An investigation of the "Continuous Tone Value"

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1 Abstract

William Birkett (Precision Color) and Charles Spontelli (Bowling Green State) gave a presentation [5][1] of a print measure that they called "Continuous Tone Value" (CTV). They have identified the need in the industry for a print parameter that behaves like density, but which is derived from colorimetric measurements. Birkett and Spontelli are offering CTV as a single number means for characterizing the saturation of an ink that is based on colorimetric values. The value is to serve as an alternative to optical density.

The authors presented this concept again at the July meeting of CGATS SC3 and SC4, with the aim of endorsement of the parameter through this committee.

In this paper, I compare the CTV to density and to ΔE on a collection of solid ink patches.

2 The data set

A test form was printed on a sheet fed press, using fifteen different stocks. The stocks were selected as a representative sampling of stocks used in commercial offset printing.

The papers used for the test were as follows:

1) Champion proofing paper white
2) Consolidated centura dull cover white
3) Consolidated centura dull text white
4) Consolidated fortune gloss cover white
5) Consolidated reflections gloss text white
6) DalEl preeminence dull cover white
7) DalEl preeminence gloss cover white
8) Fraser halopaque offset cream white
9) Mohawk 50/10 text fluorescent
10) Sappi opus gloss text white
11) Sappi somerset gloss text white
12) Sappi strobe dull cover white
13) Unisource pressmaster offset white
14) Unisource star bright opaque white fluorescent
15) Weyerhauser cougar opaque white fluorescent

The set includes uncoated, low gloss and high gloss papers. Some have very little fluorescence, some have fluorescence. There is a variety of brightness.

Each test form had a target with 36 patches of various combinations of CMYK. This 36 patch target was repeated ten times across the width of the form. When the test was run on press, the ink keys were opened wide on one side of the form and gradually tapered to the other side so that each test set was printed at a variety of ink film thicknesses.

All 5,400 of these patches (36 X 10 per form X 15 forms) were measured with a Gretag SPM50 spectrophotometer. I am indebted to the meticulous efforts of Doug Sykora for collecting this data.

I drew the solid cyan, magenta, yellow, black and paper patch data spectra from this data set for this analysis. Thus, I had the spectra for 150 solid cyan patches at ten ink film thicknesses and on fifteen different stocks, and likewise for magenta, yellow and black.

From the spectra, I computed Status T densities (paper relative), xyz values and CIELAB values (D50, 2° observer). For each of the solid patches, I computed 1) the paper relative density, 2) the CTV, and 3) the ΔE between the patch and paper.

3 How to compare

We have a proposed measurement that we wish to assess the merit of. Since this measurement is proposed as a colorimetric alternative to density, then it seems obvious that density values are the "golden standard" by which to evaluate CTV. For CTV to be useful, it must behave in a manner similar to density, since density has gained acceptance in the pressroom for evaluating the saturation of an ink.

One of the assessments that I will be making through this paper is the comparison of CTV with density. CTV will thus be deemed successful to the degree that a simple relationship exists between CTV and density.

One might well ponder, however, whether density is truly the ultimate measure to compare to. How is density used in the pressroom? Why has it gained acceptance?

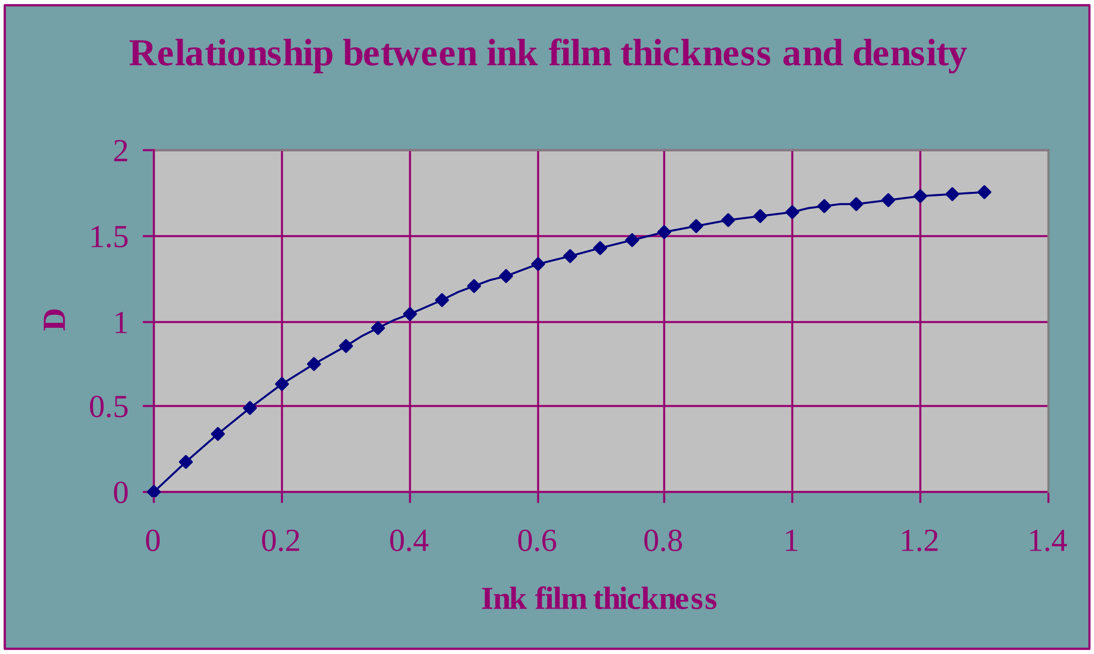
Density values serve three purposes in the pressroom: as a metric for process control of ink film thickness, as a gauge of how a pure solid will be perceived, and as a means to calculate tone value increase, which is a metric for the process control of dot gain[1].

