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(54) **Method and apparatus for liquid development**

(57) An electrostatic latent image development method and apparatus, includes a process nip (59) formed by operative engagement of first (10) and second (40) movable members for positioning a thin layer (58) of liquid developing material (54) in pressure contact with an electrostatic latent image which generates imagewise electric fields across the layer (58) of liquid developing material in the process nip (59). The process nip (59) is defined by a nip entrance and a nip exit, wherein the process nip and the nip entrance are operative to apply compressive stress forces on the layer (58) of liquid developing material thereat, and the nip exit is operative to apply tensile stress forces to the layer of liquid developing material, causing imagewise separation of the layer of liquid developing material corresponding to the electrostatic latent image. The layer (58) of liquid developing material is defined by a yield stress threshold in a range sufficient to allow the layer of liquid developing material to behave substantially as a solid at the nip entrance and in the nip (59), while allowing the layer of liquid developing material to behave substantially as a liquid at the nip exit.

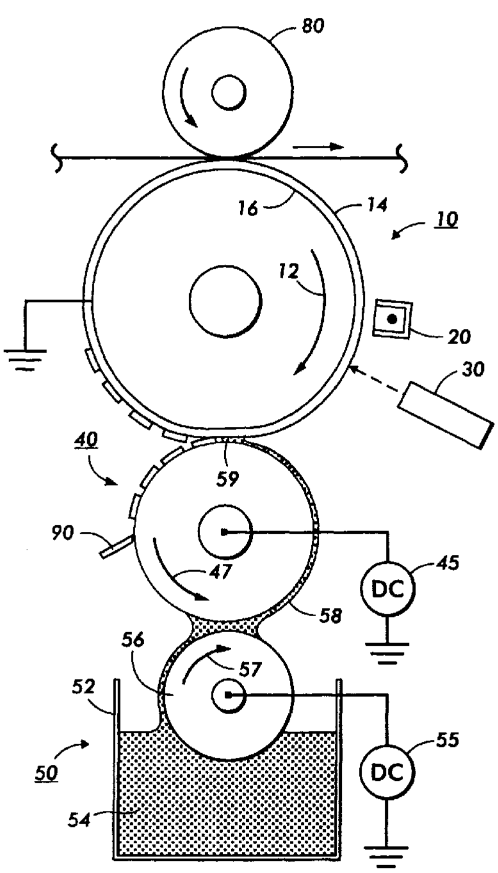

FIG. 1

EP 0 913 743 A2

Description

[0001] This invention relates generally to liquid developing material based electrostatic latent image development, and, more particularly, concerns a method and apparatus for development of an electrostatic latent image, wherein a substantially uniform layer of liquid developing material is brought into pressure contact with a latent image bearing surface in the vicinity of an electric field for causing selective image-wise separation of the liquid developing material layer to produce a desired output image corresponding to the latent image.

[0002] Generally, processes for electrostatographic copying and printing are initiated by selectively charging and/or discharging a charge receptive imaging member in accordance with an original input document or an imaging signal in order to generate an electrostatic latent image on the imaging member. The electrostatic latent image is subsequently developed into a visible image by a process in which charged toner particles are brought into the vicinity of the latent image and caused to migrate to image areas of thereof. Typically, the developing material may be comprised of carrier granules having marking or toner particles adhering triboelectrically thereto, wherein the toner particles are electrostatically drawn away from the carrier granules and attracted to the latent image areas to create a powder toner image on the imaging member. Alternatively, the developing material may comprise a liquid developing material comprising a carrier liquid having charged pigmented marking particles (or so-called toner solids) immersed therein, wherein the charge on the marking particles is created by a soluble ionic surfactant, or so-called charge director material dispersed and/or dissolved in the liquid carrier/marking particle composition to create an electrochemical reaction which results in the exchange of ionic species between the marking particles and micelles formed by the charge director. In the case of traditional liquid developing material based development processes, the liquid developing material is generally applied to the surface of a latent image bearing member, with the charged marking particles being caused to electrophoretically precipitate from the liquid developing material dispersion so as to migrate to and be deposited upon the image areas of the latent image to form a developed liquid image.

