Ink Density Profile on Indigo Developer Roller

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Abstract

The binary ink developer (BID) in the HP-Indigo press converts low viscosity ElectroInk® into a paste-like layer that is presented to the photoreceptor to form a real image. Liquid ink starts in the ink tank and is pumped into the BID where electrophoresis transfers electrically charged ink solids onto the developer roller. The adherent is subsequently compacted mechanically and electrically by a squeegee roller to produce the layer that interfaces with the photoreceptor that moves at 2.15 m/s in state-of-the-art HP Indigo presses. Nominal average solids concentration on the developer roller after exiting the squeegee is 25 wt %, as determined by removing the ink layer from the developer roller and comparing wet and dry weights.

Ink transfer characteristics depend on ink solids content, which in turn varies with ElectroInk® formulation and BID operating parameters. Quantification of ink solids content on the developer roller facilitates ink development and provides insight into BID operation. In this work we describe the use of a unique tool developed in-house for profiling ink density on the developer roller. This device controllably removes submicrometer strata of ink from the rotating developer roller by applying a step-wise variable force to a scraping blade in contact with the roller. We find that the solids distribution within the paste layer varies depending on the electrophoretic and the squeege roller voltages. A typical concentration profile starts at a minimum furthest from the roller, peaks within the paste layer and then drops again as the developer roller surface is approached. We discuss the origin of this profile.

Introduction

In the HP-Indigo liquid electrophotographic (LEP) press, liquid ElectroInk® at about 2 wt % solids concentration is pumped from the ink tank into the binary ink developer (BID) [1,2], where the ink is compacted to an average concentration of about 25 wt % on the developer roller. The paste-like deposit is then electrostatically transferred to areas of the photoreceptor that had been photo-discharged by the laser write head. The developed image is subsequently transferred to a heated intermediate transfer medium and then to the substrate.

Complex electrophoretic, fluid dynamic and electrostatic processes occur in the BID to produce a uniform layer of ink across the length and circumference of the developer roller. An indication of the uniformity of this layer is evidenced from color consistency data ($\Delta E<1$) described in the July 2005 Seybold Report [3]. The BID handles standard process color ElectroInk®, spot colors and the expanded color gamut provided by IndiChrome® inks for commercial and industrial applications [4,5]. A more detailed view of ElectroInk® movement within the BID is provided with reference to the cross-sectional drawing of the BID unit shown in Fig. 1. Ink enters the gap between the metal electrode and developer roller, where an electric field of ~2 kV/mm draws negatively charged ink to the surface of the roller by electrophoresis. After exiting the electrode region, ink on the developer roller encounters the squeegee roller, which electrostatically and mechanically compresses the ink into a paste-like layer while rejecting excess fluid and loosely bound ink particles. The condensed charged layer is then presented to the photoreceptor where it responds instantaneously to the latent image, supporting the process speed of 2.15 m/s in HP Indigo presses introduced in Drupa08. Ink not transferred to the photoreceptor is stripped from the developer roller by a positively biased cleaning roller, returning the developer roller to an ink-free condition prior to re-entering the electrode region.

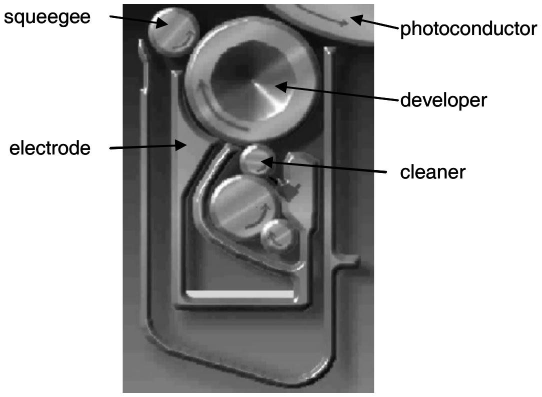

Fig. 1. *Drawing of binary ink developer (BID) unit used in the HP-Indigo press.*

Each of the three transfer processes in the press (developer-photoreceptor, photoreceptor-blanket and blanket-substrate) depends upon a variety of parameters, including solids content in the ink. ElectroInk® is optimized for a wide variety of performance criteria, and the resulting ink formulations perform differently when run through the BID. One important metric of ink behavior is the solid content of ink on the developer roller after leaving the squeegee. The average solids concentration can be determined by thermal weight loss analysis of ink scraped from the roller. While this gives useful information for evaluating ink performance, knowledge of the solids density profile on the roller would enable additional, more sensitive, discrimination to be made among ink variants.

