In this, the first in a series of technical articles, Mr Wilbert Streefland of Technology Coaching BvbA looks at colour difference during printing production and the problems of representing visual colour difference by instrument and the consequential problems of instrumental colour control in production.

COLOUR DIFFERENCE DURING PRODUCTION

During the 13th FEFCO technical conference it was suggested that I consider writing an article on perceptual colour difference equations. After careful consideration I decided to avoid this extremely difficult area of human perception and neuroscience — but there are important aspects of this work that influence the setting and maintaining of colour standards in the packaging printing industry.

The problem

All colour standards and agreed tolerances used in the industry are mostly agreed by people with "normal" vision. We are all familiar with the standard proof, signed by a senior person from the customer and the counterpart from the supplier. This is the piece of printed paper, plastic or metal referred to in times of serious dispute, often involving large sums of money! Here is where the problems start. The supplying company (printer) measures the standard and the printed sample in question with a spectrophotometer and calculates a ΔE value for the colour difference. Values are shown to be within the agreed tolerance signed by the customer but all present can physically 'see' that there is a colour difference and the finished job is not what was required by the customer. By now, both parties are pointing fingers, apportioning blame and thinking of compensation (or the cost of rejects). So what has gone wrong?

Customers and suppliers can place too much reliance on instrumental measurement of colour difference. Even though a ΔE value may have been agreed, there can still be a 'visual' colour difference.

The theory

In 1806 Thomas Young proposed that the retina of the human eye has three types of cone sensors that respond to red, green or blue parts of the spectrum. This was further developed by Helmholtz at the end of the 19th century. In 1920 Schrödinger published a paper titled, "Theory of Colour Measurement in Daylight Vision". In this paper, it was suggested that any spectral colour can be matched by a linear combination of the three basic colours of red, green and blue. It follows therefore, that any two colours can be represented in this way so the colour difference is the 'distance' between these two colours.

Unfortunately, reality is not so simple because Helmholtz and Schrödinger showed that the geometry relating to the colour coordinates is not a familiar 3-dimensional Euclidean geometry where

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the shortest distance between two points is a straight line. Colour co-ordinate geometry is 'Riemann' geometry, where the distance between two points is a curve or geodesic and the shortest distance is the geodesic involving the least colour change. During the development of this three colour theory there was a rival four colour theory developed by Ewald Hering using red, green, blue and yellow. Schrödinger showed a relationship between the two colour theories — colours specified in one could be represented in the other.

The Result

The ΔE values calculated for acceptable limits of colour difference should only be applied to that colour and for small difference in that colour. This is because our practical equations assume a simple geometric relation between the colour coordinates and they do not represent the visual process of discerning colour difference. The eye-to-brain pathway is sophisticated and, as yet, not fully understood and there is no model for it. Instrumental measurements do not predict what we see.

Comparing colour difference

It is quite easy to show the behaviour of the different colour equations when we change the printed ink film thickness. The colour difference equations used are:

— CIELAB ΔE
— CIE94 ΔE94
— CMC ΔECMC
— CIEDE2000 ΔE00

The experiment was as follows. We prepared standard process colour ink samples for a flexo printer. These process colours were printed using an anilox roll that had a wet ink film of 10µm. The roll used had different bands engraved across its width. It had bands that might transfer the following wet ink films: 5.4µm, 8.2µm, 10.0µm, 12.2µm, 14.7µm and 18.2µm. Ink samples were prepared for yellow, magenta, cyan and black and full tone printed on white paper. For each of the colours, the spectral reflectance data (intensity at each wavelength) was measured for the six individual printed bands and the colour difference was calculated using the colour difference equations between the colours of the individual bands printed using the 10µm band as the 'standard'. The colour difference values for the bands 5.4µm and 8.2µm were multiplied by -1, only for the purpose of making a graph.

For each colour difference equation a graph was plotted showing all colours evaluated. Each graph presents the colour difference as a function of the wet ink film thickness.

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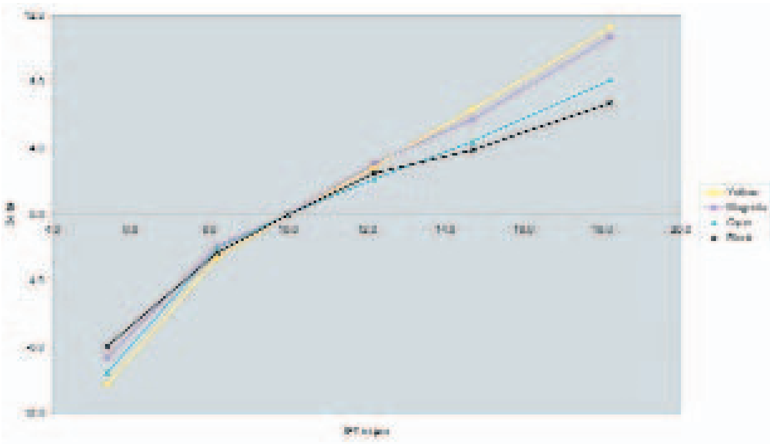
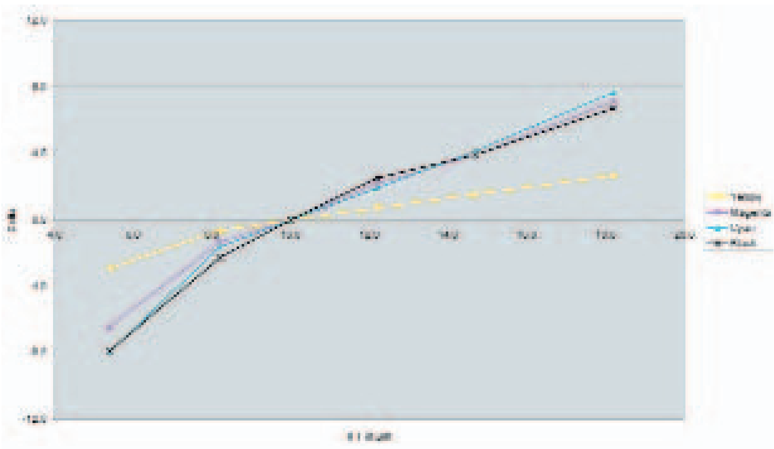


