A Gonio-photometric Analysis of Ink Jet Bronzing

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Abstract

Bronzing is an optical phenomenon often observed in inkjet and some other ink/paper systems and is generally considered to be a detriment to image quality. An instrumental technique has been developed for characterizing bronzing based on gonio-photometric analysis in red, green, and blue light. Analysis of the instrumental results can be shown to relate directly to Fresnel specular reflectance factors, ρ. Measurements of ρ were made in red, green, and blue light to quantify chromatic attributes of gloss. The analytical metrics were shown to relate both to the underlying optical properties of the inks and to the visual perception of gloss attributes.

Introduction

Bronzing refers to a reddish, rusty, or yellowish hue in the gloss reflectance of a printed image and has been observed for many decades in various printing inks and printing processes.[1] It is a generally objectionable attribute, and much literature has been devoted to the measurement and the elimination of the bronzing. The objective of the current study was to develop an analytical technique for measuring bronzing. As will be shown, the analytical technique that was developed provides useful information about the optical mechanism of bronzing. In addition, the analysis is capable of predicting the visual impact of bronzing.

Bronzing is both a chromatic attribute and a goniophotometric attribute. As a result, several reports have been published on techniques of bronzing analysis based on spectro-goniophotometry.[2,3] The goniophotometric techniques used in these reports were based on traditional techniques of varying either detector angle, source angle, or both. Recent reports have shown that goniophotometry based on the variation of sample angle, α, while holding detector and source angles constant, can provide unique insights into the optical properties responsible for the observed gloss.[4,5,6] In the current work, bronzing has been analyzed using sample angle goniophotometry with measurements made in red, green, and blue portions of the spectrum.

The Micro-Goniophotometer

The instrument used in this study is called a micro-goniophotometer (μ-G) and has been described in detail previously[4,5,6]. In the current work, the μ-G was used to measure the specular reflectance factor, ρ, of printed samples based on the measured area, A, under the BRDF, as described pereviously.[6] This was done by measuring A_{ref}, the area for a reference material of known specular reflectance, ρ_{ref}, and then calculating the specular reflectance of the sample, ρ, using equation 1.

$$\rho = \rho_{ref} \frac{A}{A_{ref}} \qquad (1)$$

According to Fresnel's Law, the value of ρ is a function of (1), the index of refraction of the printed ink, and (2) the angle, θ, of the light source and the camera relative to the normal to the reflecting surface. It can be shown[4,5,6] that θ is a constant in the μ-G instrument and is equal to half the angle between the camera and the light source. By changing the source/camera angle, θ can be changed, and data such as that illustrated in Fig. 1 can be generated. A value of ρ > 0.1 for an organic ink indicates a complex index of refraction, $\kappa_o > 0$, where κ_o is proportional to the extinction coefficient of the ink. As will be shown, $\kappa_o > 0$ is the optical property responsible for bronzing.

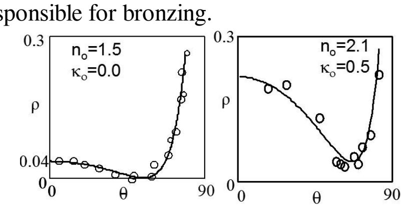

Figure. 1: *Illustration of μ-G analysis of ρ vs. θ. The left and right graphs show data measured by the μ-G for two different inkjet black inks. The solid lines are Fresnel's law with optical constants n_o and κ_o.*

The Inkjet Samples

The inkjet samples used in this study were printed with a proprietary test printer using either Cyan ink or K Black ink at 2400x1200 dpi addressability. Both inks were non-commercial, experimental inks observed to display very high bronzing. Fig. 2 illustrates the printed pattern generated for each of the four ink types. All samples were printed on a high gloss, photo quality paper.

Gray scale levels were varied in order to induce different bronzing levels. Details of the GE formulation and the halftone algorithm are proprietary and were used only as a means of generating a set of samples with a wide range of visual bronzing. The intent is to demonstrate the utility of the micro-goniophotometer for measuring the bronzing phenomenon.

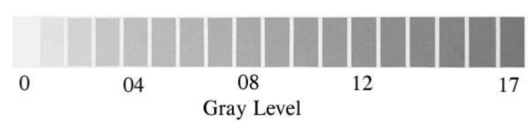

Figure. 2: *Printed sheet showing the variation in printed gray level. 0 is zero ink and 17 is complete ink coverage .*

Black Ink Bronzing vs. Gray Level

The amount of bronzing visually observed in the black ink varied with gray level. Prior to measuring bronzing with the μ-G, the characteristics of the gray level were examined using a reflection densitometer to measure D, and a PIAS imaging microscope by QEA, Inc, to measure the halftone dot area fraction, Fig. 3 illustrates the halftone structure of gray level 02, at D=0.17, and Fig. 4 shows D vs. F.