3.1 Process control for ink film thickness

As a process control device, density correlates with ink film thickness. A number of studies have shown that on a given stock, there is a well behaved relationship between ink film thickness and density. Three fine papers ([2], [3], and [4]) investigate the formulae that have been used.

The graph below illustrates the Tollenaar-Ernst equation, which is a personal favorite of mine, since it has only two free parameters. The graph is merely an example of the relationship. The units on the x-axis are merely relative, and the scaling of the y-axis is based on a purely hypothetical ink.

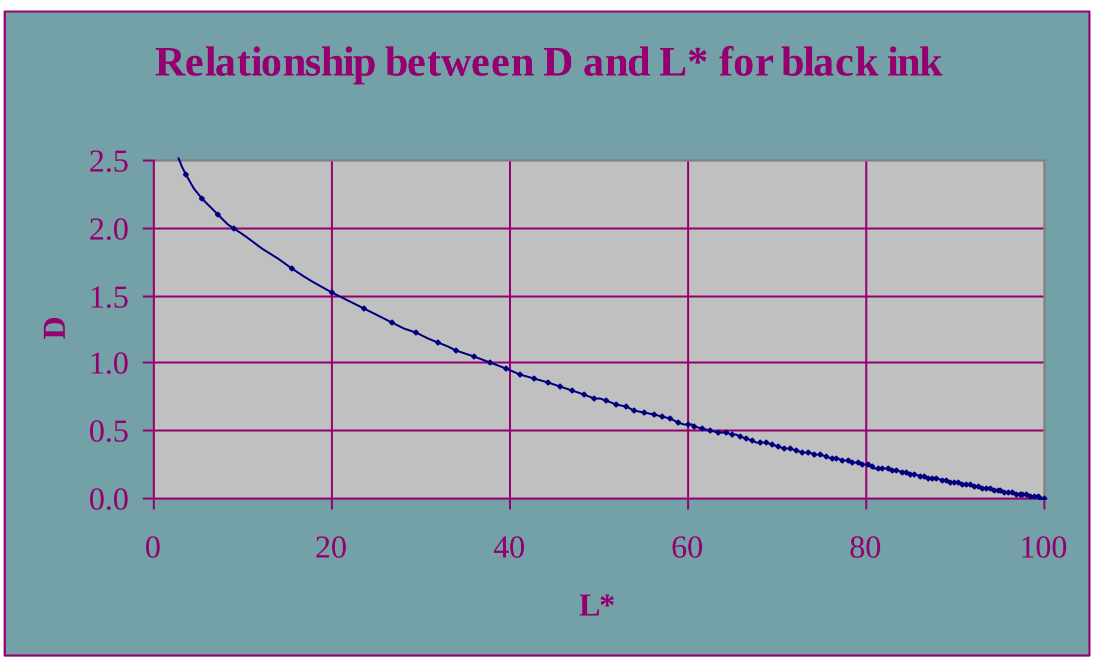
[1] I intend "tone value increase" to mean the number resulting from application of the Murray Davies equation, and "dot gain" to refer to the



This relationship is not perfect. Ideally for process control of ink film thickness, one would like to have a relationship that was strictly linear. At high ink film thickness, the density will saturate, and so will no longer be an effective measure of ink film. This is a shortcoming of density.

3.2 Gauge of how a pure solid will be perceived

The second correlation that makes density useful is between density and what we perceive as the strength of a color. The graph below shows that (at least for black ink) the relationship between density and L* is not all that far from linear.



I chose to compare CTV against density and to also compare the ΔE between the ink and the paper. The latter seems a reasonable extension of CIELAB, although the size of the ΔEs in this case will be much larger than those anticipated by CIE.

