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A sleeveless magnet roller developing system was studied by using a non-magnetic toner and an iron carrier. A developing roller made from a sintered ferrite magnet, with 32 magnetic poles and 0.025 T in magnetic flux density, was employed in this study. Imaging characteristics and developing behavior were examined in the sleeveless magnet roller developing system in both normal and opposite developing directions. The influence of toner concentration on the developing characteristics was also examined. It was confirmed that the developing system had an optimum developing condition for best imaging properties. It was also found that the toner concentration in the developer was stable during continuous printing. These results suggest that developing characteristics can be controlled by automatic control of the toner concentration.

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Introduction

Electrophotographic printers have the capabilities to produce high resolution images at high speed printing and low noise. Owing to these favorable characteristics, these printers are widely used as printing devices for personal computers and on-demand printings, where high quality image and high-speed printing are important. To improve the image quality of electrophotographic printers, the diameter of the exposure beam has been reduced and small particle size toners are introduced.

A dry development process has been commonly used for photocopying machines as developing method for electrophotographic process. Dual-component development, magnetic mono-component development and non-magnetic mono-component development, etc. are all well known as electrophotographic development processes. Dual-component developer usually consists of toner and magnetic carrier beads. It is necessary to control the toner concentration of the developer because the toner charge plays an important role in image qualities. Therefore, electrophotographic systems employing dual-component development process are large and complicated but suitable for high-speed printers. Compared to a dual-component development process, magnetic mono-component development process offers the advantage of size reduction. However, the magnetic mono-component method has problems when it comes to color printing.

Non-magnetic mono-component developer does not contain magnetic powder and does not need magnetic carrier beads. The control of the toner concentration is unnecessary for non-magnetic mono-component developers making it possible to make smaller printers at lower cost. High resolution and color images can easily be obtained by using small size particles and color toners, respectively. For that reason, the number of photoprinters employing non-magnetic mono-component developing process is increasing. However, it is well known that non-magnetic mono-component developers often change their printing characteristics easily because of the high stress at the developing stage of the printing process in high-speed printers.

Recently new electrophotographic technologies have been developed to solve the problems of cost reduction and environmental concerns. For example, a cleanerless development system that does not generate waste toner is generally known.[1–3] Both a non-magnetic toner without a magnetic carrier and a magnetic toner with a magnetic carrier are employed in development systems. The dual-component developer can be applied for color and high-speed printers because of a lower stress for toner than the mono-component developer.

We have investigated an electrophotographic development system that uses a sleeve-free magnet roller.[4–5] By removing the metal sleeve and flanges of the normal magnet roller, and by using a roller with more magnetic poles and a metal shaft instead, the development unit of this system can be simplified. These changes increase mechanical reliability and reduce the costs of production. We have examined the sleeveless development system in order to achieve low-cost monochromatic printing system. The fundamental characteristics of the magnetic

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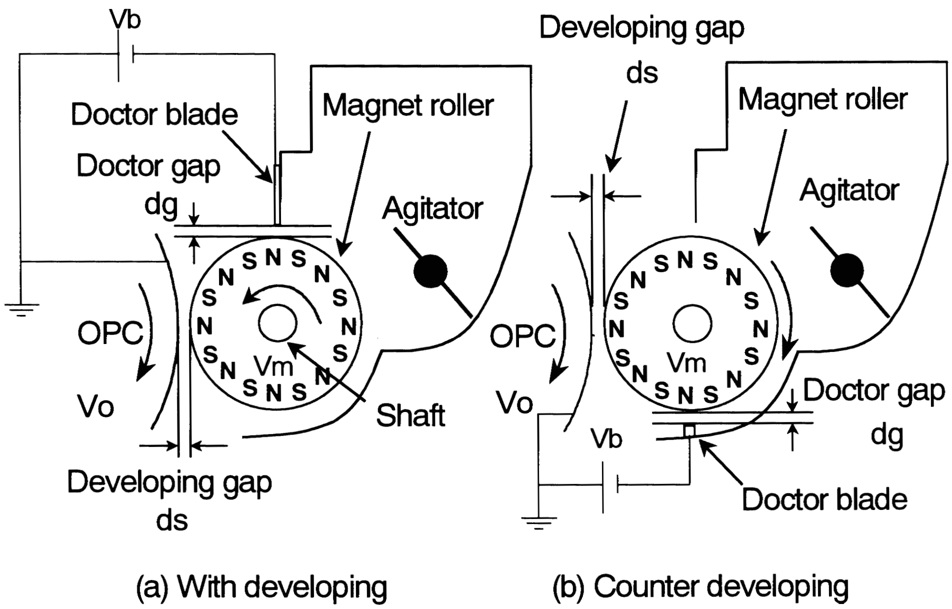

