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Savit et al.

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[45] **July 10, 1973**

[54] **ELECTROSTATIC DEVELOPING SYSTEM WITH CYLINDRICAL DRUM LIQUID CONTACT UNIT**

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Related U.S. Application Data

[62] Division of Ser. No. 813,531, April 4, 1969, Pat. No. 3,669,073.

[52] **U.S. Cl.**..... **118/637,** 177/37 LE, 118/DIG. 23, 355/10

[51] **Int. Cl.**..... **G03g 13/00**

[58] **Field of Search**..... 118/410, 414, 423, 118/424, 637, DIG. 23; 117/37 LE; 355/10

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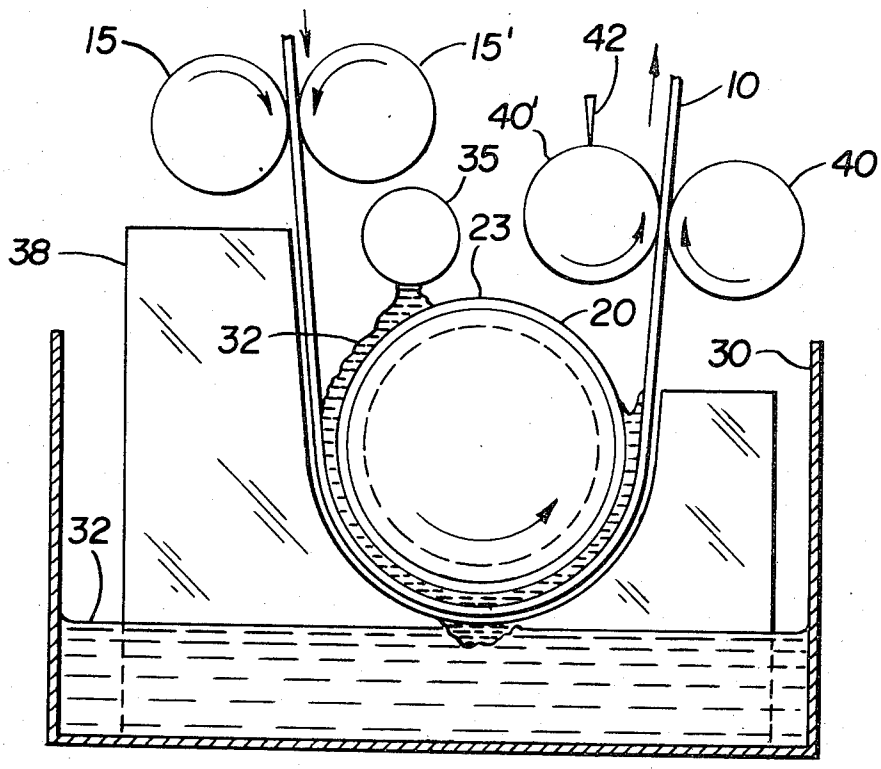
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Attorney—Lowell G. Wise

[57] **ABSTRACT**

Liquid developer system for electrostatic printing. Latent images carried on a sheet or web are developed by distributing a liquid carrier containing toner particles over a foraminous cylindrical drum. The latent image surface is contacted with the liquid developer carried on the drum, and excess liquid is removed from the contact area through small openings in the drum surface.