3.3 Means to calculate dot gain

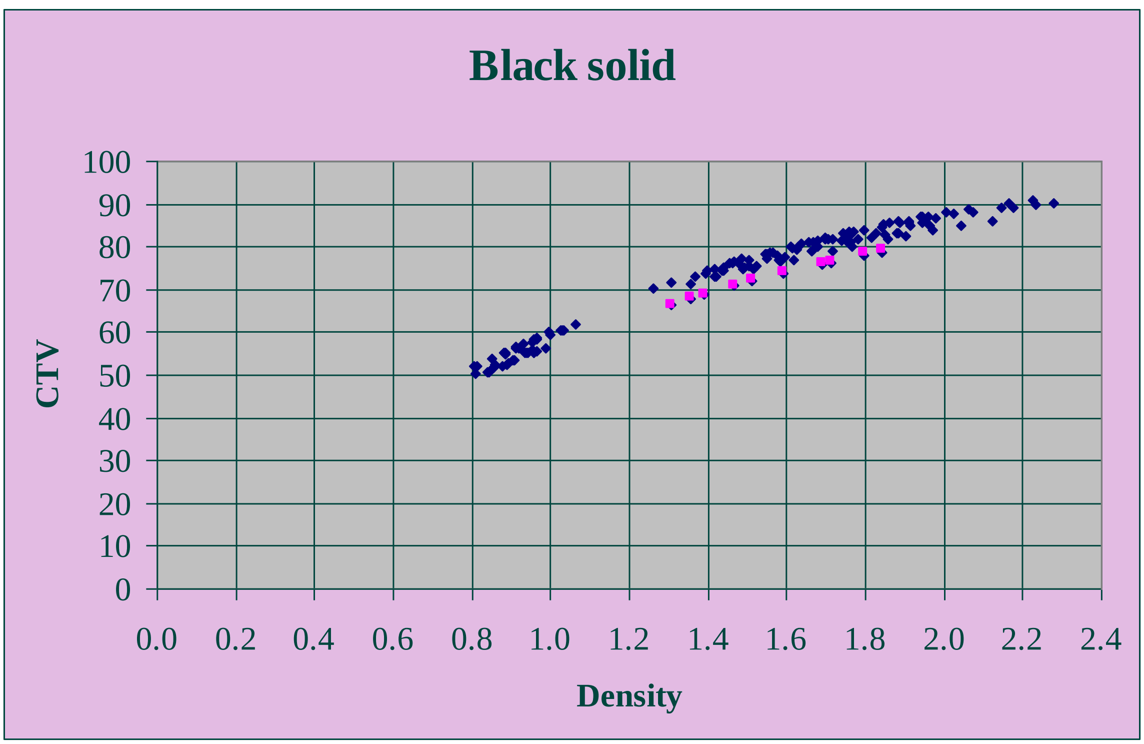
Density is also used in the pressroom to measure dot gain. This enables the control of the color of midtones in the image. The Murray-Davies equation is an equation based on some simplifying assumptions that allows one to calculate the effective dot area of a midtone.

A colorimetric analog to density must also provide for the measurement of dot gain. Birket and Spontelli [1] have offered a calculation for this as well. Comparison of this to the conventional dot gain computation will be left to another paper.

4 Correlation with density

4.1 Black solids

I show below scatterplots of CTV versus density for the four solid patches. Each scatterplot includes data from fifteen papers at ten different ink film thicknesses.



First, a comment on the two sets of densities shown in the graph. There were four uncoated stocks in the data set. Solid ink densities of ink on these stocks are appreciably lower than that on the coated stocks. Hence, the points representing densities from 0.8 to 1.1 are from uncoated stock. Points with densities between 1.2 and 2.3 are on coated stock.

The black solid plot shows a good correlation between density and CTV. Knowing the CTV, one could make a pretty good guess as to the density, and vice versa. There are one set of dots, however, that seem to depart distinctly from the rest of the curve. These have been highlighted by plotting in magenta. These points were all based on measurements from paper 6. The table below shows that paper 6 has the lowest L* value, but also a rather large b* value. Which of these is the reason for the difference?

Paper	L*	a*	b*
1	94.45	0.10	2.72
2	94.86	0.70	-1.38
3	95.54	0.88	-2.76
4	94.06	0.84	-1.07
5	94.67	1.20	-1.50
6	88.87	-0.21	4.07
7	95.05	0.85	-2.64
8	92.73	0.44	-1.93
9	91.40	-0.30	0.00
10	92.29	0.81	-2.17
11	95.75	0.55	-2.16
12	91.44	-0.28	6.42
13	90.03	0.19	-0.61
14	91.86	1.34	-5.37
15	92.97	1.32	-5.94

My suspicion was that the L* value is the culprit. One difference between the calculations for CTV and for density is the way the paper is corrected out. In the case of density, paper relative measurements are arrived at by subtracting the density of the paper. Equivalently, the reflectance of the solid patch is normalized by dividing by the reflectance of the paper. For CTV, the paper relative function is achieved by subtracting the Lx, Ly and Lz values of paper from those of the solid. This is not equivalent to normalizing the xyz values.

I tested my hypothesis by computing the Lx, Ly, and Lz values based on x, y, and z values that had been normalized by dividing by the x, y, and z values of the paper.

With the nonlinearity function *f* defined as in CIE 15.2,

$$f(q) = \begin{cases} \sqrt[3]{q}, & q > 0.008856 \\ \dfrac{903.3q + 16}{116}, & q \le 0.008856 \end{cases}$$

Here are the original equations as defined by Birkett and Spontelli:

$$L_x = 116 f(x) - 16$$

$$L_y = 116 f(y) - 16$$

$$L_z = 116 f(z) - 16$$

$$CTV = \sqrt{\frac{(L_{xp} - L_x)^2 + (L_{yp} - L_y)^2 + (L_{zp} - L_z)^2}{3}}$$

