

Influence of Light Scattering in Colorant Layers on Reflection Spectra of Tertiary Color Images

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Abstract

Xerographic color prints, now expected to launch into photo-finishing market, suffer from their insufficient maximum density compared with 2.0 or more of the conventional photographic print. Factors to be analyzed include light scattering in the pigment loaded colorant layers. In this report, the amount of scattered light was measured under a 0/45° geometry with samples consisting of a primary colorant layer on a transparent backing sandwiched between a pair of glass plates. The results indicate that the scattered component acts to suppress the maximum density of pigment-based, secondary or tertiary color images, but that, by choosing an appropriate order of color superimposition, the maximum density can be made close to that of photographic prints. The spectral reflectance of tertiary color images was calculated by using the scattered and the reflected light of primary color images, showing a satisfactory agreement with the measured spectra.

Introduction

With the recent remarkable image quality improvement, color xerography is launching into not only printing but also photo-finishing markets. The xerographic color gamut has been expanded almost to that of lithography by using flashed pigments and polyester resins with low molecular weight for color toners.^{1,2} However, the maximum density (D_{\max}) of xerographic secondary or tertiary color images is still not enough compared with that of conventional photographic prints.

To raise those xerographic D_{\max} 's, some optical factors need be analyzed. The effect of surface reflection on D_{\max} seems negligible for glossy images. One of the remaining factors is light scattering in the pigment loaded colorant layers.

The present report discusses a method to quantify the scattered light impinging colorant layers, as it acts to decrease D_{\max} .

Experiments

Sample Preparations

Uniform primary colorant layers of representative xerographic, lithographic and silver halide photographic

images were formed on pertinent scatter-free transparent films. The silver halide print was included in the experiment as its colorant layer is regarded free of light scattering.

The key of the present analysis is to measure the reflected and scattered light with the same sample.

Simulated tertiary color sheets were obtained by superimposing three primary color samples, filling the inbetween spaces with tetradecane ($n=1.41$) for light index matching.

Scattered Light Measurement (Fig. 1(b))

The scattered light in each colorant layer that decreases the D_{\max} value under 0/45° geometry was measured with the following procedures.

In order to eliminate surface scattering, a piece for measurement was prepared by sandwiching each sample with a pair of cover glasses and filling the space between the cover glass and the sample surface with tetradecane.

The piece was placed on a light trap where the spectral reflectance was measured with an X-Rite 968 (D50, 2°) that conforms to the 0/45° geometry CIE standard.

In this configuration, only the scattered component caused by the light index fluctuation in the colorant layer is measured, as the transmission component and the scattered one at both surfaces cannot enter the light detector arranged obliquely to the impinging light direction.

The intensity of scattered light thus measured is relative to that of a perfect diffuser.

Reflected Light Measurement (Fig. 1(a))

In order to make the transparent sample reflective, the sample was placed on a diffuse white backing (Teslin made by PPG Industries, Inc.) wetted with tetradecane.

Reflection pieces were prepared by taking similar measures to eliminate surface reflection.

The reflectance of the resulting pieces was measured with the X-Rite 968 under a black backing condition.

Results & Discussions

Scattering Spectra of Primary Colors

The scattering and reflection spectra of the xerographic primary color samples are shown in Fig. 2.

The yellow colorant layer (YL) exhibits the most intense scattering with a peak of about 3% near 500nm. In

the case of the magenta layer (ML), the scattering has a peak near 600nm. In either case, the scattering peaks at the bathochromic side of the absorption edge. It is evident that among the three colorants, scattering is significant for YL and ML while that of the cyan layer (CL) is far weaker.

Layer Order Optimization for Tertiary Color

Figure 2 indicates that the light scattered by YL must be well absorbed by ML. When YL lies beneath ML, the incident light to be scattered by YL is first weakened by

ML, and the scattered light again absorbed by ML. Thus, the intensity of the scattered light from YL is drastically reduced.

In contrast, as the scattered spectrum for ML does not coincide with the absorption of YL, the layer order between YL and ML has a far less effect on the scattering caused by ML. However, as the ML scattering spectrum coincides with the CL absorption spectrum, the scattering caused by ML can be effectively reduced by placing CL above ML.

