CHAPTER 2

THEORY AND LITERATURE REVIEW

2.1 History of Electrophotography

Electrophotography is a non-impact printing, by using the printer or the copier. The concept of electrophotography consisted of a photoconductor and developers. A photoconductor will be charged and subsequently discharged by the light to form an electrostatic latent image that is developed into a real visual image by attracting developers or charged toner particles. The developed image is then transferred to a paper and fused. Chester Carlson first invented electrophotography in 1938 by using sulfur as a photoconductive material and lycopodium powder as the original toner. Haloid Corporation (now called Xerox) introduced the copier in 1959, by using selenium metal as the photoconductor. The first commercial dry toners were styrene-methacrylate polymers and had a negative electrical charge. During the 1970s IBM and Kodak developed copiers, based on organic photoactive materials and positive charging toners. During the 1980s Canon and Minolta started introducing low speed copiers based on selenium and cadmium sulfide photoconductors and using negative toner. Since the 1980s many combinations of single- and two-component development and positive and negative toner have been used in the industry.[2]

2.2 The Electrophotographic Process

The six basic steps of electrophotographic process in reproducing a copy print shown in Figure 2-1 are as follows:[2]

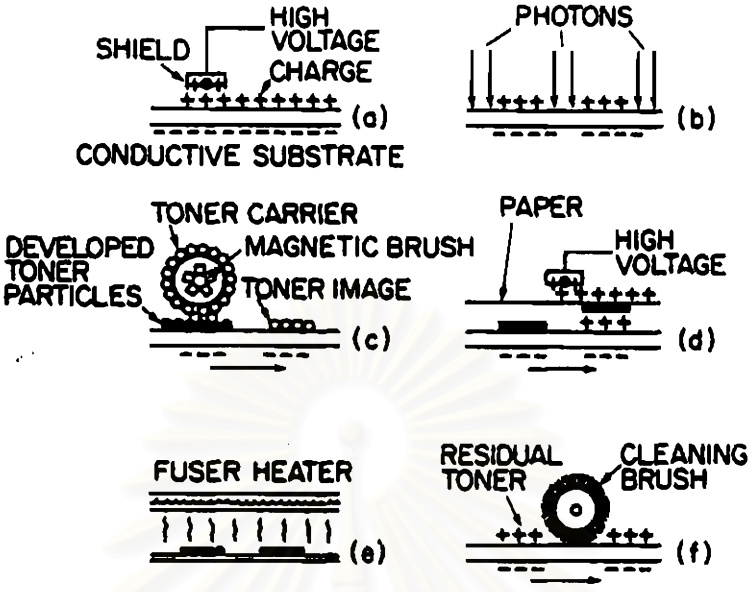


Figure 2-1 The basic steps in the electrophotographic process: (a) charging step, (b) exposure step, (c) development step, (d) transfer step, (e) fusing step, (f) cleaning step

2.2.1 Charging step, the photoconductor is covered with ions through the uses of a wire or grid biased to high voltage.

2.2.2 Exposure step, the light reflected from the white area of the original image discharges on the surface of the photoconductor, but the dark image leaves the charge and forms a latent image of charge.

2.2.3 Development step, the charged toner particle are transported to the latent image by the electric field. The negative toner is used for positive latent image on the selenium photoconductor, and the positive toner is used for negative latent image on an organic photoconductor.

2.2.4 Transfer step, a piece of substrate is broght into contact with the developed image on the photoconductor. The corona charging over the paper with the same polarity ions as the photoconductor is given to produce a large electric field between the substrate and the toner, and break the adhesive bond between the photoconductor and toner. The toner will redeposit onto the substrate.

2.2.5 Fusing step, the toner is fused into a permanent image on the paper by applying heat and/or pressure, hot roller fusing, cold pressure roll fusing, radiant fusing or flash fusing, vapor or solvent fusing.

2.2.6 Cleaning and erasing step, the photoconductor surface must be cleaned of the residual toner from the photoconductor, and the latent electrostatic image erased by an electrostatic brush, a vacuum system, or by a rubber wiper blade.

2.3 Single- and Two-Component Developers

There are two methods of charging the dry toner and transport to the latent image, single- and two-component development.[2]

2.3.1 Single-component development, the charged toner is brought into contact with the latent image without using carrier, to reduce the volume of developer housing, reduce cost and improve reliability. There are two types of this toner, magnetic toner and non-magnetic toner. The magnetic material is added to the magnetic toner, allows magnetic forces to transport toners through the development zone to the electrostatic latent image under a magnetic control. The commercially developing unit consists of magnetic roll, rotating nonmagnetic donor sleeve, magnetic blade, and toner hopper as shown in Figure 2-2.

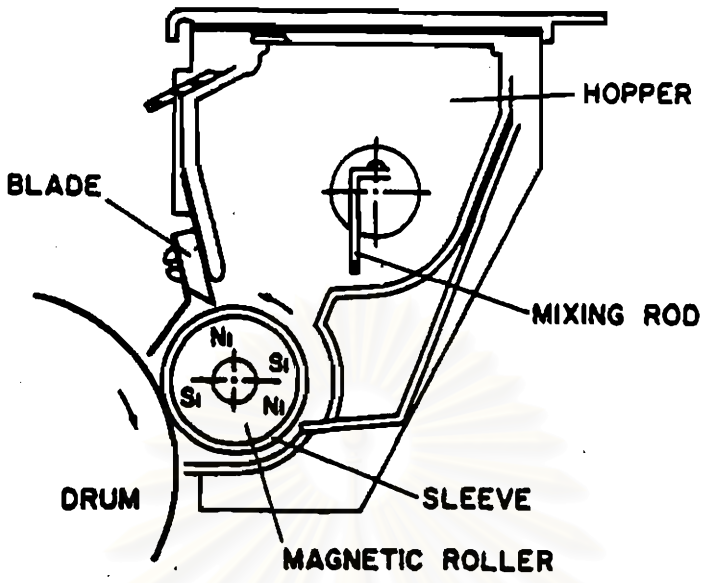


Figure 2-2 Single-component development unit.

The magnetic roll is used to transport toners to the development zone which is spaced from the photoreceptor drum. The magnetic toner is triboelectrically charged at the blade nip that is spaced from the donor surface. The toners can be charged by induction and at last the opposite charge flows through the conductive tonerbrush to attract by the charge image of the photoconductor, as the schematic diagram in Figure 2-3. The non-magnetic toner without the magnetic material is used for a full color printing because the magnetite is generally black and can be effected on the color reproduction.

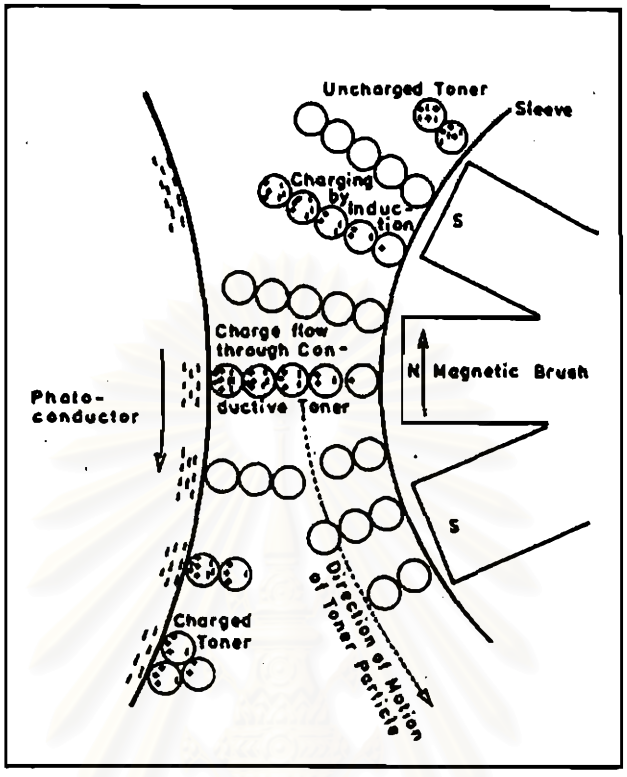


Figure 2-3 Mechanism of development with inductive single-component magnetic toner.

