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Stabilization of Liquid Developed Images

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Abstract

The aim of this work is to stabilize toned images after liquid development process. To this end we constructed an image-conditioning device. The device, vacuum-assisted blotter, is able to compress the liquid toned images by an applied electrostatic field and remove excess fluid from the liquid image by transporting fluid through the porous blotter using vacuum. The vacuum-assisted blotter consists of a hard, conductive porous core, an open-celled, semiconductive foam sleeve, and an open-celled, insulative skin. The device has been demonstrated to be effective in producing cohesive images and removing excess fluid for the subsequent transfer process.

Using the vacuum-assisted blotter, we are able to remove all fluid surrounding images and we have not observed the limit on fluid removal. This fluid removal rate can be controlled by a pressure difference across the image (generated by a vacuum). The resulting toner concentration is determined by the consolidation stress, which can be created electrostatically or mechanically. The observed toner concentration is consistent with the theory of random ballistic deposition of “sticky” particles.

Introduction

In order to produce high quality images in liquid immersion development (LID), the toned images from the development process must remain intact as the forces from transfer subsystem act on it. The integrity of the image layer depends on the cohesiveness of the toner particles. Thus it is important to increase the integrity of the toned images.

We have developed a device to increase the image integrity. We have constructed a vacuum-assisted blotter (VAB). We use the VAB to consolidate the toner particles and to extract the fluid. With this device, we can condition the toned image to the desired range of cohesion needed for image transfer.

Function and Structure of VAB

Figure 1 depicts the structure of VAB. A VAB device consists of three porous components: a core, an elasomer sleeve, and a skin. The core provides the support for the whole device, and is usually conductive to provide an electrical bias. The elastomer sleeve gives the proper nip needed for biasing and fluid removal, and is typically semiconductive. We designed both core and sleeve to have large porosity for low impedance to fluid flow. The function of the skin, which has micron sized pores, is to prevent toners from entering the porous media, and to act as a vacuum seal when saturated with fluid. The skin is desired to be thin for, again for low impedance to fluid flow.

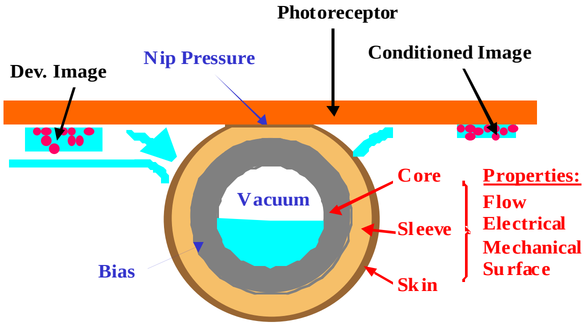

Figure 1. Structure of a VAB device.

We apply an electrical bias to the core of the VAB, generate a vacuum inside of the device, and load it against the photoreceptor to form a pressure nip.

The functions of VAB are 1) to compress the toned image, 2) to remove excess carrier fluid around the compressed image, and 3) to prevent toners from being back-transferred onto the VAB surface. The applied electric bias is of the same sign as the liquid toners. The electric field has the function of both image compaction and the prevention of toner back-transfer. The pressured nip ensures uniform contact and consolidates the image. The vacuum induces pressure difference that drives captured fluid through the porous components to be reclaimed.

Demonstration of VAB

Fluid Removal. From a physical point of view, the VAB is a combination of elasto-hydrodynamic flow in the nip formed between the roll and the photoreceptor and flow through composite porous media in the blotter. The elasto-hydrodynamic flow arises because ink is forced through a narrow gap and the hydrodynamic pressure forces are sufficiently large to deform the elastomer (see Figure 2). The flow of a Newtonian fluid in a narrow gap obeys the Reynold’s equation that is commonly associated with lubrication:

$$Q(x) = Uh(x) - \frac{h(x)^3}{12\mu}\frac{dP}{dx} \tag{1}$$

Where ***Q(x)*** is the flow rate per unit length of the device, ***U*** is the photoreceptor speed (and the surface velocity of the VAB roll), ***h*** is gap which is a function of the process direction ***x***, ***P*** is hydrodynamic pressure and μ is the fluid viscosity.