[0003] Regardless of the type of developing material employed, the toner or marking particles of the developing material are typically uniformly charged and attracted to the latent image via electrostatic fields for forming a visible developed image corresponding to the latent image on the imaging member. The developed image is subsequently transferred, either directly or indirectly, from the imaging member to a copy substrate, such as paper or the like, to produce a "hard copy" output document. In a final step, the imaging member is cleaned to remove any residual developing material and/or charge therefrom in preparation for a subsequent image forming cycle.

[0004] The above-described electrostatographic process is well known and has been implemented in various forms to facilitate, for example, so-called light lens copying of an original document, as well as for printing of electronically generated or digitally stored images where the electrostatic latent image is formed via a modulated laser beam. Analogous processes also exist in other electrostatic printing applications such as, for example, ionographic printing and reproduction where charge is deposited in image-wise configuration on a dielectric charge retentive surface (see, for example, U. S. Patent No. 4,267,556 and 4,885,220, among numerous other patents and publications), as well as other electrostatic printing systems wherein a charge carrying medium is adapted to bear an electrostatic latent image. It will be understood that the instant invention applies to all various types of electrostatic printing systems and is not intended to be limited by the manner in which the image is formed on the imaging member or the nature of the latent image bearing member itself.

[0005] As described hereinabove, the typical electrostatographic printing process includes a development step whereby developing material including toner or marking particles is physically transported into the vicinity of a latent image bearing imaging member, with the toner or marking particles being caused to migrate via electrical attraction of toner or marking particles to the image areas of the latent image so as to selectively adhere to the imaging member in an image-wise configuration. The development process is most effectively accomplished when the particles carry electrical charges opposite in polarity to the latent image charges, with the amount of toner or marking particles attracted to the latent image being proportional to the electrical field associated with the image areas. Some electrostatic imaging systems operate in a manner wherein the latent image includes charged image areas for attracting developer material (so-called charged area development (CAD), or "write white" systems), while other printing processes operate in a manner such that discharged areas attract developing material (so-called discharged area development (DAD), or "write black" systems).

[0006] Numerous and various alternative methods of developing a latent image have been described in the art of electrophotographic printing and copying systems. Of particular interest with respect to the present invention is the concept of forming on a surface a thin layer of liquid developing material having a high concentration of charged marking particles, with the layer being brought into contact with an electrostatic latent image on another surface, wherein development of the latent image occurs upon separation of the first and second surfaces, as a function of the electric field strength generated by the latent image. In this process, toner particle migration or electrophoresis is replaced by direct surface-to-surface transfer of a toner layer induced by image-wise fields. For the purposes of the present description, the concept for latent image development via direct surface-to-surface transfer of a toner layer via imagewise fields will be identified generally as Contact Electrostatic Printing (CEP). Exemplary patents which may describe certain general aspects of CEP, as well as specific apparatus therefor, may be found in U.S. Patent No. 5,436,706 and 5,596,396, issued to Landa et al., as well as other patents cited therein.

[0007] Image quality in electrostatographic printing applications, including CEP, may vary significantly due to numerous conditions affecting image development, among various other factors, including but certainly not limited to the materials and particle interaction within the liquid developing material, as well as charge levels, both in the latent image, as well as in the developing material itself, which generate the electric fields necessary to cause toner migration, electrophoretic precipitation or, in the case of CEP, selective imagewise toner layer separation for producing the desired output image. Moreover, in the specific case of CEP, wherein a layer of liquid developing material is subjected to contact pressure in addition to electrical fields, it has been found that the behaviour of the fluid layer under pressure or stress forces is also an important factor in defining the image quality of the output image. In this regard, it is important to note that different liquid materials display different flow behaviours when different stresses are applied thereto.