2.3.2 Two-component development

The two-component developer is the mixture of the toner and the carrier beads. There are two types of toner developments; cascade development and magnetic brush development. The cascade development was the earliest form of two-component development but not practical now. The carriers are too large and coarse granular of sand, glass or steel which limited the electrode spacing, and the carrier flow through the development zone because the developer mixture was poured or cascaded over the photoreceptor surface. The toner particles are separated from the carrier and deposit on the latent image by the electrostatic image force agitation from rolling and bouncing. The magnetic brush development are the

most accepted technique for toner development. The carrier beads are small, 50 - 150 μm in diameter, and fabricated from magnetic materials: iron, steel, or ferrite, with a polymer coating on the surface. The beads tend to form a bristle-like chain in the magnetic field, hence the name magnetic brush development.

The carrier provides two functions for the toner; charge generation on the toner by rubbing against the toner to generate the desired magnitude and sign of charge on the toner, and transport the toner through the developer housing. As many as 10^3 toner particles attach to each carrier bead through the electrostatic forces and transported by using magnets on the magnetic carrier beads. The structure of a typical two-component development housing is shown in Figure 2-4, consists of the toner dispenser, the paddle mixer of developers (carrier and toner), and the development magnet roll. Figure 2-5 show a schematic of the magnetic brush between the developer roll and the photoreceptor, and electrostatic forces drive the toner to the image on the photoreceptor, while magnetic forces hold the carrier beads on the roll.

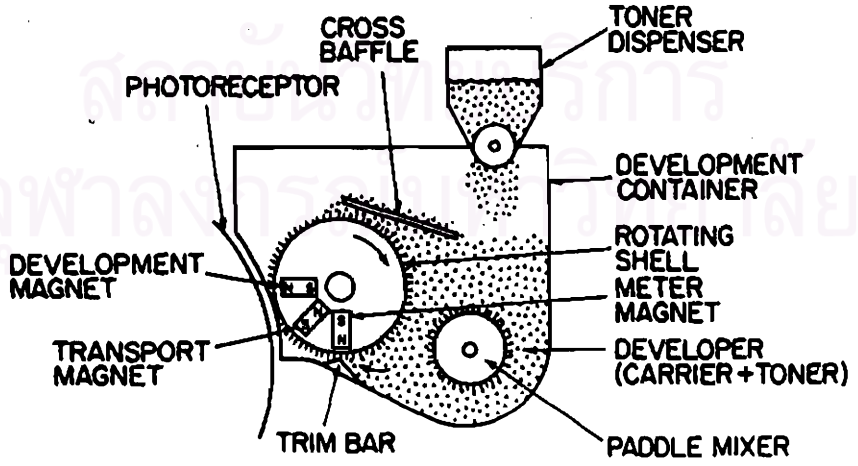


Figure 2-4 Structure of a typical two-component development housing.

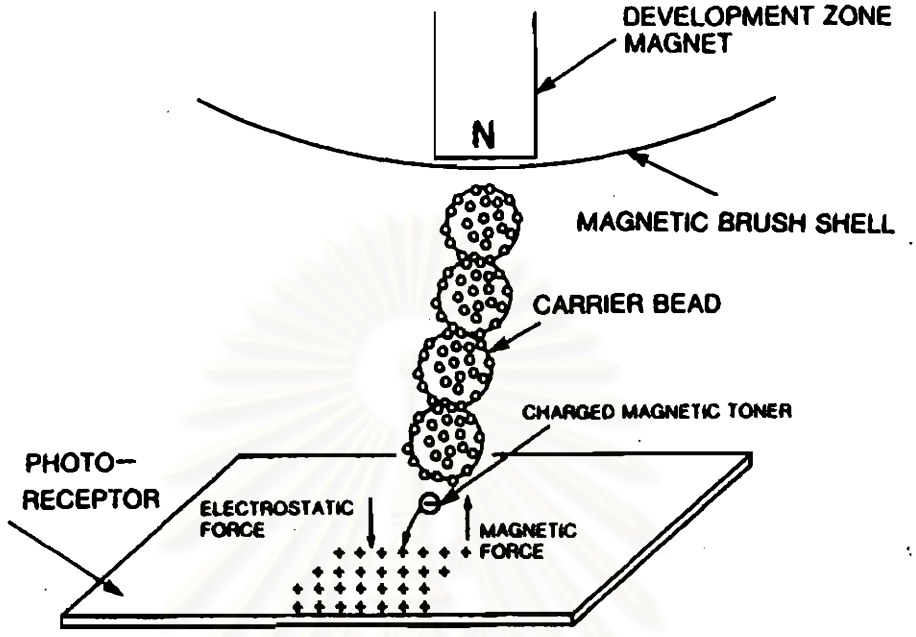


Figure 2-5 Schematic development, indicating direction of electrostatic and magnetic force on toner above an image.

2.4 Toner Components

Dry electrophotographic toners consist of a colorant in a binder resin and contain charge control additives, surface additives, magnetic additives, and waxes.[2]

2.4.1 Resin

The role of the resin in a toner is to bind the pigment to the paper. The thermoplastic is mainly used to physically fuse and fix the image to the paper by fusing method. The primary consideration of selecting a polymer are the fusing or melting properties. There are four classes of polymers used for fabricating dry toners.

a) Copolymers of styrenes & methacrylates or acrylates, the molecular weight ranges are 50,000 - 60,000 and the glass transition temperature are 50 - 60°C. They are melted by heated roll and flash fusing.

b) Polyesters are of low melt viscosity and melted by radiant fusing. The molecular weight ranges are 8,000 - 10,000 and the glass transition temperature are 52 - 54°C.

c) Epoxies, the molecular weight ranges are 1,000 - 10,000 and the glass transition temperature are 60 - 100°C. They are melted by heated roll and flash fusing.

d) Crystalline polyethylenes or copolymer of polyethylene, they are low molecular weight, 500 - 15,000, and the melting temperature are 86 - 130°C. They are fixed by cold pressure, roll fusing and release agent.

2.4.2 Colorants

The carbon blacks are usually used in black toner at a 5 - 15% loading. Magnetite is used to allows for magnetic control. Nigrosine are good black pigments and used for reduction of the carbon black. Other pigments are used in addition to black. The pigments are usually used in color toners, copper phthalocyanines are often used for cyans and blues, azo for yellows, and quinacridones or rhodamines for magentas and reds.

2.4.3 Charge control additives

Charge control additives are added to a toner to give an adequate charge level or rate of charging. For positive applications, the quaternary ammonium salts

are used in color toner, and nigrosines are used in black toner. For negative applications, acidified carbon blacks, fumed silica and metal complexes are used.

2.4.4 Surface additives, such as fumed silicas, are used to improve flow properties and transferring to paper by lowering the adhesion of the toner to the photoreceptor.

2.4.5 Magnetic additives, 60 - 70% of the magnetite is added for toner transport in single-component development, and 15 - 20% of the magnetite is added for controlling machine dirt in two-component development.