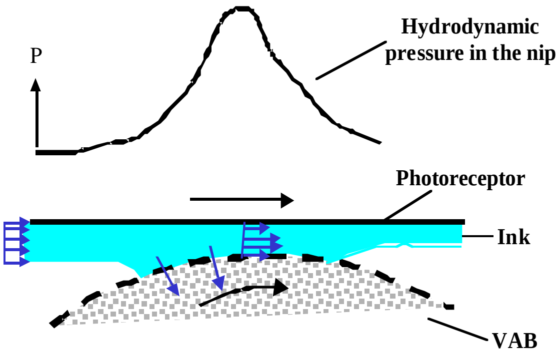

Figure 2. Elasto-hydrodynamic flow in nip

Flow through Composite Porous Media

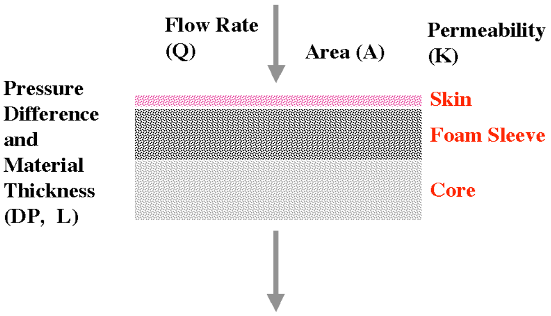

Figure 3. Parameters critical to flow through composite porous media

The differential between the nip pressure on the surface and the vacuum pressure in the core of the VAB drives the fluid removal.

Figure 3 shows the parameters important to fluid flow through a composite porous media. Darcy's law defines the relationship between the flow rate per unit area, q, with the permeability K, the pressure difference ΔP, and the layer thickness L:

$$q = K / L \times \Delta P / \mu \qquad (2)$$

where

$$L / K = (L / K)s + (L / K)f + (L / K)c . \qquad (3)$$

Here subscript ***s***, ***f*** and ***c*** are skin, foam and core layers respectively. $\boldsymbol{\Delta P = P - P_v}$, where $\boldsymbol{P_v}$ is the vacuum pressure, and $\boldsymbol{q = -dQ/dx}$.

Finally the gap h is defined as $h = h_0 + v(\Delta P,\ F_e,\ F_t)$, where h_0 is the static gap, and v is the deformation of the elastomer caused by the hydrodynamic pressure ΔP, electrostatic forces F_e and toner contact forces F_t. For Hooke's law, $v = (\Delta P + F_t + F_e)/E$, where E is elastic modulus of the elastomer..

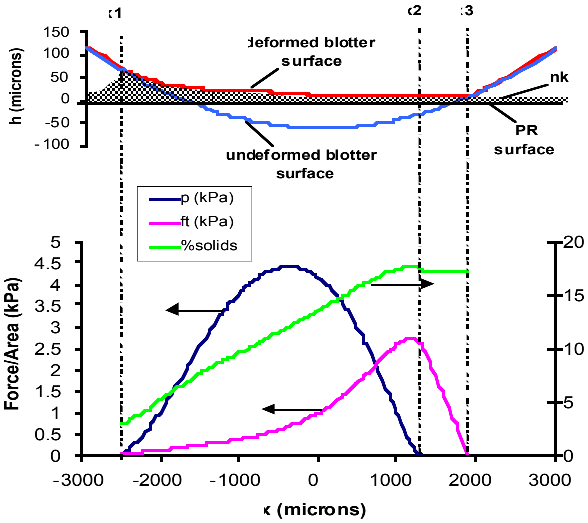

Figure 4. Nip geometry (top), and hydrodynamic pressure (p), toner consolidation stress (ft) and solids concentration in the nip (bottom)

We have implemented a model to calculate the fluid removal rate as a function of the process and blotter material parameters. Figure 4 shows a calculation from the model for vacuum pressure of 2.5 kPa and process speed of 0.254 m/s. The incoming image is 20 microns thick at 9% toner volume concentration and the outgoing image is approximately 10 microns thick at 18% toner volume concentration. At the top of figure 4, the nip geometry is shown. The blue line is the undeformed surface of the VAB roll and the red line is the deformed surface. x1 is the entrance contact point. x2 is the point where the nip pressure recovers to atmospheric pressure and x3 is the point where the blotter loses contact with the image. At the bottom of Figure 4, the load on the VAB surface due to hydrodynamic pressure (p) and toner consolidation stress (ft) is shown. Also shown is the toner packing fraction in the nip. Note that fluid tends to accumulate in the entrance region resulting in a local solids concentration below that of the incoming image.

Figure 5 shows the fluid removal rate per linear meter of the device as a function of the vacuum pressure. The diamonds, squares, and triangles are the experimental measurements for process speed of 0.508 m/s, 0.254 m/s, and 0.127 m/s respectively. The solid lines are the predictions from the model. The VAB device has been demonstrated to have wide latitude against process speed.