[0008] It is well known that simple fluid such as water, isopar, can be characterized by a single viscosity. It can be shown that the viscosity of a complex fluid such as a liquid developing material will vary as a function of the stress applied thereto. Indeed, a specific parameter, known as yield stress, is commonly used to characterize a given complex fluid in terms of known rheological properties corresponding to a minimum threshold stress below which the liquid behaves as a solid and above which the material behaves as a liquid. Thus, certain fluid or liquid compounds will not flow unless acted upon by at least some critical stress. The yield stress is typically expressed in terms of shear stress. However, the yield stress characteristic can also be related to other stresses which can be applied to a complex fluid layer, including compression or tensile stresses. The yield stress becomes a required parameter for defining or describing the threshold stress below which the flow of fluid compound is zero or at least negligible, and is generally a function of the materials making up the liquid, as well the interaction of particles dispersed in the liquid, and the relative concentrations thereof. It is also important to note that electrical fields can change the yield stress threshold of a liquid material.

[0009] In the case of liquid developing materials and their use in electrostatographic processes, in particular, Contact Electrostatic Printing processes, the liquid developing material, in the form of a thin layer supported on a surface which is brought into pressure contact with a second surface in a development nip formed therebetween, is exposed to at least two stresses: a compressive stress in the nip as well as at the entrance thereof; and a tensile stress at the nip exit as the developed image is separated into image areas on one surface and background areas on the other surface. In order to optimize the resultant image quality, it is desirable that the toner layer have sufficient yield stress to allow the toner particles therein to maintain their integrity while being exposed to these particular stress forces. Thus, preselecting materials having a particular yield stress and selectively varying the yield stress of a given liquid developing material, can be particularly useful in defining operational parameters for optimization of a contact electrostatic printing process.

[0010] US-A-5,596,396 discloses an imaging apparatus including: a first member having a first surface having a latent electrostatic image formed thereon, wherein the latent electrostatic image includes image regions at a first voltage and background regions at a second voltage; a second member charged to a third voltage intermediate the first and second voltages and having a second surface adapted for resilient engagement with the first surface; and a third member adapted for resilient contact with the second surface in a transfer region. The imaging apparatus also includes an apparatus for supplying liquid toner to the transfer region to form on the second surface a thin layer of liquid toner containing a relatively high concentration of charged toner particles, as well as an apparatus for developing the latent image by the selective transfer of portions of the layer of liquid toner from the second surface to the first surface.

[0011] US-A-5,619,313 discloses a method and apparatus for simultaneously developing and transferring a liquid toner image. The method includes the steps of moving a photoreceptor including a charge bearing surface having a first electrical potential, applying a uniform layer of charge having a second electrical potential onto the charge bearing surface, and image-wise dissipating charge from selected portions on the charge bearing surface to form a latent image electrostatically, such that the charge-dissipated portions of the charge bearing surface have the first electrical potential of the charge bearing surface. The method also includes the steps of moving an intermediate transfer member biased to a third electrical potential that lies between said first and said second potentials, into a nip forming relationship with the moving imaging member to form a process nip. The method further includes the step of introducing charged liquid toner having a fourth electrical potential into the process nip, such that the liquid toner sandwiched within the nip simultaneously develops image portions of the latent image onto the intermediate transfer member, and background portions of the latent image onto the charge bearing surface of the photoreceptor.

[0012] In accordance with one aspect of the present invention, there is provided an imaging system comprising: a first movable member for having an electrostatic latent image formed thereon including image areas defined by a first voltage potential and non-image areas defined by a second voltage potential; a second movable member for having a layer of liquid developing material coated thereon; and a process nip formed by operative engagement of said first movable member and said second movable member for positioning the layer of liquid developing material in pressure contact with said first movable member, wherein the electrostatic latent image on said first member generates imagewise electric fields across the layer of liquid developing material in said process nip; said process nip being defined by a nip entrance and a nip exit, wherein the nip and the nip entrance are operative to apply compressive stress forces on the layer of liquid developing material thereat, and the nip exit is operative to apply tensile stress forces to the layer of liquid developing material for causing imagewise separation of the layer of liquid developing material thereat, for creating a developed image corresponding to the electrostatic latent image; and the layer of liquid developing material being defined by a yield stress threshold in a range sufficient to allow the layer of liquid developing material to behave substantially as a solid at the nip entrance and in the nip, while allowing the layer of solid-like liquid developing material to fail under image-wise tensile stress along image-background boundary at the nip exit.