2.4.6 Other additives, a release agent such as silicone oil is added to prevent the adhesion of the toner to the roll during fusing.

2.5 Characterization of Toner

2.5.1 Rheology

The rheological characteristic of a toner is effected on fixing behavior. The degree of fixing must also be sufficient to ensure durability of the copy. The fixing process by mean of heat and pressure comprises several partial steps; sintering together of the melting toner particles, spreading the molten particles along the paper fiber, wetting the surface of the paper, penetration into the network of the paper fiber, and cooling and resetting of the toner. The following characteristics are dependent on the copolymer ratio, molecular weight, branching and crosslinking of the polymers, and correlated to the toner fixing behavior.

a) The glass transition temperature (T_g) is the transition temperature where the polymer changes from a hard glass to a rubbery state, measured in a differential scanning colorimeter, which looks for the change in heat capacity at the transition.

b) The minimum fixing temperature ($T_{fix,\ min}$) is the temperature to fix the image on the paper or the degree of fixing attains a certain level.

c) The cold offset temperature (T_{CO}) is below the minimum fix temperature which the adhesion power between the roller surface and the toner is greater than the bonding power between the not-yet-molten toner particle on the paper.

d) The hot offset temperature (T_{HO}) is above the minimum fix temperature which the toner is so fluid and leaves traces of the image on the fuser roll.

e) The blocking temperature is the temperature at which significant sintering occurs.

f) The fixing window, $T_{HO} - T_{fix,\ min}$ is the range of toner fixing temperature.

2.5.2 Colorimetrics

The black toners should be able to generate high optical density with practical developed masses. The highlight color toners should be able to develop an optical density of the color with the tinting strength or chroma of color and pleased hue. The process color developers (cyan, magenta, yellow and black) should generate as wide a color spectrum as possible. Each pigment is typically evaluated for lightfastness, and can produce the largest gamut possible.

2.5.3 Particle size

Toner particle sizes are generally 7 - 12 μm in diameter. The smaller sizes have been found to improve color copy quality with noise reduction. Toner particle sizes and size distribution are measured by two techniques; the electrolytic displacement method by using the Coulter counter to measure the volume size distribution of the toner, and the optical method by using the E-SPART image analyzer.

2.5.4 Charging

The charge of toner is correlated to the nature of toner composition, the carrier bead coating, or the mixing condition. Triboelectric charging of toner and carrier are often determined of the work function or the position on triboelectric series of polymer. The location of the charge on a toner particle is determined in part by the different in energy levels between the charge exchange sites. When the toner and the carrier are contacted, the one lower on the series become the electron acceptor or negative charge, and the one higher on the series become the electron donor or positive charge. There are two quantities of the toner charge measurement:

a) Charge-to-mass ratio (q/m) by a blow-off tribo measurement as shown in Figure 2-6. This is a typical method for the two-component developers, by putting the developers in a metal cage with mesh screen to allow the toners but not the carrier beads to escape as the schematic in Figure 2-7. The toner particles are blown off, and the charge and mass differences resulted are measured. The useful range of charge for 10 μm toner particles is from 10 - 30 μC/g. Toner charge above 30 μC/g are difficult to strip from the carrier and deposit little mass on the

photoreceptor. Toner charges below 10 μC/g are difficult to control, generating machine dirt and unwanted image background on the copy.

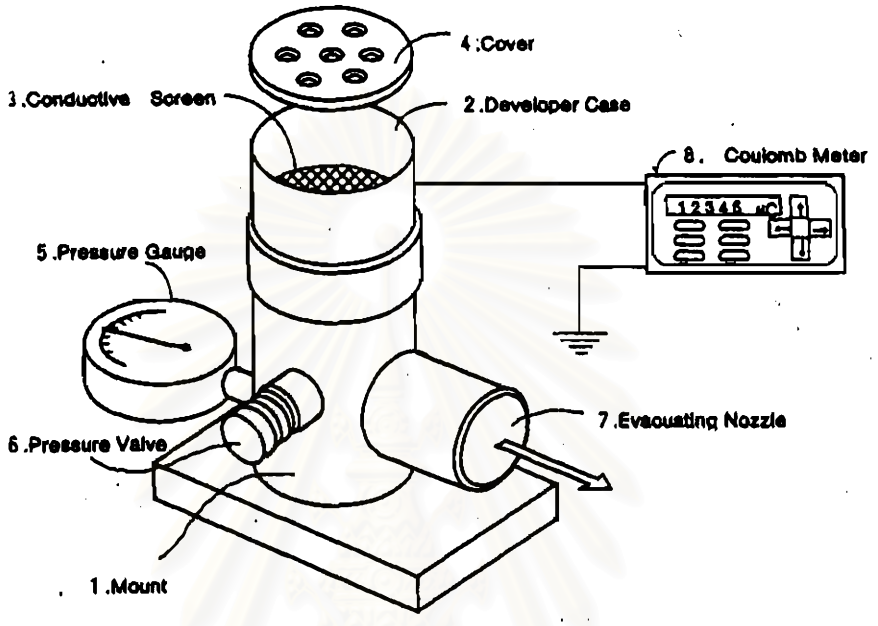


Figure 2-6 Apparatus of a blow-off measurement

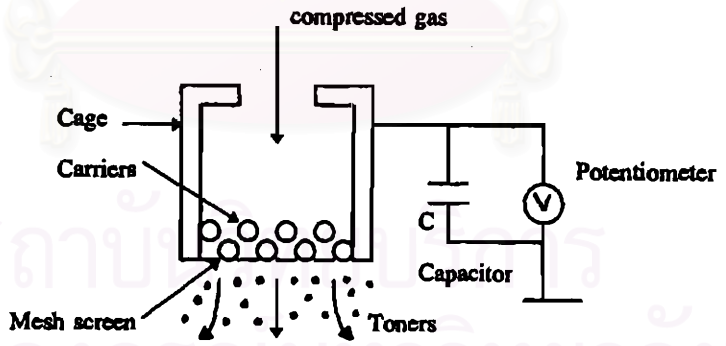


Figure 2-7 Conventional blow-off method

b) Charge-to-diameter ratio (q/d) by charge spectrograph measurements, a q/d meter or an E-SPART analyzer[3], see Figure 2-8. This is a typical method for the single- and two-component developers which measures the charge and diameter of toner particles with a computer analysis of the collected filters. For two-component

developer, the toners are separated from the carrier by the blow nozzle and fall into the toner injection tube as shown in Figure 2-9. The q/d meter is able to measure the distribution of charge/diameter values (fC/10μm) and the charges in different diameter classes of developer. Most theories predict that the charge will be proportional to the toner area.

