Toner Charging and Deposition in Single-Component Development of Electrographic Images—A Theoretical Analysis

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The layer model of single-component development is applied to investigate toner charging and deposition, in particular, the electrical interaction of the toner mass with the solid layers it comes into contact during these two processes. By considering the time dependence of charging and deposition, it is shown that the dielectric relaxation times of the metering blade and the donor-roll coating play important roles in maintaining ghost-free image quality. A possible mechanism of ghost image formation is suggested. The optimum values of the dielectric relaxation times are specified in relation to the development time and charging time, and, hence, also in relation to the process speed and development housing geometry.

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Introduction

While different embodiments of single-component development (SCD) exist for electrographic images,[1] the ones most successfully implemented in automatic copiers and printers share the common features that the toners are carried to the latent images by a donor-roll and that the toners are predominantly charged during their contact with the metering blade. This article describes a theoretical analysis of charging and image-wise deposition of toners in such a SCD system, with the emphasis on understanding the electrical interaction between the developer and the solid layers it comes into contact during these two processes. The magnetic force that may or may not be used to assist toner transport has little direct effect on the two processes, and, hence, is not considered in this analysis.

Theoretical investigations of toner deposition in SCD have treated the toner mass either as an array of individual particles (i.e., particle models) or as a uniform layer of charged dielectric material (i.e., the layer model).[2,3] Because the present investigation was initially inspired by the issue of image ghosting, which has been observed to depend on the electrical properties of the solid layers in contact with the developer,[4] it was decided to follow and extend the layer model approach.

Although in reality toner charging precedes image-wise deposition, the analysis of deposition is presented first. This reversal of order facilitates the discussion of image ghosting as a consequence of the inability to recharge equally the toner in areas of the donor-roll where there are different amounts of remaining toner from the previous cycle.

Toner Deposition in SCD

In addition to some differences in the mathematical description of electrical interaction between the toner and the neighboring layers, the present approach extends the existing work by Hosoya and Saito[3] by introducing a set of differential equations to describe the time dependence of the relevant quantities. This enables the inclusion of phenomena such as free-toner generation and dielectric relaxation of the donor-roll coating and the metering blade into the discussion.

Mathematical Model of Toner Deposition. The SCD zone is represented by a set of five plane-parallel layers shown schematically in Fig. 1. The metallic donor-roll is coated with a resistive layer (C-layer) of dielectric thickness D_C. The thickness of toner layer on the donor-roll side (T-layer) is L_t and the dielectric constant is k_t. The toner layer (D-layer) developed on the photoreceptor (PR) is assumed to have the same dielectric constant k_t, but a different thickness L_d. Between the two toner layers is an air gap of thickness L_A. The dielectric thickness of the PR is denoted by D_P.

The charge densities in the two toner layers are assumed uniform and have the same value q. The fields in these layers $E_t(x)$ and $E_d(x)$, respectively, are linear functions of the distance x. The C-layer, the air gap, and the PR are assumed space-charge free and, hence, the fields E_C, E_A, and E_P are uniform within each layer. An area charge density Q_C exists at the interface between the C- and T-layers, and another Q_P exists at the interface between the D-layer and PR. The donor-roll is held at a bias voltage V_{DB}, and the PR substrate is grounded.

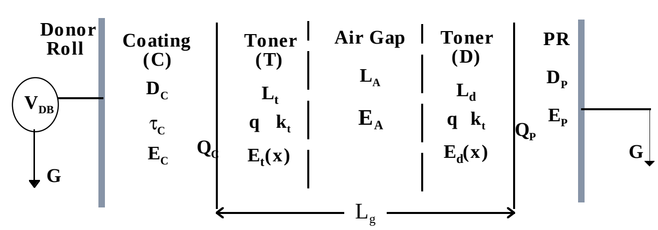

Figure 1. Schematic of single-component development zone.

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Applying Gauss' theorem at each interface, the fields in the layers and the voltages across the layers can be expressed in terms of the field in the air gap E_A. Equating the sum of voltages to the bias voltage V_{DB}, and solving for E_A, one has,

$$E_A = [\varepsilon_o(V_{DB} - V_S) + Q_C D_C + qL_t(D_C + D_t/2) - qL_d(D_P + D_d/2)]/\varepsilon_0\Sigma_D, \quad (1)$$

where ε_o is the permittivity of free space (and air), $D_t = L_t/k_t$ and $D_d = L_d/k_t$ are the dielectric thickness of the two toner layers, respectively, and

$$V_S = Q_P D_P/\varepsilon_0, \quad (2)$$

is the PR surface voltage before entering the development zone. The Σ_D represents the sum of all dielectric thickness $\Sigma_D = D_C + D_t + L_A + D_d + D_P$.