Figure 1. Schematic drawing of sleeveless magnetic roller developing system.

carriers and the developing conditions have been studied by using a magnetic toner and several kinds of magnetic carriers. The optimum size and electric resistivity of the carrier were found to be 35 μm and 10^7 Ω cm, respectively. We have also obtained an optimum speed of the sleeveless magnetic roller.

Recently, full color printing and a further reduction of cost are required in the printing market. To meet the demands of the market, it is necessary to investigate the sleeveless development system by employing a non-magnetic toner. We have examined the basic characteristics of dual-component development for the sleeveless development system by using a non-magnetic toner and a magnetic carrier. The basic data for the study of the sleeveless development system with the non-magnetic toner can be found in our previous article.[5]

In this study, development characteristics and image properties were investigated by using a non-magnetic toner and a magnetic carrier as a developer. We then reduced the magnetic flux density of the sleeveless magnetic roller for color printing. Effect of toner concentration of the developer on the development characteristics was also investigated.

Experimental

Magnet Roller for the Sleeveless Developing System

A conventional development unit usually consists of a rotating non-magnetic metal sleeve and a fixed magnetic roller, which is magnetized with several poles and fitted to the sleeve. On the other hand, a sleeveless developing system consists of a symmetrically magnetized rotating magnetic roller and a metal shaft as shown in Fig. 1. The number of magnetic poles is larger in the sleeveless developing roller than in the conventional roller. A roller made from a sintered ferrite magnet, with 32 poles and 0.035 T in magnetic flux density, was employed in previous study. Our preliminary experiments confirmed that high and low magnetic flux density of the magnetic roller had some adverse effects on output images. Therefore, the sleeveless magnetic roller with 32 poles and 0.025 T in magnetic flux density was employed in this study. The magnetic roller is 20 mm in diameter and has a length corresponding to an A4 size paper. Surface treatment such as a nickel plating of the magnetic roller was not used, thus making the surface of the roller insulating.

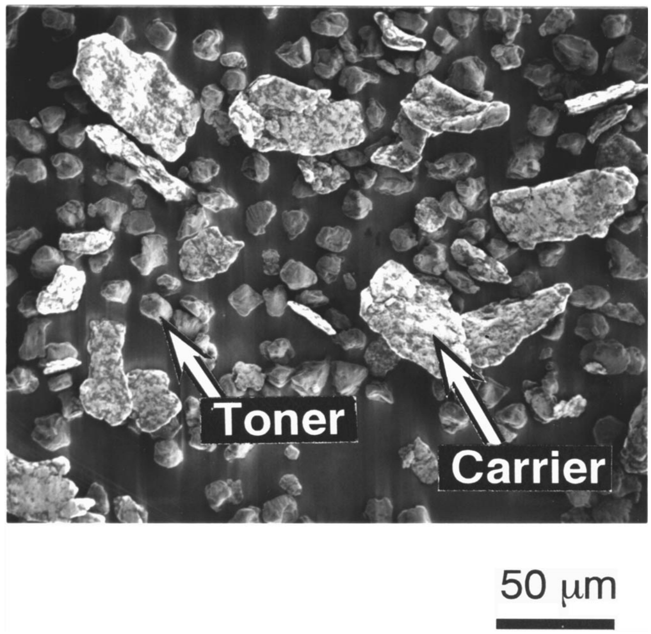

Figure 2. Scanning electron micrographs of the sample developer.

Developers

A non-magnetic toner was prepared to characterize the developing performance of the sleeveless magnetic roller in this study. The non-magnetic toner was made of polystyrene-acrylic copolymer as main resin, polypropylene, carbon black, and charge control agent. The charging polarity of the toner is negative. The volume mean particle size of the non-magnetic toner is approximately 10 μm.