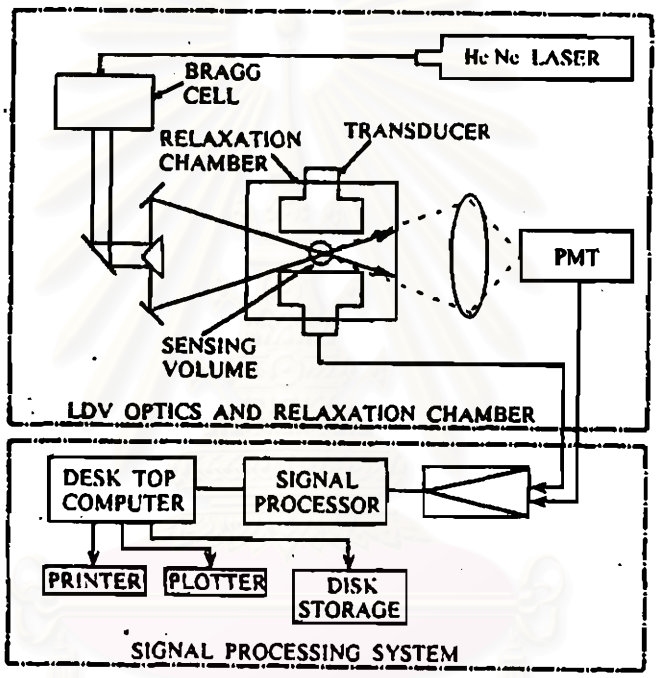


Figure 2-8 Schematic diagram of an E-SPART analyzer

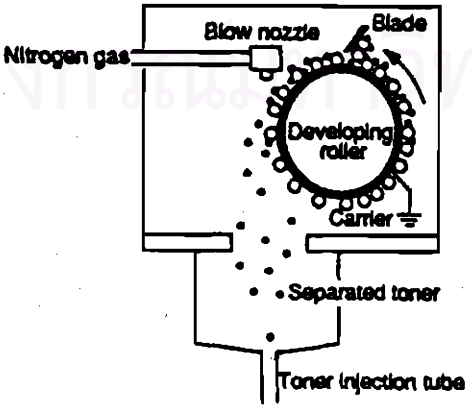


Figure 2-9 Method of an E-SPART analyzer.

2.6 Toner Fabrication

The particle size and size distribution are parameters that can strongly influence the quality of copy, and these are in turn influenced by manufacturing techniques. Currently, there are two methods of producing commercial toners; the polymerization technique and the melt-mixing technique. The great bulk of toner is manufactured by a melt mixing method consisting of a multistep process. The pigments and internal additives with the base toner polymer are melt mixed, the temperature during the melt mixing is 80 - 150°C, the pigmented polymer is broken into particles of the desired size by cooling the molten toner at room temperature, and then it is rough crushed and micronized by a impact action in a high velocity air jet. The unwanted sizes are removed to give a narrower size distribution, the mixed sizes are classified to a narrow particle size distribution averaged 5 - 20 μm or the desired size, the small and the large particles of the toner are subjected to the attrition separate the desired toner size by passing through the classifiers, and the narrow size toner particles are blended with the external additives.[2]

2.7 Carrier Materials

In the case of two-component developer, the combination of toner and carrier properties must be chosen to obtain the correct amount of electrostatic charge on the toner so that the right amount is attracted to the oppositely charged image area. The carrier imparts a static charge to the toner particles by the surface contact with the toner during mixing which is triboelectrification. It is important that the toner should not be charged too high, so that it cannot be stripped from the carrier, or too low, so that it is not held by the carrier and settles in nonimage areas, causing background on the copy.

2.7.1 Steel (spherical)

The developer with Teflon-coated spherical steel carrier, was quite insulating; consequently, the solid area reproduction was poor, and background and machine dirt have been the source of problems.

2.7.2 Iron (irregular)

Most of the iron particles are oxidized to control the resistivity and partially coated to control the electrostatic charging. For irregular powder, the high points are oxidized and poorly coated, to supply the required resistivity, while the valleys are better coated, to supply the charging effect required.

2.7.3 Soft ferrites (spherical)

The resistivity of ferrite is lower than the insulating sand or glass and higher than the iron or steel. Ferrites have semiconducting properties, have resistivities in the range desired, 10^{6} - 10^{12} Ω.cm, because they are transition metal oxides and magnetic ceramic materials, which in some applications can be used without partial coating for toner charging. The size range is variable, from 10 - 120 μm for the spherical ferrites, which are raising some interest in the industry. The spherical powder is formed by the spray drying step. The saturation magnetic moment are 20 - 75 electromagnetic units per gram. Too high a moment will result in a stiff brush, scratch the image, nonuniformities in the solids and ragged edges on the line copy.

2.7.4 Hard ferrites (spherical)

The hard ferrites are small and permanent magnet type of ferrite. These carriers are commercially used for a high speed (23 copies/min), full color copier which can give color highlights at higher speeds.[4]

2.8 Literature Review

2.8.1 Toner particle size

In 1990, Sato et al.[5] studied the optical image density of nonfused toner images on paper as a function of toner mass, focusing on the influences of toner particle size on image density. Toner particle size must become smaller to realize higher resolution, and the image density must be maintained. The relationship of toner particle size, mass, image density, and that of the number of toner layers and image density were determined. The mean radius of toner particles were based on the toner particle cross section to calculate the theoretical image density. Toner size is generally measured with a Coulter counter to provide size distributions and mean radius based on volume and population, as shown in Figure 2-10.

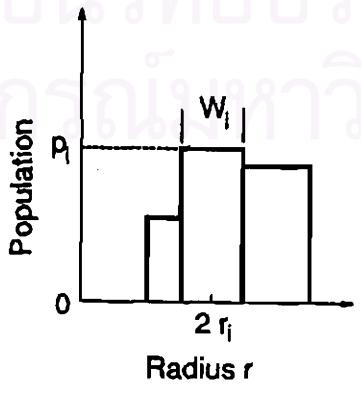


Figure 2-10 Particle size distribution

They found that smaller particles of toner produce higher image density with less toner mass. To get the same image density, toner mass decrease must be proportional to the mean radius of the toner particle size. In addition, they confirmed that the number of toner layers determines the image density, independent of the toner particle size, and that 2 layers of toner almost saturate the image density.

In 1993, Mizes[6] have found an analytical expression that gives the graininess as a function of toner size. The graininess may be due to noise in the xerographic subsystems. At some level, the noise will be limited by the finite toner size. Graininess depends on three features: the magnitude of the optical density fluctuations, the average optical density, and the spatial frequency of the optical density fluctuations. The larger toners will tend to degrade the graininess while the smaller toners will tend to improve the graininess, as shown in Figure 2-11. Smaller toners fit more easily into empty spaces left in a halftone dot than larger toners.

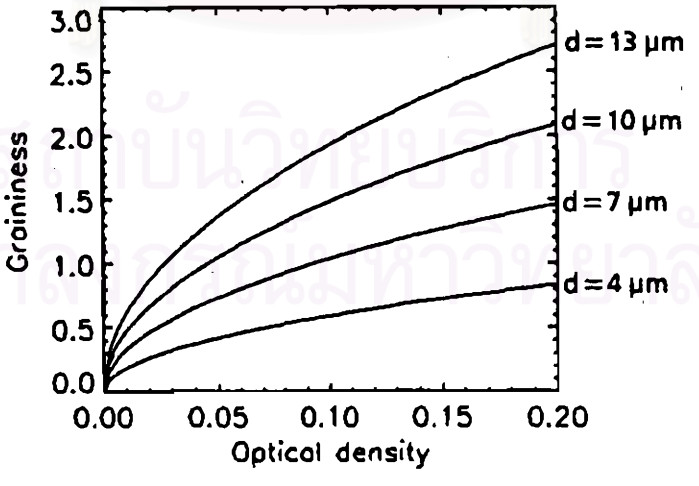


Figure 2-11 Relation of Graininess and Optical density

2.8.2 Toner charge properties

In 1988, **Sasaki**[7] presented the toner flow dynamics, simulation of changes in triboelectrific charge of developer in consideration of toner supply and consumption. The most important part of toner flow is triboelectrification which gives significant influence to the image quality. The developing process is dependent on the triboelectric charge which are affected by the process conditions and by the charging rate, the discharging rate and the toner concentration. These factors depend on the materials of the carrier and toner. The factors which cause the triboelectric charge to deteriorate are focused on the toner adhesion to the carrier particles and the toner pulverization. The adherence of toner reduces the carrier surface area, effective to triboelectrification, resulting in a decrease in the probability of contact with toner and in maximum possible charge on toner surface (Q*). Also the pulverization of toner increases the surface area, resulting in an increase in Q*.