The development is manifested by the increase of toner layer thickness L_d at the expense of L_t. Because the mobility of toner particles in the air gap can be estimated from Stokes' formula to be of the order of 10^{-2} cm^2/Vs^5, the time needed for a toner to move across the air gap (of width ~100 μm) at the development field (of ~10^4 V/cm) is very small (~0.1 ms) compared to the typical development time (~0.1 s). Thus, the time required for development is mainly used for the generation of free-toners for transfer to the D-layer, while the transfer itself can be regarded as instantaneous. In other words, this is an "emission-limited" process. Furthermore, the rate of free-toner generation is likely proportional to the field E_A in the air gap. Then, the toner layer thickness L_t decreases with a time rate equal to the generation rate and can be written as

$$d(qL_t)/dt = -\sigma_A E_A \quad (3a)$$

or,

$$dL_t/dt = -(\sigma_A/q)E_A \quad (3b)$$

where the toner charge density q is assumed constant in time during development and the proportionality constant σ_A gives a measure of free-toner generation rate. (We will discuss more on the physical meaning of σ_A later). From the conservation of toners, the time rate of change of L_d, the developed toner layer thickness on the PR side, is then

$$dL_d/dt = -s_r(dL_t/\mathrm{dt}) = s_r(\sigma_A/q)E_A\ , \quad (4)$$

where s_r is the ratio of the donor-roll surface speed to the PR speed. The integration of Eq. 4, with the initial conditions $L_t = L_{tO}$, $L_d = 0$ at t = 0, yields the toner conservation relation as

$$L_t(t) + L_d(t)/s_r = L_{t0}\ . \quad (5)$$

The layer thicknesses L_t and L_d are also constrained by the condition that the sum of L_t, L_d , and L_A must remain constant (neglecting the curvature of the development zone) and equal to the development gap width L_g ,

$$L_t(t) + L_A(t) + L_d(t) = L_g\ . \quad (6)$$

Concurrent to the toner deposition, the resistive C-layer undergoes dielectric relaxation, manifested by a change in the interface charge density Q_C. The time rate of change of Q_C is assumed represented by the ohmic relation,

$$dQ_C/dt = \sigma_C E_C = (\varepsilon_0 E_A - qL_t - Q_C)/\tau_C\ , \quad (7)$$

where σ_C is the conductivity and $\tau_C = k_C\varepsilon_0/\sigma_C$ is the dielectric relaxation time of the C-layer. In the second equality, the expression for the field in the C-layer E_C follows from Gauss' theorem.

Defining the development voltage by $V_d \equiv V_{DB} - V_S$, the threshold value can be obtained from $E_A = 0$ in Eq. 1 with the initial conditions $L_t = L_{to}$, $L_d = 0$, and $Q_C = Q_{CO}$ as

$$V_{dth} = [V_{DB} - V_S]_{th} = -[qL_{t0}D_{t0}/2 + (Q_{CO} + qL_{t0})D_C]/\varepsilon_0, \quad (8a)$$

where $D_{t0} = L_{t0}/k_t$. For a given bias voltage V_{DB}, the threshold value of the PR surface voltage V_S, is then,

$$V_{Sth} = V_{DB} + [qL_{t0}D_{t0}/2 + (Q_{CO} + qL_{t0})D_C]/\varepsilon_0. \quad (8b)$$

This threshold voltage V_{Sth} should have a value near the background area voltage, i.e., a small value near zero for charged-area-development (CAD) and a large value near the maximum charge acceptance of the PR for discharged-area-development (DAD). Once the V_{sth} is chosen for CAD or DAD, the appropriate donor-roll bias voltage V_{DB} can be determined from the initial values L_{t0} and Q_{CO} according to Eq. 8b.

The coupled equations, Eqs. 3 through 7 can be solved for the time evolution of the developed toner layer thickness L_d. While a compact analytical solution cannot be obtained for the general case, the general feature of the time dependence can be expected to consist of a rapid increase of L_d with time, followed by a gradual approach to the final value. The final value is reached when either the air-gap field vanishes ($E_A = 0$) or the toner on the donor-roll is exhausted ($L_t = 0$), whichever occurs first. The features of the final state are illustrated in the next subsection with a special case for which simple analytic solutions can be obtained.

Asymptotic Solutions for a Special Case: $\tau_C = 0$. Consider the case in which the relaxation time τ_C of the C-layer is short compared to the development time so that the C-layer can be considered fully relaxed (i.e., $E_C = 0$) during the development (referred to as the $\tau_C = 0$ case). Then, from Eq. 7, the interface charge density Q_C is given by

$$Q_C = \varepsilon_0 E_A - qL_t. \quad (9)$$

Substituting this relation into Eq. 1, the air-gap field E_A can be rewritten as

$$E_A = \frac{[\varepsilon_0 V_d + qL_t D_t/2 - qL_d(D_P + D_d/2)]}{\varepsilon_0(D_t + L_A + D_d + D_P).} \quad (10)$$

Similarly, the threshold voltage, Eq. 8, now reads

$$V_{dth} \equiv [V_{DB} - V_S]_{\mathrm{th}} = -qL_{t0}D_{t0}/2\varepsilon_0. \quad (11)$$