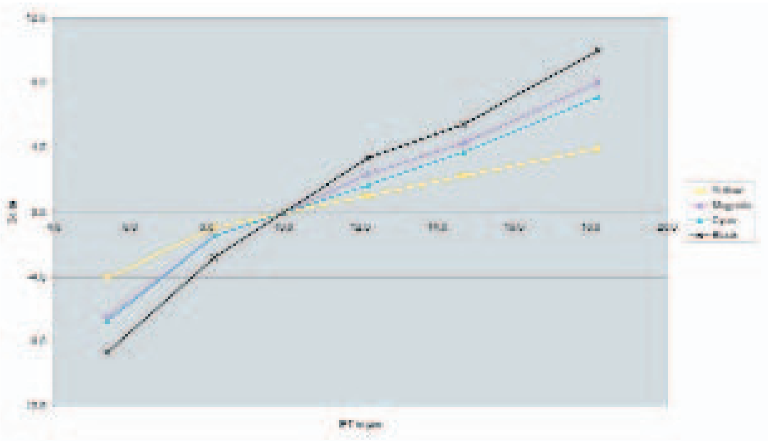
The calculated colour difference, using CIELAB, shows for the 4 tested colours similar colour differences between 8 µm and 12 µm wet ink film thickness.

Graph 1
The results using the colour equation CIELAB DE



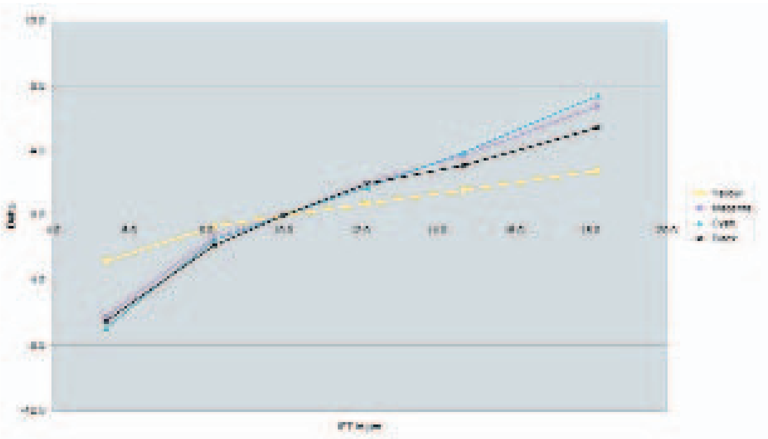
The calculated colour difference, using CEI94, shows for yellow a different colour difference behaviour as a function of wet ink film thickness then for the other 3 colours.

Graph 2
The results using the colour equation CIE94 ΔE94



Graph 3. The results using the colour equation CMC ΔECMC

The calculated colour difference, using CMC, shows for yellow and black a different colour difference behaviour as a function of wet ink film thickness than for the other two colours.



Graph 4: The results using the colour equation CIEDE2000 DE00

The calculated colour difference, using CIEDE2000, shows for yellow a different colour difference behaviour as a function of wet ink film thickness than for the other 3 colours.

What can we learn?

This was only a small experiment. It might need repeating using more colours and substrates. The applied procedure might help to evaluate a colour difference equation that shows the same value and linearity for all colours when the colour difference results from a difference in printed wet ink film. The wet ink film thickness might be the biggest variable that influences colour during printing. One could question if the wet ink film was changing compared with the values indicated. We were not able to prove this, but it is possible to use copper analysis (blue and green colour) of the printed ink on the surface of the substrate relative to the copper content of the wet ink sample used. This test might give an insight on how well the anilox roll is made.

During the experiment we used the same anilox roll and substrate for printing all the wet ink samples. If you do a perceptual evaluation of the printed samples, then you see little colour difference for the yellow compared to the other three colours — simply because the human eye is not so sensitive to yellow (no yellow cones in the retina). However, the wet ink film thickness difference is the same for all the printed samples!

Our understanding from this experiment is that some colour difference equations are not particularly useful in production where ink film thickness variation might be the dominating factor in creating colour difference.

In practice, this means if you agree with your customer CIELAB ΔE < 4 as a production tolerance, then you might be able to deliver if the ink film thickness variation on your machine is less then ± 2 μm for a nominal ink film thickness of 10 μm independent of the colour printed. For any other colour equation you need to find out the production colour tolerance for each individual colour. Thus, a customer might say, "I only accept CIEDE2000 ΔE00 < 3", in which case your equipment might only be able to achieve it for yellow and not for any other colour. It is then just a matter of time before the complaints start and there is nothing you can do about it. Your printing equipment is doing the best it can — it might result in you no longer using a measuring device for colour, and that is probably turning the clock back.

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Conclusion

- Different ΔE values need to be agreed for different colours, not just process colours;
- Machine capabilities need to be quantified so that realistic ΔE values are agreed;
- The final accept or reject will be the customers eye taking process capabilities into account;
- Customer and supplier must agree on the colour equation/measuring system to be used;
- Major colour contrasts in the final art work must be taken into account.

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