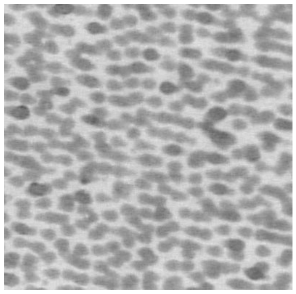

Figure. 3: *Black ink at gray level 02. Measured density D=0.17.*

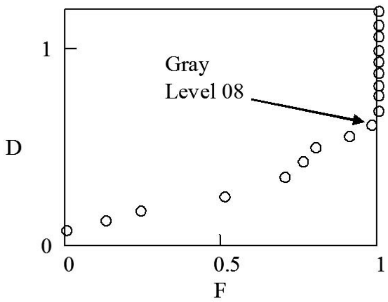

Figure. 4: *Yule-Nielsen analysis of black ink. D is visual density and F is dot area fraction measured with the QEA PIAS instrument.*

The density increases linearly with F, indicating the halftone dots are significantly smaller than the mean paper scattering distance. At Gray Level 08, the dot overlap covered all of the paper substrate and made F=1. Beyond Gray Level 08, ink continued to build up with a corresponding increase in density.

The micro-goniophotometer (μ-G) was used to measure the Fresnel reflectance factors, ρ, for each gray level of sheet KH in red, green, and blue light. The results are shown in Fig. 5. Two distinct regions are evident. These regions are to the left and to the right of Gray Level 08 where the dot area fraction goes to F=1.

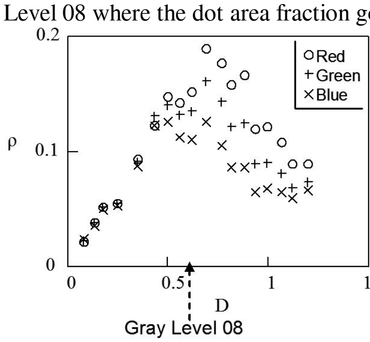

Figure 5: *Fresnel reflectance factors, ρ, in red, green, and blue light versus density, D, for all gray levels of the black ink.*

The data on the left of Gray Level 08 in Fig. 5 indicate no bronzing. That is, the red, green, and blue values of ρ are equal to each other at each gray level. The increase in ρ with respect to the measured dot area fraction is shown in Fig. 6, and the linear increase can be rationalized as illustrated in Fig. 7 and equation (2). No Yule-Nielsen type behavior is apparent, which is expected since specular reflectance does not involve lateral scattering within the bulk of the substrate.

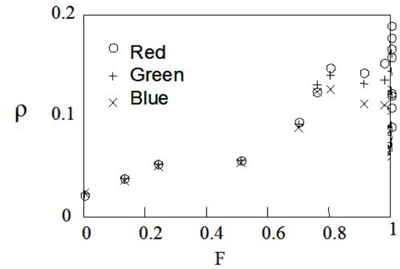

Figure 6: *Black ink Fresnel reflectance factors versus F(dot area fraction) measured with the QEA PIAS instrument.*

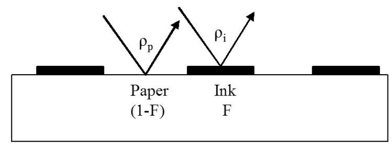

Figure 7: *Schematic diagram of specular reflectance below Gray Level 8 where density is linearly related to dot area fraction, F. ρ_p and ρ_i are Fresnel reflectance factors for the paper and the ink respectively.*

$$\rho = F\cdot\rho_i + (1\text{-}F)\cdot\rho_p \tag{2}$$

Fig. 5 shows that above Gray Level 08, the reflectance values are in the order $\rho_{red} > \rho_{green} > \rho_{blue}$. This results in a yellowish hue for the bronzing phenomenon, which is in agreement with visual observations. Beyond Gray Level 08, where F =1, the value of ρ_{red} initially increases, and then decreases as the amount of ink goes up. As we go up the tone scale in Fig. 5, the values of ρ_{green} and ρ_{blue} begin their decline at density values lower than does ρ_{red}. No hypothesis is offered for this behavior.

The tone scale of the Cyan ink also was examined in detail and also displayed a linear D vs. F relationship (not shown), again indicating the halftone dots were much smaller than the lateral scattering distance of light in the paper. Like the black ink, the cyan also reached F = 1 at Gray Level 08, and density increased with gray levels beyond level 08. Fig. 8 shows the behavior of the Fresnel reflectance factors as a function of density and of dot area fraction. Unlike the black ink, the cyan shows a significant break in the linear relationship between ρ_{red} vs. F at F=0.7 (Gray Level 05). No hypothesis is offered for this behavior.