[0013] In accordance with another aspect of the present invention, an electrostatographic imaging process is disclosed, comprising: providing a first movable member for having an electrostatic latent image formed thereon including image areas defined by a first voltage potential and non-image areas defined by a second voltage potential; providing a second movable member for having a layer of liquid developing material coated thereon; and forming a process nip by operative engagement of said first movable member and said second movable member, said process nip being defined by a nip entrance and a nip exit; positioning the layer of liquid developing material in pressure contact with said first movable member in said process nip, wherein the electrostatic latent image on said first member generates imagewise electric fields across the layer of liquid developing material in said process nip; applying compressive stress forces on the layer of liquid developing material at the nip and the nip entrance; applying tensile stress forces to the layer of liquid developing material at the nip exit for causing imagewise separation of the layer of liquid developing material thereat; and providing the layer of liquid developing material so as to have a yield stress threshold in a range sufficient to allow the layer of liquid developing material to behave substantially as a solid at the nip entrance and in the nip, while allowing the liquid developing material along the image-background boundary to behave substantially as a liquid at the nip exit.

[0014] Particular embodiments of a method and apparatus in accordance with this invention will now be described with reference to the accompanying drawings; in which:-

FIG. 1 is an elevational view schematically depicting a contact electrostatic printing (CEP) apparatus of the type used for development of an electrostatic latent image by placing a layer of concentrated liquid developing material in pressure contact with a latent image bearing surface;

FIG. 2 is another elevational view schematically depicting an alternative embodiment of a CEP apparatus in accordance with the present invention, incorporating an optional subsystem for varying toner solids concentration in a layer of liquid developing material in order to provide a liquid developing material layer having an optimized yield stress for the CEP process;

FIG. 3 shows a more detailed illustration of the CEP process, and, in particular, the process nip in which compressive and tensile stress forces are applied to the layer of developing material in the vicinity of imagewise electric fields for generating a developed image in accordance with the present invention; and

FIG. 4 shows a graphic representation of the relationship between shear stress and viscosity for liquid developing materials having various toner particle concentration levels, illustrating the yield stress threshold thereof.

[0015] Reference is now made to FIG. 1 which illustrates an imaging apparatus constructed and operative in accordance with a preferred embodiment of the present invention. The apparatus of FIG. 1 comprises a first movable member in the form of an imaging member 10 including an imaging surface of any type capable of having an electrostatic latent image formed thereon. An exemplary imaging member 10 may include a typical photoconductor or other photoreceptive component of the type known to those of skill in the art of electrophotography, wherein a surface layer 14 having photoconductive properties is supported on a conductive support substrate 16. Although the following description will describe, by example, a system and process in accordance with the present invention incorporating a photosensitive imaging member, it will be understood that the present invention contemplates the use of various alternative imaging members as are well known in the art of electrostatographic printing, including, for example, but not limited to, non-photosensitive imaging members such as a dielectric charge retaining member of the type used in ionographic printing machines, or electroded substructures capable of generating charged latent images.

[0016] Imaging member 10 is rotated, as indicated by arrow 12, so as to transport the surface thereof in a process direction for implementing a series of image forming steps in a manner similar to typical electrostatographic printing processes. It will be understood that, while imaging member 10 is shown and described herein in the form of a drum, the imaging member may alternatively be provided in the form of a continuous flexible belt which is entrained over a series of rollers, and is movable in the same direction as shown.