Both experiments and model show that the fluid removal rate increases with vacuum but is limited by the consolidation of the toners in the image. The maximum achievable consolidation depends on the total pressure (due to hydrodynamic and electrostatic forces) on the toned image.

For the device tested, this was around 20% packing fraction. In general, the mechanical load and electrostatic bias control the effect of vacuum on the fluid removal rate. At higher loads, and higher electrostatic biases, the fluid removal rate is only weakly dependent on the vacuum. For high loads, the device may operate in a squeegee mode where most of the fluid removal occurs in the entrance region. The compliance of the elastomer and the effective impedance of the porous layers of the VAB are additional critical parameters that drive the response to vacuum. Even at zero vacuums some fluid removal is achieved because the hydrodynamic pressure in the nip is greater than atmospheric.

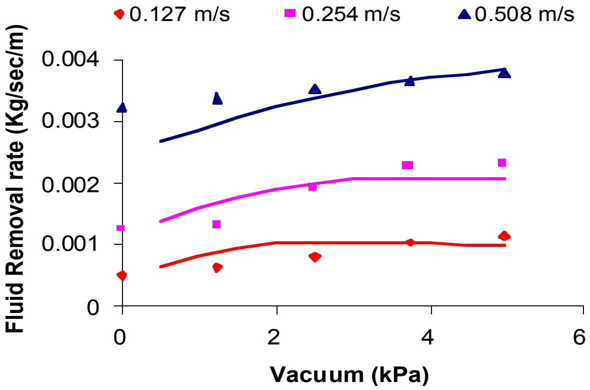

Figure 5. Comparison of predicted (solid lines) and measured fluid removal

Compaction of Toned Images. We have shown that within the design of the VAB, the device exhibit large latitude in fluid removal rate. The VAB device is capable of removing all fluid outside of the image network that is defined by the toner packing structure. The toner packing structure determines the cohesion of the image.[1]

For liquid inks, the structure of the image changes through two stages as the toner particles are consolidated. In the first stage, the image consists of clusters of aggregated particles. The packing of clusters is lower than the packing fraction of randomly deposited sticky particles, which in terms of particle packing, gives the lowest pack fraction.[2] As the image gets consolidated, the clusters decompose and the packing fraction will approach that of randomly deposited sticky particles, which in volume ratio of particles to total volume is estimated to about 18%.[2] In the second stage, the consolidation stress will break the bonding, the inter-particle adhesion, between particles. Consequently, the packing fraction of the image will increase toward the value of the random closed pack of 58% by volume.[2]

The electrostatic force generated through biasing the VAB device is capable of compressing the image through the first stage of consolidation. Figure 6 shows the resulting packing fraction from applying an electrical field. The x-axis is presented in terms of consolidation stresses in kilo-pascals. The packing fraction is in volume ratio of toners to total. We converted the electrostatic field (E) to consolidation stress (σ) by using the relationship proposed for an ensemble of spherical particles[3]:

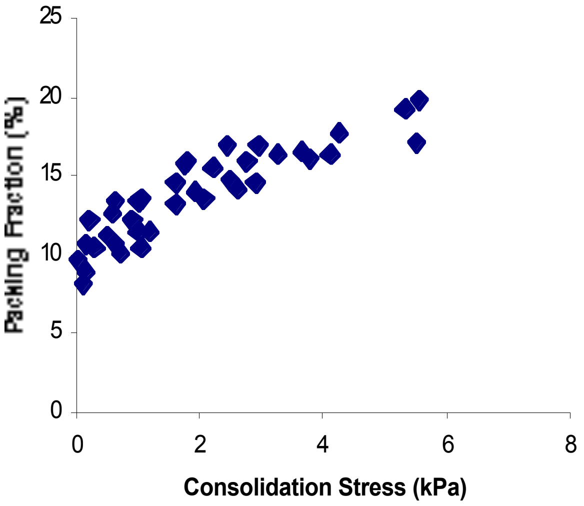

Figure 6. Compaction of toned images by electrostatic field.

$$\sigma = \frac{1-\varepsilon}{\varepsilon^{3/2}\pi d^2} F \tag{4}$$

Where ε is the void ratio, $\boldsymbol{d}$ is the diameter of the particles, and F the cohesive force per contact. We computed $\boldsymbol{F}$ from the value of the voltage difference ($\boldsymbol{V}$) between the toned image and the blotter:

$$F = qE = q\frac{V}{L} \tag{5}$$

Using q deduced from the electrophoretic mobility of toner particles, ~ $3\text{x}10^{-17}$ C, and a typical electric field of 40 Volts/micron gives an image of about 15% packing fraction by volume, will convert into a consolidation stress of about 1.6 kPa.