Bolte[8] presented the mechanical stability of xerographic developers in 1988. The consistency of the printed image over time is dependent upon the stability of the triboelectric charging process. Environmental conditions of humidity and temperature influence charge exchange. The toner has changed its charging characteristics during agitation. Time history in mixing experiments show a typical time history of a developer which has been agitated in a roll mill blender for an extended time, as shown in Figure 2-12.

After a few minutes the charge to mass ratio is 9 μC/gm. With continued mixing the charge rises to about 20 μC/gm at 20 hours and falls thereafter. Also shown is the recoverable toner concentration, the apparent toner concentration based on the weight of toner removed in a toner blowoff measurement. The loss in

toner charge accompanies a loss in recoverable toner mass. The surface of carrier is totally covered with the toner that has changed its charging characteristics during agitation. The toner was removed from the carrier and fresh toner was gently remixed with the carrier.

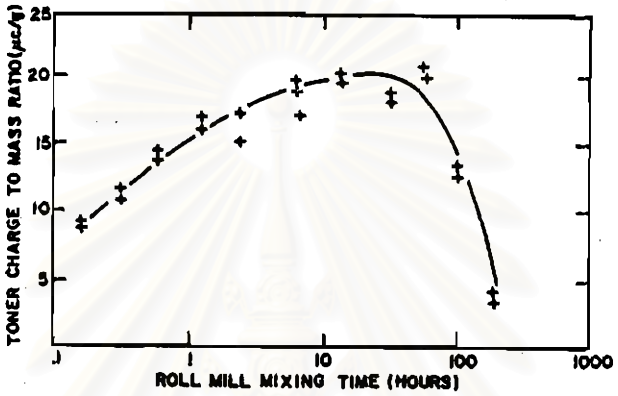


Figure 2-12 Time History of Developer Mixing

In 1989, Anderson[9] presented an electronic model of triboelectrification of two-component electrophotographic developers, which predicts the relationship between toner charge-to-mass ratio and toner concentration, toner particle size, and carrier particle size. It is also shown to be consistent with changes in charging resulting from varying the composition of blended polymer carrier coatings. Charging occurs by exchange of electrons between acceptor and donor sites, see Equation 2-1 to 2-3.

Acceptor site $A + e(-) \leftrightarrow A(-)$ (2-1)

Donor site $D \leftrightarrow D(+) + e(-)$ (2-2)

$A + D \leftrightarrow A(-) + D(+)$ (2-3)

Mixing of the toner and the carrier leads to an equilibrium distribution of electrons among acceptor and donor sites on the carrier and on the toner. The model can be used to estimate the relative concentration of acceptor and donor sites on the surfaces of the toner and the carrier. He showed that Q/M should be proportional to the different between the ratio of donor sites to acceptor sites (D/A) of the toner and the D/A of the carrier. Thus, the donor-to-acceptor ratio of materials establishes a triboelectric series. If one material has a higher D/A than another, it will charge positively against it. If it has a lower D/A, then it will charge negatively. Furthermore, the greater the difference in D/A of two materials, the greater Q/M will be.

In 1991, **Yamazaki** et al.[10] presented the toner surface-charge density and development efficiency in two-component development systems. Two-component development systems have been studied by varying the toner and carrier surface area median size (d_{50}). It has been found that development efficiency of the toner in solid areas is determined by the toner surface charge density (q/s_t). The relationship between development efficiency, electrostatic charge, toner size and their effect on image quality have been reported as relations between q/s_t and the surface-area ratio of n toners to a carrier (ns_t/s_c).

The two-component developer was prepared by adding the toner to the carrier at a mixing weight ratio $X = Tc / (1 - Tc)$ in 20 minutes for saturated electrostatic charge (q) by triboelectrification. The M/A, the image density (ID.) and the q/m of toners were measured by using a blow-off tribo measurement, at 20°C and 50% RH. The surface-charge density on toner particles is given by

$$q/s_t = (1/3)\, \rho_t r\, (q/m), \qquad (2\text{-}4)$$

where s_t is the surface area of spherical toners, ρ_t is the specific weight of toners, and r is the median radius of spherical toners. The contact electrostatic field (E_k) and the surface-charge density (q/s_t) on toner particles generated by triboelectrification with *n* particles of toners on one particle of a carrier are shown in Figure 2-13. The lower q/s_t increases the image density, and the development efficiency of the toner in solid areas and developed toner-mass per unit area on the photoreceptor (M/A) are determined by the toner surface-charge density (q/s_t).

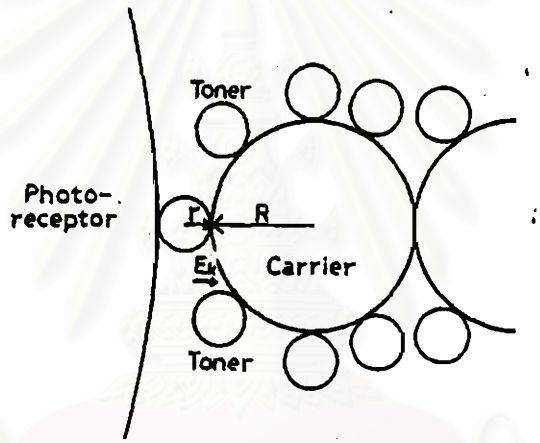


Figure 2-13 Triboelectrification by n particles of toners on a carrier in the two-component development.

The contact electrostatic field (E_k) is determined by the different between work functions ($\Delta\phi$) of toner and carrier, independent of the surface area ratio of *n* toners to one carrier (ns_t / s_c). The surface-area ratio (ns_t / s_c) is related to the radius of toner (r) an carrier (R), the specific weight of toner and carrier, the mixing-weight ratio of toner to carrier (X),

$$ns_t / s_c = (\rho_c R / \rho_t r) X \qquad (2\text{-}5)$$

In 1992, Gutman and Hartmann[11] have investigated the time dependence of the charge-to-mass ratio, q/m, of two-component developer on toner concentration, toner size, degree of dispersion of the carbon black in the toner polymer, developer mixing intensity, and developer mixing duration. Two-component developer, with a toner concentration (C) from 1 to 5%, were measured for charge-to-mass ratio as a function of roll-mill mixing time. The toner particles were 10 to 20 μm and carrier particles were 100 to 200 μm. The relationship between the carrier and toner charge-to-mass ratio is given in Equation 2-6.

$$q/m_{\text{toner}} = -1/C \cdot Q/M_{\text{carrier}} \qquad (2\text{-}6)$$

The carrier charge-to-mass ratio increase rapidly from zero and approaches a consistent value that changes very slowly thereafter that depends on the toner concentration, as shown in Figure 2-14.