16 Claims, 5 Drawing Figures



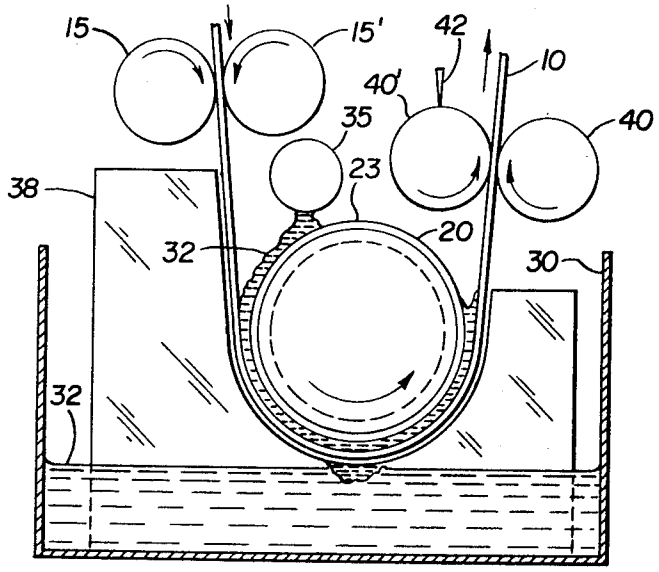


Fig. 1

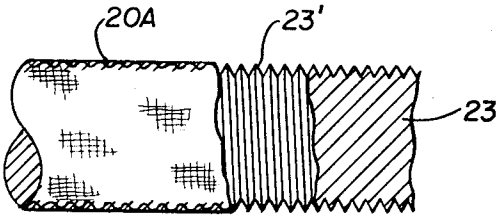


Fig. 2

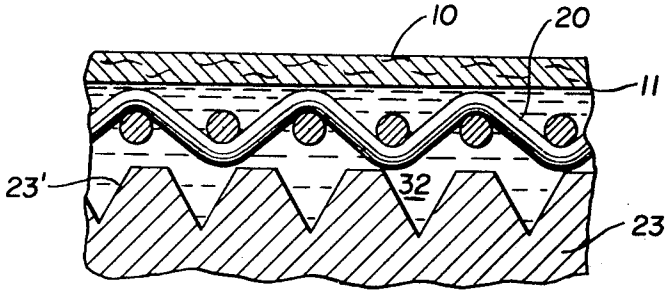


Fig. 3

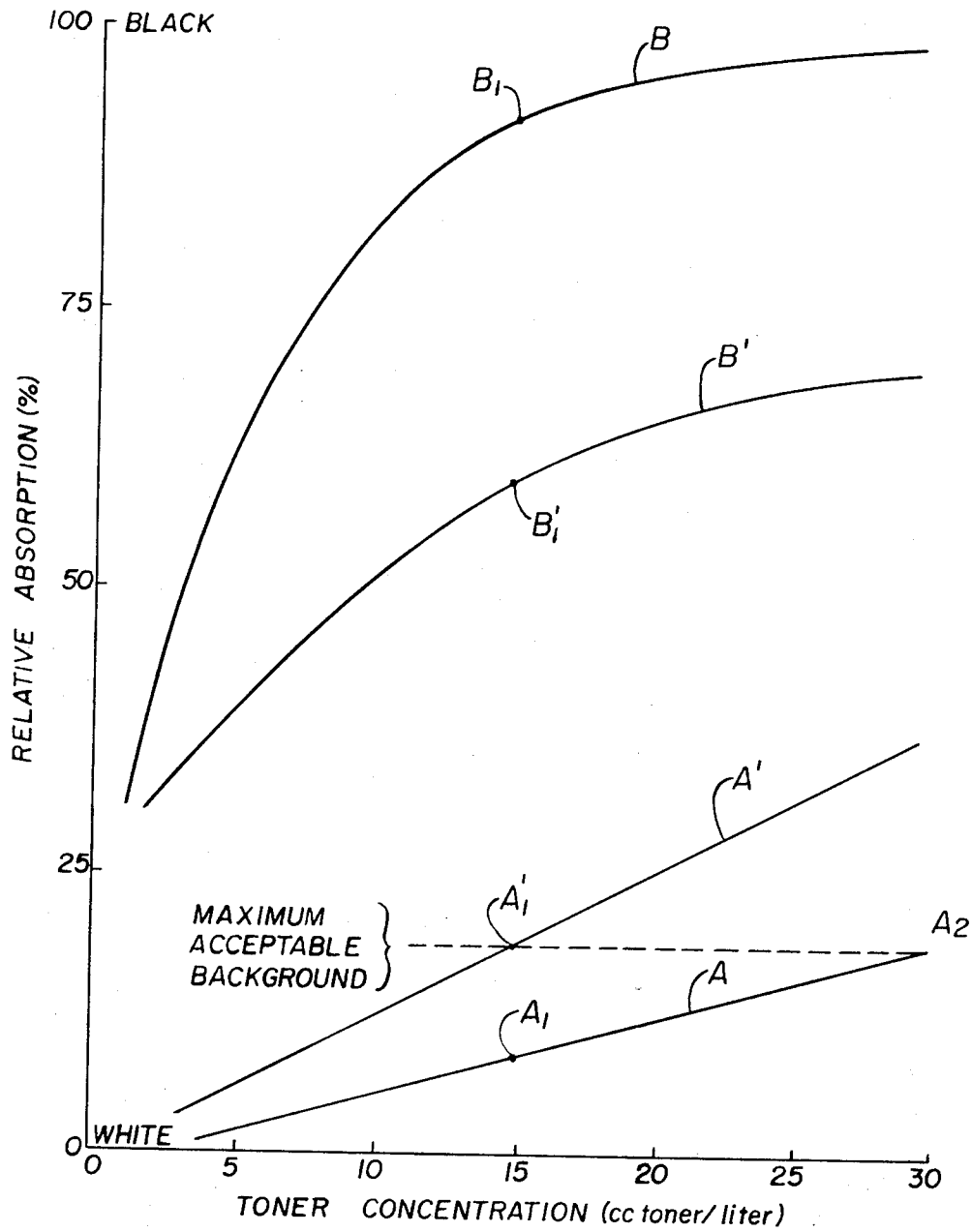

100
BLACK
75
50
25
0
WHITE
RELATIVE ABSORPTION (%)
B
B1
B'
B1'
A'
A1'
A2
A
A1
MAXIMUM
ACCEPTABLE
BACKGROUND
0
5
10
15
20
25
30
TONER CONCENTRATION (cc toner/liter)