The quantity of a specific ink formulation transferred to the developer roller, and ultimately to the photoreceptor, depends upon the electrode-developer and squeegee-developer voltages. Optical density of printed layers gives an accurate measure of the pigmented solid transferred to the photoreceptor and the associated voltage dependencies, but it says nothing about the attendant liquid. To establish the relationship between BID voltages and liquid content, direct measurement of solids concentration on the developer roller is desired. In this paper we describe a measurement technique that allows us to determine the ink density profile on the developer roller by controlled scraping with a spring-loaded blade. This method was used to examine the effect of electrode and squeegee voltages on ink density profiles.

Measurement of Solids Density Profile

To determine the non-volatile solids (NVS) profile on the developer roller, a tool was designed and built that applies controlled, variable force to a glass scraping blade mounted on a linear stage. Sequentially deeper strata of ink are removed from the roller as the scraping force is incrementally increased. A photograph of the apparatus is shown in Fig. 2. Scraping force was adjusted by the number and strength of springs inserted into the apparatus, and the force was zeroed by a counterweight. Blade position along the developer roller and blade angle were set by a micrometer stage mounted on a rotatable support. Small misalignments between blade edge and developer roller axis were addressed by rotary and transverse linear bearings linking the blade holder to the linear stage. The nominal two second extraction time was measured to within 0.1 sec (5%) by monitoring cleaner current with a digital scope while scraping. At the end of collection the blade was swiftly withdrawn from contact and tilted into a horizontal position to prevent ink from flowing to the underside of the blade or dripping off before the blade is removed.

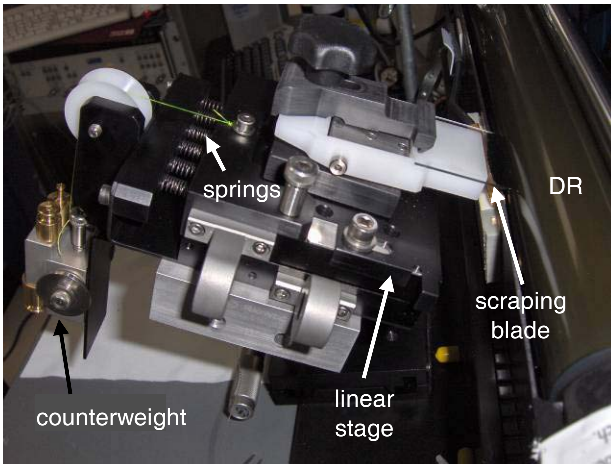

Fig. 2. Variable force scraping tool showing glass scraping blade contacting developer roller (DR).

A series of 13 samples were collected for each BID operating condition. Ink collection force was incremented between 20 and 450 g by employing combinations of 1 to 11 springs having two different spring constants. Following ink collection, NVS percentage and ink removal rates were quantified by thermal weight loss analysis. Dielectric carrier liquid was removed by two, hour-long anneals, first in a convection oven at 130 C and then on a vacuum hotplate at 170 C. Samples were weighed before and after annealing on a Mettler-Toledo analytical balance with 0.01 mg resolution; NVS fraction was defined as the final dry weight divided by the initial wet weight. Photographs of ink samples taken after annealing at two extremes of the force spectrum are shown in Fig. 3. Ink collected at low force flowed more and hence clearly had lower viscosity than ink collected at high force, where the entire ink layer was removed from the roller.

The influence of BID voltages on NVS profile was examined by varying squeegee and electrode voltages around the standard operating voltages, which were established prior to ink collection by running a press color calibration. The calibration procedure automatically sets BID voltages to values that produce the correct optical density (thickness) for each color. Color calibrated BID voltages were: electrode = -1270 V, developer = -525 V, squeegee = -800 V and cleaner = -300 V. Following color calibration the BID unit was removed from the press and positioned in a fixture that housed the variable force scraping tool. In addition to the calibrated voltages, electrode and squeegee voltages were incremented 200 V above and below the standard values.

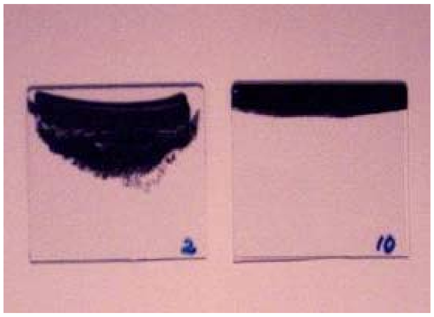

Fig. 3. Electroink samples collected at low (left) and high (right) force. Photographs were taken after annealing to drive off dielectric carrier fluid.

Effect of BID Voltage on Solids Density Profile

Vary Squeegee Voltage

NVS and removal rate as a function of scraping force for ink samples collected at squeegee voltages of -575, -800 and -1000 V are presented in Figs. 4 and 5. Both increase with scraping force up to a critical value, beyond which saturation occurs and all ink is removed from the roller. These data corroborate the observation that the viscosity, and now the solids content, is lower at lower scraping force. At large force a clear distinction is seen among the three squeegee voltages; higher voltage deposits more, higher density ink on the developer roller. In fact, total ink weight on the roller increased by roughly 50% (see Fig. 5) by increasing squeegee voltage from -575 to -1000V. So, while most ink deposition occurs as ink passes between the electrode and developer roller, additional electrophoretic development occurs at the leading edge of the squeegee-developer nip.

