Dry Developer of Toner for Electrophotography

Akira Fushida
Mita Industrial Co., Ltd.*

1. Introduction
A copier may be one of the most available office automation machines which have been promoting rationalization and efficiency leading to improvement of business works. It is broadly classified into three methods: a direct electrofax (EF), an indirect electrophotography (PPC; Plain Paper Copier), and a diazo method. In 1984, close to 2,280,000 PPC machines were produced, which occupied the share of 97.3 percent in the whole copier markets. It may be considered that a copy quality is affected essentially by a developing method and a toner (developer). The production of the toner for PPC in 1984 is estimated to reach about 30,000 tons in the world.

Various kinds of toner, which have been available together with the expansion of PPC market, are broadly divided into two types; dry and wet type. Today, the two-component dry toner is dominant, which consists of a carrier (iron powder) and a toner (colored powder). With regard to a one-component type, which consists of only toner itself, low-cost copier has been increasing in production to satisfy the needs of miniaturization and simplification. The toner is used for not only these applications but also an electrostatic printer, an electronic plate making machine, and a laser printer where an electrophotographic principle is applied. Based on this consideration, a dry-type toner (developer) will be described in the present paper.

2. Outline of electrophotographic process

The electrophotographic process, which was invented basically by C.F. Carlson in 1938, is classified into two methods: an electrofax method (EF) that fixes directly images on a photoconducting material and a xerographic technique (PPC) that transfers images on plain paper. In this section, the xerographic process is outlined (Fig. 1).

In general, a xerographic process consists of

(1) Charge: The surface of the photoconductor is charged uniformly in the dark.

(2) Exposure: Images are charged on a photoconductive plate.

(3) Development: Developed toner images are transferred on to a paper sheet.

(4) Transfer: The developed image is transferred onto the paper sheet.

(5) Fixing: The transferred image is fixed on the paper sheet.

(6) Cleaning: The photoconductive drum is cleaned for the next copy.

Fig. 1 Basic process of xerography

Fig. 2 Process of PPC copier

* 2-28, Tamatsukuri 1-chome, Higashiku, Osaka, 540
TEL. 06 (764) 3857
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Exposure: Exposure toward the surface of the photoconductor allows the electrostatic latent image to form.

Development: Toner particles with electrical charges opposite in polarity to the latent image are deposited on the photoconductor.

Transfer: The image formed with toner particles is transferred on the transfer paper by corona discharge from the backside.

Fixing: The toner image is fixed by heating and the final copy is obtained.

Cleaning: An excessive toner remaining on the photoconductor is cleaned off.

The copies are continuously obtained by repeating the above processes.

The essential point of development is that the toner particles charged with a certain polarity by mixing in a short time are transferred to the process of a latent image forming.

For example, the quality of magnetic brush development depends on:
- the developing condition such as transferred amount of developer, a magnet arrangement, the gap between a photoconductor and a sleeve, and rotation speed ratio, etc.
- the uniformity and stability of toner concentration, charge quantity during mixing of adding toner and developer.
- the control of toner concentration (This is not required for a one-component toner).
- the characteristics of developer such as electromagnetic, flowing, mechanical, and thermal-resistant characteristics.

Classification of dry development and dry developer

There are two kinds of dry developer for electrophotography, as listed in Table 1. One is a two-component developer which consists of a toner containing colored pigment and thermoplastic regin, and a carrier having a function of adding charge on the toner. Another is a one-component developer which consists of a toner alone. In practice, there are several kinds of inherent characteristics involved in each of them; insulation or conductivity, and magnetism or non-magnetism. These various kinds of developer are employed, according to the developing method. Today, the magnetic brush development, which uses an insulated, non-magnetic toner for two-component developer and an insulated magnetic toner for one-component developer, is dominant. The variety of development methods will be referred to in the later section.

4. Dry developer

In general, an electrophotographic process

![Electron micrograph of toner](image)

| Table 1 Classification of dry developer and development |
|--------------------------------------------------------|
| Developer (toner/carrier)                              | Development               |
| Two-component system                                   |                          |
| Insulated nonmagnetic toner/bead carrier               | Cascade                  |
| Insulated nonmagnetic toner/magnetic carrier           | Magnetic brush           |
| Insulated magnetic toner/magnetic carrier              |                          |
| One-component system                                   |                          |
| Insulated nonmagnetic toner                            | Fur brush                |
| Conductive nonmagnetic toner                           | Powder cloud             |
| Conductive magnetic toner                              | Open chamber             |
| Insulated magnetic toner                               | Magnedynamic             |
|                                                         | Jumping                  |
consists of the processes of charge, exposure, development, transfer, fixing, and cleaning. Toner is related directly to the four processes such as development, transfer, fixing, and cleaning as shown in Table 2.

The following properties should be taken into consideration for practical application.

