Toners for High Quality Digital Production Printing

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Abstract

Digital revolution has affected many aspects of our daily life. Its biggest impact can be seen in many different emerging communication pathways and how information today is shared across the globe on routine basis. Digital printing has been at the forefront of this change. Many advances have taken place in the development of toners to take advantage of digital imaging. Many diverse demands that have been placed on the printed matter has led to the development of specialized materials used in toner formulations and as well as the methods for the generation of these marking particles. Selection of toner polymer(s) entails consideration for process speed, fusing techniques, development methods, image gloss, etc. By advancing towards smaller particle size of toners, factor such as cost, fusing ease, image relief and dot integrity can be affected to yield prints that are make them as unique and as appealing as off-set output. There is a move in the toner industry to exploit the manufacturing advantages that are offered by chemically prepared toners (CPT). However, a comparison between CPT and conventional ground toners indicate that the method of manufacturing is far less important than the properties that must be incorporated in toner particles for a given EP process and situation.

Introduction

With the arrival of digital age, demand for digital printing has also increased. But this need is accompanied by higher expectations from digital printing. With analog copier, a photocopy with better print quality than original was neither achievable nor expected. With the advent of digital printing, it is possible to make each image as unique, and with image quality that parallels what was once thought to be only possible with offset printing. The trends in the development of toners for digital such printing applications mirrors the expectations that have been placed on the output. There are new environmental as well as health and safety issues that play a role in defining the toner composition along with manufacturing techniques.

In addition to the high image quality and consistency that has become the cornerstone of digital printing, there are many other benefits that have come to be associated with digital printing. With digital printing it is possible to realize on-demand, short run and distributive printing. With offset printing it is very cost effective to make thousands of impression of the same image. Since image is written on the photoconductor every time, with digital printing it is possible to include variable data and produce documents that are unique and do not require the time and cost associated with set-up and plate making that is inherent with lithography.

At each step of the electrophotographic cycle, the toner characteristics play a critical role in determining the final quality of the resulting print. Some of the toners factors such as size, shape, chemical composition, colorants and melt viscosity are usually optimized to work with an existing process. Alternatively, these factors could be selected so that a more robust and cost effective process is the outcome. In the printing industry, toners are also commonly referred to as either DryInk® or marking particles, which further illustrates the narrowing of gap between digital printing and lithography.

Toner & Developer Composition

Most of the high-speed color digital printers are based on a two-component system in which the toner particles are mixed with magnetic carrier particles. Carrier particles can be either ferrite or a magnetite. Image quality of print is not only determined by the size of the marking toner particle but equally by the size of the carrier particles used. The volume average diameter of typical carriers that are used in the printing industry ranges from 20 to 200 microns. Soft carrier ferrites such as Cu-Zn ferrites are generally 40 to 60 microns and are used more commonly. In general, smaller carrier particles provide images with higher image resolution. A Scanning Electron Micrograph of a hard ferrite that represents the smallest developing particle that is currently used in digital printing is shown in Figure 1.

With smaller carrier particles, not only a high definition imaging is possible, the load of toner particles attached to carrier surface (usually referred to as toner concentration) is also increased. This ensures that adequate amount of marking particles are available to develop the latent image and thereby reducing the take-out sensitivity and promoting high-speed printing.

The toner particles consist primarily of clear resins such as polyester or styrene-acrylate copolymer. The other optional additives to toners include, charge control agent, pigment(s), waxes and other specific additives. The toner ingredient selection determines the performance as well as the appearance of the final output. The totality of the formulation has an impact on the developer life and dictates reliability and robustness of the digital printing device.