An iron carrier, which gave good results in our previous study, was employed. A dual-component developer

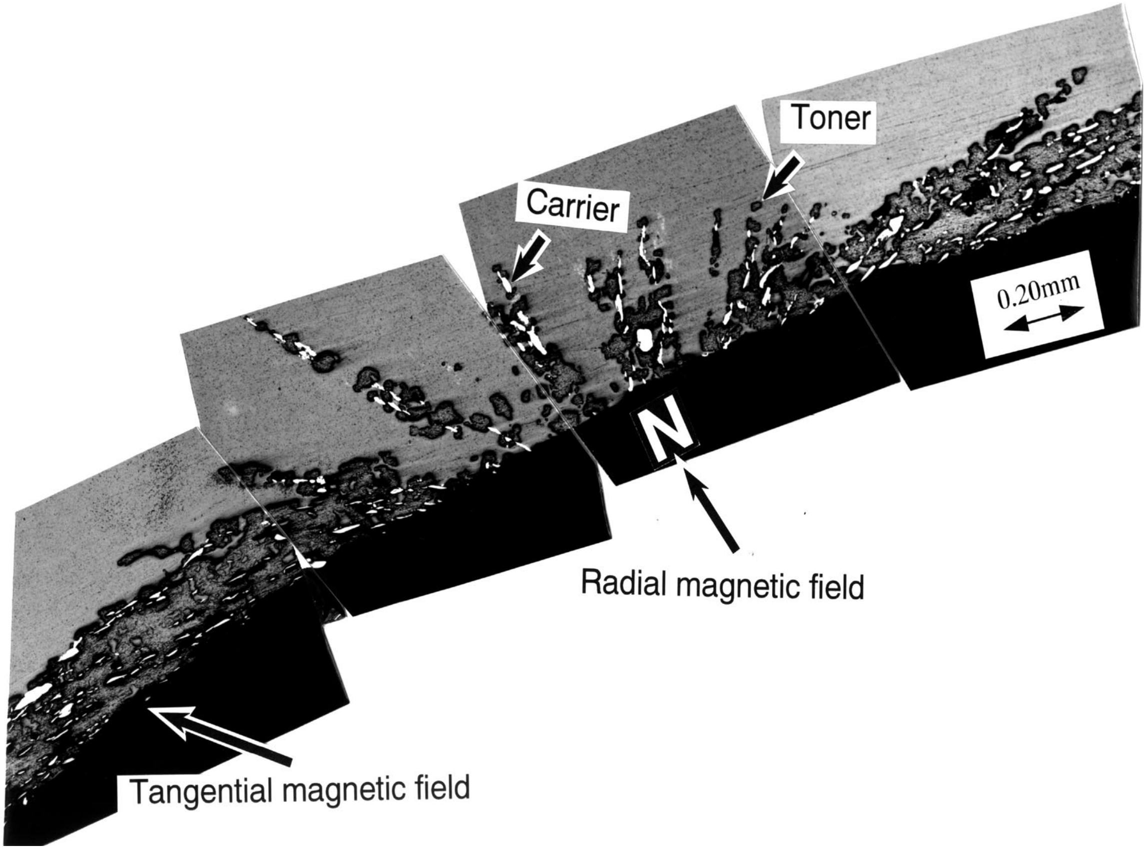

Figure 3. Photomicrograph of the cross section of the magnetic brush on the magnetic roller.

was prepared with the non-magnetic toner and the iron carrier. The iron carrier was coated with silicone polymer, and its volume mean particle size measured by a Coulter counter was approximately 30 μm. Figure 2 shows the developer used in this study. The shape of the iron carrier was flat. Actually, carrier particle size was distributed widely as shown in Fig. 2. If we assume a 60 μm diameter iron carrier with 5 μm thickness, we can estimate that the toner concentration for monolayer coverage of the toner was about 30 wt %. The toner concentration of the developer was changed form 10 to 50 wt %.