At the lowest squeegee voltage the difference between squeegee and developer voltages is only 50 V, a value comparable to the additional negative potential introduced by the charged ink. Consequently, there is no additional electrophoretic deposition or electrostatic compaction of ink, and the layer is correspondingly thinner (lower removal rate) and lower density. Increasing voltage difference to 275, then 475 V introduces a large field between squeegee and developer, depositing more solids and increasing NVS.

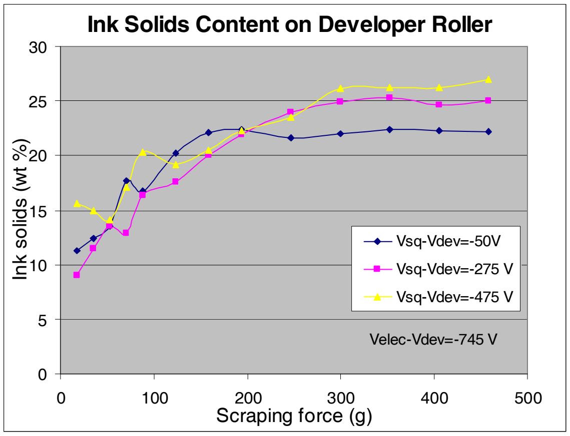

***Fig. 4**. Solids content (NVS) of ElectroInk® removed from developer roller over a range of scraping forces. Squeegee voltage changed between data sets.*

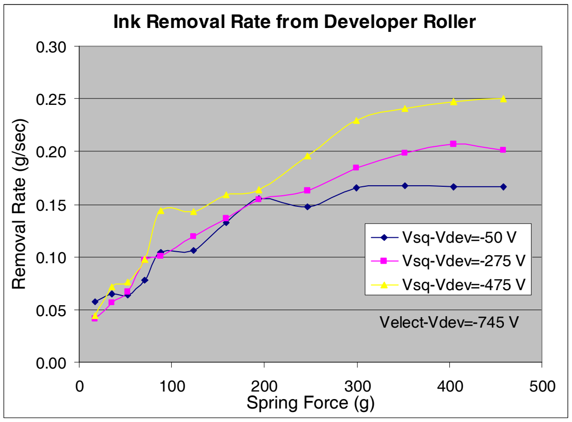

***Fig. 5**. ElectroInk® removal rate from developer roller over a range of scraping forces. Squeegee voltage changed between data sets.*

Vary Electrode Voltage

Similar trends in NVS and removal rate were found when varying electrode voltage. In this case BID voltages were set to their color calibrated values and the electrode voltage was set to either -1070, -1270 or -1470 V. Again, both NVS and removal rate increased with spring force until they reached saturation and all ink was removed from the roller. As expected, more ink was deposited on the developer roller as the electrode voltage increased. A noteworthy observation is that a 200 V deviation in either squeegee or electrode voltage from color calibrated values produced similar changes in NVS and removal rate; a 400 V swing in electrode voltage deposited 50% more adherent by weight, as did a 400 V change in squeegee voltage. Ink density at saturation was also higher for higher electrode voltage.

Calculation of NVS Profile

The NVS profile on the roller can be derived from polynomial fits to average NVS and rate data by first calculating the differential amount of solid and liquid collected within each ink stratum and then converting collected weight to thickness by employing collection time and various experimental constants (blade width, roller tangential velocity, dielectric carrier and solid densities). The resulting NVS profiles shown in Figs. 6 and 7 contain several interesting features: 1) the profiles are non-uniform, 2) low density ink (10-15 wt %) resides on the surface, 3) a peak in NVS occurs about 2 µm from the roller-ink interface and 4) ink density and total film thickness depend on squeegee and electrode voltages, and do so similarly.

Lower ink density at the roller surface occurs because the electrophoretic driving force, i.e. the field between electrode and developer roller, is reduced by charge screening as more ink is plated. The NVS profile is further modified by the squeegee, where electrostatic compaction accentuates this effect, driving additional carrier liquid to the surface. Low solids concentration in the outermost layer has two benefits in press operation: 1) reduction in friction between rollers in the BID and 2) facilitation of ink release from the photoreceptor during transfer to the blanket. This measurement technique allows direct measurement of surface density as a parameter in Electroink development.