I define the relative colorimetric tone values as follows

$$L_{rel,x} = 116 f\left(\frac{x}{x_p}\right) - 16$$

$$L_{rel,y} = 116 f\left(\frac{y}{y_p}\right) - 16$$

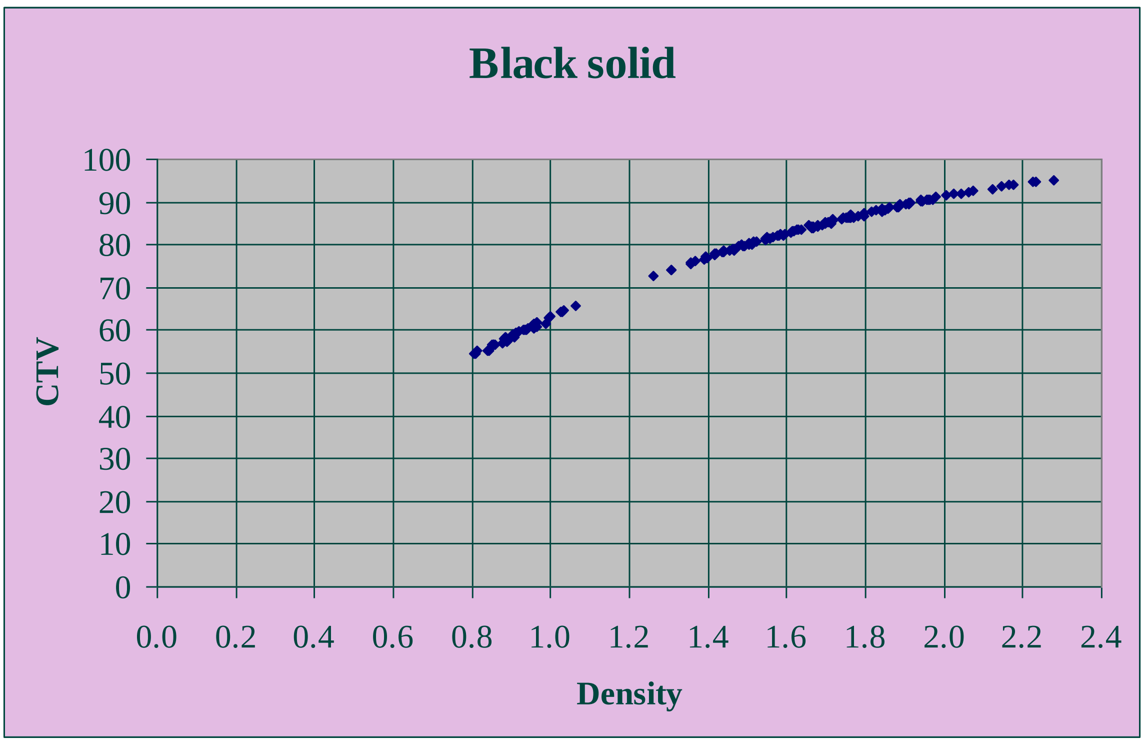
$$L_{rel,z} = 116 f\left(\frac{z}{z_p}\right) - 16$$

$$CTV_{rel} = \sqrt{\frac{\left(L_{rel,xp} - L_{rel,x}\right)^2 + \left(L_{rel,yp} - L_{rel,y}\right)^2 + \left(L_{rel,zp} - L_{rel,z}\right)^2}{3}}$$

Since $L_{rel,qp} = 1$ (they are the L values for paper, normalized against paper),

$$CTV_{rel} = \sqrt{\frac{\left(1 - L_{rel,x}\right)^2 + \left(1 - L_{rel,y}\right)^2 + \left(1 - L_{rel,z}\right)^2}{3}}$$

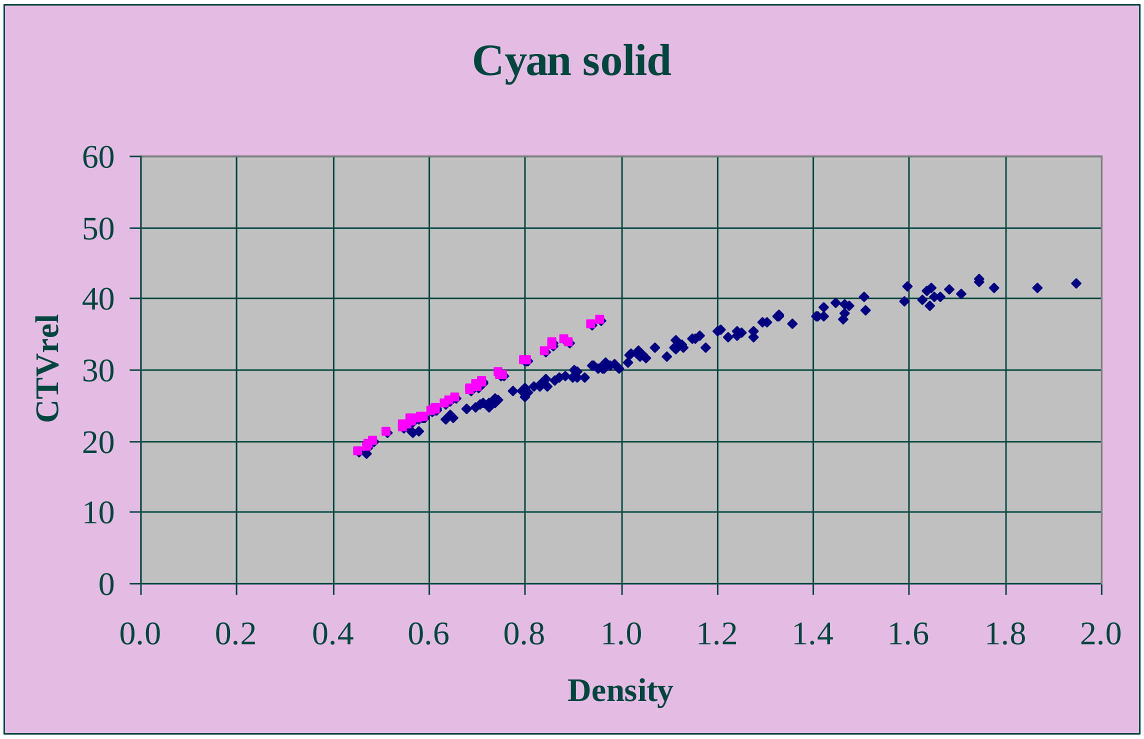
The resultant scatterplot is shown below. It is clear that the relationship between CTV_{rel} and density now shows a very clean relationship.