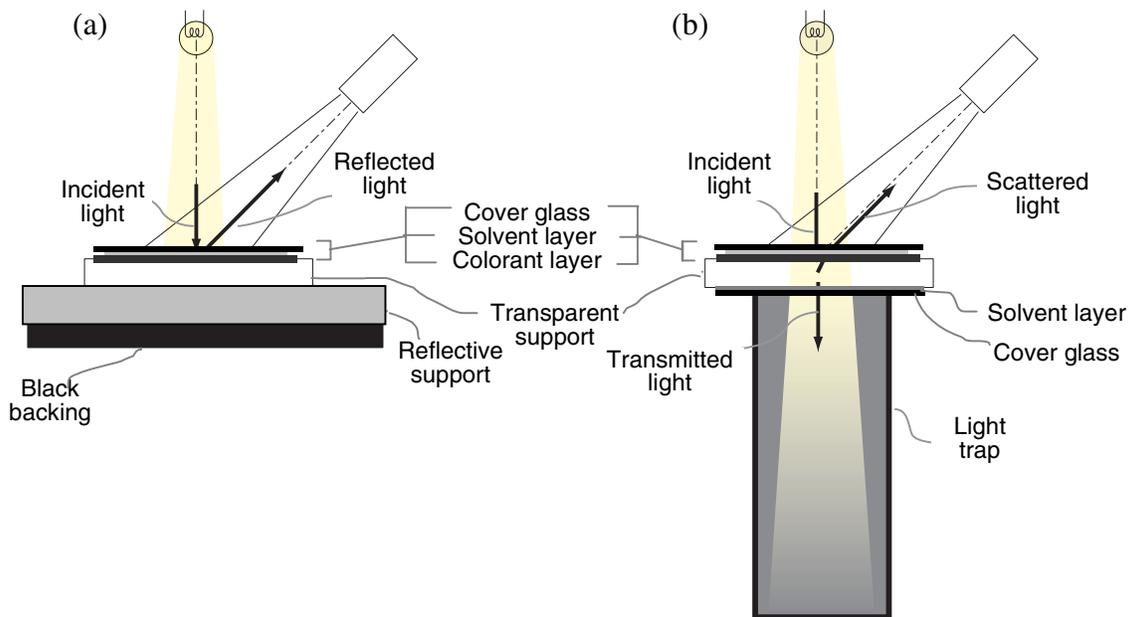


Figure 1. Measurement schematics for (a) reflected and (b) scattered light.

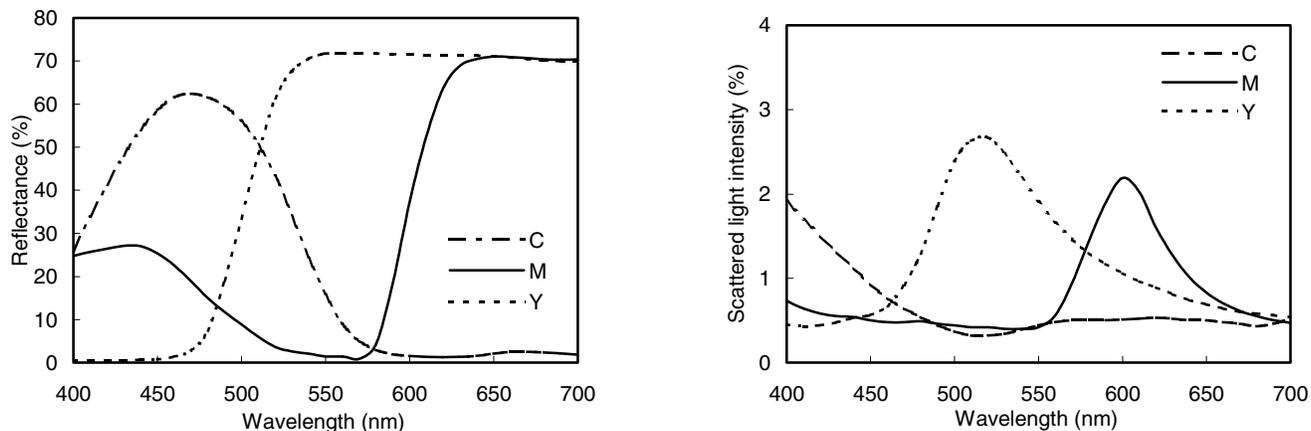


Figure 2. (a) Scattered and (b) reflected light spectra of xerographic primary color samples.