Fig. 4

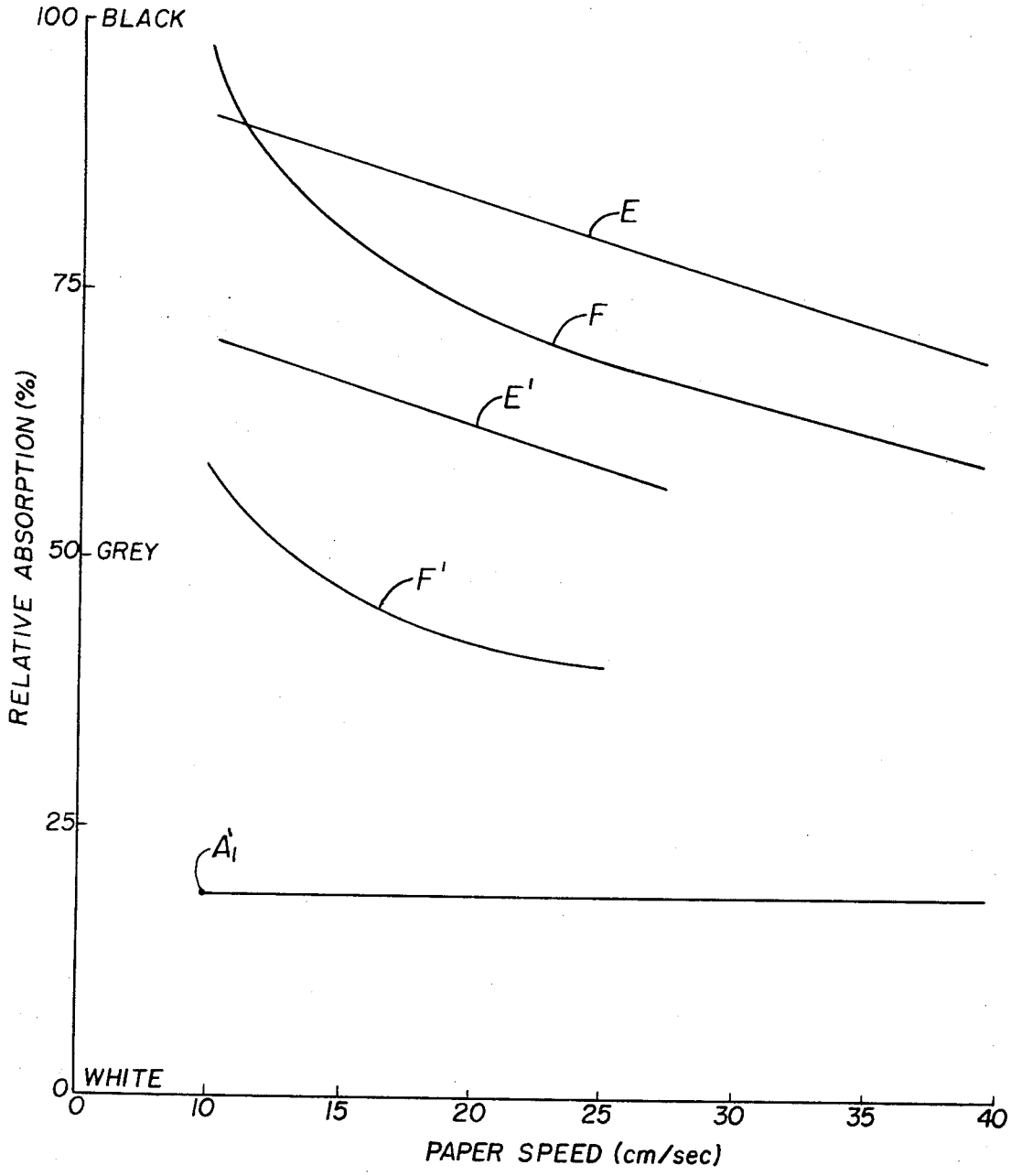

100 BLACK
75
50 GREY
25
0 WHITE
RELATIVE ABSORPTION (%)
E
F
E'
F'
A'1
0
10
15
20
25
30
35
40
PAPER SPEED (cm/sec)

Fig. 5

ELECTROSTATIC DEVELOPING SYSTEM WITH CYLINDRICAL DRUM LIQUID CONTACT UNIT

REFERENCE TO COPENDING APPLICATION

This application is a division of copending U. S. Patent application Ser. No. 813,531, filed Apr. 4, 1969 now U. S. Pat. No. 3669073.