Experimental Conditions

To study the influence of development condition and toner concentration on developing characteristics and image property, electrophotographic output images were obtained using the developer. For that purpose, a conventional laser beam printer with process speed of 25 mm/s was used in this study. This printer employed an organic photoconductor (OPC) drum, dual-component magnetic brush developing system and a heat roller fusing process. In order to control the ratio (Vm/Vo) of peripheral velocity of the magnet roller (Vm) and that of the OPC drum (Vo), the driving device of the magnetic roller in the printer was modified. Figure 1 shows the schematic of the sleeveless magnet roller developing system. Figures 1(a) and 1(b) indicate the difference of the rotational direction. Figure 1(a) shows the normal developing direction, where the rotational direction of the magnet roller and the OPC drum is opposite. We call this direction of development "with developing". On the other hand, the rotational direction of the magnet roller and the OPC drum is the same in Fig. 1(b). We call this direction of development "counter developing". Both the development units have a doctor blade made of a copper plate. The doctor blade was located with a gap (dg) of 0.30 mm from the sleeveless magnet roller. The developing gap (ds) between the OPC drum and the magnet roller was varied from 0.30 to 0.50 mm while the doctor gap was kept constant at 0.30 mm, as mentioned above, to investigate the change in developing characteristics and image properties.

We will now describe the form of magnetic brush on the sleeveless magnetic roller. The radial field to the surface of the magnetic roller was formed on the magnetic pole. On the other hand, the tangential field to the surface of the magnetic roller was formed between the S pole and the N pole. Figure 3 shows the cross section of the magnetic brush on the magnetic roller. It was confirmed that the magnetic brush was sparse in the radial field but thick in the tangential field. It was also confirmed that the height of the magnetic brush in the radial field was approximately 1.5 or 2 times higher than that in the tangential field. We believe that the reason for this difference is that the height of the developer in the tangential magnetic field remains at 0.3 mm after going through the doctor blade. However, the developer in the radial magnetic field rose and stretched out after going through the doctor blade.

Two kinds of the print units were modified so that we could apply arbitrary bias voltage through the doctor blade. The image density of output images obtained was measured with a reflecting densitometer (Macbeth : RD-914). The background fog density was measured by using a color difference meter (Nippon Denshoku Kougyo:

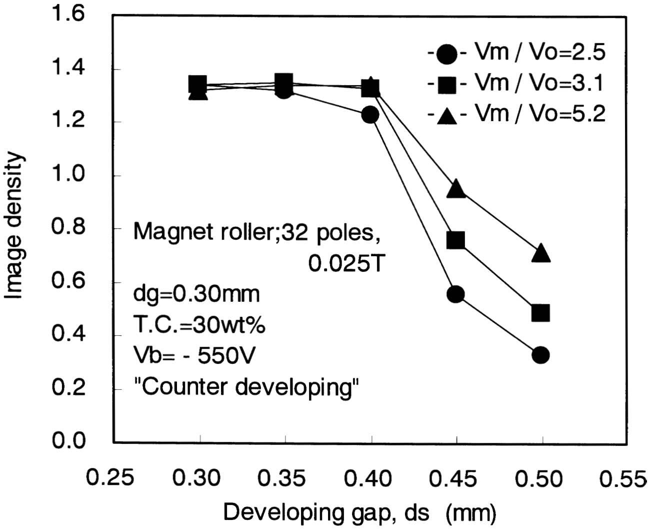

Figure 4. Relationship between image density and developing gap in case of "counter developing".

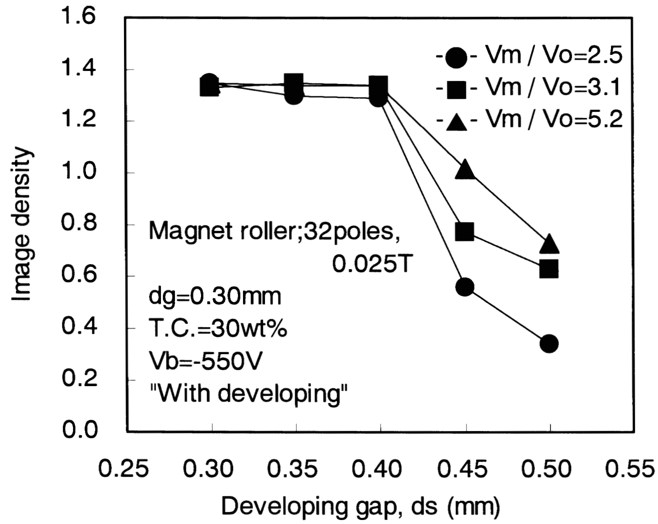

Figure 5. Relationship between background and developing gap in case of "counter developing".