As CL shows the least scattering among the three, the layer order of Y, M and C from the bottom must certainly be the most desirable in order to minimize the scattered light of the tertiary color.

Figure 3 shows the reflected and scattered light spectra of xerographic tertiary color samples. In the figure, the layer order is expressed from the support side. The validity of the above speculation is confirmed.

Now, in a strict discussion of reflected light spectra, surface reflection and multiple reflection must also be taken into account. But, for samples with a flat surface, the former factor is negligible, and for high density samples such as tertiary color ones the latter contributes little, too. Accordingly, for samples satisfying the above conditions, reflectance (R_t) is assumed to be the sum of the scattered light (R_s) and the reflectance dependent on the colorant layer absorption alone. The latter factor will be designated as R_a , which was determined by subtracting the absorbed light in the colorant layer from the reflectance of the white backing.

Figure 3 also includes the spectra of R_a obtained by subtracting R_c from R_t according to the above assumption.

As R_a is constant independently of layer order in Fig. 3, the assumption must be correct. Then, the color order with the minimum R_s can maximize the density.

With lithographic samples, similar results with more intense scattering (particularly of YL) were obtained as shown in Fig. 4. Such difference in scattering may come from the difference in pigment dispersion conditions for the two systems.

Figure 5 shows the scattered spectra for the silver halide photographic samples, indicating that far weaker scattering takes place for primary as well as tertiary colors than in the xerographic and lithographic samples.

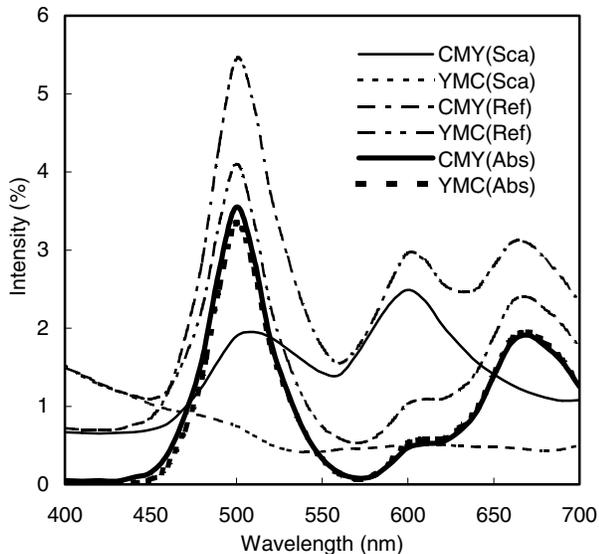


Figure 3. Spectral intensities of R_s , R_t and R_a of xerographic tertiary color samples.

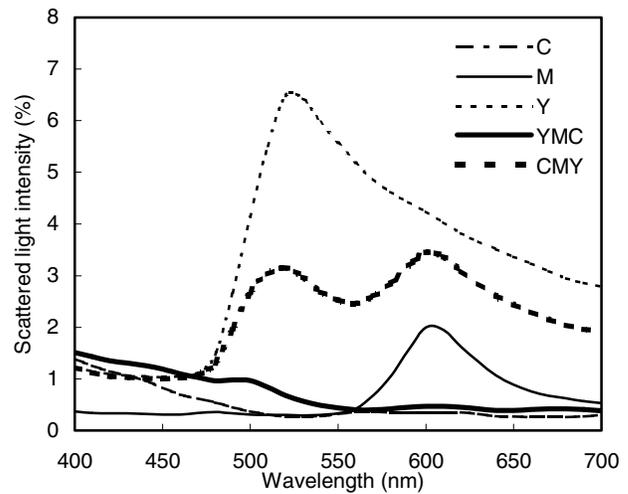


Figure 4. Scattered light spectra of lithographic samples.

