Advances in Liquid Toner Technology

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Abstract

Dry toner technology remains the dominant technology in electrophotography and recent improvements in print speed and image quality have helped to secure this position. However, there has been a resurgence of interest in liquid toner technology. Recent advances in toner chemistry and liquid electrophotographic processes have opened new opportunities to exploit the inherent advantages of liquid systems. This paper discusses recent developments in liquid toner chemistry and processes that have the potential to effect substantial reductions in print cost, increases in print speed and reductions in the environmental impact without sacrificing image quality or the other inherent advantages of liquid systems.

Introduction

Liquid inks have a history of several hundred years in the printing industry. They are used in a broad range of applications including both the analog and digital printing areas. Starting their journey in letterpress and lithographic printing, it was not until 1955 that they entered the digital arena, when Metcalfe and Wright demonstrated the use of liquid inks in an electrophotographic printing process[1]. Their work laid a foundation for the successful advancement of liquid toner technologies through the second half of the 20th century and into the new millennium.

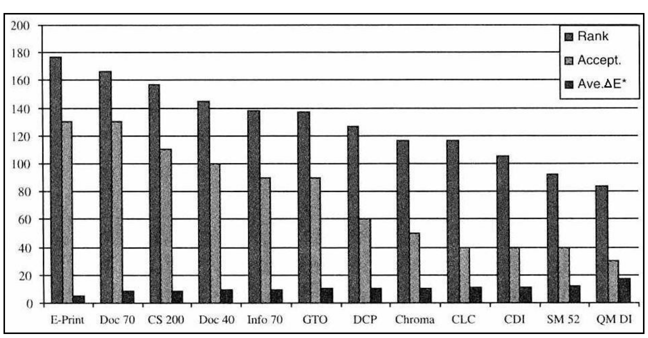

Figure 1. Comparative assessment of various digital and analog printing presses[2]

The main advantages of liquid toners are small particle size (~1µm), wide colour gamut, low fusing temperatures and absence of dust problems. These features together make it possible to produce high quality images at high speed for graphic art printing applications. The credentials of liquid toner systems were demonstrated by a comparative performance assessment of different digital and analog presses undertaken recently by George Simonian.[2] The liquid toner system in this study came on top of the list in all categories including visual assessment, acceptability and colour matching (Figure 1).

In the office printing market there is also an increasing demand for continual improvement in image quality and print speed, whilst meeting strict environmental, health and safety regulations.

Despite the fact that high print speed and quality have been achieved by conventional analog printing technologies, digital technologies utilizing conventional liquid toners have yet to match all these quality targets simultaneously. The existing printing processes based on conventional liquid systems have some limitations that prevent realisation of the full potential of liquid toners. However, a new liquid toner technology that has been the focal point of over a decade of research and development effort led by Research Laboratories of Australia (RLA) is believed to offer high image quality and print speeds, is environmentally friendly, and significantly reduces running costs.

Conventional Liquid Toner Technology

Image development in a typical liquid electrophotographic printing process is often associated with liquid immersion development (LID) and is based on an electrophoretic movement of charged toner particles through the carrier fluid across a preset and clearly defined development gap, in the vicinity of 100µm. A relatively large development gap is a necessary prerequisite for most LID printing systems, when used in combination with a low concentration toner, to achieve sufficient image density. Depending on the type of development process, either charged or discharged area development (CAD or DAD, respectively), the toner particles accumulate either on the surface of the photoreceptor in the high potential regions or in the discharged areas. To enhance the development process and deliver high image quality at high printing speeds in a typical LID process, several conditions must be met.

Particle Charge

A typical LID toner has several main ingredients including an insulating dielectric fluid (carrier liquid), toner particles consisting of pigment or dye and binding resin, charge control agent (CCA) and other additives to control the dispersion stability, shelf-life and rheological properties. Although most colloidal systems acquire some charge without the addition of CCA, the level of this charge in LID developers is usually low. The addition of the correct type and amount of CCA results in a substantial increase in the particle charge via a charge exchange mechanism between the CCA and the particles. The end result is a toner system that contains charged particles, counter ions that are usually formed in inverse micelle structures and free undissociated molecules of CCA.