[0017] Initially, in the exemplary embodiment of FIG. 1, the photoconductive surface 14 of imaging member 10 passes through a charging station, which may include a corona generating device 20 or any other charging apparatus for applying an electrostatic charge to the surface of the imaging member 10. The corona generating device 20 is provided for charging the photoconductive surface 14 of imaging member 10 to a relatively high, substantially uniform electrical charge potential. It will be understood that various charging devices, such as charge rollers, charge brushes and the like, as well as inductive and semiconductive charge devices, among other devices which are well known in the art, may be utilized at the charging station for applying a charge potential to the surface of the photosensitive imaging member 10.

[0018] After the imaging member 10 is brought to a substantially uniform charge potential, the charged surface thereof is advanced to an image exposure station, identified generally by reference numeral 30. The image exposure station projects onto the charged photoconductive surface a light image corresponding to the input image. In the case of an imaging system having a photosensitive imaging member, the light image projected onto the surface of the imaging member 10 selectively dissipates the charge thereon for recording an electrostatic latent image on the photoconductive surface 14, wherein the electrostatic latent image comprises, in image configuration corresponding to the input image information, image areas defined by a first charge voltage potential and non-image areas defined by a second charge voltage potential. The image exposure station 30 may incorporate various optical image projection and formation components as are known in the art, and may include various well known light lens apparatus or digital scanning systems for forming and projecting an image from an original input document onto the imaging member 10. Alternatively, various other electronic devices available in the art may be utilized for generating electronic information to create the electrostatic latent image on the imaging member. It will be understood that the electrostatic latent image may be comprised of image and non-image areas that are defined by regions having opposite charge polarities or by regions having distinguishable first and second voltage potentials which are of the same charge polarity.

[0019] As previously noted hereinabove, in a typical electrostatographic printing process, after the electrostatic latent image is generated on the surface of an imaging member, the latent image is developed into a visible image by transporting developing material into the vicinity of the latent image bearing imaging member, wherein the differential voltage potentials associated with the image and non-image areas of the latent image induce the selective attraction of individual toner particles to image areas of the latent image. In the case of liquid developing material based systems, the liquid developing material transported toward the latent image is typically a low solids content liquid composition having a relatively low concentration of charged toner particles dispersed in a liquid carrier agent, wherein image development occurs due to electrophoretic precipitation of the charged toner particles from the liquid dispersion. By contrast, in accordance with the contact electrostatic printing process to which the present invention is directed, a thin layer of relatively high toner solids content liquid developing material having a relatively high concentration of charged toner particles dispersed in the liquid carrier agent is brought into pressure contact with the entire surface of the latent image bearing imaging member 10, whereby the developed image is created by separating and selectively transferring portions of the liquid developing material layer in correspondence with the image and non-image regions of the latent image. The layer of high solids content liquid developing material is generally characterized as having a solids content on the order of approximately 20% or greater, wherein the solids content of the liquid developing material is made up of charged marking or toner particles. Thus, in accordance with the contact electrostatic printing apparatus illustrated in FIG. 1, a liquid developing material delivery system is provided for transporting a layer of high solids content liquid developing material, or so called "toner cake", wherein the toner cake is separated into image and non-image segments. Image development occurs as a function of surface to surface transfer of an assemblage or aggregate of particles making up a particular section of the toner cake as opposed to electrostatic attraction of individual toner particles dispersed in a carrier liquid.

[0020] The toner cake has a solids content on the order of approximately 20% or greater and is brought into pressure contact with the surface of the imaging member 10. The toner cake can be created in various ways. In accordance with the exemplary embodiment of FIG. 1, a second movable member in the form of a liquid developing material layer applicator 40 is provided in combination with a liquid developing material supply apparatus 50, including a reservoir 52 adapted to accommodate a supply of liquid developing material 54, generally made up of toner particles immersed in a liquid carrier material and also typically including a charge director for providing a mechanism for producing an electrochemical reaction in the liquid developing material composition which generates the desired electrical charge on the toner particles.