For a given development voltage V_d the asymptotic value ($t \to \infty$) of developed toner thickness L_{dx} can be determined by eliminating L_t from Eq. 5 and solving for L_d from dL_d/dt = 0 or $E_A = 0$ in Eq. 10. This yields for $s_r = 1$,

$$L_{dx} = (\varepsilon_0 V_d/q + L_{t0}^2/2k_t)/(D_P + D_{t0}) \quad (12a)$$

or for $s_r \neq 1$ with $\alpha \equiv (1 - 1/s_r^2)/2k_t$, $\beta \equiv D_P + D_{t0}/s_r$, and $\gamma \equiv \varepsilon_0 V_d/q + L_{t0}^2/2k_t$,

$$L_{dx} = [(\beta^2 + 4\alpha\gamma)^{1/2} - \beta]/2\alpha. \quad (12b)$$

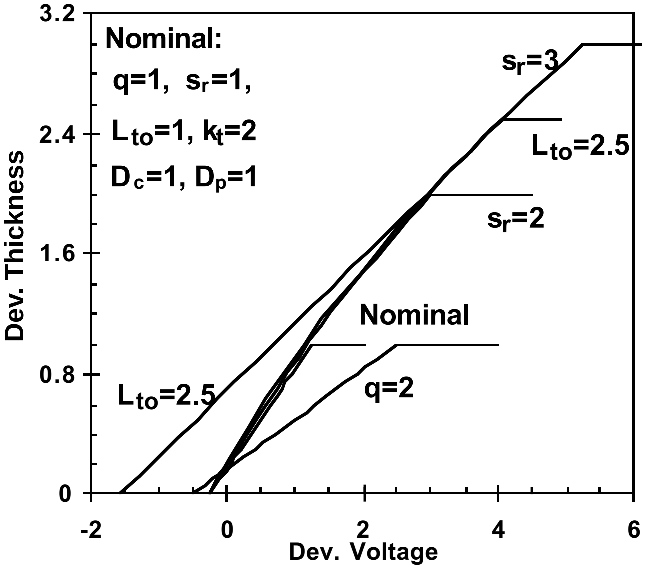

Figure 2. Asymptotic value of developed toner thickness versus development voltage for the special case of $\tau_C = 0$. The parameter values for the nominal case are given in the figure. In other cases, one of the parameter values designated is varied. The unit of voltage is given in terms of the unit charge density q_0 and the unit length L_0 as $V_0 = q_0 L_0^2/\varepsilon_0$.

As the development voltage V_d increases, the L_{dx} calculated from Eq. 12 can reach the maximum value allowed by the toner conservation, Eq. 5, namely $L_{dx} \leq s_r L_{t0}$. This marks the end of the field-limited development and the beginning of the supply-limited regime. The development voltage at which this transition occurs V_{SL} is obtained by equating the right side of Eq. 12 to its maximum value $s_r L_{t0}$. This gives, for both Eqs. 12a and 12b,

$$V_{SL} = s_r q L_{t0}(D_p + s_r D_{t0}/2)/\varepsilon_0. \quad (13)$$

For the special case discussed here, the development characteristics expressed as the developed toner layer thickness L_d versus development voltage V_d can be determined from Eqs. 12 and 13 for a given set of parameter values. A few examples are shown in Fig. 2. In this and the following figures, the unit voltage V_0 is related to the unit charge density q_0 and the unit length L_0 by

$$V_0 \equiv q_0 L_0^2/\varepsilon_0. \quad (14)$$

With a convenient choice of $L_0 = 10\mu$m and $q_0 = 10\mu$C/cm^3, this unit has a value of $V_0 \approx 100$ V. From Fig. 2, it can be seen that the threshold is followed by a range of V_d in which the developed layer thickness L_d increases (linearly only if $s_r = 1$) with V_d before it reaches the supply-limited value, Eq. 13. This range is known as the dynamic range and corresponds to the regime of field-limited development. The width of dynamic range is given by

$$W = V_{SL} - V_{dth} = qL_{t0}[D_p s_r + D_{to}(s_r^2 + 1)/2]/\varepsilon_0 \quad (15)$$

and, hence, increases with the toner charge density q, the speed ratio s_r, and the initial toner layer thickness L_{t0}, as illustrated by the examples in Fig. 2.

The gamma G, a well-known measure of gray-scale reproducibility, is the inverse of the slope of development curve in the dynamic range and is given by

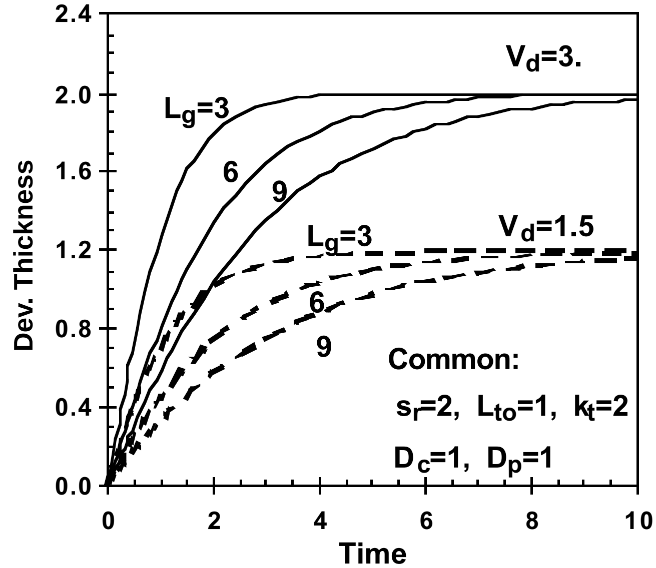

Figure 3. Time evolution of developed toner thickness at two development voltages V_d and three values of air-gap width L_s. The relaxation time of coating is $\tau_C = 0.1\tau_0$. The unit of time $\tau_0 = \varepsilon_0/\sigma_A$ is defined in Eq. 17.