My first conclusion is that computing CTV_{rel} based on paper relative xyz values will correlate better with paper relative density. Since this variant on CTV is a rather small change numerically, and yet it cleans up the black appreciably, I will use this variant throughout the rest of this paper. The difference between relative and non-relative CTV is not illustrated here for the other inks, but the results are similar.

4.2 Cyan solid

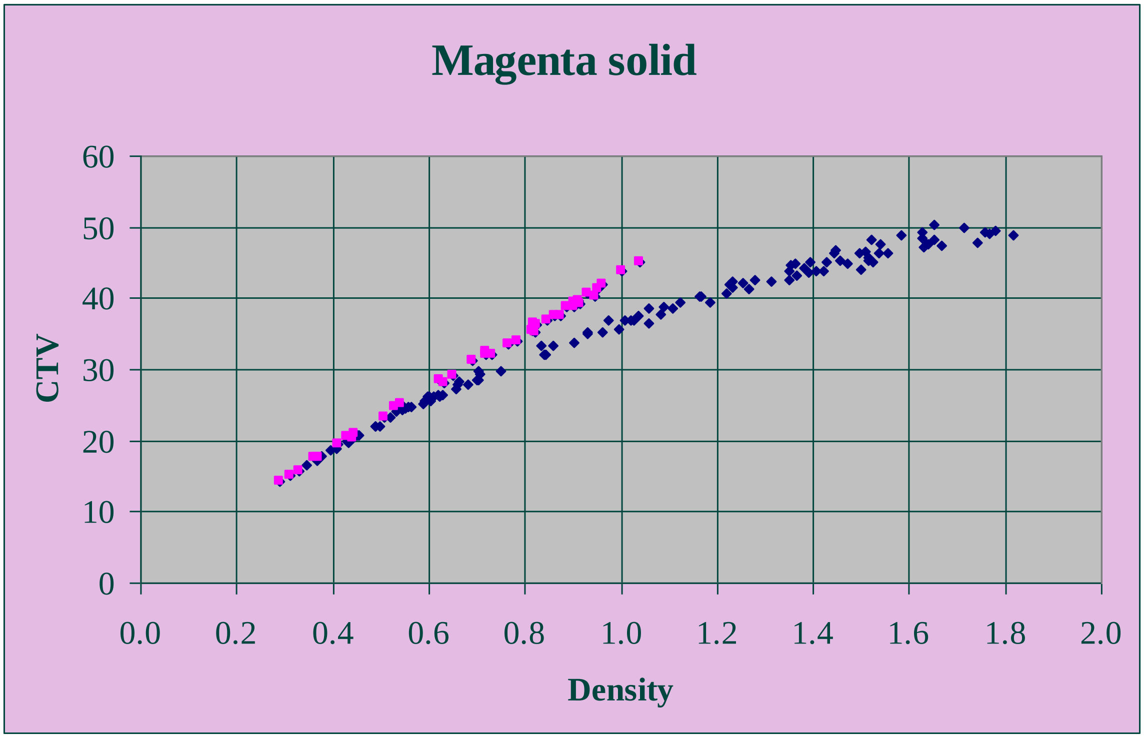
Below we have the scatterplot of CTV_{rel} versus density for the collection of solid cyan patches. Here the relationship is not as clean. The plot shows distinct signs of coming from two distinct populations. Indeed, the smaller group that fits a rather straight line between densities of 0.4D and 1.0D is comprised entirely of samples from uncoated stock. This is indicated by plotting the measurements on uncoated stocks in magenta.



The conclusion regarding the CTV_{rel} for cyan solids is that the correlation between density and CTV_{rel} is different for coated and for uncoated stocks. This is an undesirable property, although not necessarily an issue. Generally speaking, one does not wish to compare measurements taken on coated stock with measurements taken on uncoated stock. It is also fair to ask whether the anomaly is in density or if it is in $CTV_{rel.}$!

