The Effect of Drying Rate on Inter-Color Bleed

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Abstract

Printing with colored water based inks on plain papers, typical of ink jet printing, causes ink droplets to bleed into one another. The magnitude of the bleed depends on drying mechanism, ink and paper properties, and on interactions between ink and paper. This study reports data on intercolor bleed as function of drying time (or absorptive and evaporative drying).

A methodology for characterizing intercolor bleed is presented. Experimental data is also presented which shows the transient and steady state dependence of intercolor bleed on ink and paper properties, ink and paper interactions, and on drying rates.

An empirical model is proposed for relating intercolor bleed to ink and paper properties. Printing conditions and ink properties which aid in controlling intercolor bleed are discussed.

Introduction

In Ink Jet Printing, tiny aqueous based ink droplets are deposited on paper in a predetermined manner so as to create images which could be text, pictorials and other image classifications. These ink droplets penetrate the paper and spread on the paper by several mechanisms. The predominant mechanism is capillary driven liquid movement into the pores of the paper, absorption of liquid into paper fibers, and vapor diffusion. A diffusion approach has been used in a phenomenological sense to model the overall mechanism with reasonable success by many investigators, to cite a few [1-4].

In color printing, the spreading of ink droplets will cause different colors to run into one another. This would create undesired color mixtures which could create false rendering of the image, and also be undesirable aesthetically.

Several factors determine the extent to which ink droplets will spread on paper. Paper properties which could be important factors include pore size distribution in the paper, the surface finish of the paper, and free surface energy of paper. Ink properties which are important factors include surface tension and viscosity. Another important factor is the rate at which the ink image is dried.

This paper presents experimental data which relates the magnitudes of transient and steady intercolor bleed to ink and paper properties, ink and paper interactions, and on drying rates.

An empirical model, based on dimensional analysis principles, is proposed for relating intercolor bleed to ink and paper properties. Finally, printing conditions and ink properties which aid in controlling intercolor bleed are presented at the poster session.

Empirical Model

To help understand the results presented in a predictive manner, an empirical model is developed to relate the magnitude of intercolor bleed to ink and paper properties and to other factors which drive intercolor bleed.

Figure 1 is a sketch of two adjacent ink droplets of different colors, before and after they have run into one another due to spreading. Initially, the two droplets have initial radii of a1(0) and a2(0) and are separated by the boundary AA.

After time t, droplet 1 travels by a maximum radial distance $\delta_1(t)$ into the domain of droplet 2, while droplet 2 travels by a maximum radial distance $\delta_2(t)$ into the domain of droplet 1.

A maximum intercolor bleed distance of $\delta(t) = \delta_1(t) + \delta_2(t)$ is established.

The predominant mechanism by which ink droplets flow on the surface of the paper consists of liquid flow by capillary forces on the surface of the paper due to randomly interconnected voids on the paper surface[5,6,8]. In addition to surface spreading of ink, the droplets penetrate the paper due to capillary forces, absorption of liquid into the paper fibers, and vapor diffusion within the paper. Phenomenologically, a diffusion approach has been successful in treating the combined mechanisms on a macroscopic scale. Since there is a wetting delay before the liquid begins to spread and penetrate the paper, the time t does not begin as soon as the ink droplet strikes the paper. Furthermore, with time, the liquid is depleted from the paper surface due to penetration, so that the spreading is time limited.

A dimensionless parameter to measure the intercolor bleed between adjacent droplets is defined as

$$\beta(t) = \delta(t)/a \qquad (1)$$

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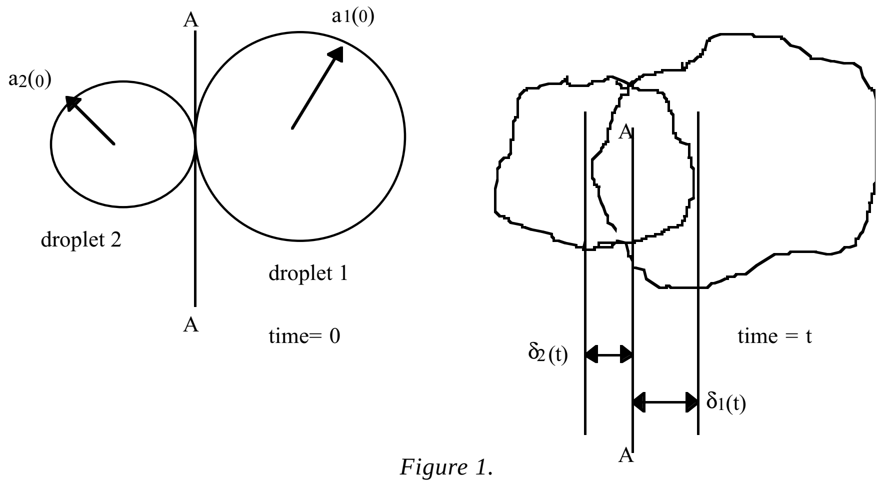

Figure 1.

where $\delta(t) = a(t) - a(0)$ is the radial excursion at time t
a = average radius of droplets at time t=0.