[0021] Generally, the liquid carrier medium is present in a large amount in the introductory supply of developing material 54. Initially, the liquid carrier medium is present in an amount of from about 90 to as much as 99.5 percent by weight, although the percentage amount may vary from this range provided that the objectives of the present invention are achieved. By way of example, the liquid carrier medium may be selected from a wide variety of materials, including, but not limited to, any of several hydrocarbon liquids conventionally employed for liquid development processes, including hydrocarbons, such as high purity alkanes having from about 6 to about 14 carbon atoms, such as Norpar® 12, Norpar® 13, and Norpar® 15, and including isoparaffinic hydrocarbons such as Isopar® G, H, L, and N, available from Exxon Corporation. Other examples of materials suitable for use as a liquid carrier include Amsco® 460 Solvent, Amsco® OMS, available from American Mineral Spirits Company, Soltrol®, available from Phillips Petroleum Company, Pagasol®, available from Mobil Oil Corporation, Shellsol®, available from Shell Oil Company, and the like. Isoparaffinic hydrocarbons provide a preferred liquid media, since they are colorless, environmentally safe. These particular hydrocarbons may also possess a sufficiently high vapor pressure so that a thin film of the liquid evaporates from the contacting surface within seconds at ambient temperatures.

[0022] The toner particles or so-called marking particles can comprise any particulate material that is compatible with the liquid carrier medium, such as those contained in the liquid developing materials disclosed in, for example, U.S. Patents 3,729,419; 3,841,893; 3,968,044; 4,476,210; 4,707,429; 4,762,764; 4,794,651; and 5,451,483, among others. Preferably, the toner particles should have an average particle diameter ranging from about 0.2 to about 10 microns, and most preferably between about 0.5 and about 2 microns. The toner particles may be present in amounts of from about 5 to about 20 percent by weight, and preferably from about 1 to about 4 percent by weight of the developer composition. The toner particles can consist solely of pigment particles, or may comprise a resin and a pigment; a resin and a dye; or a resin, a pigment, and a dye or resin alone.

[0023] Suitable resins include poly(ethyl acrylate-co-vinyl pyrrolidone), poly(N-vinyl-2-pyrrolidone), and the like, including, for example Elvax®, and/or Nucrel®, available from E.I. DuPont de Nemours & Co. of Wilmington, Delaware. Suitable dyes include Orasol Blue 2GLN, Red G, Yellow 2GLN, Blue GN, Blue BLN, Black CN, Brown CR, all available from Ciba-Geigy, Inc., Mississauga, Ontario, Morfast Blue 100, Red 101, Red 104, Yellow 102, Black 101, Black 108, all available from Morton Chemical Company, Ajax, Ontario, Bismark Brown R (Aldrich), Neolan Blue (Ciba-Geigy), Savinyl Yellow RLS, Black RLS, Red 3GLS, Pink GBLS, and the like, all available from Sandoz Company, Mississauga, Ontario, among other manufacturers; as well as the numerous pigments listed and illustrated in U.S. Patents 5,223,368; 5,484,670, the disclosures of which are totally incorporated herein by reference. Dyes generally are present in an amount of from about 5 to about 30 percent by weight of the toner particle, although other amounts may be present provided that the objectives of the present invention are achieved.

[0024] Suitable pigment materials include carbon blacks such as Microlith® CT, available from BASF, Printex® 140 V, available from Degussa, Raven® 5250 and Raven® 5720, available from Columbian Chemicals Company. Pigment materials may be colored, and may include magenta pigments such as Hostaperm Pink E (American Hoechst Corporation) and Lithol Scarlet (BASF), yellow pigments such as Diarylide Yellow (Dominion Color Company), cyan pigments such as Sudan Blue OS (BASF); as well as the numerous pigments listed and illustrated in U.S. Patents 5,223,368; 5,484,670, the disclosures of which have been previously indicated to be incorporated by reference. Generally, any pigment material is suitable provided that it consists of small particles that combine well with any polymeric material also included in the developer composition. Pigment particles are generally present in amounts of from about 5 to about 60 percent by weight of the toner particles, and preferably from about 10 to about 30 percent by weight.

