometer responses to increasing silver metallic ink film thicknesses.

Densities calculated from spectral products: Relatively equal densities calculated from the visual, red, green and blue band widths responses agree with the neutral gray visual appearance of the silver metallic ink. The first and lightest sample measured, showed density values of 0.151, 0.153, 0.146, and 0.122 for the visual, red, green and blue band widths responses respectively. Still in the same filter order, this changed to 0.665, 0.672, 0.659 and 0.647 for the last and darkest sample measured. The correlation of determination values for the first lighter ten measurements are 0.97216, 0.971304, 0.972424 and 0.973616 for the visual, red, green and blue filters responses respectively. For the last eight darker readings the correlation determination values decline to 0.896155, 0.887586, 0.896526, and 0.909691 for the visual, red, green and blue band widths responses respectively.

Regardless of the spectral range, very close to 97% of all mathematically convolved density values are thus attributable to an increase in IFT in the lower IFT range, while in the higher IFT range the correlation is very close to 90% ± 1% (see data in Appendix C).

The correlation between IFT increases and density is marginally better for mathematically convolved blue filter density units and is generally better throughout the spectral range for lower as opposed to the higher IFT range (see Figure 5).

Although the mathematically convolved density units of a spectro-densitometer start at a somewhat lower density value and end at a significantly lower density unit than the measured filter values of a conventional densitometer, the correlation between IFT and densities is nearly identical for both the conventional densitometer and the spectro-densitometer.

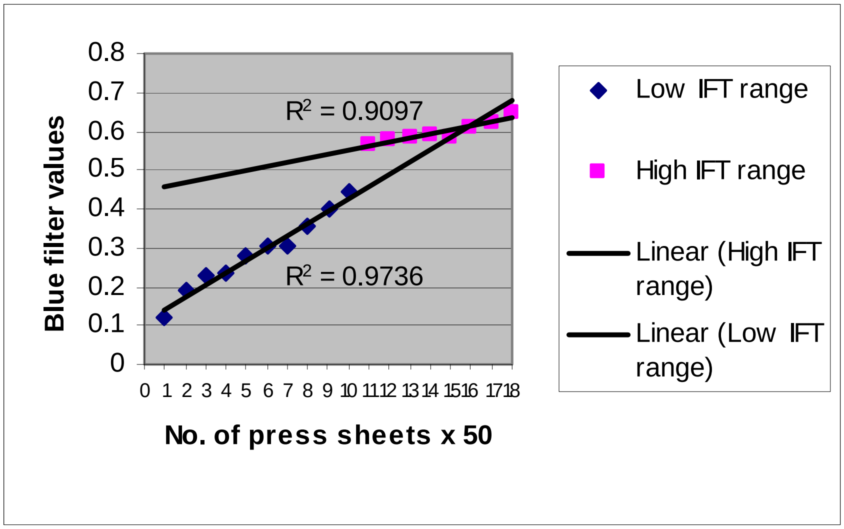


Figure 5: correlation of densities calculated from spectral products with increasing silver metallic ink film thicknesses.

CIE L*a*b* as measured with a spectrodensitometer: Throughout the measurement range both CIE a* and b* are hugging the neutral color axes very closely, but as the concentrations of pigment changed, on account of increasing amounts of ink, the hue will also shift somewhat (see data in Appendix D). In the CIE a* dimension the hue of the silver metallic ink changed from a slightly red to a slightly green color cast. The difference between the lightest and the darkest sample is 1.23 CIE a* units, and as such is quite miniscule, but the correlation between IFT and CIE a* in the lower IFT range is with a correlation of determination value of 0.9452 of some significance. The correlation in the high IFT range drops however to an insignificant r^2 of 0.4781 (see Figure 6). Given the very small hue changes that accompany extremely large IFT increases, the high CIE a*/IFT correlation should be viewed with some wariness as the sample is primarily a neutral gray with only the slightest color cast.

