CHAPTER 2

THEORETICAL CONSIDERATIONS AND LITERATURE REVIEW

2.1 Theoretical Considerations

2.1.1 *The electrophotographic process*

The electrophotographic process is based on six basic steps: charging, exposure, development, transfer, fusing, and cleaning. First of all, in the charging step, the photoconductor drum is charged with high voltage. Second, in the exposure step, an optical system forms a latent image on the photoconductor drum. Next, in the development step, toner, which has opposite sign from the latent image, is in a normal developing system. Then, in the transfer step, a paper sheet is brought to contact onto the photoconductor drum, and the backside of the paper is charged with ions opposite in polarity from the toner. The toner is transferred to the paper by higher electrostatic force of the paper. After that, in the fusing step, the paper is passed through the fuser and the toner is melted. Finally, in the cleaning step, the photoconductor drum is cleaned to get rid of the residual toner.[4]

2.1.2 *Toner components*

Dry toners consist of a colorant in a polymer binder. In addition, a particular toner design may contain a charge control agent to control the charge magnitude, surface additives control fluidity and cleaning properties, magnetic additives to aid in toner control, and waxes to help toner release from the fuser roll.

2.1.2.1 Resin/Binder

The function of resin in a toner is to bind the colorant to the substrates to form a permanent image. The selection of a polymer is depended on the fixing technique. For example, styrene copolymers, epoxies, and polycarbonate copolymer are used in flash fusing because they have low Tg values.

2.1.2.2 Colorants

The colorant which is most common in the electrophotography is carbon black. Important properties of carbon blacks for applications are their dispersibility in the polymer resin and their tendency to charge either positive or negative. Besides carbon black, there are other materials that can be used to make black toners, for instance, magnetite is used to control magnetic properties of toner, and nigrosine is used as charge control agent as well as black pigment. For full color electrophotography, the organic pigments are used because of their good lightfastness. For example, copper phthalocyanines are used for cyans and blues, azo pigments for yellows, and quinacridones or rhodamines for magentas and reds.

2.1.2.3 Charge control agents

Charge control agent, charge agent, CCA, is added into a toner when the pigment does not give a sufficient charge level or an adequate rate of charge. CCA is used in both positive and negative charging applications. For positive applications, the quaternary ammonium salts are used, especially, in full color applications because of their colorless. Besides, nigrosine is a black pigment that is also used as charge control agent for positive applications. For negative applications, acidified carbon blacks, and metal complexes are used.

2.1.2.4 Surface additives

Surface additives are used for improving fluidity and cleaning properties of the toner. Fumed silicas, for example, are added to the surface of toner to promote the flow properties and improve transferring by lowering the adhesion of the toner to the photoconductor drum. For blade cleaning, zinc stearate is blended with the toner to lubricate the blade when passing over the photoconductor drum.

2.1.2.5 Magnetic additives

Magnetite is necessary for single-component applications in order to transport the toner through the developer housing and contact the latent image upon magnetic control. In addition, magnetite is also used in two-component applications, it offers advantages in controlling machine dirt.

2.1.2.6 Other additives

Other additives are used in some application, for example, silicone oil is used as a release agent for the fuser roll. It prevents the adhesion of the toner to roll during fusing.[5]

2.1.3 *Toner charging*

2.1.3.1 Two-component charging

Two-component system consists of two materials: a carrier, and a toner. The carrier has two functions: generating charge for the toner, and transporting the toner pass through the developer housing. First, the rubbing between the carrier and the toner generates the magnitude and sign of charge on the toner surface. Second, the toner particles attach together to the carrier bead through the electrostatic forces and then can be transferred through the machine by using the magnetic carrier beads. Therefore, the charge on the toner is controlled by the selection of its chemical nature.[6]

2.1.3.2 Single-component charging

In this system, it is not the carrier to generate charge, but there are donor roll materials to generate the right polarity charge. The toner layer is formed on the donor roll by either electrostatic or magnetic forces. Then, it is passed through a charging zone and enter the development zone.[7]

2.2 Literature Review

The toner is the important factor that affects print quality of the electrophotography. As toners are electrostatically charged particles, therefore, many researchers put attempts to develop devices to measure toner charge properties and to explain the relation between charge properties, q/m, q/d, and toner components such as types of polymer binder and CCA, and their concentrations on print qualities. Triboelectric charging has been attributed to a wide variety of mechanisms including mass transfer, ionic transfer and electron transfer, however it is not clearly understood about its actual mechanisms.[8]

Katsuwada and Nakamura[9] used Millikan's Oil Drop apparatus to measure the amount of electric charge on a single particle, because the Blow Off Tribo measurement cannot determine the magnitude and the sign of an electric charge on one particle of a toner. The charge quantity and the radius of a single particle of toner in air can be determined by this apparatus. The quantity of electric charge of toners is nearly proportional to the third power of radius of toner particles, especially the type of spherical toner. In different types of triboelectric charging, the quantity of electric charge of a toner is different in terms of charging mechanism, but shows a similar tendency of radius dependence of electric charge for toner particles.