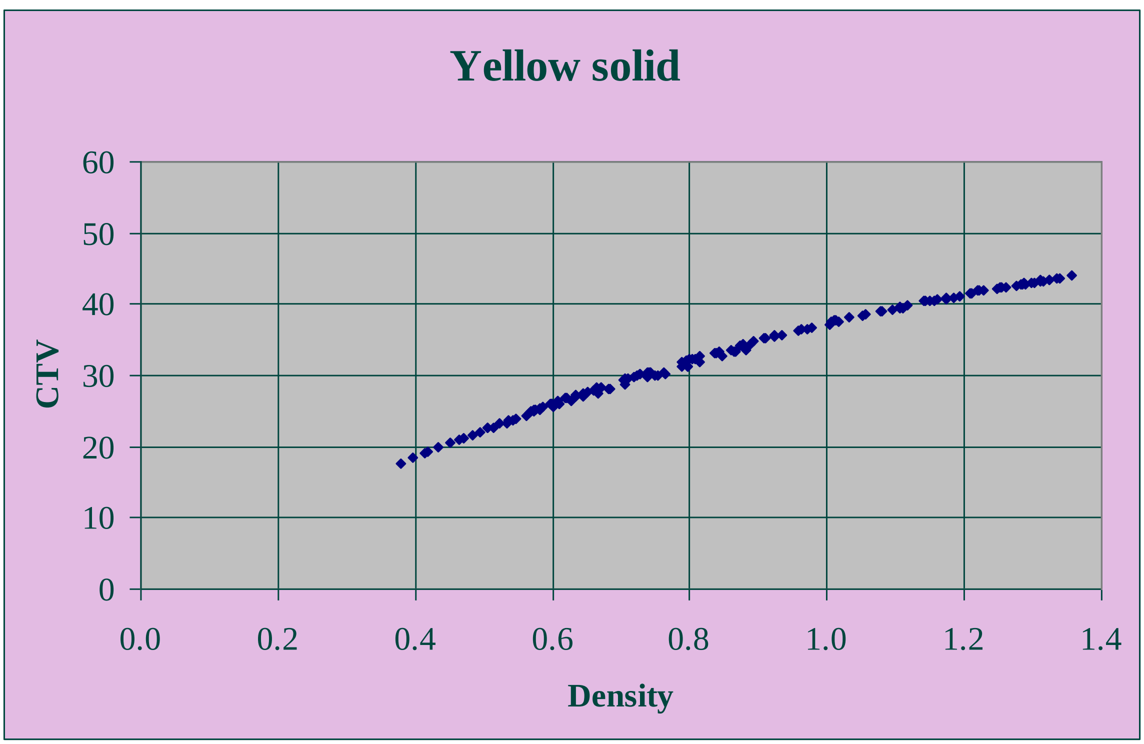
4.3 Magenta solid

The scatterplot for magenta is shown below. Once again, it is apparent that coated and uncoated stocks behave much differently.



4.4 Yellow solid

Below, we see the scatterplot for the yellow solids. This scatterplot looks similar to the scatterplot for black solids in that there is not a difference between coated and uncoated stocks.



4.5 Why the difference?

There is clearly a difference between black and yellow inks as compared against magenta and cyan. Black and yellow inks show a consistent relationship between CTV_{rel} and density, whereas for cyan and magenta, the relationship depends upon the type of stock.

For black ink, this simple relationship stems from the fact that ink that is truly black has x, y, and z values that are nearly the same. Since black density is measured using the y tristimulus function, a simple formula from black density to black CTV_{rel} could be derived. This is a function of one variable.

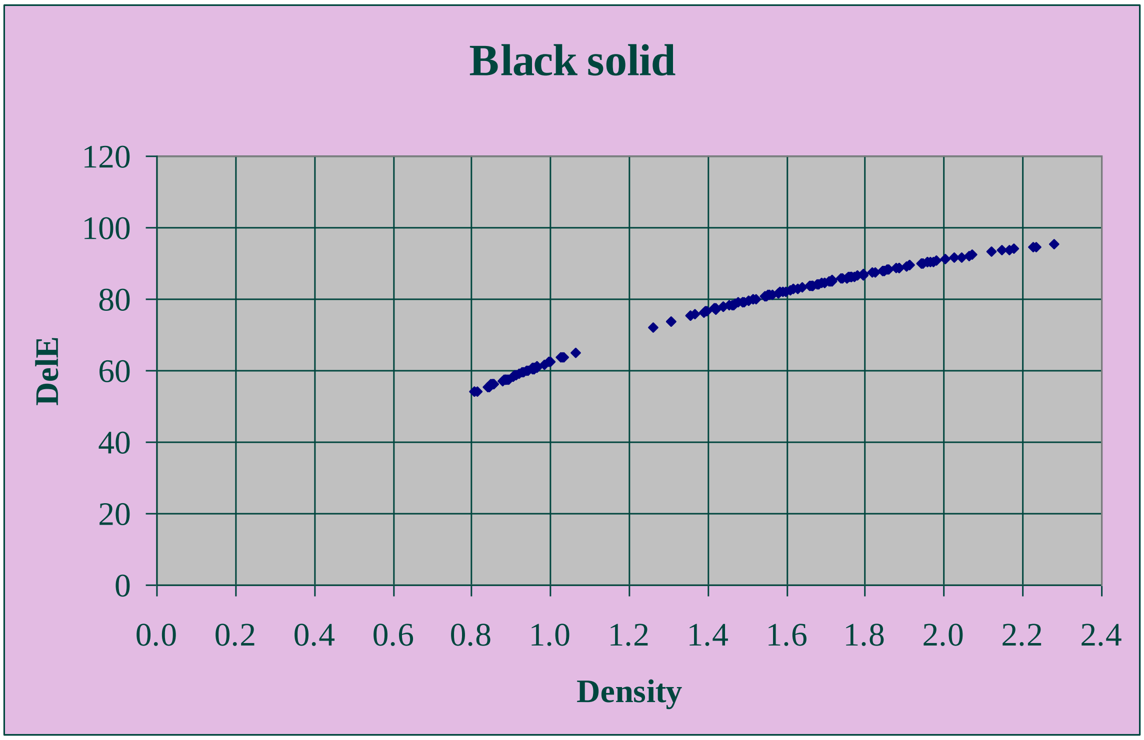
Yellow is equally simple, in that difference between a weak and a saturated yellow shows up almost completely in the z values. Thus, CTV_{rel} for yellow is also primarily a function of a single variable.

My guess is that cyan and magenta are different in that the relationship between CTV_{rel} and density is a function of more than one variable.