$$G = W/s_r L_{t0} = q[D_P + D_{t0}(1/s_r + s_r)/2]/\varepsilon_0. \quad (16)$$

Another feature seen in Fig. 2 is that although the developed thickness in the high-voltage supply-limited regime increases in proportion to the speed ratio s_r, the increase is negligible in the low-voltage field-limited regime. In other words, the developed toner thickness can be increased by increasing the speed ratio only at higher development voltages. For the same reason, the gamma, Eq. 16, does not increase with s_r though the dynamic range does.

Time Evolution of Toner Deposition. The asymptotic behavior of development characteristics for the special case of $\tau_C = 0$ (also for the $\tau_C \to \infty$ case) can be predicted from the analytic expressions (as those given in the previous subsection for $\tau_C = 0$) and the roles of each material or process parameter in toner deposition determined. Note that among these parameters, the development gap width L_g does not appear in these expressions and, hence, the development characteristics appear independent of L_g. This somewhat counter-intuitive result is a consequence of considering only the asymptotic values. For a finite development time, Eqs. 3, 4, and 7 can be solved numerically for the time evolution of the development. Examples of the time evolution of developed toner thickness L_d obtained from such numerical calculations are shown in Fig. 3 to illustrate the dependence of development on the gap width L_g. The unit of time τ_0 is defined in terms of the parameter σ_A introduced in Eq. 3 by

$$\tau_0 \equiv \varepsilon_0/\sigma_A. \quad (17)$$

The dielectric relaxation time of the C-layer is assumed to be $\tau_C = 0.1\tau_0$ in Fig. 3. The physical significance of the time unit τ_0 will be discussed shortly. As expected from Eq. 12, the long time values (at $t > 10\tau_0$) of developed toner thickness are seen independent of L_g. However, because the air-gap field E_A is a function of L_g (see Eqs. 1 and 6), the rate of development should depend on L_g. The approach to the final value is faster for the smaller gap. Therefore, for a finite development time (e.g., at $t \leq 5\tau_0$), the developability can be significantly larger for smaller gap widths.

Ideally, the development time must be long enough for the developed toner thickness to approach the saturation value. From the results shown in Fig. 3, this means that the development time t_d should be about 10 units of time or longer. For a typical value of $t_d \approx 0.1$ s, this requires the time unit to be $\tau_0 \approx 0.01$ s or less. From the definition of τ_0 in Eq. 17, this requires the parameter σ_A to be greater than about 10^{-11} S/cm. As defined in Eq. 3, the parameter σ_A is a measure of the free-toner generation rate. Thus, the above specification of σ_A together with a typical value of the air-gap field $E_A \approx 10^4$ V/cm can be translated into a specification for the free-toner (charge) generation rate of $\sigma_A E_A > \approx 10^{-7}$ C/cm^{2}s. For a toner of size 10 μm and a charge density of 10 μC/cm^3, the toner charge would be of the order of 10^{-14} C/particle. Then, the above generation rate corresponds to about 10^7 free-toner S/cm^2, or a monolayer (10^6 toner/cm^2) of free-toners in 0.1 s. For a shorter development time, the parameter σ_A or the generation rate $\sigma_A E_A$ must be proportionally larger for the development to reach the saturation value within the development time.

Donor-Roll Surface Voltages and Relaxation in the C-Layer. Another important electrical observable in SCD is the donor-roll free-surface voltage V_r measured before and after development when there are only two layers C and T. From the condition that the field at the free surface is zero, the donor-roll surface voltage V_r is given by

$$V_r - V_{DB} = [qL_t^2/2k_t + (Q_C + qL_t)D_C]/\varepsilon_0. \qquad (18)$$

Before the development, the toner layer thickness is $L_t = L_{t0}$. After the development, the toner layer thickness L_{tx} on the donor-roll can be obtained from that on the PR, L_{dx}, and the conservation relation, Eq. 5, as

$$L_{tx} = L_{t0} - L_{dx}/s_r. \qquad (19)$$

Thus, measurements of the donor-roll surface voltage V_r coupled with the development data (on L_{dx}) can be used to calculate the interface charge density Q_C, which in turn gives information on the dielectric relaxation in the donor-roll coating layer. This is demonstrated by the following numerical simulations.