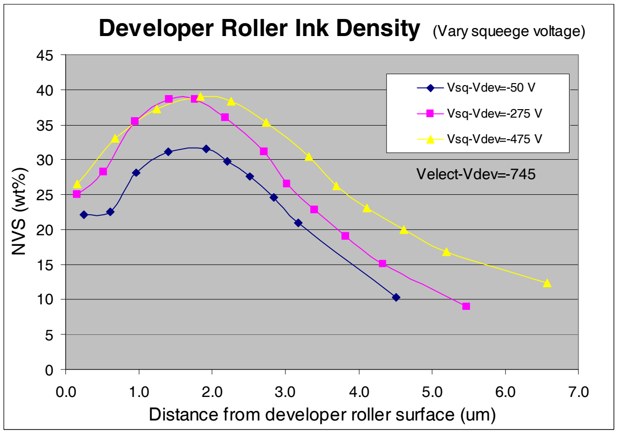

***Fig. 6**. Ink density (NVS) profile on developer roller calculated from ink scraping data in Figs. 4 and 5. Profiles determined for three squeegee voltages.*

Perhaps the most interesting aspect of the NVS profile is the displacement of the peak from the BID roller surface, its expected location based on the magnitude of electric field during electrophoretic deposition. This shift likely arises from the inability of fluid to escape from ink closest to the developer roller as the squeegee field tries to further compact the ink. In this scenario, as strong electrostatic forces attempt to draw ink solids towards the roller, widely spaced, more mobile particles away from the roller surface gain momentum while moving forward, allowing them snuggle together while simultaneously creating gaps for removal of displaced fluid. The layer adjacent to the surface is already denser, and hence those particles take longer to initiate much movement. Once the intermediate layer compacts, there is significantly reduced egress for trapped fluid in the layer next to the roller, leaving the interior more or less immobilized within the nip time available.

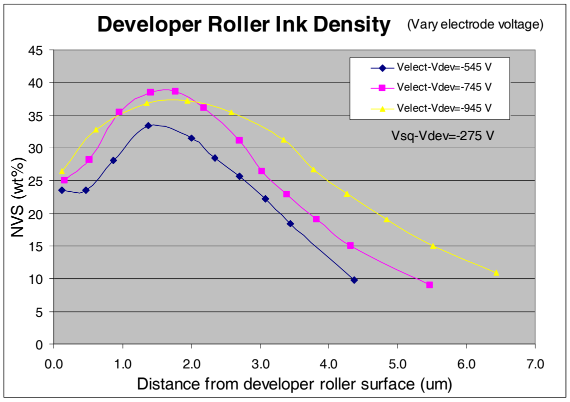

***Fig. 7**. Ink density (NVS) profile on developer roller calculated from ink scraping data in Figs. 4 and 5. Profiles determined for three electrode voltages.*

Figures 6 and 7 show surprisingly similar ink density profiles as squeegee and electrode voltages are varied. Increasing either squeegee or electrode voltages by 200 V leads to comparable broadening of the NVS profile and an addition of 1 µm in film thickness. The basic reason for the increase is clear. Loosely bound particles and a sizable fraction of the fluid entering the squeegee-developer nip are rejected due to the squeezing action, leaving only sufficiently adherent particles and the accompanying fluid. A higher electrode voltage creates a thicker, more compact initial layer, while a higher squeegee voltage drives particles harder against the developer roller. How the same voltage difference translates to a similar thickness change is more difficult to explain. One interesting sidelight is that the increased squeegee voltage profile appears slightly more peaked than that for the increased electrode voltage. Similarly the lower squeegee voltage profile seems less peaked than the decreased electrode voltage counterpart. This is consistent with the notion that a higher squeegee field causes more aggressive particle movement toward the developer roller for a comparable ultimate layer thickness.

Conclusions

Measurements of ElectroInk® density on the Indigo developer roller were made using a variable force scraping apparatus. With this tool, submicrometer strata of ink are removed from the developer roller, enabling ink density profiling. Ink solids density was non-uniform across the thickness of the deposited layer and strongly influenced by BID voltages. The utility of this measurement can be expanded by coupling ink density profile data with charge measurements to determine the charge density profile on the developer roller. This measurement provides valuable feedback in the development of Indigo ElectroInk® and additional insight into BID operation.

References

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Author Biography

Thomas Anthony received his Ph.D. in Materials Science and Engineering from Stanford University in 1984 and joined HP Laboratories that same year. During his first twenty years at HP he worked as a technical contributor and project manager while developing magnetoresistive recording heads and spin tunneling memory devices (MRAM). He currently is a Laboratory Scientist in the Commercial Print Engine Laboratory of HP Labs, where his research focus is on LEP technology.

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Omer Gila joined HP Laboratories in 2001 working on digital commercial printing technology and in 2003 became the group’s project manager. Prior to HP Labs, 1999 – 2000, Omer held the position of COO of Oniyah printing in Israel. During the years 1994 – 1999, he worked in Indigo as the color control manager. Omer holds a B.Cs in Physics and Mathematics since 1989 from the Hebrew University and M.Sc in Physics, 1992 Weizmann Institute of Science.