BACKGROUND OF THE INVENTION

This invention relates to the art of electroprinting. In particular, it provides apparatus for developing electrostatic latent images with a liquid developer having solid particles suspended in a carrier. The advantages of liquid developing have been recognized, especially in process control, development time, compactness of equipment and image quality.

Such printing systems are used in photocopy machines, data printers, facsimile devices, multi-color printers, etc. Since a common utility for liquid developing of electrostatic patterns is found in office copy machines, most of the description is devoted to these types of machines; however, numerous applications for the invention exist and the teachings of this disclosure may be applied to other systems by a skilled worker.

A typical liquid electroprinting apparatus comprises (1) a photoconductive element which is capable of retaining an electrostatic charge on its surface which charge is removed from selected areas by exposure to electromagnetic radiation, such as a paper sheet or web coated with zinc oxide in a resin binder; (2) means for creating a uniform electrostatic charge over the photoconductive surface, e.g., a corona; (3) means for altering the charge in desired areas, such as an optical exposure system to form a latent image; (4) means for directing the surface bearing a latent electrostatic image in contact with a liquid developer composition; and (5) means for separating the developed surface from the liquid developer. The present invention is directed specifically to the developing step in which the latent electrostatic image is contacted with a liquid carrier having finely divided opaque particles which are attracted to the charged areas of the latent image and deposited on the surface.

The common types of liquid developing machines use an immersion technique in which a copy paper bearing the latent image is dipped into a tank containing a volatile hydrocarbon liquid carrier with suspended carbon particles. Total immersion of the copy paper results in excessive pickup of developer liquid, and longer drying time is needed to remove the volatile carrier from the developed copy. Also, contacting the unimaged back side with liquid developer is objectionable because of retention of developer particles which contact the back side. In previous liquid developer systems using the immersion tank method, the use of a sealing coat has been necessary to provide a barrier for preventing particle accumulation on the back side.

While electrostatic printing can be applied to numerous combinations of background and toner colors, this discussion and the description of the invention will be directed primarily to the development of latent images on a white paper with black toner particles. A goal of many workers in the electroprinting or electrophotography field is to produce an office copy machine or the like which is capable of reproducing a variety of materials. Line copy such as typewritten material can be reproduced with sufficient fidelity by many electrostatic systems; but half-tones or continuous tones, such as present in photographs, are a much greater challenge to the art.

Deposition of particles onto an electrostatically charged surface is effected by having opposite electrical charges between the imaged areas and the particles in suspension. In a typical liquid developer system an inert liquid carrier of high resistivity has small particles of opaque material dispersed in it. These toner particles usually include a pigment with a resin, which functions as a charge director and adhesive fixer. An electrical charge is developed due to surface coating phenomena as well as diffences in the dielectric properties of the carrier and toner materials. When an electrically insulating surface receives an electrostatic charge of opposite polarity to the toner particles, as by passing the surface through a corona, the toner particles are attracted to those portions of the surface which retain the electrostatic charge. This attraction results in deposition of particles on the surface, with most particles being deposited in those areas having a greater electrostatic charge. Some particles are adsorbed in uncharged areas and toner particles will mechanically adhere to completely uncharged sheets. In addition, the depositable particles in present commercial developers exhibit some of the properties of dipoles and consequently the shape of the field or, the field gradient, is as important as the average field strength of the latent image areas.

At the edge of a large latent image area the change in the field is at its maximum, and toner particles are ordinarily deposited more heavily in such areas. This phenomenon is known as edge enhancement, which represents a difficult problem in obtaining good copies for those patterns having large black areas. To render the charged area equally attractive to particle migration, an intensifier can be placed in contact with developer liquid and in close proximity to the charged surface during development. This intensifier is an electrically conductive structure which shapes the field by creating separate fields between the intensifier and each of the charged points on the latent image surface. The fields become geometrically normal to the surface. The intensifier can be grounded, biased with a direct current potential, or insulated electrically from the rest of the developer unit.