Examples of development characteristics (L_{dx} versus V_d) calculated from the numerical solutions of Eqs. 3 through 7 are shown in Fig. 4(a), for three values of dielectric relaxation time τ_C (of the C-layer), given in units of τ_0 defined by Eq. 17, at a development time of $t_d = 10\tau_0$. The effect of τ_C on the development characteristics is weak. However, the corresponding donor-roll surface voltages $V_r - V_{DB}$ at t_d calculated from Eq. 18 using these L_{dx} values are quite sensitive to τ_C values, as illustrated in Fig. 4(b). The curves are uniquely determined by the ratio τ_C/τ_0 and are sensitive to the τ ratio in the range between 1 and 100. For small values of $\tau_C/\tau_0 \leq 1$, the $V_r - V_{DB}$ varies only by about $0.2V_0$ over the whole dynamic range of V_d (about 0 to $3V_0$). In contrast, for large values of $\tau_C/\tau_0 \geq 100$, the corresponding variation is about one V_0. This means that different areas of the donor-roll coating will enter the next charging and imaging cycle with different initial values of Q_C, depending on the development voltages at these areas in the previous cycle. Thus, slow relaxation of the C-layer can have important effects on the cyclic stability of development (e.g., image ghosting) as discussed further in the next section.

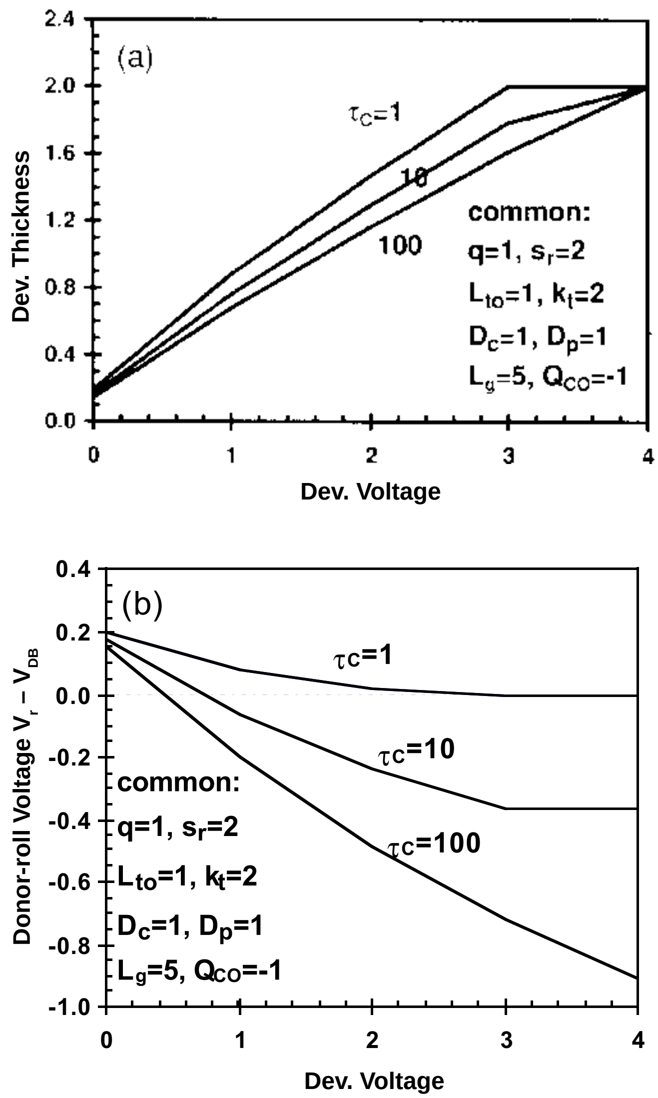

Figure 4. (a) Developed toner thickness L_d and (b) donor-roll surface voltage $V_r - V_{DB}$ versus development voltage V_d after a development time of $t_d = 10\tau_0$ calculated for different values of C-layer relaxation time τ_C (in units of τ_0).

Toner Charging in SCD

Experimental observations suggest that toners in SCD are predominantly charged during their contact with the metering blade. For single-component developers (which consists of only toners), the charging of toners requires transporting the charge to, or removing the counter-charge from the toner mass. (In contrast, for two-component developers, the developer remains charge neutral even after the toners are charged). Therefore, independent of whether the toner charging mechanism is triboelectrical or by charge injection, it involves charge transport between a power supply and the toner mass via the contacting solid layers (metering blade and/or donor-roll). In this section, this charge transport is described mathematically to examine how the electrical properties of the contacting layers affect the charging efficiency and, in turn, the cycling stability.

Mathematical Model of Toner Charging. Consider the metering gap geometry shown schematically in Fig. 5.

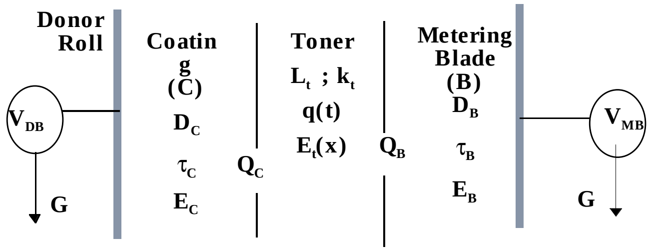

Figure 5. Schematic geometry of metering gap.

On the left side, the toner layer (T-layer) is in contact with the resistive coating (C-layer) of the donor-roll held at a bias voltage V_{DB}. On the right side, it comes in contact with the metering blade (B-layer), which is also resistive and is connected to a power supply at a bias voltage V_{MB}. There is, in general, no space-charge in the resistive layers, and thus, the fields in the C- and B-layer, denoted by E_C and E_B, respectively, can be considered as spatially uniform. The bulk charge density in the toner layer is assumed uniform and has the (average) value $q(t)$, whose time dependence is to be examined.