The nature and intensity of the charge exchange reaction in the LID developers is known to be sensitive to any contaminants in the toner, environmental conditions and the type of CCA.[3] This in turn has a direct effect on the particle charge and hence, electrophoretic mobility of toner particles. Stabilization of the charge properties and performance of conventional liquid toners is a challenging task, usually achieved at the expense of increased toner cost.

Small Particle Size

A small particle size of ~ 1µm is a distinct advantage of liquid developers compared to any other toner system. It provides high print resolution, excellent edge definition and low pile height on the final substrate. Small particle size also makes it possible for liquid toners to meet glossiness, graininess and dot gain requirements of the graphic art printing applications.[4]

Unlike dry toners, the small toner particles in liquid systems are contained within the carrier liquid that prevents particles from becoming airborne. As a result, there are virtually no restrictions on particle size in liquid toners so they are well positioned to meet strict environmental safety regulations for dust contamination.

Low Viscosity

As toner particle sizes are substantially smaller than the development gap, they need to travel a relatively long distance before reaching the deposition location. To reduce the drag force exerted on the toner particles during electrophoresis, the toner carrier viscosity must be low.

Most traditional non-aqueous liquid toner systems are formulated using low viscosity hydrocarbons as the carrier liquid.[5] Whilst these liquids are proven to be suitable for this purpose due to their chemical compatibility and relatively low cost, their volatility at room temperature and lack of compliance to VOC regulations are of continually increasing concern to the end users.[6]

Reduced Particle Concentration

The other means to improve particle electrophoresis is to minimize the interaction between particles by simply decreasing particle concentration.

In the majority of printing applications utilizing conventional liquid toners, the particle content is low and normally does not exceed 2-5%. Whilst low solid content offers several advantages, such as the ability to print continuous tone images and maintain a reduced level of background, it results in high liquid carry-out on the print medium and excessive emissions into the atmosphere during the print drying stage.

High and Uniform Electric Field

Electrophoretic mobility of toner particles is a direct function of electric field strength in the development region. The existence of a finite gap that is much larger than the pixel dimensions in a printing system using conventional liquid toners leads to image non-uniformity problems, such as edge or "xeroxing" effect, and the need to apply high voltages to achieve sufficient electric fields during the development process.

Directions for Advancement of Liquid Toners

The ability of printing systems utilizing conventional liquid toners to deliver very high image quality comes at a cost to environmental safety, print speed, running cost and substrate flexibility. Table 1 below summarises some limitations of conventional liquid toner systems in relation to all these aspects.

Table 1. Inherent Limitations of Conventional Liquid EP

Environmental and Safety Regulations	❑ High content of volatile carrier ❑ VOC regulations may require use of abatement technology ❑ Air quality requirements (safety limits and odor)
Print Speed	❑ Development process speed is limited ❑ Extended drying time at high speed
Running Cost	❑ High toner consumption rate ❑ Increased engine dimensions ❑ VOC abatement ❑ Substrates may require pre-coating ❑ Controlled environment is required for consistent print results
Substrate Flexibility	❑ Substrates may require pre-coating ❑ Restricted range of substrates

Analysis of the main limitations of conventional liquid toner technologies enables one to suggest the following possible solutions for further advancement of liquid toner systems.

Alternative Carrier Liquids

Selection of alternative carrier liquids that are environmentally friendly, i.e. they have high boiling point, are non-volatile, odorless, non-conducting and compatible with other toner ingredients. Amongst many materials available from the chemical suppliers, only a few meet these requirements.

The key practical candidates for replacing volatile hydrocarbons as the main carrier in conventional LID are silicone fluids, vegetable oils and high boiling point and low volatility hydrocarbons. A good example of incorporating alternative carrier materials into a novel liquid toner is a system based on silicone fluids.[7]

The consequence of switching to low volatility and high boiling point carrier liquids is a substantial increase in viscosity; if these carriers were incorporated into a traditional liquid system, the outcome would be a substantial decrease in toner electrophoretic mobility.