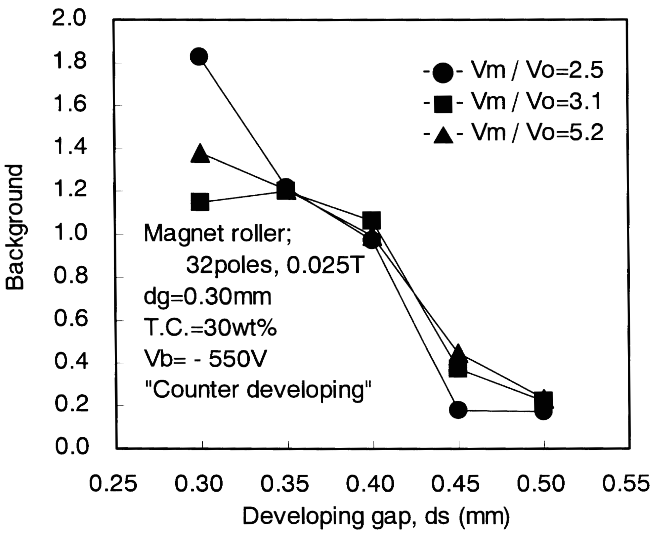

Figure 6. Relationship between image density and developing gap in case of "with developing".

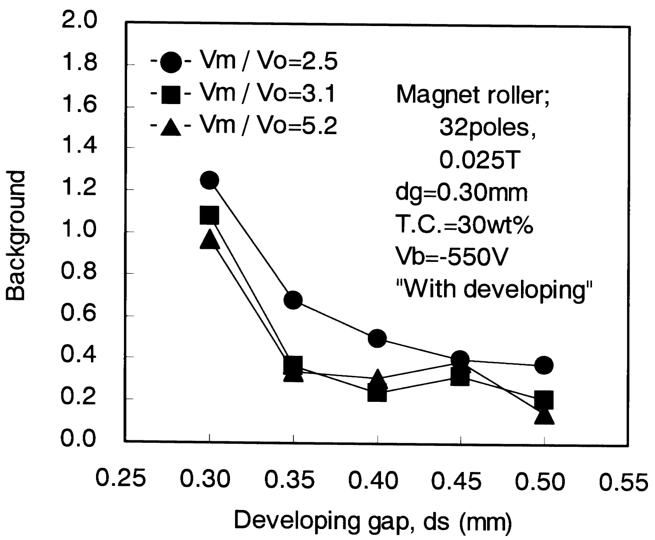

Figure 7. Relationship between background and developing gap in case of "with developing".

ND504DE). All experiments were carried out at room temperature.

Results and Discussions

Development Conditions and Image Properties

Figure 4 shows changes in image density with developing gap for three values of the ratio (Vm/Vo) in case of the "counter developing" method, where the rotational direction of the magnet roller and the OPC drum is same. The toner concentration of the developer was 30 wt %, and a bias voltage of –550 V was applied to the doctor blade. When the doctor gap was constant (0.30 mm), an acceptable image density was obtained at the developing gap of less than 0.40 mm. However, we observed that the image density decreased rapidly with a developing gap larger than 0.45 mm. These results show that the image density depends on the developing gap. In other words, the height of the magnetic brush of the developer is very important in determining image density in the development system. Changes of the image density increased in accordance with a decrease in the ratio (Vm/Vo) of peripheral velocity of the magnet roller and the OPC drum. Figure 5 shows relationship between the background fog and developing gap in the same developing condition with Fig. 4. The background fog increased with a decrease in the developing gap. The developing gap larger than 0.45 mm gave sufficiently less background fog at all ratios of peripheral velocity of the magnet roller and the OPC drum. Because the image density and the background fog are compatible, it is difficult to obtain an acceptable image quality in the "counter developing" method as shown in Figs. 4 and 5.

Figure 6 shows the relationship between image density and developing gap in the case of the "with developing" method, where the rotational direction of the magnet roller and the OPC drum is opposite with each other. In terms of the image density, the "with developing" method gave similar results with the "counter developing" method as shown in Fig. 4. The dependence of the image density on the ratio (Vm/Vo) of peripheral velocity of the magnet roller and the OPC drum was similar to the case of the "counter developing" method.