A second major problem in liquid developing of electrostatic latent images is that of local depletion of toner particles in the area of heavy deposits. In order to prevent excessive accumulation of particles on the uncharged or weakly charged background on the copy paper, liquid toner compositions are usually rather dilute. Typical developers contain only a few grams of depositable particles per liter of liquid. Accordingly, increasing the developer concentration to compensate for local depletion and increase the black density of copies is usually attended by increased particle deposition in the background areas.

SUMMARY OF THE INVENTION

It has been discovered that electrostatic images can be developed by contacting the surface bearing of the latent image with a liquid carrier having suspended toner particles carried on a moving foraminous surface and having an integral or closely adjacent intensifier. In the apparatus of this invention developer liquid is distributed evenly between the image-bearing surface and a cylindrical drum having a network of small holes

which permits excess developer carrier and particles to be removed from the interface between the charged surface and the foraminous surface while providing a controlled volume of liquid developer in reservoirs adjacent the developing copy. The spacing of the intensifier from the charged surface can be closely controlled to obtain even deposition throughout large black areas. This is accomplished by constructing the developer system with a conductive foraminous roll surface or supporting a non-conductive porous surface with the intensifier structure. The foraminous contact surface is constructed to move along with the sheet or web of copy paper by providing a continuous band in the form of a rotary drum. This system results in high developing speed, good black density, even distribution of toner particles in large black areas, and low background levels.

THE DRAWING

FIG. 1 is a schematic side view of a developing system, showing a drum-type liquid contact section, copy feed and separation units;

FIG. 2 is a side view of the developer drum of FIG. 1, partially cut away;

FIG. 3 is an enlarged scale cross-section view of a latent image-bearing paper in contact with a wire mesh foraminous surface during developing;

FIG. 4 is a graphic plot of light absorption vs. toner concentration; and

FIG. 5 is a graphic plot of absorption vs. developing speed.

DESCRIPTION OF THE INVENTION

The primary functions of the liquid developing systems according to the present invention include the shaping of the electrostatic field during particle deposition to effect a controlled point-to-point accumulation of toner solids in which adjacent charged areas in the latent image have a minimum influence on one another, and providing a sufficient reservoir of dispersed toner particles to compensate for local depletion at the interface between the liquid developer and heavily-charged image areas. In order to achieve these objects, a careful consideration of the properties of each component of the system is valuable.

The developer liquid itself has two main components, a carrier liquid and suspended solid opaque particles. In a typical system the carrier liquid consists essentially of an inert organic material having high electrical resistivity (low conductivity); the more common carriers, such as mineral spirits, have a resistivity value in the range of about 10^{10} to 10^{18} ohm-cm, with 10^{14} to 10^{15} ohm-cm being preferred. In order to promote high electrophoretic mobility of the charged toner particles during the deposition process, low viscosity is also desirable, especially for high-speed printing systems. Numerous desirable carriers exist which have viscosities in the thinner ranges, usually from less than a centipoise to several centipoises. Another property which should be considered in the wetting of the image-bearing copy surface and foraminous surface by the carrier. This is usually no problem where ordinary liquid carriers and materials of construction are used, but there should be sufficient affinity between the carrier liquid and foraminous surfaces to assure an adequate supply of developer liquid in the reservoirs of the foraminous surface adjacent the latent image.

The developer particles for use with high resistivity organic carriers are preferably mixtures of solid pigments and charge-directing resins with a particle size up to a few microns. Stable dispersions of carbon black particles in mineral spirits can be formed with the aid of dispersants. The preferred particle sizes are less than one micron average size; but, particles larger than one micron can be tolerated if no plugging of the system results. Typical developer compositions including carbon black, asphalt and resin are described in U. S. Pat. No. 3,399,140. Other finely divided opaque particles may be used provided they give the necessary deposition density and can migrate electrophoretically in a liquid carrier. The high electrical resistivity of the liquid carrier permits suspended colloidal particles to retain electrical charge, and these suspended particles migrate toward the oppositely charged areas of the latent image by electrophoresis. Also, the high resistivity of the carrier prevents discharge of the latent image areas. This attraction between toner particle and image surface is sufficient to hold the deposited particle until it is fixed. Even when the developed image is subject to rapid movement of fluid, most of the deposited particles adhere in the desired areas.