High Particle Concentration

The other means to address strict environmental and health regulations is to reduce the amount of carrier in the toner, thereby minimising the amount of liquid carry-out to the substrate. This possibility was considered by several researchers in the past,[8-9] and continues to this day.[10-11] Liquid toners with increased solid content offer many other benefits including reduced toner consumption rate, high process efficiencies and reduction in running costs.

The biggest challenge to progress in this direction is in formulating highly concentrated toners that have simultaneously good dispersion stability, sufficient charge and small particle size. In fact, attempts to substantially increase particle concentration in liquid systems typically lead to increased particle-particle interactions. As a direct result, these systems become more prone to particle aggregation; the thickness of the electrical double layer is reduced resulting in reduction in electrophoretic mobility. In addition, concentrated systems become non-Newtonian and their high shear viscosity increases.

If one prepares a liquid toner using an alternative carrier liquid with high particle concentration, and then attempts to produce a print using a conventional liquid EP printing systems, the result is likely to be very poor. The reduced electrophoretic mobility of the concentrated toner would not permit developing high image contrast with low level of background at the required process speeds.

Novel Liquid Toner Technology

For over a decade, RLA has been working on toner chemistry and printing process solutions to demonstrate the feasibility of using high concentration, environmentally friendly toner systems for printing high quality images at high speed. The main efforts have been focused on improving dispersion stability, flow behaviour and charging characteristics of concentrated liquid toner formulations, and on the development of a dedicated printing process that provides the best match to these novel liquid toners.

The liquid toner EP process at the heart of this novel technology uses high concentration and high viscosity toner (HVT) having solid contents in the range of 10-40% by weight – the values similar to some offset inks. Colorant content is ~ 3-8 times higher than other conventional liquid toners and up to 10 times higher than a typical inkjet ink. Furthermore, HVT toners are manufactured using commodity raw materials and pigments used in traditional printing inks. As such, HVT toners can potentially deliver similar performance with respect to print density, colour, lightfastness and print durability.

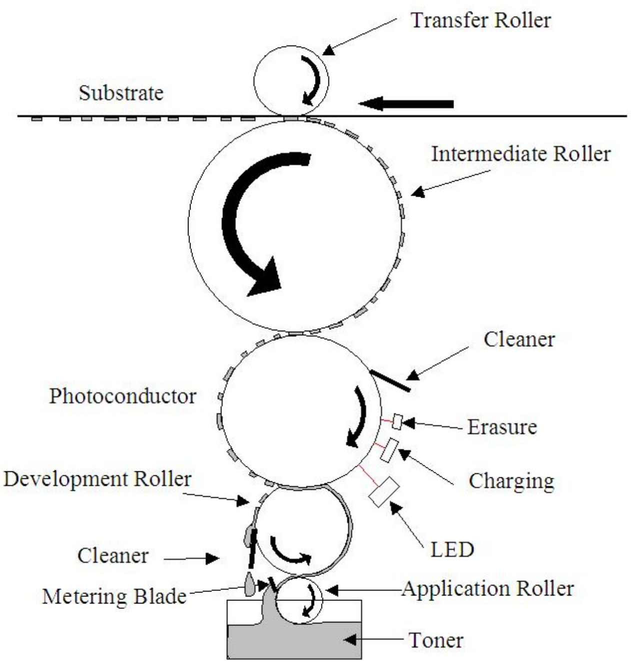

Figure 2. Layout of an EP system utilizing novel concentrated liquid toners

A critical step in achieving good performance with concentrated liquid toners is to reduce the development gap.

The development mechanism employed in the HVT printing process is known as "soft-contact".[12] whereby rollers or belts and the photoreceptor imaging member are in contact while toner is transported through the development and transfer nips (Figure 2). The absence of a pre-set gap in the development process reduces the traveling distance for toner particles and enables the establishment of high fidelity electric fields across a thin toner film of several microns in the development nip which significantly enhances toner electrophoresis (Figure 3).