Applying Gauss' theorem to the layer boundaries and adding all the voltages across the layers to $-(V_{DB} + V_{MB})$, the field in the B-layer can be written as

$$E_B = [\varepsilon_0(V_{DB} + V_{MB}) + Q_B(D_C + D_t) + Q_C D_C + qL_t(D_C + D_t/2)]/(D_B + D_C + D_t)\varepsilon_{B,} \quad (20)$$

where D are the dielectric thickness; L_t is the thickness of the T-layer; ε_B and ε_0 are the permittivities of the B-layer and free space; respectively; and Q_C and Q_B are the area charge densities at the interfaces, C/T and T/B, respectively. Both Q_C and Q_B are, in general, functions of time. Note that while the C-layer moves with the toner layer, the B-layer remains stationary and contacts new layers of toner continuously. Therefore, for uniform charging across a large area of toner layer, the charge at the T/B interface should remain constant in time

$$dQ_B/dt = 0. \quad (21)$$

The charging of the T-layer is described by equating the time rate of change of the total toner layer charge qL_t to the conduction current flowing into the toner layer

$$d(qL_T)/dt = -\sigma_B E_B + Q_C/\tau_i = -\varepsilon_B E_B/\tau_B + Q_C/\tau_i, \quad (22)$$

where the first term is the current from the B-layer with σ_B denoting the conductivity and $\tau_B = \varepsilon_B/\sigma_B$ the dielectric relaxation time of the B-layer. The second term represents the injection current from the C-layer with τ_i denoting the injection time constant. Similarly, the time rate of change of the interface charge density Q_C can be expressed as

$$dQ_C/dt = \sigma_C E_C - Q_C/\tau_i = (\varepsilon_B E_B - Q_C - qL_T)/\tau_C - Q_C/\tau_i, \quad (23)$$

where σ_C is the conductivity and $\tau_C = \varepsilon_C/\sigma_C$ is the dielectric relaxation time of the C-layer. In the second equality, the expression for the field in the C-layer, E_C, follows from Gauss' theorem.

After one passage of the donor-roll through the development zone, the toner layer consists of areas with different amounts of residual toners depending on the toner usage in the previous development. The initial value of toner charge q_i for Eqs. 22 and 23 is the weighted average of the charge on the residual toner (with large q) and on the fresh toner (with small q). A larger q_i corresponds to a smaller amount of fresh uncharged toner. The initial value of Q_C depends on the dielectric relaxation in the C-layer as described in the previous section.

The objective here is to determine the latitudes of the relaxation time τ within which toner layers with different initial values q_i can be charged to the same final value during the contact with the blade. The results are shown and discussed below.

Requirements on Layer Relaxation Times. Examples of the time evolution of toner charge density $q(t)$ obtained from the solution of Eqs. 22 and 23 are shown in Fig. 6. In this figure, the four parts differ in the values of the relaxation times τ_C and τ_B. The five curves in each part correspond to different initial values of toner charge density q_i. The charging time t_{chg} (= contact distance/donor-roll speed) is chosen as the unit of time. The constant charge density at the T/B interface is $Q_B = 0$. The C-layer is assumed fully relaxed before entering the metering gap, thus, the initial value of Q_C is $Q_{ci} = -q_i L_t$. The C/T interface is assumed non-injecting, i.e., $\tau_i = \infty$. The bias voltages are $V_{MB} = 0$ and $V_{DB} = -0.25\text{V}_0$, where the unit is defined in terms of the unit charge density q_0 and the unit length L_0 by Eq. 14.

The four parts of Fig. 6 show that different areas of toner layer with various initial q_i values can be charged in a given charging time to the same level, i.e., independent of the history of the toner areas, only if the relaxation times of the C- and B-layer are both 2 or more orders of magnitude shorter than the charging time $\tau_C \leq 0.01\tau_0$, and $\tau_B \leq 0.01\tau_0$. Otherwise, the toner charge for the next development is influenced by the image density of the previous development and can lead to image ghosting as discussed later.

Figure 7 shows the results of toner charging with a fixed initial value of toner charge density q_i, but different initial values of Q_C, which as discussed with Fig. 4 can be found in areas of different development voltages in the previous passage if the relaxation time of the donor-roll coating τ_C is long. Again, it is seen that relaxation times τ_B and τ_C must be shorter than 1/100 of the charging time for memory-free charging.

The effect of charge injection from the donor-roll coating is shown in Fig. 8 for the case of initial toner chage $q_i = 0.5q_0$ and four sets of relaxation times τ_C and τ_B. In all cases, a significant deficiency in toner charge results (from neutralization of toner charge by injected charge) if the injection time constant τ_i is not longer than 10 times the charging time.

A Mechanism of Ghost Image Formation. One of the image quality issues with SCD is the formation of ghost images which has been attributed to charge accumulation on the high-resistivity donor-roll coating by Aoki, Mutsushiro, and Sakamoto.[4] The investigation described here indicates the underlying cause of charge accumulation is inefficient dielectric relaxation in the donor-roll coating and metering blade.