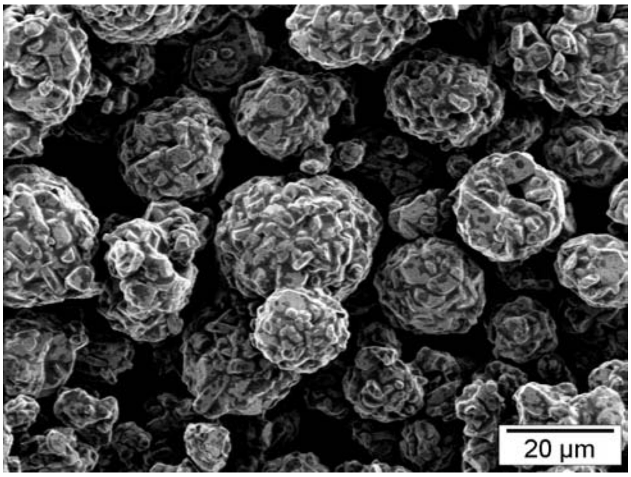

Figure 1. Scanning Electron Micrograph of small hard ferrite high definition carrier particles.

Toner Manufacturing

Toners are conventionally manufactured by a melt blending operation. The ingredients of a toner formulation are kneaded together in an extruder to achieve a uniform dispersion of components. The extrudate is cooled and pulverized by impaction to reduce the particles size to the desired level. Resulting product is then classified using a cyclone type device to remove the fine end of the particle size distribution. Separated toner fines are usually recycled by adding them to subsequent melt extrusions.

Toner pulverization and classification are the most challenging part of the toner manufacturing process, Several advances have been made in the grinding and classification equipment that provide better toner yields and sharper cut points. When particles are reduced using impaction, the fracture mechanics dictates that increase in the energy required would scales with the surface area of the particles generated. This relationship is shown in Figure 2 where energy used is plotted against toner particle size. With current manufacturing equipments, it is often observed that toner yield is independent of toner size except at very small toner particle size. When making 6 microns or larger toner particles, a 80 percent is quite typical. When the particle size of toner is reduced to 4 microns, toner yields drop to less than 60 percent. In order to generate small toner particles at high yields, better rotor and nozzle designs need to be investigated.

Alternatively, the toners can be prepared by chemical means. Such toners are often referred to as Chemically Prepared Toners (CPT). Such toners are being preferred not only for their ability to make very small toner particles more economically, but also because these techniques allow toner manufacturers to comply with several environmental regulations. These toners can be prepared by a variety of techniques and several different methods of CPT manufacturing are being practiced in the industry today. The first commercially available CPTs were produced by suspension polymerization method. In this method, monomer droplets are dispersed in an aqueous phase. Size of the droplets is chosen to represent the final particle size of the toner. Any additives that need to be incorporated in toner are dispersed in the monomer phase prior to the polymerization of the binder.

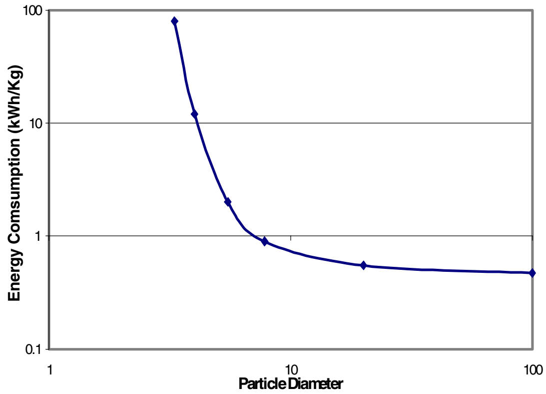

Figure 2. Plot showing the increase in energy consumption as toner particle size is reduced.

Another method uses several different kinds of small emulsions of preformed vinyl polymer. These emulsion particles can range from 50 to 200 nm in size. By controlling the conditions, different emulsions are allowed to aggregate till the desired particle of the toner is achieved. This method is called emulsion aggregation method and resulting toners are called EA toners.

Both of the techniques described above are essentially limited to using vinyl type of monomers or polymers. As a results there has been an increase in the number of styrenic color toners that being manufactured today. Typically, condensation polymers such as bisphenol A fumerate polyester are exclusively used to manufacture color toners by the conventional melt compounding process. Polyester binders, because of their polar nature, are better suited for providing better pigment and charge control agent dispersion in toners. Another reason for selecting polyesters binders is that they are mechanically tougher even at low melt viscosity. Vinyl polymers are quite brittle at low molecular weights that are necessary to achieve high gloss and color saturation. As a consequence, most EA toners are higher in melt viscosity and provide low gloss prints than color toners for digital presses that polyester based and prepared by conventional processes.