This factor is believed to give an advantage over conventional gap development processes in terms of print speed capabilities. As an example, high resolution and good contrast images have been produced at RLA at process speeds in excess of 2.5 m/s (Figure 4).

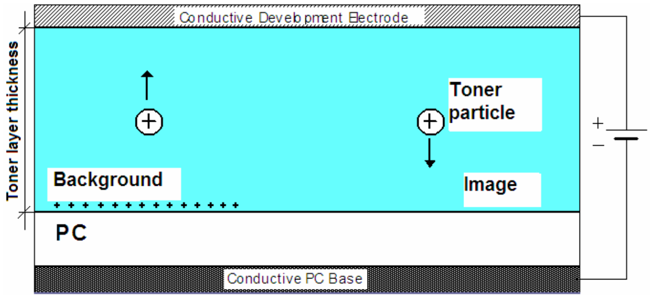

Figure 3. Development mechanism of an EP process using novel concentrated liquid toner

Figure 4. 5 pt characters produced at 1.5m/s print speed using HVT process

The HVT printing process uses novel design concepts in the development and transfer assemblies to create a process resembling a traditional offset printing process with the associated robustness, stability and serviceability.

The use of an intermediate transfer member designed to conform to surfaces of various morphologies enables efficient and uniform transfer onto a wide variety of printing media including different types of paper, metal, foils, laminates, plastics, glass etc. Therefore, good transfer characteristics can be achieved without the need for an additional coating on the majority of these printing media.

Figures 5 and 6 illustrate typical image quality produced by the process discussed in this paper.

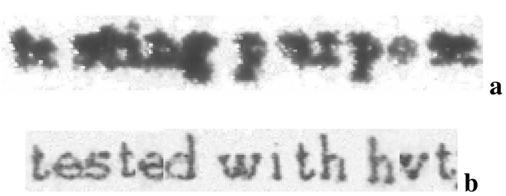

Figure 5. One point text produced using the HVT printing process versus Dry EP ("a"-DocuPrint C1250; "b" – HVT)

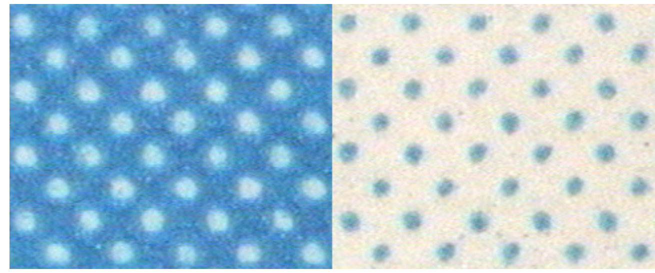

Figure 6. 600dpi "black" and "white" dots produced by HVT process

Conclusion

Novel liquid toner EP printing technologies have emerged during the past decade that have shown the potential to push the boundaries of conventional low viscosity and low solid content liquid toner printing processes towards higher printing speeds, greater substrate flexibility and superior environmental and safety compliance. An example of such a novel technology solution is a liquid toner EP process being developed by Research Laboratories of Australia. The key combination of a "soft-contact" process with viscous and concentrated liquid toners provides the advantages of an environmentally friendly liquid toner system that offers high print quality, high print speed capability, substrate flexibility and low running cost.

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Biographies

Alex Ozerov received his Master's degree in Physics from Nizhny Novgorod University, Russia, in 1983. He has over 20 years of experience in research and development of novel technologies in a wide range of applications from microelectronics and material science to radar systems and printing. He joined Research Laboratories of Australia in 1994 and has been working there as a principal technologist in the area of liquid electrophotographic processes. At present, he manages High Viscosity Toner Division at RLA.

Owen Crees has a PhD in surface and colloid chemistry, and more than 30 years of experience in industrial and commercial research and development in a wide variety of fields. He joined Research Laboratories of Australia in 2001 as the Director of Research and Technology and is currently the CEO.