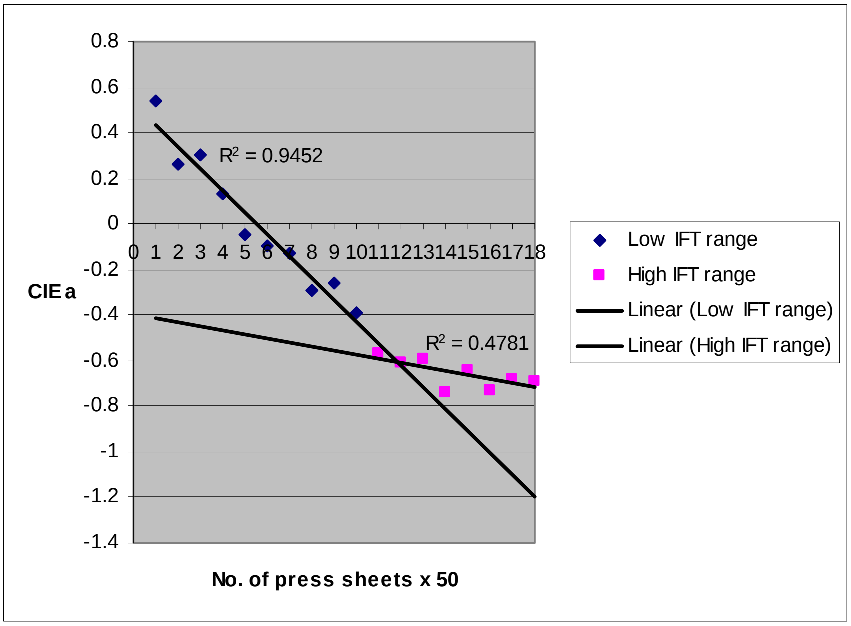


Figure 6: Correlation between ink film thickness increases and CIE a.*

In the CIE b* hue dimension the silver metallic ink grew to be less bluish with increasing amounts of ink. The difference between the lightest and the darkest sample is quite small with 2.8 CIE b* units and the IFT/CIE b* correlation in both the lower and upper IFT ranges is relatively insignificant with r^2 values of 0.6672 and 0.7974 respectively (see Figure 7 and data in Appendix D).

As might be expected, increasing amounts of silver metallic ink caused its silvery appearance to become darker. A difference of 32.32 CIE L* units, between the lightest and the darkest sample denotes this darkening effect quite clearly. The correlation of definition values of 0.9317 and 0.9809 for the lower and upper IFD ranges respectively are higher than any other instrumentation results used in these series of tests (see Figure 8 and data in Appendix D). It can therefore be stated that in the lower IFT range 98% of the changes in CIE L* values are attributable to changes in IFT, while in the upper IFT range 93% of the changes in CIE L* values are attributable to changes in IFT.