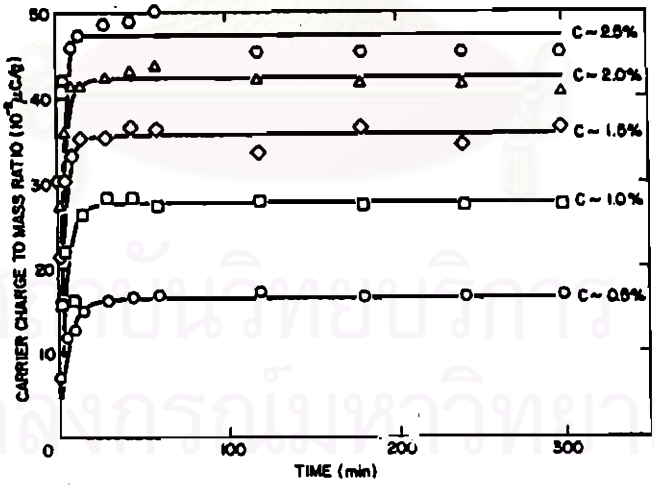


Figure 2-14 Measurements of the charge-to-mass ratio of the carrier as a function of roll-mill mixing time for several values of the toner concentration, C

They have discussed some of the mechanisms that control charge-to-mass ratio is a synthesis of four ideas. First, the physical model uses a characteristic

energy to describe the charging tendency of each of the component materials. Second, charge exchange is described using a model that depends on the electric field between each pair of contacting materials. Third, the contact probability of the various materials is represented by the percent area coverage of each material. Lastly, the effect of the mixing system is described by parameters related to the frequency and intensity of mixing. During contact, charges flow from the field surface states of Material 2 to the empty surface states of material 1, as shown in Figure 2-15

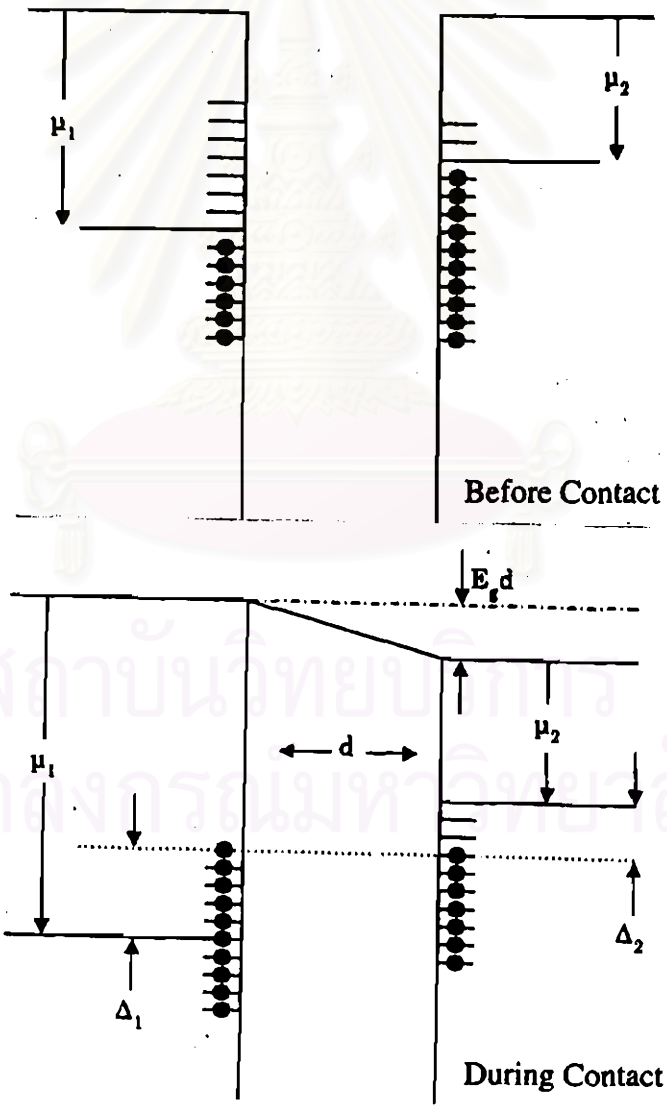


Figure 2-15 Energy level diagram for the contact charging model

In 1992, **Mehlin and Hess**[12] explained the working principles of the q/d meter, the measurement of the distribution of charge/diameter value (q/d). The charges in different diameter classes of developers can be measured by a toner blow-off technique (y-direction) with an air flow (x-direction), as shown in Figure 2-16.

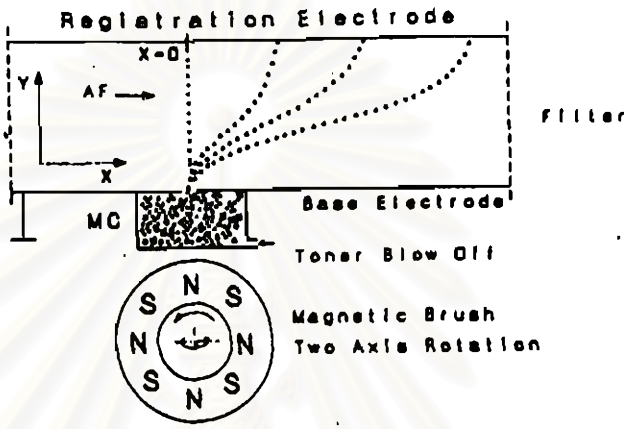


Figure 2-16 Diagrammatic representation of the deflection unit of the q/d meter

The particles with the same charge but a different diameter, will be deflected differently (distance x) because a large particle will have a higher air resistance than a smaller one. Determination of the influence on q/d distribution of developers were concluded that the developer parameters (i.e., chemical composition, electric conductivity), activating parameters, and outside parameters (i.e., electric and magnetic field in the development zone of a copy machine) have a strong effect on the quality of a copy.

In 1992, **Akagi**[13] evaluated the detachment field of charged toner particles by varying the size, composition, materials and surface structure. The charge and adhesion controlling of the smaller particle size toners in the range of less than 10 μm, becomes more difficult. He found that for 7 μm toner particles, it was difficult to obtain a satisfactory development and transfer efficiencies. Therefore, in

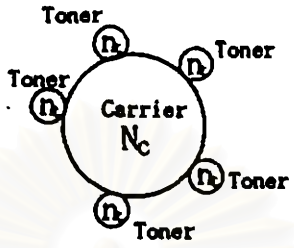
order to find out how well the small toner is matched to the xerographic process, toner adhesion forces, the electrostatic and Van der Waals force to adhesion force, have been discussed. It is clear that detachment field is nearly proportional to the toner charge as measured by q/d. The adhesion force can be varied by changing the materials and surface structure of toner particles which results in changing the surface charge.

The magnetic toners in a two-component development process were measured for the tribo-charge and the particle size distribution by Ming-Chu et al.[14] in 1992. They found that the small particle size and large q/d value of the toners can improve the print quality in image resolution and image density. The toner surface-charge density is related to development efficiency in a two-component developing system. Their results show that the larger toner particle size, the lower toner tribo-charge, the higher toner mass per unit area, and the toner developed on the drum surface will be increased.

In 1993, Schein[15] studied the toner q/m dependence on the toner concentration in a toner-carrier mixture. He explained that in the surface state theory of electrostatic charging, charge is exchanged between surface states of the two materials, driven by the surface work function difference between the materials. They reported an experiment that distinguishes between the low and the high density limits of the surface state theory in the toner-carrier geometry.

Takahashi and Kishimoto[16] described in many papers that the toner charge-to-mass ratio, q/m, of a two-component developer decreases with increasing the toner concentration, T/C. In 1994, they also investigated that there were three

dependent types of the toner q/m on T/C in which they presented a new charging model as shown in Figure 2-17.