The advantages of this invention can be achieved with several modifications of the foraminous roll. Since the image-bearing surface is usually copy paper having thin cellulosic substrate and a photoconductive coating, the flexibility of the copy can be used in the design of mechanical components for making a cylindrical drum developer system. The desired control of the electrostatic field shape can be achieved either with a non-conductive foraminous roll in combination with a conductive intensifier or with an integral structure in which the foraminous roll is constructed of an electrically conductive material, such as metal, low-resistance elastomers or carbon fibers. The foraminous surface can be provided by weaving the outer roll surface, or by providing a perforated sheet. The opening size is important because excess liquid developer having toner particles is removed from the interfacial area between the copy and the band by passing through the pores of the band. The openings must not be so large as to prevent the formation of the liquid reservoirs in the openings of the band. The precise maximum size is determined by the surface tension of the liquid on the developer roll surface material, thickness of the foraminous structure and superficial ratio of solid areas to open areas. For most developer compositions, a maximum toner particle size is about 5 to 20 microns, but high quality liquid toners have mostly submicron particles. It has been found that image quality deteriorates when the openings are larger than about 450 microns. For a drum-type developer system, the preferred pore size is 35 to 400 microns, which corresponds to about 400 to 40 mesh size (U. S. Sieve). The ratio of open area to closed area is usually about 9:1 to 1:9.

A preferred embodiment of the liquid developing system is shown in FIGS. **1** and **2**, where a flexible copy paper **10** is fed to the developer section by guide rolls **15** and **15'**. The latent image-bearing surface enters the development contact zone tangential to a foraminous drum surface **20**, comprising a woven metal screen **20A** held on a support roll **23**. The drum **20** is wider than the extremities of the sheet or web **10**, to assure development of the entire electrostatic image. A suitable drive system, such as an electric motor, provides means for

rotating the drum **20** co-directionally with the advance of the image-bearing surface **10.** A helical groove **23'** between the body of inner roll **23** and screen **20A** permits excess liquid developer **32** to be removed from the interfacial development zone. The flexible copy paper **10** is guided around the cylindrical drum **20A** by a plurality of support ribs **38.** These ribs are located within developer tank **30** and are spaced apart from the drum surface **20A.** The spacing can be varied by adjusting the distance between the ribs and the foraminous roll surface. Developer tank **30** is positioned under the cylindrical drum **20** and a desired amount of liquid developer composition is maintained in the tank, by liquid level sensing or other means for controlling quantity. Liquid developer is distributed onto the foraminous surface **20** by a flow control system comprising a pump and spray header **35** having a plurality of holes spaced laterally across the width of the drum **20.** The fluid pumping rate need not be closely controlled provided there is sufficient liquid developer provided to completely develop the electrostatic images. One of the main advantages of this invention is the inherent regulation of liquid developer which results from this system. The even distribution of carrier and toner particles is achieved by the flow of excess liquid developer through the pores of the drum **20.** This is observed when the liquid flows over the band surface and is removed by gravity or by pressure of the copy paper on the band. While there is no critical relationship beyond the minimum amount of developer liquid supplied, a flow rate of about 4–12 milliliters of liquid developer per minute per square cm. of outside drum surface area is satisfactory for a typical system using a 100 mesh foraminous roll and a linear developing speed of 10–30 cm/sec.

The proper amount of liquid developer adheres to the drum, forming liquid reservoirs in the interstitial areas between the solid portions of the drum and creating a thin film of liquid at the interface between the image-bearing surface **10** and drum **20.**

When local depletion of the particles from the film adjacent areas of heavy electrostatic charge occurs, the toner particles migrate electrophoretically from the reservoirs in fluid communication with the thin film and reconstitute the particle concentration in the film.

Eccentricity in the drum surface can cause uneven deposition due to the alterations in the electrostatic field caused by variable intensifier distance from the charged paper. Surface deviations of more than ½ percent of the roll diameters should be avoided.

The support roll **23** can be constructed of a perforated metal tube having large holes (0.2–1 cm. diameter) uniformly spaced around the cylindrical surface to permit the flow of liquid from the mesh cover **20A.** The type of configuration shown in FIGS. **1** and **2** is useful for supporting 90 + mesh screens.

The position of the liquid distributor **35** is not critical, but best results were obtained when the liquid stream contacted the drum surface along a lateral line about midpoint above the radial center and periphery of the drum. A portion of liquid **32** flows toward the interior of foraminous screen **20A,** along a channel formed by helical groove **23',** and over the side edge of the paper. Reversal of direction for the flexible paper as it passes through the development section provides a liquid trough, and a portion of the liquid developer is retained on the outer surface of the durm **20** and the excess flows laterally over the sides of the trough into the tank **30.** The exit squeeze rolls **40** and **40'** are arranged to maintain a contact angle of about 90° to 190° around the lower half of the drum.

The enlarged cross-section view in FIG. **3** shows a woven wire mesh foraminous surface **20A** supported on a grooved support **23, 23'** as in FIG. **2.** A quantity of liquid developer **32** is carried by the wire mesh **20A** in the interstitial volumes between the wires, with excess liquid being removed through grooves **23'.** An image-bearing surface is in direct contact with the liquid developer. A paper sheet **10** is coated with a layer **11** of photoconductive material, such as zinc oxide in a binder. The interconnected points on the wire mesh serve as an integral intensifier.