1. Electrical property

Toner particles are charged by friction, corona discharge, charge injection by electrostatic induction, etc. The triboelectrical charging is most often used, and in particular, the charge is caused by the friction with carrier particles. The polarity of charge (positive or negative) follows the triboelectrical series. The charge quantity and its attenuation depend radically on its own electrical resistance, which is controlled at a given resistance, for example, about $10^{13} \, \Omega \, \text{cm}$ for two-component system.

2. Particle size

Since a particle size of toner has influence on image quality like resolution, it must be controlled at 10 to 15 $\mu$m in an average diameter. This is because when the size is larger, the resolution is reduced in spite of

Table 2  Relationship among electrophotographic process, toner particle property, and picture quality

| Electrographic process | Toner particle property | Picture quality |
|------------------------|-------------------------|-----------------|
| Development            | Electrical property     | Image density   |
|                        |  - Polarity             |                 |
|                        |  - Charge               |                 |
|                        |  - Permittivity         |                 |
|                        |  - Electric resistance  |                 |
| Transfer               | Mechanical property     | Tone            |
|                        |  - Particle geometry    |                 |
|                        |  - Particle size        |                 |
|                        |  - Particle size distription |         |
|                        |  - Flowability          |                 |
| Cleaning               | Thermal property        | Resolution      |
|                        |  - Glass transfer temperature |             |
|                        |  - Specific heat        |                 |
| Fixing                 | Rheological property    | Fog             |
|                        |  - Melting viscosity    |                 |
|                        |  - Melting elastico- viscosity |         |
better flowability, and when it is less than 5 μm, fog is apt to take place and productivity is reduced.

(3) Thermal and rheological properties
The thermal and rheological properties are considerably related to the fixing process. When a heat roller is used, in particular, the initial fixing temperature, cold offset, hot offset, winding of transfer paper around the roll, etc. should be taken into consideration. In addition, in consideration of stability of toner keeping and the temperature rise in copier equipment, toner is required not to be blocked under 40 to 50°C. Toner components should be modified carefully because their characteristics have serious influence on two or more electrophotographic processes which result in deciding a final image quality.

The suitable use of one-component developer may demand more careful design, as this developer must play double roles of a toner particle and a carrier particle in a two-component developer.

For a carrier particle in a two-component developer, on the other hand, the performance appropriate to the developing process is required, which is essentially dependent on material, particle size, geometry, electrical and magnetic property, etc. The following materials can be utilized as a carrier:
(i) Glass beads coated with resin
(ii) Iron filings or ferrite powder coated with resin
(iii) Iron filings treated with surface oxygenation
(iv) Resin particles dispersed with magnetic particles
The carrier has a wide range of variety in geometry from irregular to spherical shape, with a diameter of 10 to 500 μm.

5. Composition of dry toner
The toner materials which are available chiefly are a two-component insulated non-magnetic toner and a one-component insulated magnetic toner. The compositions of these toners are listed in Table 3. The following materials are often used for these toners,
(i) Thermoplastic resins: polystyrene, styrene-acryl copolymer, polyester, epoxy, polyethylene, and polypropylene
(ii) Dye and pigment: carbon black, nigrosine, and spirit black
(iii) Charge control agent
   For positive polarity: electron donor like nigrosine, metal salt of fatty acid, and quaternary ammonium salt
   For negative polarity: azo-dye containing metal
(iv) Magnetic material: magnetite and ferrite
(v) Other material (additives): colloidal silica and fatty acid
The significant points for toner design are:
- having well-balanced functions required for electrographic process.
- high quality and long life
- environmental stability
- safety (harmlessness)
- stable preservation
- processing
- low cost

Table 3 Component of toner

| Component of toner | Two-component toner | One-component toner |
|--------------------|----------------------|---------------------|
| Thermoplastic region | 80 ~ 90 (wt %) | 30 ~ 60 (wt %) |
| Dye or pigment (stain) | 5 ~ 15 | 0 ~ 10 |
| Charge control agent | 1 ~ 5 | 1 ~ 5 |
| Magnetic pigment | 0 | 40 ~ 65 |
| Others (fluidizing material) | 0 ~ 5 | 0 ~ 5 |
6. Production process of toner

Although there are many ways in production of toner: mechanical size reduction, spray drying, micro-cupsel forming, polymerization, etc., it is almost obtained practically by mechanical size reduction and partly by spray drying for magnetic toner. Figure 3 shows typical production processes of mechanical size reduction and spray drying.

The following is outlined about the size reduction process.

(i) Mixing of materials

Toner materials such as resin, pigment, dye, charge control agent are mixed to accomplish the subsequent process of heating and kneading in a short time by ribbon blender, V-type mixer, etc.

(ii) Heating and kneading

The mixed materials are melted by heating and kneaded uniformly by using heat roller mill, heating kneader, etc. to prevent fog and scattering of toner particles and promote durability and cleaning treatment.

(iii) Size reduction

After cooled, they are crushed to 1 ~ 3 mm in size by hammer mill or feather mill, and then ground to 10 to 15 μm by jet mill or pin-type mill, etc.

(iv) Classification

The ground toners are classified to satisfy an acceptable size distribution. Air classifiers are often utilized for this purpose.