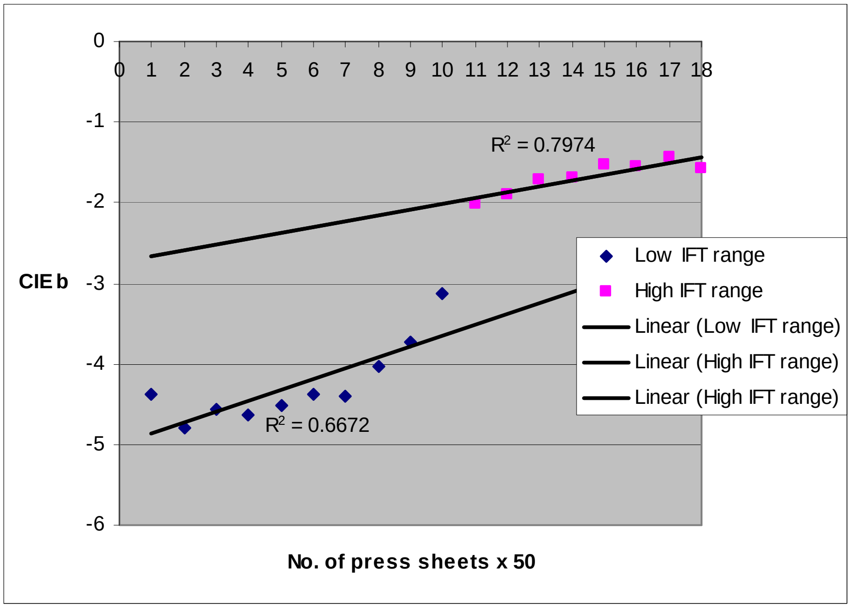


Figure 7: Correlation between ink film thickness increases and CIE b.*

To partially surmount the previously discussed subjectivity of determining optimal silver metallic appearances the silver metallic hue 877 C found in a Pantone Matching System formula guide patch was measured. Also measured was a silver metallic image on the title page of an industry magazine, known to be printed in the offset lithographic process. One of the feature articles in the magazine extols the advantages of a new type of silver metallic ink formulation (Metalure®), which was used for some image elements on the said title page.

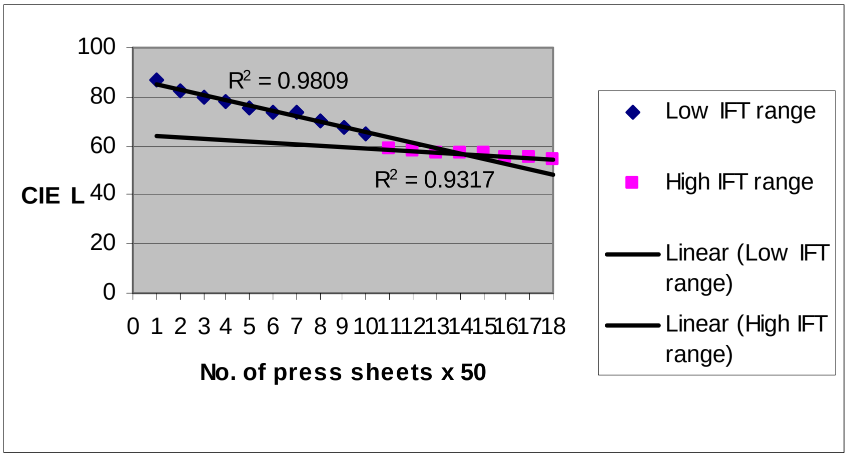


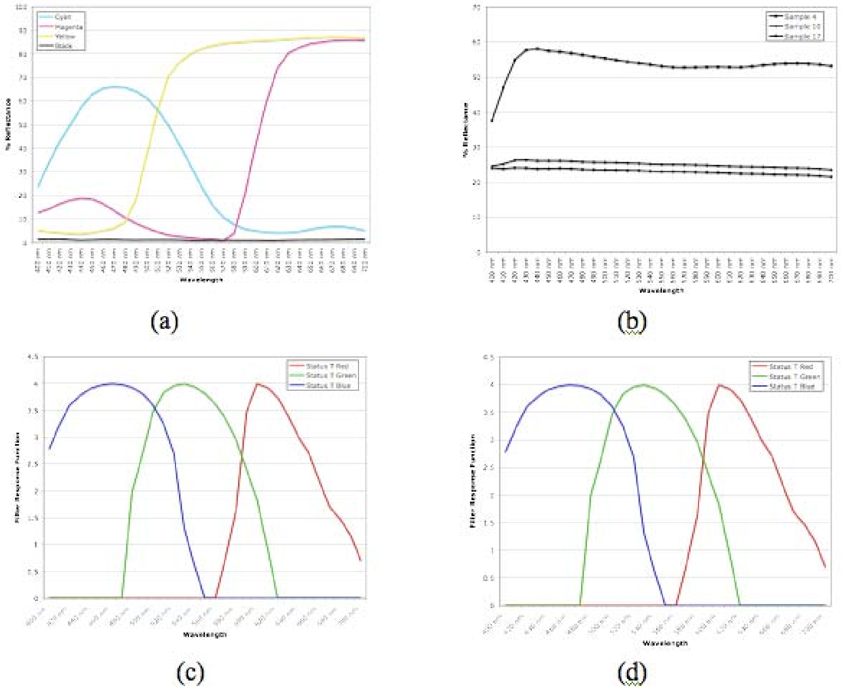
Figure 8: Correlation between ink film thickness increases and CIE L.*

The Pantone formula guide patch measured L* 55.20, a*-082, b* -1.57, and the cover image had L* 61.95, -0.49, b* 0.59 values. The test reading that is closest to the Pantone formula guide patch is the 17th sample, whereas the closest test reading to the cover image is the 10th reading. It can thus be argued that industry *norms* were achieved, although, in the case of the Pantone formula guide patch, this match was possible only with an excessively thick ink film. The most probable explanation for having to run an ink film that was thicker than the dampening system could repel, is the fact that the Pantone formula guide was printed by a process other than offset lithography. Closer examination of the Pantone color guide patch under high magnification confirmed this assumption.