Functional dependence for Intercolor bleed on ink, paper and other parameters is postulated by appealing to the Young-Laplace equation, the Hagen-Poiseuille Equation, Boyle's equation and the Lucas-Washburn equation[5-8], to yield

$$\beta(t) = \text{function}(R_c, \sigma, \mu, t, \gamma_{SL}, a), \tag{2}$$

where R_c = average pore radius of paper
σ = surface tension of ink
μ = viscosity of ink
t = time
γ_{SL} = liquid-solid (ink-paper) interfacial tension
a = average droplet radius.

An empirical approach of this nature may capture enough physics of the phenomenon so as to make the projection of Intercolor bleed as function of ink and paper properties more systematic. Dependence of Intercolor bleed on temperature is not included in this formulation in a direct manner. Since ink viscosity and surface tension are strongly dependent on temperature, the empirical approach should be applied to results measured at a specified temperature. Results obtained while the temperature fluctuates will not be valid.

Rayleigh's dimensional analysis approach yields the functional relationship

$$\beta(t) = C\,[(R_c\,\sigma\,t)/(a^2\,\mu)]^\alpha \tag{3}$$

where C, and α are arbitrary constants. Note that the dimensionless group in equation (3) is equal to the quantity (*Re*/*We*), where *Re* and *We* are Reynold's and Weber's Numbers respectively.

This quantity is the ratio of viscous effects to free surface effects. For InterColor Bleed, the Weber Number is an important factor, since α/s is very small.

It is apparent that the dimensionless functional group contains the Lucas-Washburn equation when the contact angle is zero (the surface is totally wetted when the ink is spreading), that is

$$L(t) = [(R_c\,\sigma\,t)/(2\,\mu)]^{1/2} \tag{4}$$

where L = capillary penetration distance at time t.

C and α in equation (3) may be determined by plotting ln $\beta(t)$ versus ln $\varphi(t)$, that is

$$\ln \beta(t) = \ln C + \alpha \ln \varphi(t) \tag{5}$$

with

$$\varphi(t) = (R_c\,\sigma\,t)/(a^2\,\mu) \tag{6}$$

Experimental Data

Table 1 shows droplet radial spreading data as function of time for an aqueous formulation on plain paper. The approximate values for the properties defined in the variable φ are R_c = 5 um, σ = 40 dyne/cm, μ = 2.0 cp, a = 60 um.

Table 1.

Time, sec	Radial Spreading, µm
2.4	10.8
4.0	10.6
6.0	12.0
12.2	20.3
20.2	22.1

A plot of ln $\beta(t)$ versus ln $\varphi(t)$ yields ln C = -0.54 and α = 0.34. Figure 2 shows measured versus calculated data.

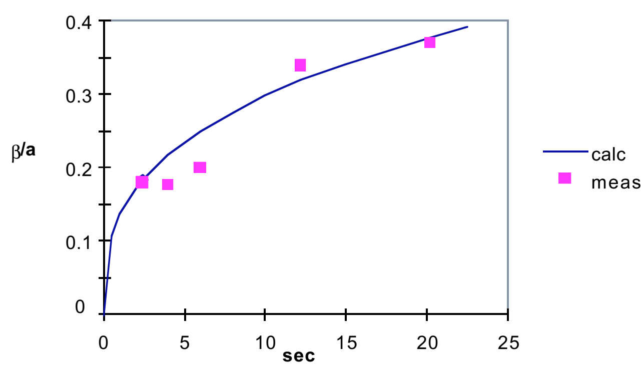

Figure 2. InterColor bleed versus time

Although ink-paper interactions are not in general Fickian diffusion processes, it is often an acceptable practice to use a diffusion approach to model them. The exponent $\alpha = 0.34$ suggests that the spreading phenomenon involved in InterColor bleed may not be modelled as a Fickian diffusion model, and a dimensional analysis as presented here is a more reasonable approach.