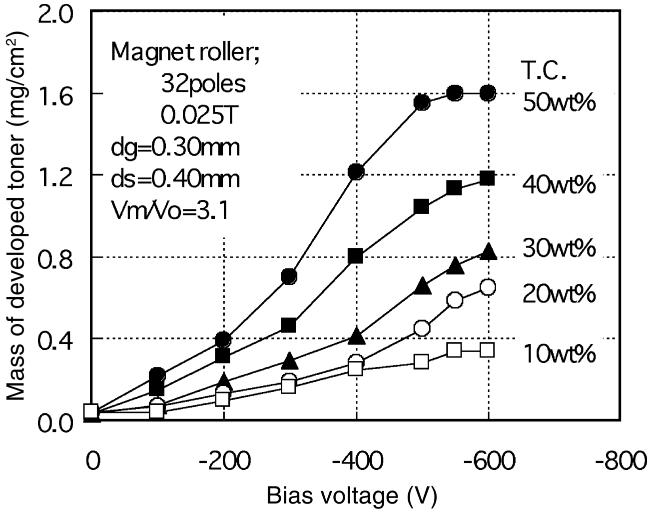

Figure 8. Relationship between developed toner and bias voltage in case of "with developing".

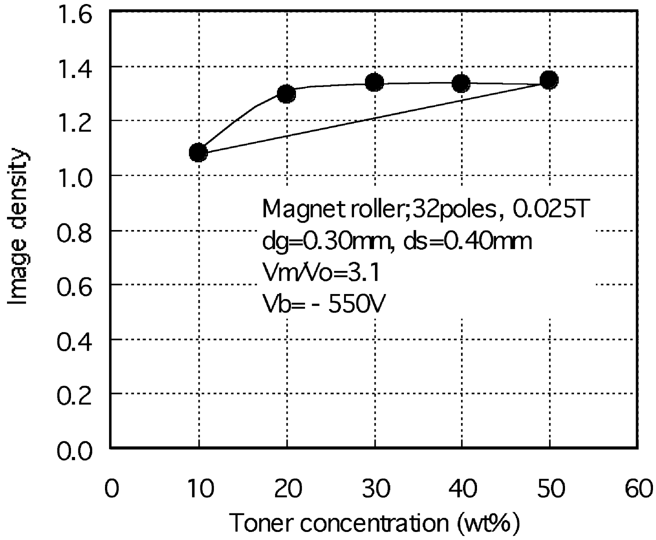

Figure 9. Relationship between image density and toner concentration in case of "with developing".

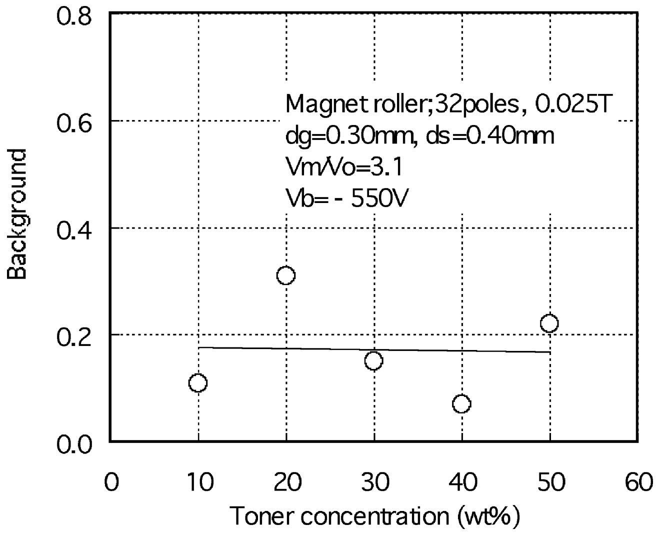

Figure 10. Relationship between background and toner concentration in case of "with developing".