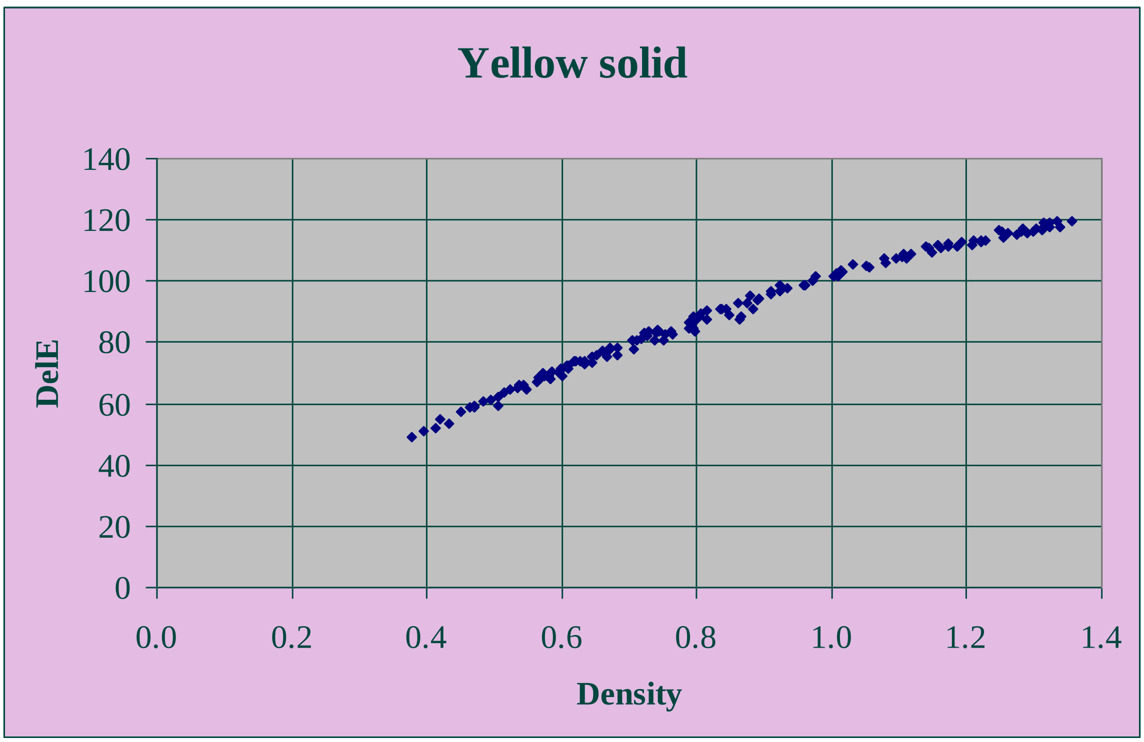
5 Correlation with ΔE

One can ask whether this discrepancy between coated and uncoated stocks in cyan and magenta is just an inherent problem with trying to develop a colorimetric analog to density. To test this hypothesis, I have preformed the same analysis between ΔE and density. The ΔE value is computed between paper and the patch. All L*a*b* values are computed paper-relative.

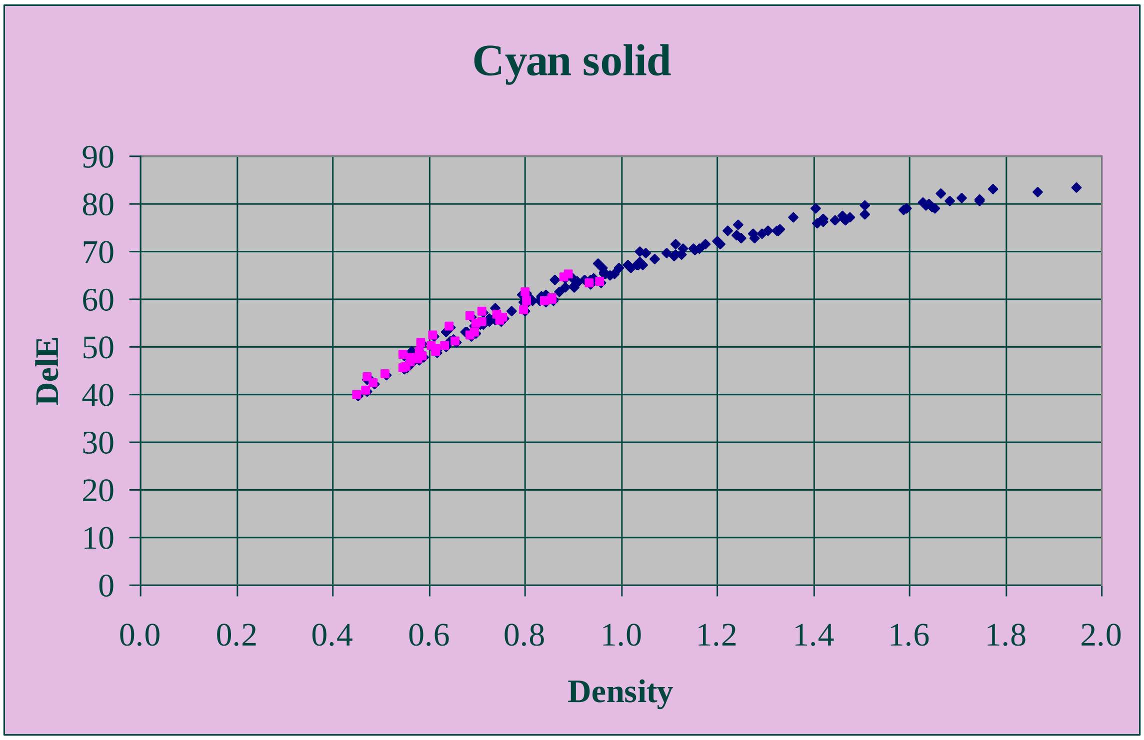
The relationship between density and ΔE for black is straightforward, as it was between density and CTV_{rel}.