Filter density vs. spectral density: There are two main ways to measure density today. In the press room one may use a traditional "filter-based" densitometer, or a "spectral-based" densitometer. In this research, the Ihara R710 is a filter-based densitometer, while the X-Rite 530 is an example of a spectral-based instrument. It is useful to note that both devices were using Status T densitometery, however these devices reported very different density readings when measuring the same sample.

It is informative to briefly analyze the data in terms of the different measuring configurations. When comparing the data from the filter vs. spectral densitometers, it is useful to note that while the absolute measured values are very different, the relative values are similar. The absolute values differ, for example, the density for the heaviest sheet measured by the filter-based instrument was 1.04, and the same sample measured with the spectral device was 0.67. Thus we see a significant difference in the absolute values.

In this paper we have plotted regression analysis for the change in ink film thickness. In this instance we are only interested in the relative change of ink film thickness and its measurement. When considering relative change we see that filter-based and spectral-based, both exhibit the same ability to predict/monitor the change in IFT. In summary we may say that while the filter vs. spectral devices differ in their absolute measurements, filter and spectral densitometers produce similar results when used to measure relative changes in the printed material and thus have similar regression analysis coefficients. Thus, either a filter or a spectral device is appropriate if the device is used for process control. But the devices could not be used interchangeably if a costumer requires a specific density.



(a) (b)

(c) (d)

Figure 9: Graph (a) shows the spectral characteristics of typical CMYK process inks. Note how the peak of the filter functions curves (c) corresponds to the highest absorption of their respective process colors. In the case of the metallic ink (b) there is no such correlation when compared to the same densitometer filter functions (d).

The large difference in absolute measurement between filter and spectral based devices is due to the way each device works. The filter based device uses physical colored filters and a monochromatic photocell sensor to detect the amount of light from the sample. The spectral instrument records the full visual spectrum (Figure 9) and then mathematically convolves this response with a filter response function. It is useful to ask the question – which one reports the true density? This project continues to address that question and other issues raised in the following concluding section.

Conclusion

The ink film thickness of silver metallic inks can be monitored relatively accurate by conventional densitometers, and by spectro-densitometers. Gloss meters are not suited to measure silver metallic ink film thicknesses regardless of the incident angle used, as their response to ink film thickness variations is erratic.

Both conventional densitometers and spectro-densitometers have a fairly accurate response to changing silver metallic ink film thicknesses in all filter channels or calculated values that correspond to filter channels. The blue filter channel response or the calculated density values that correspond to blue filter channels are marginally more accurate to measure changing silver metallic ink film thicknesses.

The CIE a* and b* values are not suited to monitor changing silver metallic ink film thicknesses, as their responses to ink film thickness variations are erratic. Also the magnitude of CIE a* and b* responses to changing silver metallic ink film thickness variations are not large enough draw definitive conclusions.

The CIE L* value has an excellent and consistent response to changing silver metallic ink film variations, although it is not significantly better than the blue filter channel responses of densitometers.

The findings of this study may be applicable to scratch-off and conductive inks, because of their similar metallic pigment constitution. Future research should be conducted with these inks to determine if opacity levels of scratch-off ink correlates adequately with density or CIE L* values. Likewise, the electric conductivity of conductive inks should be tested relative to their density and CIE L* values.

While optical densities and CIE L* values do not per se measure the metallic luster that is emitted from silver metallic inks, they do have a very high correlation with silver metallic ink film thicknesses. Metallic luster has to date not been accurately defined and is probably related to a combination of such factors as gloss, iridescence, luminescence, and fluorescence. The findings in this study must therefore be seen as useful methods to achieve silver metallic ink print consistency and repeatability.