Figure 7 shows changes in the background fog at the same development condition as that used to obtain the results of Fig. 6. The background fog decreased with an increase in the developing gap. Better background fog was obtained when the developing gap was larger than 0.35 mm at the ratios of peripheral velocity of the magnet roller and the OPC drum of 3.1 and 5.2. It can be seen that the developing gap condition affects the developing behavior in the sleeveless developing system. Output images of acceptable quality for practical application were obtained at the developing gap of 0.35 to 0.40 mm in the "with developing" method.

Influence of Toner Concentration

The influence of the toner concentration (T.C.) of the developer sustained on the magnet roller on the developing characteristics was also studied under the optimal developing condition obtained in the previously mentioned experiments. Figure 8 shows the relationships between the mass of developed toner on the OPC drum and bias voltage applied to the doctor blade. It was found that the mass of developed toner changed with the bias voltage (0 to –600 V). As the toner concentration was increased, the amount of developed toner on the OPC drum increased. The amount of toner developed on the OPC drum showed a saturation tendency at bias voltage higher than –500 V. Figure 9 shows the image density as a function of toner concentration for the developer. The image density was saturated at the toner concentration of larger than 30 wt %, which was sufficient for practical use. It was found that the mass of toner on the OPC drum of larger than 0.8 mg/cm^2 was required for sufficient image density. The change of the background fog was small in the toner concentration range of 10 to 50 wt % as shown in Fig. 10. To investigate imaging properties other than the image density and background fog, we studied the scatter around lines and line width fluctuation using optical microscope. Photomicrographs of fixed output images obtained on a plain paper are shown in Fig. 11. The photomicrographs show thin lines obtained at the toner concentration of 20 wt % to 50 wt %. As for the scatter around lines, there was no large difference between the toner concentration of 20 wt % and 50 wt %. In this case, it was necessary to consider transfer process. Similar image properties were obtained in a wide range of toner concentration. In other words, the results indicate that developing properties are stable in a wide range of toner concentration. Therefore, it can be said that the developing behavior of the toner in the sleeveless developing system is different from that in the normal developing system that uses a sleeve. The available toner concentration range in the latter system is usually narrow. The results described above may be attributed to differences in the structure of the magnetic brush on the magnetic roller. The magnetic brush on the sleeveless magnetic roller is thicker and more static than that on the conventional developing roller. The magnetic blush of the normal developing system with a sleeve is sparse and is more dynamic. These differences in the magnetic brush account for the dependence of the quality of the images on toner concentration.

Finally, the change in the toner concentration on the sleeveless magnet roller in a continuing printing was investigated to confirm the stability of the toner concentration. Black solid images were continually printed.