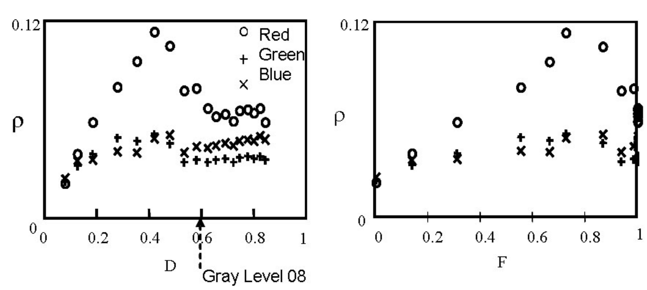

Figure 8: *Cyan ink Fresnel reflectance, ρ, versus density, D, and versus dot area fraction, F.*

The bronzing hue observed visually for the Cyan ink was distinctly pinkish. This is consistent with the relative order of the values of Fresnel reflectance shown in Fig. 8. ($\rho_{red} > \rho_{green} \approx \rho_{blue}$).

Visual vs. Instrumental Bronzing

An instrumental index of bronzing was defined by the following equations, where ρ is the average of the reflectance values over the red, green, blue, δ is the deviation from the mean, and Br in equation (5) is a bronzing index defined as the Euclidian distance from the mean ρ. Values of Br were compared with visual perception of bronzing magnitude.

$$\rho = \frac{\rho_r + \rho_g + \rho_b}{3} \quad (3)$$

$$\delta_r = \rho_r - \rho \quad \delta_g = \rho_g - \rho \quad \delta_b = \rho_b - \rho \quad (4)$$

$$Br = \sqrt{\delta_r^2 + \delta_g^2 + \delta_b^2} \quad (5)$$

The visual perception of bronzing was evaluated by cutting out each rectangle of the gray scale (0 through 17) and asking observers to sort them in order from most bronzing to least. Averaging the results for several observers provided a magnitude estimate of bronzing. Fig. 9 shows the visual magnitude of bronzing as a function of (A) measured values of density, D, and (B) the instrumental measure of bronzing magnitude, Br, defined in equation (5). Fig. 10 shows the same experiment for the cyan CH sheet.

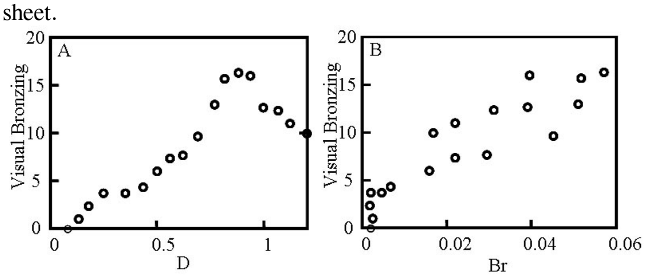

Figure 9 : *Visual Bronzing of Black ink, as a function of (A) density, D, and (B) radiometric bronzing, Br.*

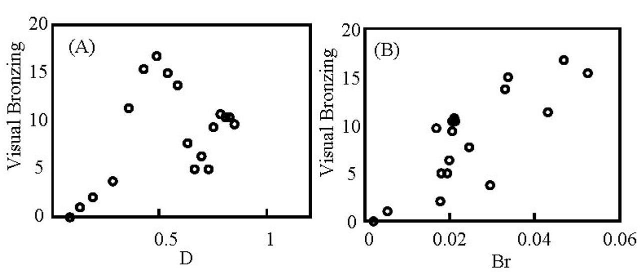

Figure 10 : Visual Bronzing of Cyan ink as a function of (A) density, D, and (B) radiometric bronzing, Br.

The bronzing index, Br, does a moderate job of predicting visual bronzing. However, correlation can be improved if the background density is taken into consideration. Intuition suggests that gloss in general is easier to perceive on a dark background. Thus, the bronzing index Bd was considered. Fig. 11 shows the correlation of the perception of bronzing magnitude versus Bd.

$$Bd = Br \cdot D \quad (6)$$

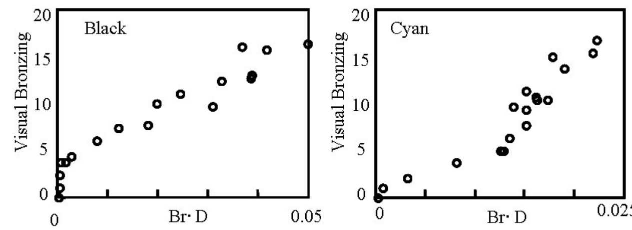

Figure 11: *Visual bronzing versus the product of Br·D for the black ink and for the cyan ink.*

The visual bronzing scales in the two graphs shown in Fig. 11 can not be compared directly. Both are arbitrary magnitude scales developed in two independent experiments in which participants were asked to sort samples from highest to lowest bronzing. Seventeen samples were used in each experiment, so the averaged data produce a magnitude scale from 0 to 17 in both cases. Clearly, therefore, a value of 10 on one scale does not relate to a value of 10 on the other scale. However, the correlation between visual bronzing and the product Br·D is very encouraging. It appears that the micro-goniophotometer shows promise as a potential tool for quantifying both the optics of bronzing and the visual appearance of bronzing.

Acknowledgement

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