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Appendix A

75º	**20º**	**60º**	**Sample No.**
80.4	8.4	55.2	1
74	9.6	59.8	2
77.8	11.2	65.8	3
75.9	10.2	63.3	4
76.7	10.7	67	5
76.5	10.6	65.8	6
77.6	11.3	68.2	7
76.5	11.7	68.7	8
77	12.2	68.6	9
75.2	11.6	65.6	10
88.1	12.3	67.4	11
87.8	12.3	67.2	12
85.7	11.9	66.1	13
90.9	12.2	66.3	14
88.8	12.2	65.8	15
86.3	11.4	66.5	16
90.6	12	70.3	17
92.6	13.1	77.8	18
0.08742047	0.737924621	0.605019379	r^2 first 10 samples
0.308497016	0.025227646	0.411869924	r^2 last 8 samples

Gloss

Appendix B

Visual filter	**Red filter**	**Green filter**	**Blue filter**	**Sample No.**
0.17	0.18	0.18	0.15	1
0.23	0.25	0.24	0.21	2
0.28	0.3	0.29	0.25	3
0.29	0.3	0.29	0.26	4
0.35	0.37	0.35	0.31	5
0.38	0.4	0.39	0.34	6
0.38	0.4	0.39	0.34	7
0.45	0.47	0.46	0.41	8
0.51	0.53	0.51	0.46	9
0.57	0.6	0.58	0.51	10
0.86	0.89	0.87	0.75	11
0.89	0.93	0.91	0.77	12
0.97	1	0.99	0.83	13
0.98	1.01	1	0.84	14
0.99	1.02	1.01	0.84	15
1.02	1.04	1.04	0.87	16
1.03	1.06	1.05	0.88	17
1.04	1.07	1.06	0.89	18
0.97531394	0.969989	0.974484	0.97583	r^2 first 10 samples
0.89323476	0.899144	0.884188	0.911053	r^2 last 8 samples

Densities (conventional densitometer)

Appendix C

Visual	Red	Green	Blue	Sample No.
0.151	0.153	0.146	0.122	1
0.223	0.228	0.217	0.188	2
0.261	0.267	0.255	0.226	3
0.27	0.276	0.263	0.234	4
0.316	0.322	0.308	0.28	5
0.339	0.345	0.331	0.303	6
0.34	0.347	0.333	0.304	7
0.391	0.398	0.383	0.356	8
0.43	0.437	0.422	0.397	9
0.472	0.479	0.464	0.442	10
0.583	0.59	0.577	0.563	11
0.594	0.6	0.589	0.575	12
0.604	0.611	0.598	0.586	13
0.611	0.618	0.605	0.593	14
0.605	0.611	0.599	0.587	15
0.629	0.635	0.623	0.612	16
0.636	0.642	0.631	0.62	17
0.665	0.672	0.659	0.647	18
0.97216	0.971304	0.972424	0.973616	r^2 first 10 samples
0.896155	0.887586	0.896526	0.909691	r^2 last 8 samples

Densities calculated from spectral products ((Spectro-densitometer)

Appendix D

L	**a**	**b**	**Sample No.**
86.49	0.54	-4.38	1
82.09	0.26	-4.79	2
79.71	0.3	-4.57	3
78.42	0.13	-4.63	4
75.19	-0.05	-4.51	5
73.48	-0.1	-4.37	6
73.3	-0.13	-4.41	7
70.35	-0.29	-4.03	8
67.69	-0.26	-3.72	9
65.22	-0.39	-3.13	10
58.36	-0.57	-2.02	11
57.79	-0.61	-1.91	12
57.2	-0.59	-1.72	13
57.22	-0.74	-1.69	14
56.78	-0.64	-1.53	15
55.67	-0.73	-1.56	16
55.66	-0.68	-1.43	17
54.17	-0.69	-1.58	18
0.980927	0.945248	0.667207	r^2 first 10 samples
0.931653	0.478099	0.797364	r^2 last 8 samples

*CIE L*a*b**