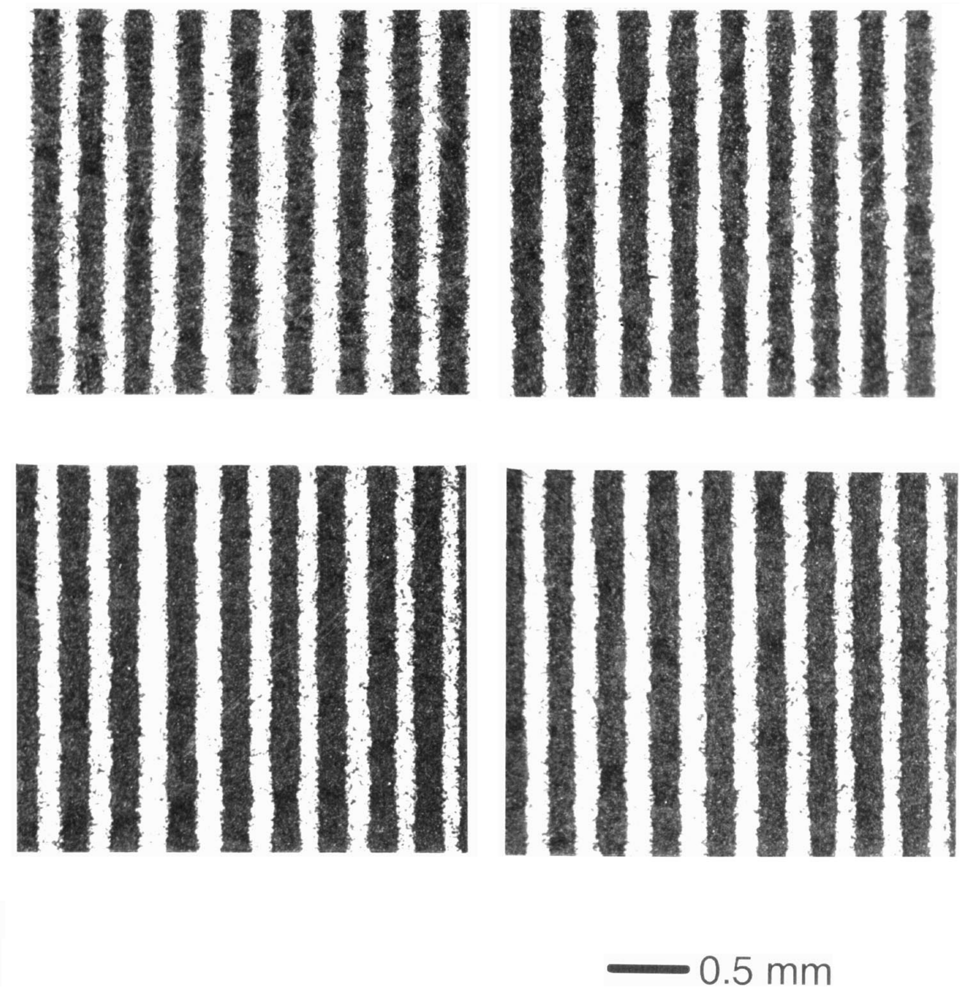

Figure 11. Photomicrographs of fixed output images on plain paper obtained by changing the toner concentration. (a) 20 wt %, (b) 30 wt %, (c) 40 wt %, (d) 50 wt %.

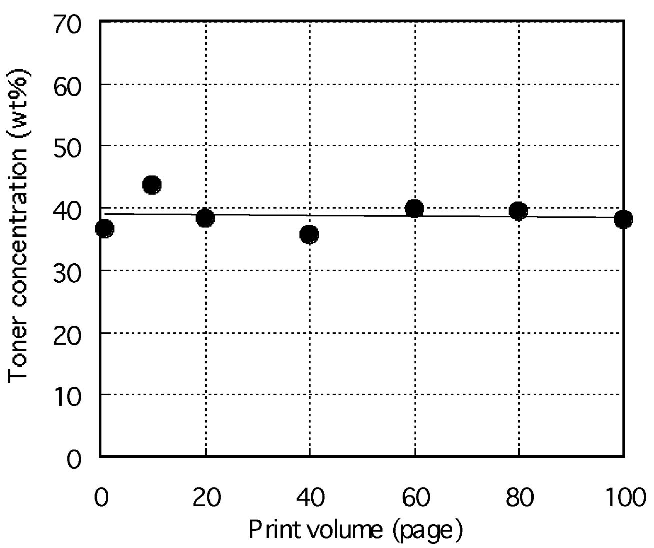

Figure 12. Change in toner concentration with print volume.

The result was shown in Fig. 12. In spite of the large amount of the toner consumption, the change in the toner concentration on the sleeveless magnetic roller was small. Although sufficient amount of toner and carrier was charged in the developer hopper, the toner concentration of the developer on the sleeveless magnet roller was controlled to approximately 40 wt % automatically. One of the reasons for these results is that fresh toner was supplied to the carrier surface from the developer sump by electrostatic force. When the surface on the carrier particle was covered with a monolayer of toner, the toner concentration was approximately 30 wt %, as mentioned above. In addition, it is expected that a small amount of toner was also present between the carrier particles on the sleeveless magnetic roller as shown in Fig. 3. We estimated that the toner concentration was in equilibrium at 40 wt % by considering both electrostatic and physical forces.

The carrier particles, however, may play an important role in keeping the toner concentration constant in this developing system.

Conclusion

The developing behavior of a sleeveless developing system was studied by using a non-magnetic toner. The influence of the developing condition and the toner concentration on image qualities were examined. The following results were obtained.

1. Image quality in the “with developing” method was better than that in the “counter developing” method, and the “with developing” method provided the optimum development condition.
2. The available toner concentration range in the sleeveless developing system with a flat iron carrier is superior to that of the sleeve rotating system because of the difference in the form of the magnetic brush.
3. The toner concentration on the magnet roller was kept at about 40 wt % automatically, even though solid black images were continually printed.

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