Kutsuwada et al.[10] modified Millikan's apparatus, using hyperbolic electrodes by inserting into the ordinary Millikan's apparatus to provide AC potential to measure the charge quantity of toner particles. The charge of toner particles observed with the modified Millikan's method is slightly higher than with the ordinary Millikan's method. The difference of these results is considered to be due to the mis-estimation of the strength of electric field used to calculate the amount of charge in the modified Millikan's method.

Takahashi et al.[11] presented the micro-probe charge detection method by using the laser scattering video recording system to measure the triboelectric charge polarity and charge distribution on toner with a toner size microprobe of about 10 μm.

They suggested that positively charged sites (donor sites) and negatively charged sites (acceptor sites) may independently coexist in one toner particle and the charge polarity of a toner particle will be governed by the polarity of the majority charge in a toner.

Kimura et al.[12] developed a spectrograph, which is a q/d measurement apparatus, with a toner separation-injection section structured the same way as in a developing unit of electrographic machine, to measure a charge distribution under actual developing conditions. The developed spectrograph was used to confirm the dependency of charge distribution depending on the speed of the developing roller.

Terris and Fowler[13] designed and built a charge spectrometer for use on both mono- and two-component toners. The instrument measures the size and charge of individual toner particles and charge distribution. The instrument was unique in its ability to measure the charge distribution and particle size effects.

Akagi[14] evaluated the detachment field of charged toner particles having various sizes, composition materials and surface structures. The detachment field is dominated by the electrostatic force in the practical region of the toner charge, and the electrostatic force strongly depends on toner surface structure. The electrostatic force significantly depends on the distribution of charge over the surface of the toner particle.

Epping[15] built a device which simulates the copy progress in the developing area including the toner feeding technique. It is a fully automated device, based on a blow off method that shows useful results to explain the decay of q/m and q/d during the lifetime of a two-component developer.

Nakamura et al.[16] improved E-SPART analyzer to measure larger particles by applying a rather lower acoustic frequency (111 Hz). The experimental results obtained on the samples of glass beads by the improved E-SPART analyzer, the measurement of particles size was proved to be applicable to the region up to 50 μm of diameter beyond the maximum size of 25 μm by the ordinary analyzer.

Ott et al.[17] used three different measuring techniques, atomic force microscopy, electric field detachment, and centrifugal detachment, to investigate small particle adhesion as charged by triboelectricity. Atomic force microscopy is used to measure toner-toner cohesion; electric field detachment is used to determine the adhesion of toner layer for understanding the effects of neighboring particles on charged particle adhesion; and centrifugal detachment is used to study particle-surface adhesion.

Macholdt[18] presented the investigation of color pigments of a toner to find a method which would allow the fine turning of the color characteristics and the triboelectrical properties of the pigment without affecting the excellent fastness and other technical properties. The color characteristics and fastness properties of organic pigment are determined by chemical constitution and solid state parameters like particle size, particle shape, crystal structure, dispersibility, and, less markedly, by the degree of crystallinity. The method is achieved by either forming rods or by shifting the particle shape to cubic crystals. The shift in the color characteristics is accompanied by a change in the triboelectric properties from negative to nearly neutral, to slightly positive. This change correlates interestingly with a shift in the particle surface charge from distinctly anionic to cationic.

Macholdt and Baur[19] observed three major tendencies of colorants, for use in full-color copiers, laser printers and short-run digital printers, which are of tailored technical improvements, such as chemical constitution, solid state properties like particle size and shape, and the crystal structure and the degree of crystallinity, for toner application. Additional demand is towards electrostatically neutral pigment, which allows combinations with all common toner resins and CCAs.

Kutsuwada and Nakamura[20] investigated the electrophotographic characteristics of chemically spherical and mechanically shattered toners. They found that the size distribution of mechanically shattered toners was broader than that of chemically spherical toners.

Wu et al.[21] compared the magnetic toners in a hybrid-component developing system and full-color non-magnetic toner in a two component developing system. The tribo-charge distribution of the magnetic and non-magnetic toners were measured by using the Epping q/d meter. The particle size distribution of the toners was measured by using a particle size analyzer. The average q/m and mass per unit (M/A) of the developed color toners on the drum surface were measured by using a suck-in method. The small particle size and large q/d value of the toners can improve the printing quality in image resolution and image density.

Anderson and Buger[22] used an electron exchange model applied to electrophotographic developers composed of two components, a toner and a carrier.