[0025] As previously indicated, in addition to the liquid carrier vehicle and toner particles which typically make up the liquid developer materials, a charge director (sometimes referred to as a charge control additive) is also provided for facilitating and maintaining a uniform charge on the marking particles in the operative solution of the liquid developing material by imparting an electrical charge of selected polarity (positive or negative) to the marking particles. Examples of suitable charge director compounds include lecithin, available from Fisher Inc.; OLOA 1200, a polyisobutylene succinimide, available from Chevron Chemical Company; basic barium petronate, available from Witco Inc.; zirconium octoate, available from Nuodex; as well as various forms of aluminum stearate; salts of calcium, manganese, magnesium and zinc; heptanoic acid; salts of barium, aluminum, cobalt, manganese, zinc, cerium, and zirconium octoates and the like. The charge control additive may be present in an amount of from about 0.01 to about 3 percent by weight of solids, and preferably from about 0.02 to about 0.05 percent by weight of solids of the developer composition.

[0026] Returning now to a description of the liquid developing material supply apparatus 50, the apparatus of the exemplary embodiment of FIG. 1 includes supply roller 56 which is rotated in a direction as indicated by arrow 57 for transporting liquid developing material onto the surface of the liquid developing material layer applicator 40 which is preferably provided in the form of a relatively thin, substantially uniformly distributed layer 58 made up of densely packed toner particles in a liquid carrier. Depending on the materials utilized in the liquid developing material composition 54, as well as other process parameters related to the printing system, such as process speed and the like, a layer of liquid developing material having sufficient thickness, preferably between 2 and 15 microns and more preferably on the order of 5 microns or less, may be formed on the surface of the liquid developing material layer applicator 40 by merely providing adequate proximity and/or contact pressure between the supply roller 56 and the roll surface of layer applicator 40. Alternatively, or additionally, an electrical biasing source 55 may be coupled to the supply roller 56 to assist in electrostatically moving the toner particles onto the surface of the layer applicator 40. Thus, in one exemplary embodiment, the supply roller 56 can be coupled to an electrical biasing source 55 for implementing a so-called forward biasing scheme, wherein the toner applicator 56 is provided with an electrical bias of sufficient magnitude and polarity for creating electrical fields extending from the supply roll 56 to the surface of the layer applicator 40. These electrical fields cause toner particles to be substantially uniformly transported to the surface of the liquid developing material layer applicator 50, for forming a layer of liquid developing material having a concentrated and substantially uniform distribution of toner particles therein.

[0027] It will be understood that numerous other devices or apparatus may be utilized for applying toner layer 58 to the surface of the toner layer applicator 40, including various well known apparatus used in conventional lithographic printing applications as well as traditional liquid electrostatographic applications, such as, but not limited to, the various known systems directed toward the transportation of liquid developing material having toner particles immersed in a carrier liquid. For example, the liquid transport system can include a fountain-type device as disclosed generally in commonly assigned U.S. Patent No. 5,519,473 (incorporated by reference herein), as is illustrated generally in the alternative embodiment of FIG. 2. In this alternative embodiment, a liquid developing material applicator 152 is provided, wherein a single piece housing fabricated from a non-conductive material defines an elongated aperture adapted for transporting liquid developing material into contact with the surface of a layer applicator 40. Preferably, the housing also includes a planar surface adjacent the elongated aperture for providing a liquid developing material application region in which the liquid developing material can flow freely in contact with the layer applicator 40. A reverse roll member 154, situated adjacent to and downstream from the liquid developing material applicator 152, is also provided. The function of this roll member 154 can be twofold: for metering a portion of the liquid carrier away from the liquid developing material as it is applied to the surface of the layer applicator 40; and/or for electrostatically pushing (via biasing source 155) the liquid developing material toward the surface of the layer applicator 40. It is noted that, with respect to contact electrostatic printing, it is desirable that the toner layer 58 (or so-called toner cake) to be brought into pressure contact with the surface of imaging member 10 should be characterized as a substantially high solids percentage composition, comprised of at least approximately 20% by weight toner solids, and preferably greater than 20% by weight toner solids.