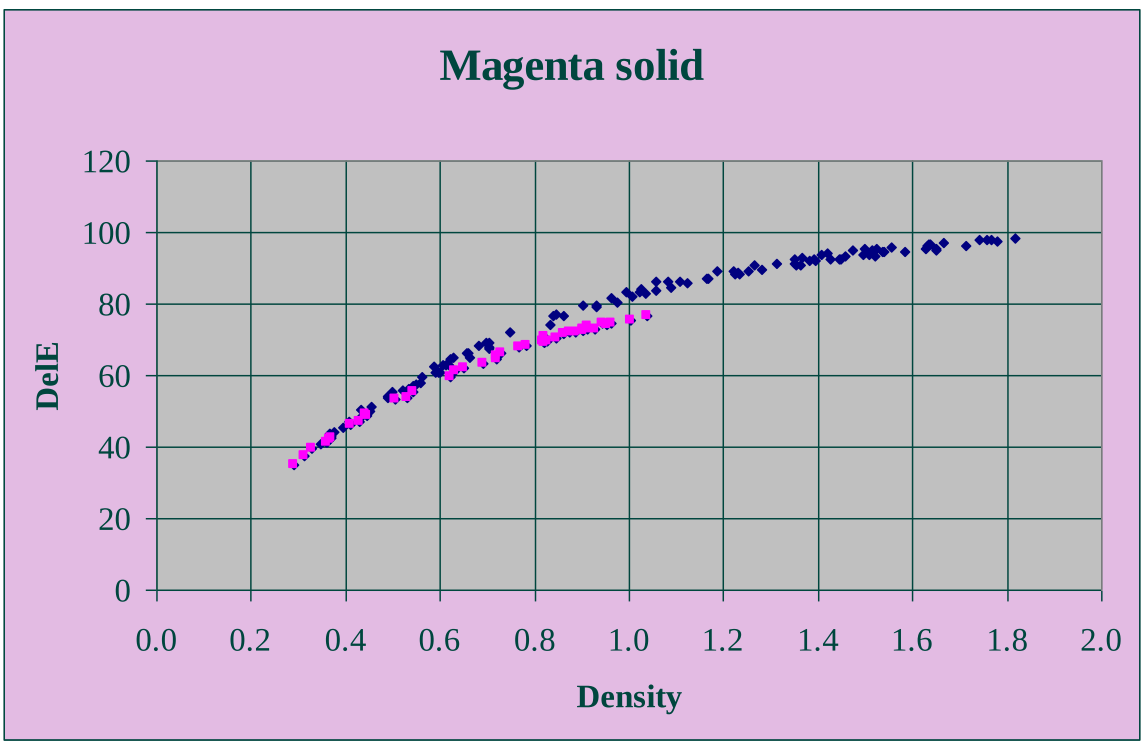
The plot for yellow ink is as well-behaved as before.



What is a surprise is that cyan has a fairly clean relationship. The measurements from uncoated stock have been plotted in a different color, but are obviously all part of the same curve.



Magenta is the only plot that shows any departure between the coated and uncoated stocks. This departure, albeit significant, is not as prominent as that of the CTV_{rel} plot.



My conclusion is that ΔE has a closer relationship to density than does the relative CTV.

Birkett and Spontelli did consider the ΔE. I quote from [5]:

For colored inks, chroma looks like a reasonable measure. But there are anomalies when measuring certain colors, like magenta. For instance, the chroma of a "pure" magenta will be greater than a "dirty" magenta, even though the visual perception of tone is reversed. The dirtier the magenta ink becomes, the less its chroma value…

A better solution is to use the ΔE between the color being measured and the paper white…

But ΔE is derived from Lab differences, and the anomalies of the chroma measure are still present.

In this paper, I did not consider various amounts of "dirtiness" of inks, primarily because I happened to have a rather convenient and complete data set that looked at varying the ink film thickness. Based on this data set, it would appear that ΔE is somewhat better behaved than CTV or relative CTV.

6 Conclusions

I have compared CTV to density. I have found more consistent results with a minor variant, the paper relative CTV.

On a large data set, I have seen that, for cyan and magenta inks, the relationship between CTV and density depends upon whether the stock is coated or uncoated. Using that same data, I find that ΔE does not have this same duality.

Bibliography

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[2] Chou, Shem, Norman Harbin, *Relationship between ink mileage and ink transfer*, TAGA Proceedings 1991

[3] MacPhee, John, John Lind, *Measurements of ink film thicknesses printed by the litho process*, TAGA Proceedings 1991

[4] Blom, B. E., T. J. Conner, *Optical density and ink film thickness; a comparison of models*, TAGA Proceedings 1990

[5] Birkett, William, and Charles Spontelli, *Colorimetric tone value (CTV) A proposed single-value measure for presswork*, presented to CGATS, July 26, 2005