The liquid carrying capacity of the wire mesh was measured for the roll configuration shown in FIGS. **1, 2,** and **3.** A support tube was cut with a helical groove (No. 11NC) having a flat land spacing of about 0.2 mm between grooves. A 90 mesh stainless steel screen was laid over the grooves. The drum diameter was about 5 cm and the length was about 25 cm. This drum structure was immersed in a typical liquid developer diluted with mineral spirit carrier. The mesh plus grooves held about 50 ml of liquid, while the mesh held about 15 ml after draining the helical groove. Dividing this value by the superficial surface area of the foraminous surface gives a unit liquid carrying capacity of about 0.04 ml/cm^2.

A series of experiments were conducted to compare the operation of the foraminous carrier and intensifier developing system to that of a standard immersion tank developer. These tests were conducted under standard conditions using two commercial electrostatic office copy machines (Apeco "Super-Stat") and commercial toner concentrate, diluent, and electrostatic copy paper. The only modification made in the machines was to replace the standard immersion tank developer with a 5 cm dia. developer roll mechanism and tank as shown in FIG. **1.** In the machines the electrostatic image is formed by passing the coated paper through a corona discharge and exposing the uniformly charged surface to light in selected areas by projecting an optical image onto the charged surface. After developing and drying the copies, measurements were made on a light absorption meter to determine how the copy background and image black density for the foraminous band system compared with the background and black of the original. The relative absorption is a measure of the light absorption changes from a white copy paper (0 percent) to a completely coated black area (100 percent).

These tests were made using a standard paper speed of 10 cm/sec. Referring to FIG. **4** of the drawing, line A shows the increase in background deposition for the improved foraminous belt system while the higher line A' shows the background for the conventional immersion system. The maximum acceptable background (A'_1) is reached at 15 cc/l for the conventional system, while the improved system can use a toner concentration of 30 cc/l (A_2) to retain this maximum, and has a lower background (A_1) at the 15 cc/l concentration.

The measurement of absorption at the center of large black areas (1 × 2 cm.) demonstrates the uniformity with which such patterns are developed in the improved system. At the 15 cc/l concentration, absorption for areas developed by the improved system (point

B_1 on line B) is about 50 percent greater than for the corresponding absorption (point B'_1) for the immersion system. This improved uniform density may be explained by the availability of toner particles in the interstitial areas of the foraminous band adjacent the latent image. The reduction in background deposition is due to the direction of toner to the charged areas and to increased turbulence at the surface of the copy.

An experimental device was constructed to establish the advantages of the improved developer for changes in linear paper velocity. The copies were charged and illuminated at standard operating speed and then released to fall through a guide into either a standard immersion developer tank with paper feed rollers, or the improved foraminous drum developer mechanism as illustrated in FIG. 1.

Both developers were capable of driving the copy paper at speeds between 5 cm/sec. and 40 cm/sec. and the developer path length was the same. The toner concentration was adjusted for each system to obtain equal background levels. Since the improved foraminous band system produces low background levels, the toner concentration was about twice that of the conventional immersion developer to produce equal background levels. In FIG. 5, this level is shown as being equal for both the immersion system and improved system with the background level corresponding to point A'_1 of FIG. 4. After developing and drying the copies, the image area and background levels were measured with a light absorption meter. FIG. 5 illustrates the results of increasing the paper speed through the developer tanks. Both the standard developer and the improved developer show similar rates of decrease in black density as speed increases.

Line E shows the relative absorption for line copy made by the improved roll-type developer (FIG. 1). Line E shows that deposition is considerably less for the conventional immersion type developer. Lines F and F' represent the relative absorption at the center of large areas for the improved and immersion systems, respectively. In each of these tests, the improved system produces about the same shape of the curve for absorption vs. linear speed, but the improved systems result in greater deposition of toner particles.

The standard prior art immersion system has a practical limit to paper speed at about 20 to 25 cm/sec. This is the result of the mechanical difficulties of forcing the paper through a curve while immersed in fluid. In the improved developer, the foraminous carrier assists the paper and controls its path as well, which allows paper speeds in excess of 40 cm/sec. to be practically attainable.

In addition to the advantages illustrated graphically in FIGS. 4 and 5, the improved developer allows the copy to be completely dry on the reverse side. This means that the copy carries only half of the fluid normally adhering to the copy and, therefore, only half as much fluid needs to be evaporated in drying. This also contributes to a distinct improvement in efficiency.

