

Charging Characterization of Colloidal Dispersions by a Plate-Out Cell

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Abstract

Charging property of liquid inks is the key in determining the performance in liquid toning. Depending on the charge density and mobility of the toner particles and other charged species in the carrier liquid, the toned images can be formed quite differently. This report describes an approach to obtain the charging property of colloidal dispersions. By bring together the experimentally measured plate-out current, the numerical models are designed to automatically determine the charging characterization of the dispersions. A charge transport model is used in which no change in the charging of all the charged species due to the variation of external field is assumed. The applicability of this method is examined with the experimental data using both regular liquid inks and dispersions of only micelle particles.

Introduction

The charge property of liquid toners, as in the case of the tribo of powder toners, determines the toning efficiency of a given development system. From the point of view of liquid ink toning, knowing that the liquid toner obtains its charge thru the electro-chemical equilibrium of charge exchange with other non-pigmented particles, the charge control agents, it is often assumed that there are three different kinds of charge species, namely, toners, counter-ions, and co-ions.[1-2]

In contrast to powder toners, the commercial liquid toners rarely carry the wrong-signed charges. Instead, there are counter-ions (inverse micelles act as the charge control agent) in liquid inks that carry the opposite signs of charge of the toner. In addition, there often are co-ions (also inverse micelles) in liquid inks that carry the same-signed charges as the toner.

Such differences in charging, liquid ink vs. powder toner, bear significance in the toner development. First, the background cleanness problem in liquid is different than the one in powder. Second, liquid toners often compete with co-ions for latent images. In other words, image charges can be neutralized by both pigmented and non-pigmented particles. Third, since the mobility of toner particles are quite different than those of the other charged particles, space charges accumulation is a concern in the toning process. Space charge, once is formed in the development nip, retards the formation of high optical density of toned images. This is similar to the case of single or two-component magnetic-brush powder toner systems, where space charge impedes the development when the toners or carrier beads are less conductive.

For the performance of a liquid toner, it is important to quantify the charge density and mobility of the co-ions and the counter-ions as well as those of the liquid toner. In the process of design and fabrication of LID inks, it is helpful to have reliable filtering or selecting processes in addition to the fixture test. One main goal of this study is to develop hardware and software that enables more quantitative means of liquid ink charging characterization. A stationary plat-out[3] is used to obtain the transient current in the process of charged particle deposition. In addition, numerical models[4] are developed to analyze the experimental data.

Experimental Setup and Procedures

A bench-top apparatus, a plate-out cell, is shown in Figure 1. It is a device made of two bare electrodes of whose gap can be accurately adjusted and maintained. Three sets of micrometers were installed to allow the adjustment of the gap in all three directions. It allows an accurate, uniform, and repeatable gap setting. Computer-controlled experimental setup and data acquisition was put in place to streamline the experimental procedure. Different electrical fields, signal forms and magnitudes can be selected and applied.

The experiments can be conducted by using either a step DC voltage or a DC voltage with a ramp in time (saw-tooth signal). A typical experimental data is shown, in black dots, in Figure 2. It was obtained using a micellar solution (no resins). The vertical axis is the current collected thru the plate-out process. A saw-tooth DC voltage is applied in a 60 milli-second period. In the first 30 milli-seconds, the voltage ramps up to, in this case, 300 V and immediately followed by another 30 milli-second ramping down to 0 V. A 300-μm gap was used in conducting this experiment.