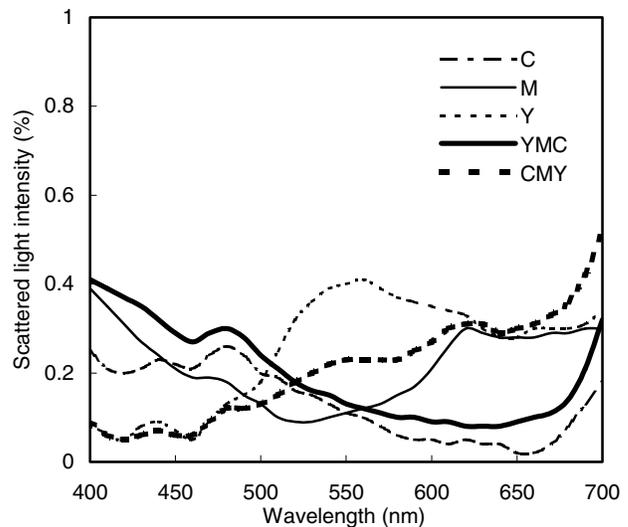


Figure 5. Scattered light spectra of photographic samples.

These results confirm that the scattering is mainly caused by pigment colorants used in xerographic toner and lithographic ink.

Calculation of Reflection Density

From the data of Fig. 3 and Fig. 5, the visual density corresponding to R_t , R_s and R_a for xerographic and photographic tertiary color samples were calculated as shown in Table 1.

Table 1 reveals that the pigment-based xerographic samples show a strong dependence of density on layer order while the dye-based photographic ones show a far less dependence.

Table 1: Visual density of xerographic and photographic tertiary color samples for the two layer orders.

	Xero		Photo	
	YMC	CMY	YMC	CMY
R_t	1.93	1.60	2.53	2.34
R_s	2.31	1.74	2.91	2.62
R_a	2.16	2.15	2.74	2.68

Calculation of Tertiary Color Reflection Spectra

By using R_a and R_s spectra of primary color samples, the reflection spectra of xerographic tertiary color samples were calculated. Multiple reflection and multiple scattering as well as the back surface reflection were all neglected.

Figure 6 shows the calculated spectra and the measured ones for the two layer orders. The figure indicates that the reflection spectra are mostly governed by R_a and R_s , supporting the above assumption of neglecting the minor factors.

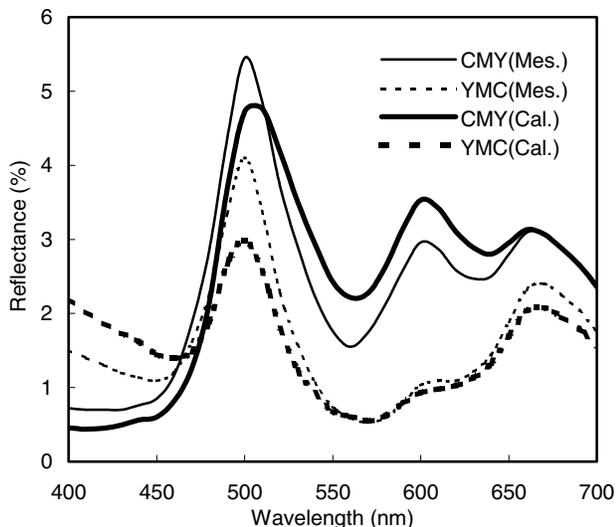


Figure 6. Comparison of the calculated and measured reflected light spectra of xerographic tertiary color samples.

Conclusions

I have proposed procedures for quantifying the scattered light intensity of colorant layers that affects the reflection properties under $0/45^\circ$ geometry. Such a light intensity of pigment-based layers was about ten times as great as that of dye-based ones. As the total reflectance simply adds up the contribution by the scattered light, it is concluded that the scattering is a factor for the insufficient D_{max} of xerographic tertiary color images. However, it is also concluded that D_{max} 's exceeding 1.9 can be achieved with an appropriate order of xerographic colorant layers which can minimize the overall scattering by considering the absorption and scattering characteristics of each primary colorant layer. In the case of the xerographic tertiary images of the present experiment, the minimized scattered light is weaker than the reflected light determined by the colorant absorption. Therefore, the above cited value for D_{max} can still be raised by increasing the thickness of the colorants.

I have been studying the relationship between the colorimetric properties of area-modulated images and the degree of dot gain thereof.^{3,4} The present experiment has revealed that the scattering of colorant layers also act to shift colors. The results obtained by the present study will be used for my future dot gain studies.

Acknowledgement

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References

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Biography

Mr. Osamu Ide received Bachelor of Science degree in physics at the Science University of Tokyo in 1985. Since then, he has been with R & D departments of Fuji Xerox Co., Ltd. Starting with xerographic product development, he is now most interested in image structure analysis to expand xerographic applications.