Some CPT manufacturing processes are based on first dissolving a preformed polyester in a suitable solvent. The solvent is uniformly dispersed in aqueous medium in the presence of a stabilizer and subsequently removed. This approach allows any soluble binder to be used as a toner resin.

All these methods of making CPT are capable of producing small toner particles with a narrow particle size distribution. The yield is generally very good but a large amount of water is necessary for particle formation and washing. In general cost, image quality, relief and ease of fusing are the main reasons for transitioning to smaller size of the toner. However, there are other toner characteristics that are also affected with smaller toner particles. They include:

- higher charge/mass
- lower development efficiency
- poor powder flow
- higher pigment loading
- higher toner viscosity due at high pigment load
- reduced electrostatic transfer

The charge/mass ratio of a toner is one single parameter that is typically used to describe the performance of a toner. This ratio is inversely related to the particle diameter and becomes larger as toner particle size decreases. This leads to reduction in development efficiency and increased difficulty in transferring the toner from the photoconductor (PC) surface to substrate. Lowering of development efficiency requires that the electric potential on the PC be increased in order to achieve required color density. Increased voltage not only diminishes the life of the photoconductor, it also causes electrical breakdown. It is perhaps because of these limitations that despite their capability going smaller, most chemically prepared toners range from 7 to 8 micron in mean volume average diameter.

Fusing

For producing a high quality output, fusing is one the most critical step in the electrophotography. Fusing techniques determine the image gloss, color saturation, reliability and image acceptance. The large numbers of image artifacts that are observed on some digital print are either caused by the fusing subsystem directly or indirectly by the silicone oil that is commonly used to aid with release from fuser roller surface. The silicone oil easily contaminates the surfaces it comes in contact with and quickly changes its surface energy.

In order to overcome some of the difficulties associated with silicone oil, other kinds of oils are being explored. Several manufactures are making toners that reduce the dependence on oil necessary for achieving good release of image from fuser surface. In some cases, fusing concepts are completely oil free while some printers use reduced oil levels. Most of these oil-less fusing toners have large amounts of release additive incorporated within the particle. Some of the adverse effects of incorporating such addenda to toner particles include poor powder flow and higher charge/mass.

One characteristic that is quite common with most of the oil-less or oil-free fusing toners is their melt elasticity. By producing toners with high elastic modulus, propensity of the toner melt to offset onto fuser surface can be avoided. However, high elasticity toners also have higher melt viscosity and are usually produced by using either a high molecular weight or slightly cross-linked polymer as toner binder. At high melt viscosity, the gloss of the image that can be produced at fixed temperature is reduced. In Figure 3, a relationship between gloss and melt viscosity is shown at a fixed dwell time and fusing temperature. The reduction in gloss is not only be limiting to appearance of a print, but it also shrinks the gamut volume that can be achieved by the process colors. This situation is made worse when fusing toners at high process speeds. In some cases attempts are made to increase the image gloss by increasing the fusing temperature or dwell time in fusing nip or both. At the moment, an oil-free contact-fusing concept has not been satisfactorily demonstrated for high-speed color digital printers. Some researchers, though, have demonstrated the feasibility of certain non-contact fusing for color images.[2]

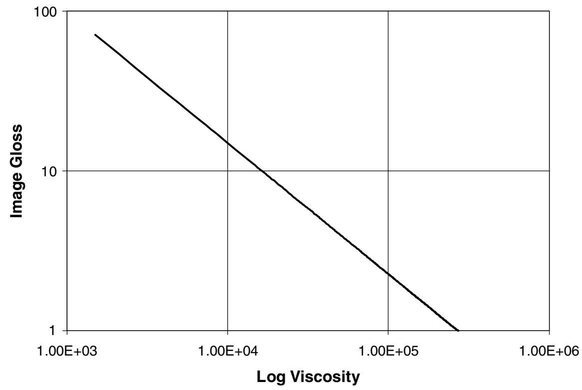

Figure 3. Dependence of Gloss on toner viscosity at constant fusing conditions.