While the invention has been described with reference to specific examples, there is no intent to limit the inventive concept except as set forth in the following claims.

We claim:

1. In a liquid developing system wherein latent electrostatic images are developed by contacting a flexible latent image-bearing surface with a liquid developer composition having developer particles suspended in a liquid carrier, the improvement which comprises:

a cylindrical drum liquid contact means having a substantially uniform foraminous outer surface with openings of about 35 to 450 microns forming reservoirs for carrying liquid developer;

means for advancing the image-bearing surface downwardly into direct contact with liquid developer carried on the foraminous surface;

support means for guiding the flexible latent image-bearing surface around the drum;

means for rotating the drum co-directionally with the advance of the image-bearing surface;

means for distributing liquid developer on the outer surface of the drum to provide developer particles suspended in the reservoirs adjacent the image-bearing surface;

electrostatic field shaping means in electrical contact with developer closely adjacent to the image-bearing surface and substantially coextensive with the effective area of contact between the image-bearing surface and developer liquid distributed in the reservoirs of the foraminous surface; and

means for advancing the image-bearing surface upwardly and separating the developed image-bearing surface from the drum and removing excess liquid, whereby reversal of direction of the flexible latent image-bearing surface as it passes around the drum provides a trough for containing liquid developer and thereby prevents liquid developer from contacting more than one side of the image-bearing surface.

2. The liquid developing system of claim 1 including means for collecting excess liquid developer from the drum in a developer tank below the drum, means for maintaining a predetermined amount of liquid developer above the drum between the foraminous surface and the image-bearing surface.

3. The liquid developing system of claim 1 including means for advancing the image-bearing surface tangentially to the foraminous surface.

4. The liquid developer system of claim 3 wherein the cylindrical drum comprises a foraminous surface supported on an inner support having a helical groove for receiving liquid developer from the foraminous surface.

5. The liquid developer system of claim 1 including means for varying the spacing between the support means and drum.

6. The liquid developer system of claim 1 including means for distributing liquid developer onto an upper surface of the drum.

7. The liquid developer system of claim 1 wherein the foraminous surface consists essentially of an electrically-conductive material thereby providing an integral field shaping means.

8. The liquid developer system of claim 7 wherein the foraminous surface consists essentially of a metal structure having electrically interconnected land areas with discrete openings to provide liquid reservoirs in the interstitial areas between the metal land areas.

9. The liquid developer system of claim 8 wherein the superficial ratio of land area to open area is about 1:9 to 9:1.

10. The liquid developer system of claim 7 wherein the foraminous surface consists essentially of a woven

metal-containing cloth fabric screen of about 40 to 400 mesh.

11. In a liquid developing system wherein a flexible web or sheet carrying a latent electrostatic image on one surface is contacted with a liquid developer having developer particles suspended in a liquid carrier, the improvement which comprises:

a rotary cylindrical drum intensifier having a substantially uniform electrically-conductive surface with openings sufficiently large to pass developer particles and a foraminous surface forming reservoirs for carrying liquid developer;

means for advancing the sheet or web downwardly toward the drum in a tangential direction with the surface carrying the latent image in facing contact with the drum;

means for distributing liquid developer onto an upper surface of the drum to provide liquid developer between the drum and the web or sheet and to fill the reservoirs on the foraminous surface with liquid developer;

support means spaced apart from the drum for guiding the flexible web or sheet around the drum, thereby forming a trough with the web or sheet for containing excess liquid developer and maintaining contact of developer with the surface carrying the latent image only;

a developer tank positioned under the drum for receiving liquid developer; and

means for removing excess liquid developer through the openings of the drum intensifier and flowing the excess liquid developer outwardly from the web or sheet surface into the developer tank; and

means for separating the web or sheet bearing a developed image from the drum.

12. The liquid developing system of claim **11** wherein the support means comprises a plurality of curved ribs spaced apart from the drum providing a contact angle for the web or sheet under the drum of about 90° to 190°.

13. The liquid developing system of claim **11** including means for distributing liquid developer from the developer tank above the drum between the foraminous surface and the web or sheet.

14. The liquid developing system of claim **13** wherein the drum has a surface liquid carrying capacity of at least about 0.04 ml/cm².

15. The liquid developing system of claim **11** wherein the openings on the drum intensifier are about 35 to 450 microns in size.

16. The liquid developing system of claim **15** wherein the foraminous surface consists essentially of a metal structure having electrically interconnected land areas with discrete openings to provide liquid reservoirs in the interstitial areas between the metal land areas, and wherein the superficial ratio of land area to open area is about 1:9 to 9:1.

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