With development in the field-limited regime, a finite thickness of toner layer remains from the previous imaging cycle. The charge on this residual toner is averaged with the fresh low-charge toners for the next cycle of charging and development. For the toner in the donor-roll area that developed the high-density image, the residual toner layer

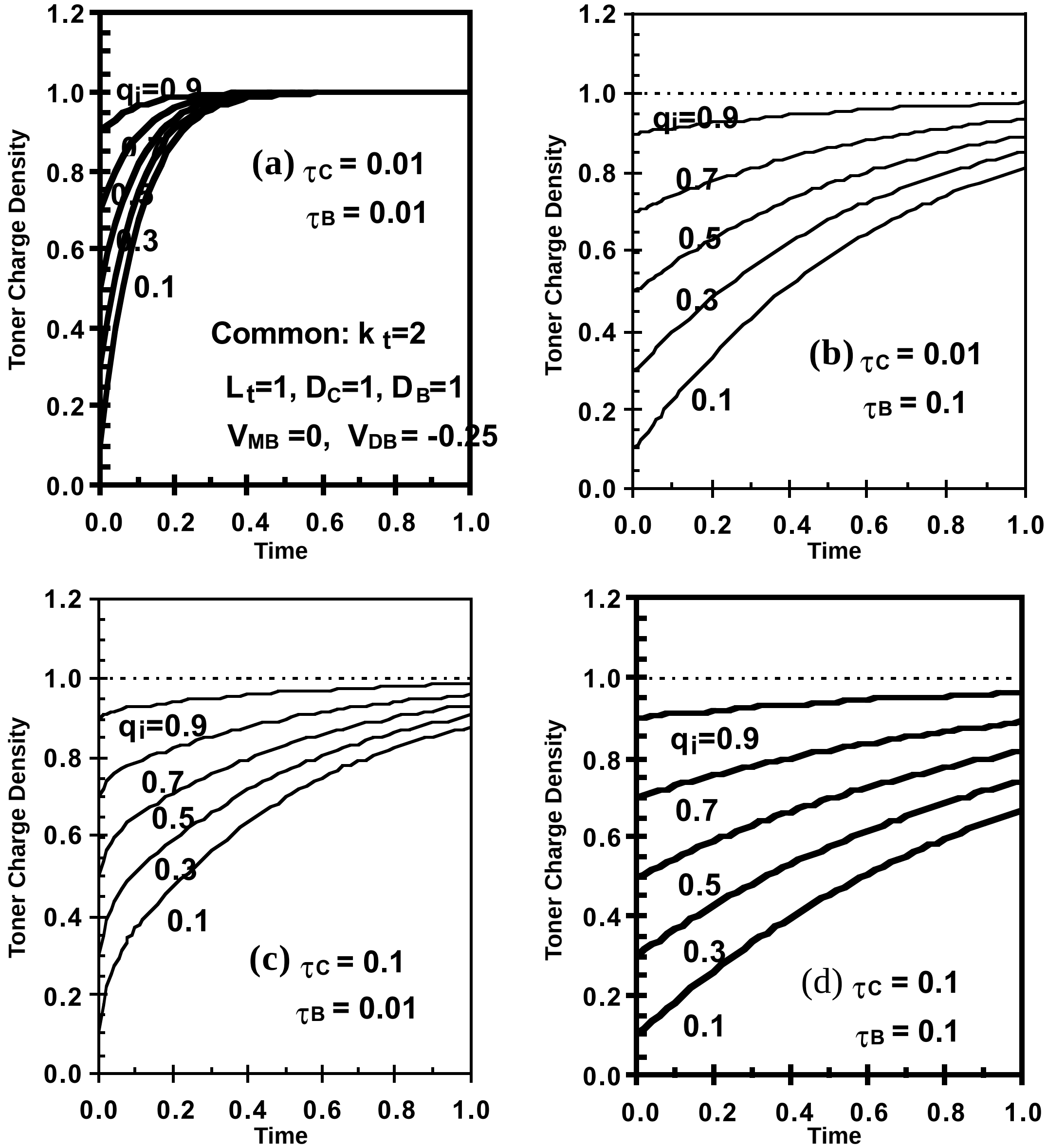

Figure 6. Time evolution of toner charge calculated with four sets of dielectric relaxation times τ_C and τ_B and 5 different initial values of toner charge density q_i. The times are in units of the charging time.