Environment and Safety

The composition of the toner particles are being developed so that they meet or exceed all the old and new rules and regulations they are subjected to. The trend towards chemically prepared toners in Japan is part due to the Green Purchasing Law that was enacted in April 2002. Many printer manufactures have moved away from Cu-Zn ferrites to more environmentally friendly magnetite. Several manufacturers recommend proper disposal methods and some instruct users to ship the waste to manufacturer for proper disposal. Use of heavy metal based charge control agent is being phased out. Many pigments and colorants that have been implicated in contributing to adverse health effects are being replaced with those, which do not have health concerns.

One of the biggest question that is facing the toner industry today is how small should the size of the marking particle be. It has been established fairly well in the literature that with smaller particles comes the risk of inhalation. Smaller dry toners remain airborne for lot longer periods and are also likely to enter the lungs. Figure 4 shows the relationship between size of respirable particulates and percent respirability. This particulate size ranges represents the fraction that can reach the alveolar region of the lung and interfere with gas exchange[3,4]. In the absence of any definitive ruling and based on electrostatic of small particles and the difficulty of pulverizing or filtering small particles, it is not likely that dry toners with mean volume distribution 5 microns or less are going to commercialized anytime soon.

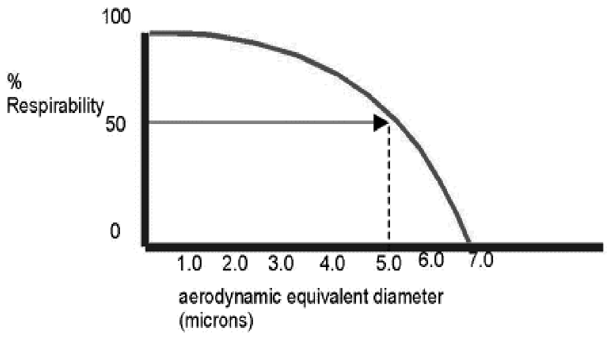

Figure 4. British Medical Research Council penetration curve for respirable particles showing 50% cut point at 5 μm.

Conclusions

The digital printing has placed higher demands on the toners used in electrophotography. In order to satisfy the many different needs from different customers, various different types of toners are being produced that range from conventionally produced melt-pulverized toner to chemically prepared toners. The new regulations also help define the future of the toners both in terms of manufacturing processes as well as the toner size and composition. Toner formulation is paramount in enabling many new electrophotographic processes that are more robust and provide consistent results.

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References

1. Edward Miskinis et al. U.S. Patent 4,546,060 (1985)
2. Domingo Rohde and Detlef Schulze-Hagenest, “Color Radiant Fusing with Continuous and Flash Fusing”, Proceedings of IS&T’s NIP 18: International Conference on Digital Printing Technologies (San Diego, CA, Sept 28 – Oct 4, 2002) p. 58-64
3. http://www.safetyline.wa.gov.au/institute/level2/ course16/lecture46/l46_02.asp
4. http://www.ccohs.ca/oshanswers/chemicals/how_do.html

Biography

Dr. Dinesh Tyagi received his Ph.D. degree from Virginia Tech in 1985 from the Department of Chemical Engineering with a thesis entitled "Structure-Property Relationships in Segmented Polymers". After one year of post-doctoral position there, he joined Eastman Kodak Company as a Research Scientist where he started worked in the toner development area. He was promoted to Senior Research Scientist in 1989 and in 1993 he was appointed Research Associate. Following year he was inducted into Kodak's Distinguished Inventors Gallery. In 1999 he joined NexPress Solutions and has continued to work in the area of toners and electrophotography. He has over 60 patents worldwide.