(v) Surface treatment

The classified toners are mixed with silica powders by V-type mixer and Nauta Mixer to promote its flowability and cleaning treatment.

Since each process above mentioned has great influence on the quality of toner, the selection of equipments and processing conditions should be taken into consideration.

7. Measurement of toner properties

The important points indicated in Table 2 are explained individually.

(1) Charge quantity

The blow-off method is used in general to measure charge quantity. As illustrated in Fig. 4, this method is based on the principle that the toners alone are blown off by high-pressure O₂ or N₂ gas from the developers which are contained in a cylindrical Faraday cage with wire nets at both sides. When toner particles are charged, a capacitor accumulates as much quantity of charge with opposite polarity as the toners taken away out of the cage. Although the value of $Q$ is obtainable by measuring the capacitor voltage from the relation of $Q = CV^2$, this procedure can provide nothing but an average value of the charge quantity.

Another method is that the polarity and relative distribution of the charge on toners are determined when they flow down along the
air stream between two parallel impressed plates, as shown in Fig. 5. In addition, it is also reported by R.B. Lewis of Xerox Corp. that the charge distribution is measured by forming the electrical field perpendicularly to the air stream, as shown in Fig. 6.

(2) Particle size distribution

The particle size distribution of toners is measured in general by Coulter counter. This method is based on the principle that the variation of electrical resistance is transformed to the distribution data. This variation is caused by the toner particles which pass through the aperture of a glass tube (aperture tube) that is placed in an electrolyte of physiological saline called Isoton II. In practice, the toner particles dispersed outside of the aperture tube are sucked toward inside by a vacuum pump.

(3) Other properties

The geometry or the surface condition is observed effectively by an electron microscope. The surface area is measured by BET method. The angle of repose, bulk density, and cohesion are measured by each corresponding tester. We are able to apply directly the measuring equipment of polymer characterization without modification: for example, a differential scanning calorimeter for glass transition temperature and softening point, and a flow tester for melting viscoelasticity.

8. Development

Typical developing techniques indicated in Table 1 are outlined as follows.

(i) Cascade development

The developer material in cascade development consists of a bead or steel material (0.2 to 0.7 mm) coated with resin, called the carrier, and toner particles. Development of the electrostatic image is achieved by cascading the toner-carrier developer over the surface of the photoconductor. Although this developing technique allows line copy images to be sta-
bilized, the image missing often takes place in the solid black area by the edge effect.

(ii) Magnetic brush development
Magnetic brush development uses a magnetic carrier of iron powder or ferrite of 50 to 200 μm mixed in 3 to 10 weight percent with an insulated toner of 10 to 15 μm. When toner and carrier are mixed, the toner acquires a charge of a certain polarity. Then, development of the electrostatic image is achieved by brushing the ferromagnetic fiber over the surface of the photoconductor. This method provides a high quality in finish copy with a sufficient continuous tone reproduction and less fog because the developer is acted as a developing electrode.

(iii) Fur brush development
Development is accomplished by using a soft fur as a carrier against which toner particles are rubbed to become charged triboelectrically. This development is difficult to control electrically because of the influence of humidity resulting from the use of fur.

(iv) Powder cloud development
The cloud-like toner particles are blown off through a fine metal nozzle, as shown in Fig. 10. Development is achieved by means of the toner deposition on the surface of the photoconductor which is spaced closely with an electrostatic latent image.

(v) Magnedynamic development
A toner of magnedynamic development consists of a resin including magnetic iron powder (magnetite) of 50 to 70 weight percent, and is covered with carbon black.

Development is conducted in the way how the magnetic brush formed on the conductive sleeve is brought near to electrostatic latent image to induce opposite-electrical charge by electrostatic induction, as shown in Fig. 11. Insulated paper
or EF method is available because of poor transfer ability for plain paper.

(vi) Jumping development

A toner used in jumping development is about 12 $\mu$m in diameter and $10^{15} \Omega$cm in resistance, including magnetite with as much as 35 weight percent. This insulated, magnetic toner material is deposited on the surface of the sleeve by triboelectrification to form the toner layer with a thickness of about 50 $\mu$m. Development is achieved by vibrating the toner layer when the gap between the sleeve and the photoconductor is maintained to be 300 $\mu$m and the a-c bias of hundred-order Hz is applied.

10. Conclusion

This report has explained the outline of kinds, required properties, production methods, etc. of dry toner developer. It is expected that the coming information society will need a wide-spread use of copier or printer in domestic work as well as in office business and that cost reduction may become the most important interest. For cost reduction, it should be taken into consideration to find out a more efficient process of toner production, in particular size reduction, classification, etc., and a new process such as spray and polymerization.

In recent years, the variety of developing techniques and developers has improved and stabilized the copy quality. However, there is a strong demand for higher quality, longer life, and less maintenance.

The author believes that better toner evolution requires not only matching to each process but also cost reduction, less pollution, easier processing, environmental stability, etc.

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