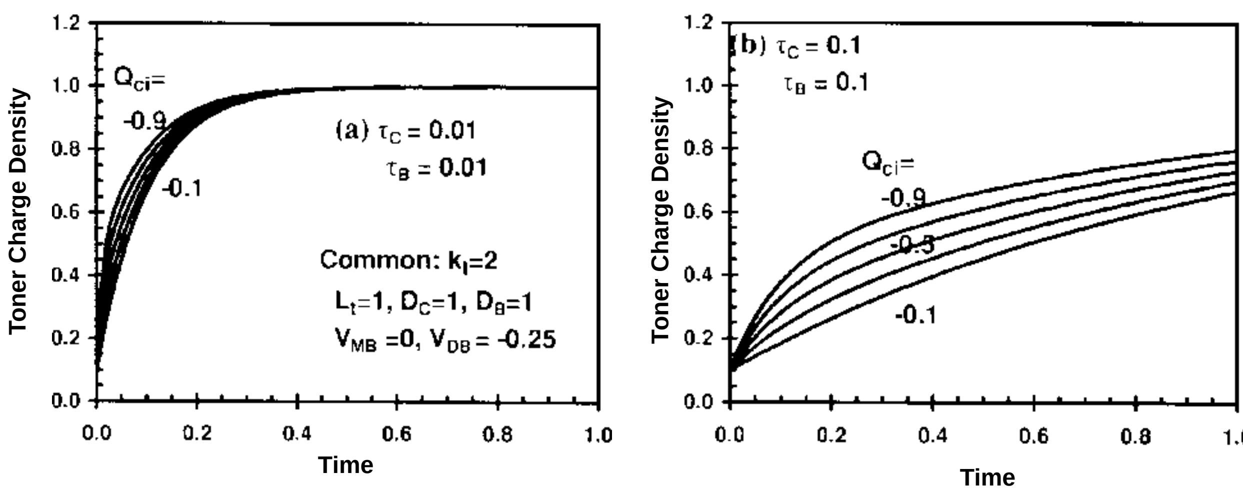

Figure 7. Charging of toners with the same initial charge density $q_i = 0.1q_0$, but different initial values of Q_c, the charge density at coating/toner interface, for (a) short and (b) long dielectric relaxation times τ_C and τ_B. The times are in units of charging time.

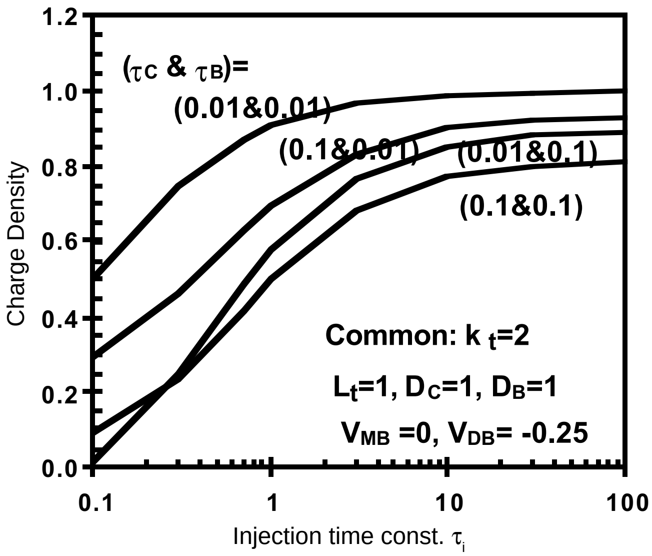

Figure 8. Dependence of toner charging on the time constants τ_i of injection from the donor-roll coating for the case with initial toner charge $q_i = 0.5q_0$ and four sets of relaxation times τ_C and τ_B. The times are in units of charging time.

is thin (or nonexistant), and, hence, the initial value of toner charge is small. If the dielectric relaxation times of the metering blade and the donor-roll coating are not short enough (≤1/100 of charging time), the final toner charge cannot reach the nominal value. With lower charge toners, the developed toner layer thickness is larger because the field limitation occurs at larger thickness and the supply limitation occurs at a lower voltage as discussed with Fig. 2. Consequently, higher image density is developed by the donor-roll area that developed high density in the previous cycle. This would appear as a (positive) ghost image.

Therefore, to achieve uniform charging independent of the history of the toner layer, sufficiently short dielectric relaxation times are required. Note that the critical parameter is the dielectric relaxation time and not the conductivity (or resistivity) of the coating and blade materials. Because the dielectric constant tends to increase with conductivity, increasing the conductivity does not always decrease the relaxation time (the ratio of dielectric constant to conductivity) in proportion.

All the relationships among the time constants determined from the above analyses, including development time $t_d \approx 10\tau_0$ to develop to the asymptotic value; dielectric relaxation time of C-layer $\tau_C \approx \tau_0$ for full relaxation of the C-layer during development; and dielectric relaxation times of C- and B-layers τ_C, $\tau_B \approx t_{chg}/100$; can be combined and translated into a relationship between the charging time and the development time as $t_{chg} \approx 10t_d$. This serves as a guideline for the design of development housing.

Summary and Conclusions

The layer model of single-component development is extended to investigate toner charging and deposition processes, in particular, the electrical interaction of the toner mass with the solid layers it comes into contact during these two processes. By considering the time dependence of the charging and deposition, it is shown that the dielectric relaxation times of the metering blade and the donor-roll coating play important roles in maintaining cyclic image stability. A possible mechanism of ghost image formation is suggested. The optimum values of the dielectric relaxation times for avoiding the image ghosting are specified in relation to the development time and charging time, and hence, also in relation to the process speed and development housing geometry.

The simplest charge transport mechanisms are assumed in the present treatment of the electrical interaction of the toner mass with the solid layers. It is conceivable that the charge transport in the materials of practical interest is more complex, e.g., involving charge trapping and nonohmic conduction. The refinement of the analysis in this respect and the confirmation of the features predicted by this analysis await the results of complementary experimental studies.

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