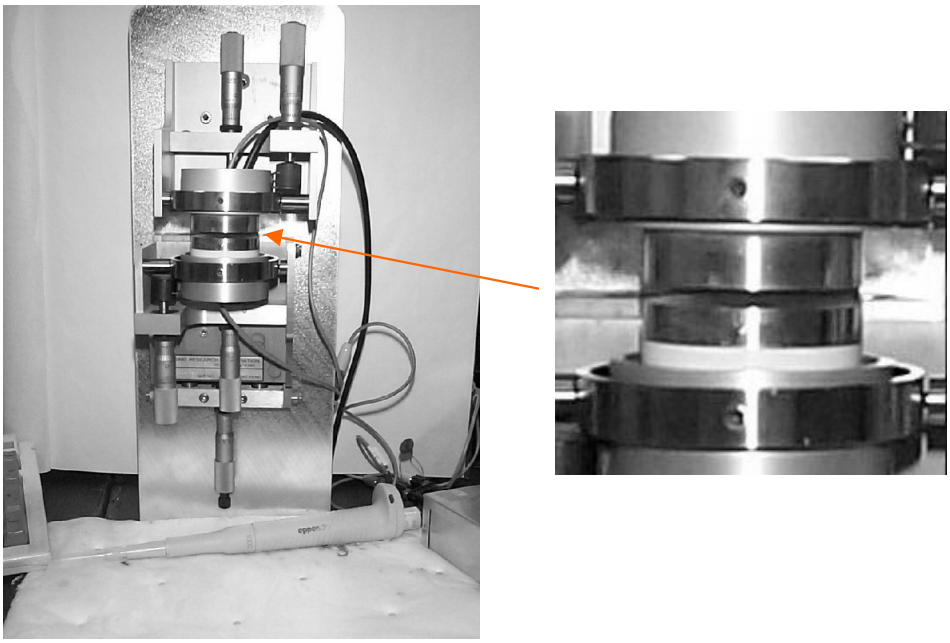


Figure 1. A plate-out cell, the experimental apparatus for ink characterization

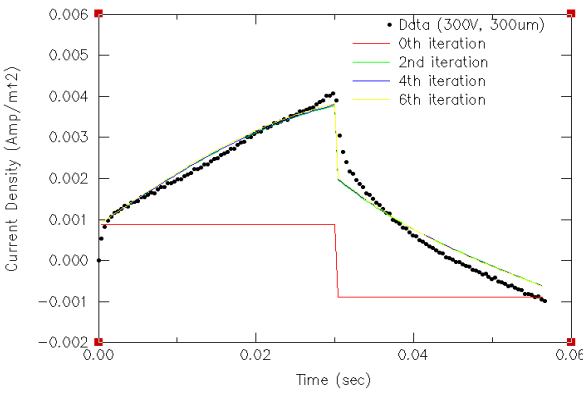


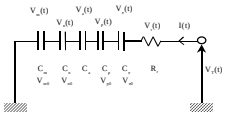
Figure 2. Numerical calculations (solid color curves) versus experimental data (black dots) of a typical micellar solution. 16 charged species are assumed to be in the solution.

Theoretical Models and Computation

After the collection of a plate-out current measurement, the corresponding numerical calculation is performed based on a charge transport model. Then, bring together the numerical results and experimental data in a matching fashion. Namely, to fit the experimental data with numerical calculations by selecting proper inputs to the numerical models. The inputs include ink-charging property, i.e., the distribution of mobility and charge density of all possible charge species. Obviously, it has to be done in an iterative fashion. The initial guessed inputs might be far from the desired set that enables a favorable matching with the data (transient current) measured.

The general structure of the numerical method can be described as two tiers --- a charge transport model and an optimization routine. At the lower level, there is a numerical plate-out model that solves the equations governing the transport of multiple charge species in the plate-out cell configuration. This plate-out model takes the mobility values and the initial concentrations of the charge species as the inputs. With a specified applied voltage, which can vary with time, it predicts the transport of the charge species, the electrical potential, the charge deposition, and the current flow across the plate-out cell as the time progresses. The basic formulation for charge transport is as the following.

Gauss's Law:



(1)

where ϕ is the electrical potential and ε is the permittivity of the carrier fluid, and n is the total number of charged species in the model.

Conservation of Charge:

$$\frac{\partial}{\partial t}\rho_i + \nabla \bullet (\rho_i \mu_i \mathbf{E}) = 0 \qquad (2)$$

where ρ_i and μ_i are the concentration and mobility of the *i-th* species, t is the time, and **E** is the electric field.

In addition, there is an optimization routine that compares the numerically predicted plate-out current and the experimental data and tries to minimize the difference between the two thru the change of the input parameters to the models, e.g., mobility and charge densities. There are many choices of variables for defining the optimization space. One option, which is used through this study, is to have a set of pre-determined species (i.e., a fixed set of discrete mobility values) and let the optimization routine determine the initial charge concentrations of the species by fitting to the measured transient current. With a properly chosen range of mobility value and a large enough number of species set, the charge density distribution of the colloidal dispersion under test can be determined. Such an optimization problem can be formulated mathematically[5] as to minimize the following

$$f(\rho_{1,}^{0}\ldots\rho_{n}^{0}) = \sum_{k=1}^{N}\left[e_k^E - e_k^M(\mu_{1,}\ldots\mu_{n,}\rho_{1,}^{0}\ldots\rho_{n}^{0})\right]^2 \quad (3)$$

which is subject to constraints

$$\rho_i^0 \geq 0 \quad (4)$$

f is the objective function (square error sum), ρ_i^0 is initial concentration of the *i-th* species (as stated above, the initial concentrations are the optimization variables here), e_k^E and e_k^M are the experimental and the model predicted values of current density at the *k-th* sampling point, *N* is the total number of the sampling points.

The inequality constraints can be treated thru the use of an exterior penalty function. Equations (3-4) can be formulated as to minimize,

$$\hat{f}(\rho_{1,}^{0}\ldots\rho_{n}^{0}) = f(\rho_{1,}^{0}\ldots\rho_{n}^{0}) + R\sum_{j\in J}|\rho_j^0| \quad (5)$$

where R is the penalty parameter, J identifies the set of violated constraints, i.e., ρ_j^0 for all $j \in J$. Through out this study, a penalty parameter R = 6 is used. It works well for the cases studied. A modified Powell's Conjugate Direction method is used for Eq. (5).

As can be seen in Figure 2, after just a couple of iterations, the curve can be matched favorably well by continually correcting the model inputs. With several more iterations of calculations, to ensure the matching reaches the optimal, the ink charging property converges to a final set. That is, both the calculated curve of the transient current and the ink charging property set cease to change substantially, thus, it completes the characterization. Computational codes and process are developed to enable a self-contained procedure.