Nc : Carrier acceptor site, n_t : Toner donor site of one particle, $N_t = \Sigma n_t$

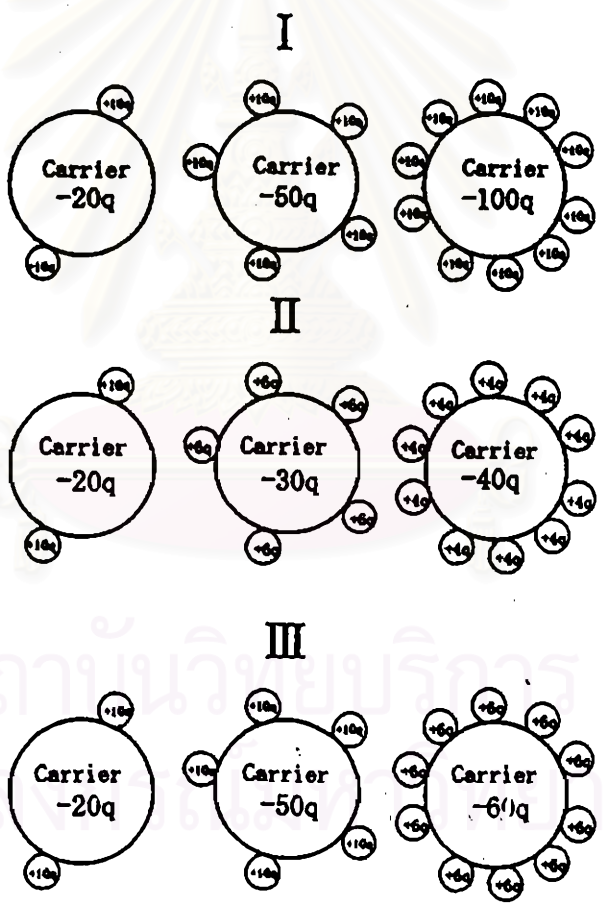


Figure 2-17 Schematic model of dependence of one particle toner charge on T/C

Type I shows that the average charge of one toner particle is not affected by the variation of T/C. Type II means that the toner charge distributed to one toner on a carrier surface decreases with increasing T/C. Type III finds that the

toner charge-to-mass ratio is the constant value to about 50% of toner coverage on carrier surface under some conditions, and is gradually decreasing over 50% coverage. These results are related to the number of tribocharge site on toner and carrier. Type I, the q/m cannot have the dependence of T/C under the condition of Nc > Nt (Nc and Nt are the maximum number of sites of carrier and toner, respectively). This means that the number of tribocharge sites is determined by the maximum of carrier charging sites. The q/m has the dependence on T/C under the condition of Nc < Nt , and q/m decreases with increasing T/C as Type II and Type III.

In 1995, **Gutman and Hartmann**[17] presented a refinement of their previous model for the interfacial electric field; the new model includes multiple layers of toner on a carrier bead and treats the surface charge distribution on each toner particle as discrete, rather than continuous. They develop a model for the contribution of the fields from all the toner particles surrounding the carrier bead to the toner-carrier interfacial electric field of the toner particle, as shown in Figure 2-18.

The toner particles in the layer closest to the carrier surface are represented by a spherical shell of charge located at $R + r_o$, but open at the pole to accommodate the particles under study. The toner particles in the second layer are represented by a second shell of charge also open at the pole. They find good agreement of the refined model with the measured dependence of toner charge-to-mass ratio on toner concentration.

A standard assumption of previous investigations of toner q/m is that the electric field near a toner particle can be modeled by assuming a uniform, continuous toner surface charge distribution, and all the charge is located at the center of the toner particle.

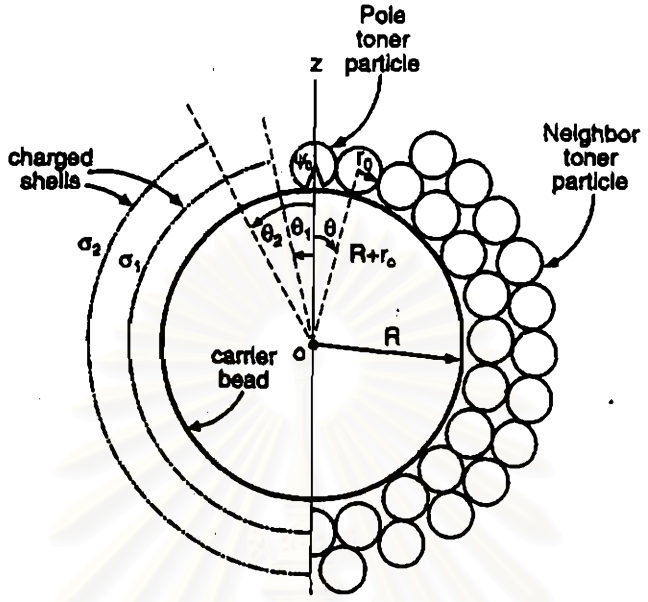


Figure 2-18 Geometry of the physical model. The right-hand side shows the assumed locations of toner particles; the left-hand side represents the electrostatic model.

2.8.3 Rheology and fixing properties of toner

There are a number of studies in the literature that elucidated some of the principles of toner fusing performance. The fixing behavior of dry toners were described by DeMejo et al., in 1990.[18] DeMejo studied the influence of rheology and molecular architecture on the fusing behavior of toners. The result shows that the hot offset temperature is mainly a function of the melt viscosity of toners with similar chemical and rheological characteristics, and the glossing response is determined primary by their elastic properties above T_g. The fusing process are depicted schematically in Figure 2-19.

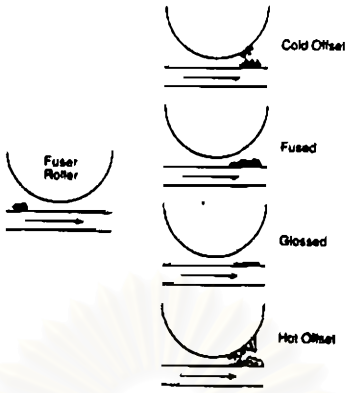


Figure 2-19 Fusing stages

The rheological principle of time-temperature superposition suggests that the fusing processes can be analyzed by their rate dependence as shown in Figure 2-20.

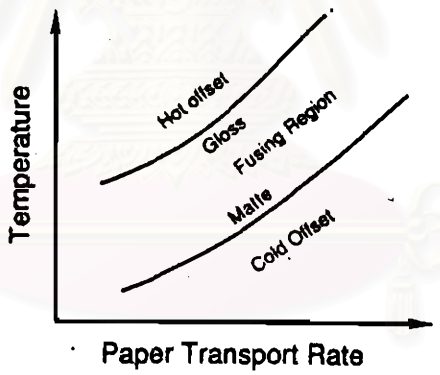


Figure 2-20 Correspondence between temperature and fusing rate

The molecular weight distributions become increasing broad as the amount of incorporated branching agent increases. The decreasing T_g with branch agent content is due to polymer composition. The elasticity was large increased with increasing branching in the lower frequency or terminal region. The melt elasticity of the toner affects the hot offset behavior, the hot offset temperature of the more highly branch materials will be higher by increasing elasticity.

In 1993, the correlation between molecular structure, viscoelastic behavior, and fusing properties were described by Forgo et al.[19] In this experiment, resins based on styrene-butylmethacrylate with a constant chemical structure but different molecular weights and polydispersities were tested. The average molecular weights (g/mol) and polydispersity (D) were analyzed by the monomer composition with the gel permeation chromatography (GPC). The viscosity number (cm^3/g) were measured by Ubbelhohde OC capillary. The melt-flow index (g/10 min) was measured with a melt flow index measuring instrument. The glass transition temperature (°C) was analyzed with Mettler DSC 30. The dynamo-mechanical measurements were used to measure the viscoelastic properties of polymers. To determine the degree of fixing, a solid area was produced as a nonfixed copy and passed through the fixing unit. The optical density was measured before and after erasure to get the degree of fixing as shown in Equation 2-7.

$$\text{Degree of fixing (\%)} = \frac{\text{optical density after erasure}}{\text{optical density before erasure}} \times 100 \qquad (2\text{-}7)$$

The molecular weight of the toner resins, the elastic and viscous portions were increased as a result of extrusion. The high temperature decreased the elastic portion. The higher value of dispersity was, the wider fixing window was. It can be concluded that the best fixing properties were observed with resins having a medium-to-high molecular weight (MW>~150,000) and high polydispersity (D>~ 10). The chemical structure effects on the fixing behavior and the rheological measurements can predict the fixing properties of a toner.