As shown in Fig. 6, the electrostatic compaction increases the image packing fraction toward the 18% value of the randomly deposited sticky spherical particles.

Figure 7 depicts the image structure represented by packing fraction as a function of consolidation stress that is generated through mechanical compaction by another device. The consolidation stress here is estimated through the total load per unit nip area. As demonstrated by Fig. 7, high mechanical pressure can overcome the inter-particle adhesion and eventually consolidated the toner particles to the structure of close packed spherical, non-sticky particles.[2]

Prevention of Image Offset. Another function of the electrostatic field is to prevent toner particles to offset onto the VAB surface. An offset can degrade the quality of the image as well as create the need of a cleaner on VAB.

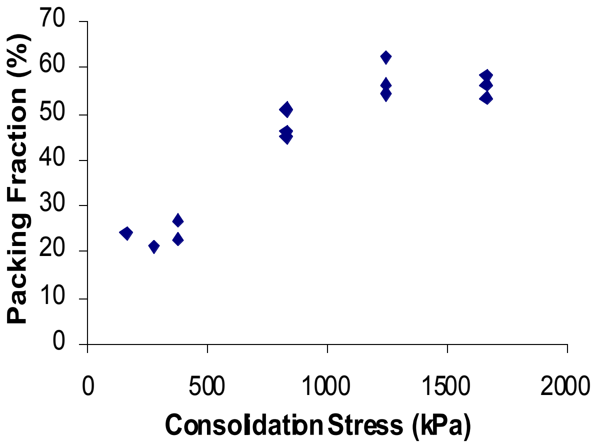

Figure 7. Compaction of toned images by mechanical pressure.

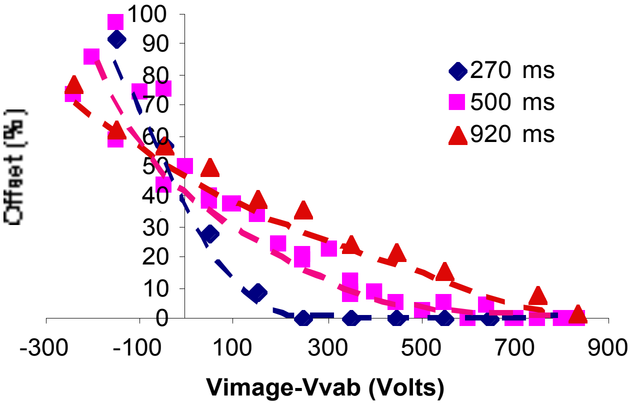

Figure 8. Effect of dwell time on the amount of image offset.

Figure 8 illustrates the effectiveness of the bias. The offset is the ratio of the optical density of image offset to VAB to the sum of optical densities of image and offset. The horizontal axis here represents the voltage difference between the image and VAB. Fig. 8 shows the effect of dwell time on the resulting offset. Fig. 8 indicates that the shorter the dwell time, the more effective in preventing offset.

The observed dwell effect indicates that as the contact time gets longer, the adhesion between toner and VAB surface increases and the cohesion among toner particles decreases. We do not have a sound theory in explaining the observed dwell effect.

Conclusion

We have designed and constructed a device to condition liquid ink images. We have demonstrated that the invented device, vacuum assisted blotter, is capable of ***1) compressing the toned image, 2) removing excess carrier fluid from the toned image, and 3) preventing toners from being back-transferred onto the VAB surface***. Depending on the design of the VAB, the device can have large latitudes of fluid removal and image compaction. The experimental demonstration confirms our theoretical prediction of the device. The observed toner compaction is consistent with the theory of random ballistic deposition of “sticky” particles.

References

1. Shu Chang et. al., *Measurement of Toner Cohesion in Liquid Inks Using a Visualization Cell*, IS&T, Toronto, Canada, 1998.
2. Howard Mizes, *The Structure of Toner Sediments Simulated with Random Ballistic Deposition*, IS&T, Orlando, Florida, 1999.
3. K. Rietema, *The Dynamics of Fine Powders*, Elseview, 1991.

Biography

Shu Chang received her B.S. degree in Physics and Mathematics from Berea College in Kentucky in 1983 and a Ph.D. in Materials Science from University of Minnesota in 1988. Since 1988 she has worked in the Wilson Center for Research and Technology at Xerox Corporation in Webster, NY. She has worked on a wide variety of topics, including liquid image conditioning, liquid toner electrostatic transfer and rheological transfer, powder transfer, and process integration, as well as issues related to particle cohesion and adhesion of dissimilar materials. She is a member of the IS&T and the American Physical Society.