Data Analysis

It was shown in the previous section that the experimental data was well matched by numerical calculation. This was accomplished by continuously adjusting the charge property, used as inputs for the numerical models. It was done also in a way that the total number of charge species is pre-determined and fixed. In the case shown in Figure 2, a total 16-charged species, 8 positively and 8 negatively charged species, were used. Each positive and negative pair has a same mobility. Further tests have shown that this fitting can not be done substantially better by the use of a larger number of charged species. A methodology is hence required to guide the determination of a meaningful number of charge species that can be used to properly represent any given ink.

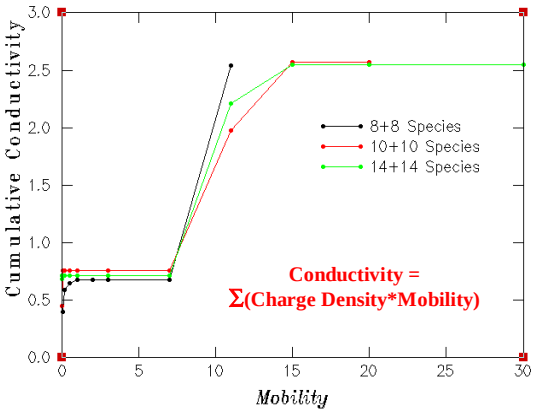


Figure 3. Three ink-charging profiles derived numerically. A dot indicates a charge species which is distinguished by its mobility. Cumulative conductivity sums up the conductivity from the first species (lowest mobility) up to the "displayed" mobility.

One way to reach such a determination is made clear as the following, as shown in Figure 3. With the execution of the numerical models, we obtained three ink-charging profiles. Each of them matches well the experimental data (black dots), depicted in figure 2. They differ in the total number of charge species. That is, they contain 16, 20, and 28 total charged species respectively. As plotted in Figure 3, the y-axis is the cumulative conductivity and x-axis displays the range of mobility of the charge species that is currently being explored. With the addition of charged species, from 16 (black curve) to 20 (red curve) and finally to 28 (green curve), the distribution of the cumulative conductivity does not vary much. It indicates that all three sets represent basically the same charge distribution profile. It also indicates that there are two distinguishable charged groups, separated by mobility. They distribute, indicated by the sharp rises in the cumulative conductivity, between mobility of 0.0 to 0.5 and 7.0 to 15.0. It can also be seen that 80% of the conductivity comes from the second groups.

Assessment of Feasibility for Ink Characterization

The same technique has been used to measure the ink charging property. In Figure 4, two sets of experimental plate-out curves, micellar solution vs. ink, are shown. In contrast to the micellar solution, numerical models do not generate data that can well fit the measured ink data.

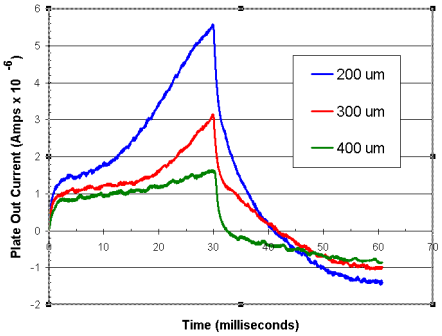


Figure 4. The plate-out currents for a micellar solution (top) and a ink, each was measured with a 300V at three different gaps, 200, 300, 400 um.

One likely reason is the "charge generation" which take place in the ink while an external field is applied. The present models assume that charged particles, micelles and toners alike, obtain instantaneously a fixed level charge the moment a minimal E-field is applied. The charge level stays constant in time even as an increase in field is imposed. It is a reasonable model for the micellar solutions as shown in the previous session. It is not quite true, however, for the inks.[6-7] Compared to the micellar solution, in Figure 4, the plate-out current of the ink stayed relatively linear and surged quickly later, indicating a state of "charge generation". It may due to either a continuing striping of micelle particles from the toner particles, or, a possible "charge injection" from the deposited toner layer. It renders the increase of the apparent conductivity. A charge generation model needs to be included for a better characterization of the liquid inks.

Summary

A charge characterization process based on the charge transport models is developed. Combining with experimental data, this process automatically determines the charge density and mobility distribution of a given charge particle dispersions like micellar solutions. For more complicated dispersions like liquid inks, it has been concluded that the apparent charge densities of the toner particles do not stay constant. In other words, the charging does not reach the possible maximum instantaneously at the moment of the application of external fields. Instead, the charging may take place, depending also on the magnate of the external field, in the time frame comparable to the toner particle plate-out time. To better characterize the charging of liquid inks, a quantitative understanding and modeling of the charge generation is needed.

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Biography

F. James Wang is a member of research & technology staff of the Xerox Wilson Center for Research and Technology. He graduated from National Taiwan University in 1983 and later received a Ph.D. degree in mechanical engineering from Columbia University in 1990. His work at Xerox includes liquid ink color electrophotography, fluid mechanics and thermal sciences. His recent research focus is in the areas of image quality of ionographic imaging and high speed liquid ink printing.