These processes involved exchange of electrons between the toner and the carrier under the assumption that all acceptor and donor sites have the same energy. If the acceptor and donor states reach a thermal equilibrium during mixing the toner and carrier, then Fermi-Divac statistic can be used to calculate the number of charged acceptor and donor sites. A theory based on these assumptions correctly predicted the observed dependence of q/m on T/C, carrier particle size, and carrier chemical composition.

Diaz et al.[23] investigated the effect of quaternary pyridinium arylsulfonate salts on charging. The effect on charging of the ionomer, poly(styrene-co-N-methyl-4-vinylpyridinium toluenesulfonate) which has pendent ion-pair groups, an "anchored" cation and mobile anion, and two molecular salts, 4-ethyl-N-methylpyridinium and tetraethylammonium toluenesulfonate, in which both of the mobile ions, are compared. An electron transfer is not likely to occur in insulating polymer systems containing salt additives except that one of the surface is a metal. Their results simply indicate that ion transfer can occur with ions other than the proton. With insulating polymer-polymer systems containing salt additives, the observed charge is more likely to result from the transfer of ions, where the more mobile ions control the charge. In conclusion, the particles containing the ionomer, poly(S-co-MVPOT5), where the ion pair has an "anchored" cation and a mobile anion, produces a higher charge than the particles containing the molecular salt analog, where both of the ions are mobile.

Baur and Macholdt[24] researched the effect of positive CCA, triphenylmethane derivatives, on charging the triboelectricity of the pure resin in sign and magnitude. With increasing numbers of SO_3H-groups, the charge control effect shifts again to the negative sign. The interaction between anion and cation has a strong influence on CCA efficiency. The efficiency of CCA itself is dominated both by chemical constitution and solid-state properties.

Barthel and Heinemann[25] researched about characteristic features of the chemical surface modified silicas, which are compared to experimental findings of silica loaded model toners with regard to toner free flow and charging. A high surface hydrophobicity of the silica used is a main requirement to achieve satisfying free flow and charging behavior of the atom systems. The positive charging toner system, the combining amino and quaternary ammonium functions provide further advantages. In the negative by charging systems, the free flow is enhanced by C-O and P=O functions grafted on a highly hydrophobic silica surface. The soft contact of the surface modified silica and the toner resins will lead to more favorable toner properties.

Kiatkamjornwong et al.[26] developed newly non-chromium containing and environmentally friendly CCAs. CCA based on boro-bis(1,1'-diphenyl-1-oxo-acetyl) with difference counter ions of Li^{+}, Na^{+}, K^{+} and Ca^{++} were used in the work to study their charging properties in terms of q/m value. The q/m value measurements with two E-SPART analyzers are of slightly difference. The Coulter Counter result is higher than those of E-SPART by about 2 times. When comparing with the mono-valent ionic complex of CCA, di-valent ionic complex can generate more charges and give the higher q/m values, due to its electronic configuration and its high reactivity to polarization and ionization.

Tsunemi et al.[27] found that a low-molecular-weight type of CCA gave high surface energy toners, which induced a more hydrophilic surface. The increasing CCA content leads to increasing background density in print. The combination of a suitable polymer and an optimum CCA type and content, and the selection of readily chargeable toner and an optimum roller material as the tribocharge donor influences an image quality.

Nguyen et al.[28] introduced an effective measurement of print sharpness by image analysis which is based on the average magnitude of the gradient of light intensity at the edges in an image. The measurement variation was repeatable within 2%, and independent of the size and orientation of the measured characters in the test print.

Kamiyama et al.[29] reported that the polymerized toner is more efficiently and uniformly triboelectrically charged than is the melt-mixed toner. Its spherical shape improves fluidity and gives smoother profile with less background fog.

Takahashi and Lee[30] presented that the dependency of triboelectric charging characteristics on toner concentration is governed by the relative difference of charging site numbers between toners and carriers. When the maximum number of the triboelectric charging site of carrier (N_c) is much more than the maximum number of the triboelectric charging site of toner (N_t), the triboelectric charging amount is controlled by the number of toner effective charging site only. When $N_c < N_t$, the triboelectric charging amount is controlled by the number of carrier effective charging site only. When $N_c = N_t$, the triboelectric charging amount is controlled by the number of toner effective charging site (lower toner concentration) and the number of carrier effective charging site (higher toner concentration).

Yamamura et al.[31] indicated that the CCA has an effect on charging characteristics. They found that a saturation charge increases and the time constant of charging up decreases with the increasing CCA amount.

Law and Tarnawskyj[32] reported the addition of silica into a toner affected charge properties. The hydrophilic silica is more sensitive to increasing humidity than is the hydrophobic silica. It decreased triboelectricity though at a very low concentration.