2.8.4 New invention of developers

In 1991, Yamamoto and et al.[20] reported the characteristics of a new magnetic developer and its development process, the Magne-Fine process (MTF). The value of gamma represents the slope of curve of output density versus input density between 0.5 and 1.0 input density. The relationship between the carrier particle diameter and the gamma of the print obtained shows that an increment in particle diameter, the gamma of the print becomes higher. The smaller carrier particles tend to be slightly affected by change of the toner concentration, which produce lower gamma values meaning that they can produce a good tonal reproduction of an original image. There are several problems using smaller carrier particles, their poor transport make background development, and the carriers were pulled to the photoconductors by increasing electrostatic force, as shown in Figure 2-21.

The relationship between the toner concentration and the print density is shown in Figure 2-22, which shows that the print density and gamma value change only a little within the range of 20 to 50% of the toner concentration, a wider range than do conventional two-component developer. The ratio of the toner and carrier will affect the print, scattering or background. Because, if the amount of the toner exceeds the limit where toner can contact the surface of the carrier, there will be uncharged toner or the toner of reverse polarity.

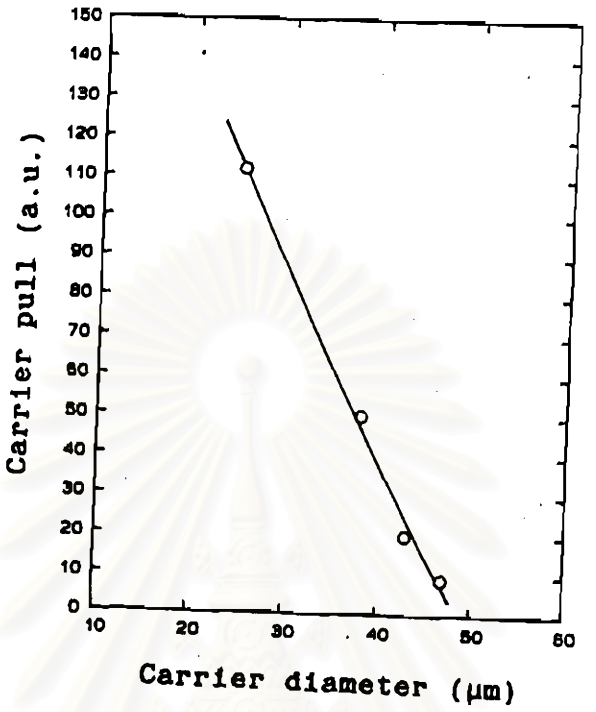


Figure 2-21 Amount of carrier pull versus carrier diameter.

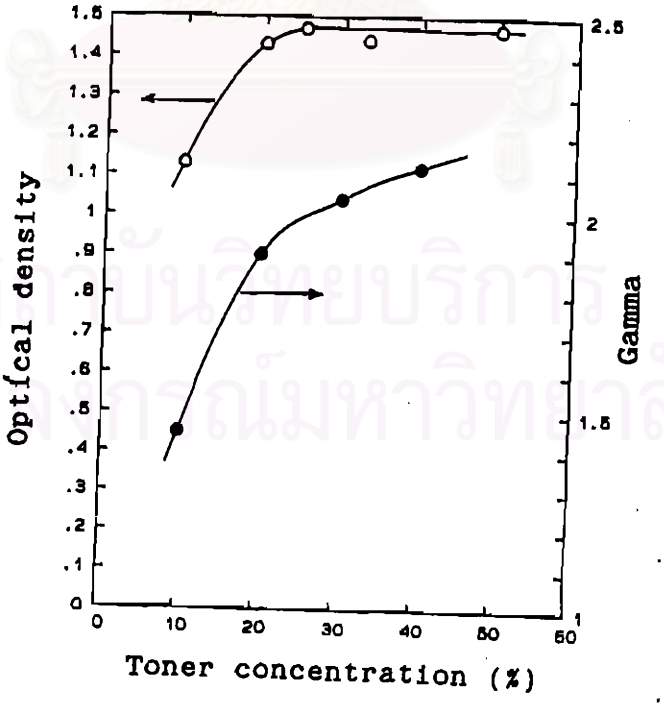


Figure 2-22 Effects of toner concentration on optical density and gamma.

In 1995, Polymerization techniques of mono- and dual- component were developed and compared with the conventional melt-mixed/crushed toner by Kamiyama et al.[21] Dual-component polymerized toner particle size (2-10 μm) is spherical with a smooth surface and higher fluidity than melt-mixed toner, as shown in Figure 2-23, which improves image quality with fine lines and small dots. Mono-component polymerized toner forms a uniform triboelectric charge, generated smoother image with less background fog.

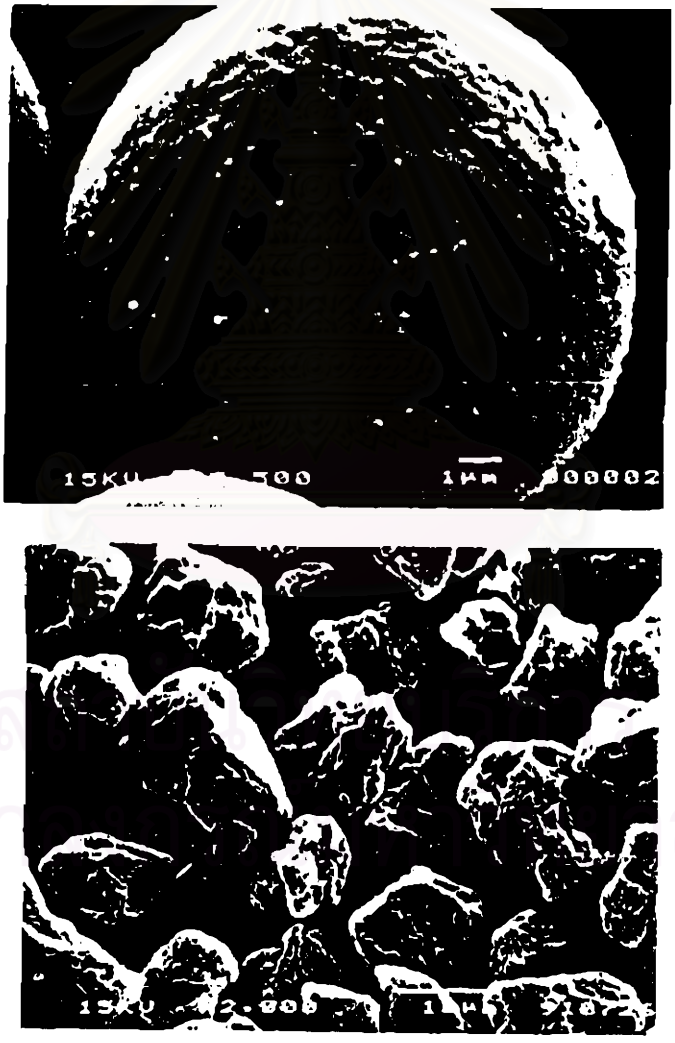


Figure 2-23 Scanning electron micrographs of polymerized toner (a) and melt-mixed / crushed toner (b)