Results from parametric studies performed indicate the following:

Figure 3 indicates that intercolor bleed increases as the initial average spot radius increases.

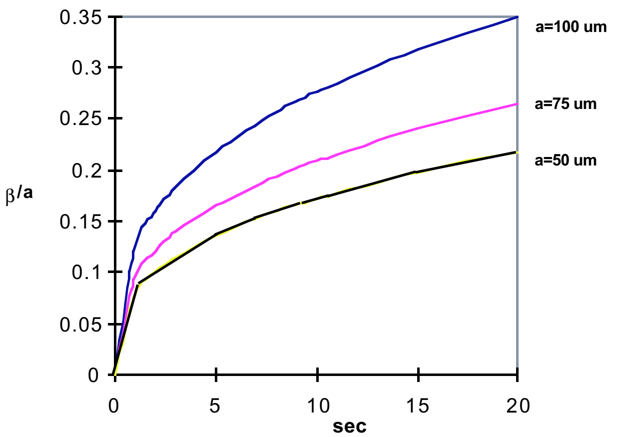

Figure 3. InterColor Bleed wrt Sport Radius

Figure 4 indicates that intercolor bleed increases as ink viscosity decreases.

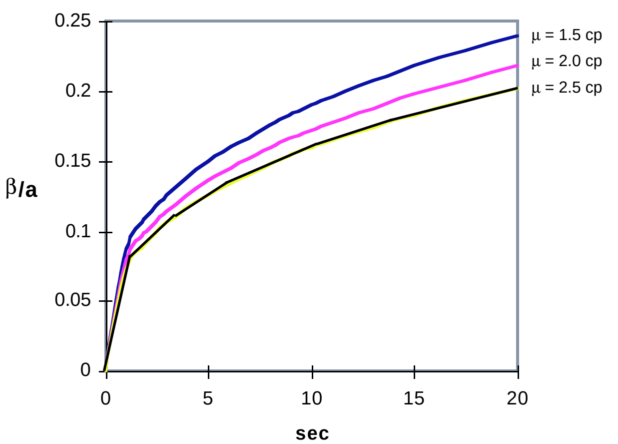

Figure 4. InterColor bleed wrt. viscosity

Figure 5 indicates that intercolor bleed increases as surface tension increases.

Although these results are observable from equation (2), the plots show the magnitude of intercolor bleed variations more clearly.

Discussion

Dimensional analysis approach has been utilized to derive an empirical equation which relates InterColor Bleed to certain parameters which may be controllable during Ink Jet Printing. The form of the equation includes the Lucas-Washburn equation, which describes the penetration of liquids into capillaries. Furthermore, the dimensionless group which was derived is a ratio of the Reynold's Number and the Weber Number. This ratio represents the ratio between viscous and free surface effects.

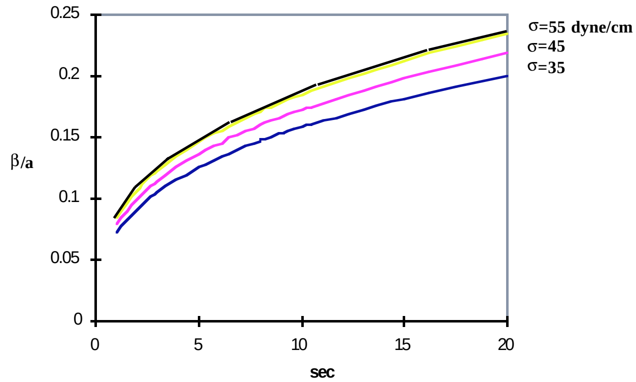

Figure 5. InterColor Bleed wrt Surface Tension

The two arbitrary constants in the equation were determined from measurements of InterColor Bleed between ink formulations and plain papers.

It has been determined that intercolor bleed increases when

(a) initial average spot radius increases,
(b) ink viscosity decreases,
(c) surface tension increases.

Variation of InterColor Bleed depends also on temperature. Although temperature was not included in the derivation of the empirical formula, intercolor bleed is dependent on temperature.

This conclusion may be inferred from the dependence of ink viscosity, ink surface tension and paper properties on temperature. Typically, as temperature is increased, intercolor bleed increases to a point, and then begins to decrease. Print samples presented at the poster session show these dependencies. These print samples also show the effect of ink properties on InterColor bleed.

The equation presented here is not unique, and it is probable that other combinations of ink and paper properties could be selected to characterize intercolor bleed.

References

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