[0028] In accordance with the present invention, after the liquid developing material layer or toner cake 58 is formed on the surface of the liquid developing material layer applicator 40, the toner cake 58 is brought into pressure contact with the latent image bearing surface of imaging member 10 by transporting the toner layer 58 through a process nip 59 formed by the operative engagement of the layer applicator member 40 and the imaging member 10. It is important to note here that the present invention is dependent upon the solid-like property of the toner cake in the process nip 59 such that the presence of hydrodynamic lift occurring in the nip, as disclosed in some prior art references noted hereinabove, is not applicable to the concepts of the present invention. Since it is an objective of the present invention to place the toner cake under pressure in the process nip 59, it may desirable to provide either the layer applicator member 40 or the imaging member 10 in the form of a conformable member (as shown in FIG. 3) for permitting the surface of one member to correspond on form or character to the opposing surface in the nip region. When the surface of the applicator member 40 bearing the toner cake is engaged with the latent image bearing surface of imaging member 10, the toner cake layer 58 is substantially uniformly distributed within the nip created therebetween such that toner particle motion and/or liquid flow is negligible with no distortion being present or induced between the toner particles in the toner cake 58. It will be understood that the presence of the latent image on the imaging member 10 may generate some fringe fields in areas of interface between image and non-image areas of the latent image. However, compared to conventional development, the present invention will substantially eliminate fringe field related image defects due to the solid-like property of the toner cake at the entrance of the nip. In fact, it is not a requirement of the invention that the toner layer in the nip be uniform or even substantially uniformly distributed within the nip, so long as the toner layer contacts, at a minimum, the desired image areas of the latent image.

[0029] In accordance with the exemplary apparatus of FIG. 1, an electrical biasing source 45 is coupled to the liquid developing material layer applicator 40 for applying an electrical bias thereto so as to generate electrostatic fields between the surface of layer applicator 40 and the image or non-image areas on the surface of the imaging member 10. These electrostatic fields generate fields in opposite directions, either toward the surface of the imaging member 10 or towards the surface of the layer applicator 40 in accordance with image and non-image portions of the latent image. Moreover, these fields cause the separation of the image and non-image areas of the toner cake layer 58 upon separation of the imaging member 10 and the layer applicator 40 at the nip exit for simultaneously separating and developing the liquid developing material layer 58 into image and non-image portions on the opposed surfaces of the imaging member 10 and the layer applicator 40. The liquid developing material layer applicator 40 may be biased so as to repel image areas, thereby producing a developed image made up of selectively separated and transferred portions of the toner cake on the surface of the imaging member 10, while leaving background image byproduct on the surface of the toner layer applicator 40. The resultant image/background separation is illustrated in the system of FIG. 1. Alternatively, the toner layer applicator 40 may be provided with an electrical bias appropriate for attracting image areas while repelling non-image areas toward the imaging member 10, thereby maintaining toner portions corresponding to image areas on the surface of the liquid developing material layer applicator 40, yielding a developed image thereon. The resultant image/background separation for this alternative is illustrated in the system of FIG. 2.

[0030] In the case of liquid developing materials and their use in a Contact Electrostatic Printing processes as described hereinabove, the liquid developing material, in the form of a thin layer supported on a first surface, is brought into pressure contact with a second surface in a process nip formed therebetween, defined by a nip entrance and a nip exit. This layer of liquid developing material is exposed to at least two very different and opposed stress forces as it is transported into, through and out of the process nip. As illustrated in FIG. 3, as the toner cake layer 58 enters the process nip 59 and travels therethrough, compressive stress forces 100 and 102 are generated and exerted upon the toner cake layer 58. Thereafter, as the toner layer exits the process nip 59 and the toner cake layer 58 is separated into image and background areas on the opposed surfaces of the imaging member 10 and the toner layer applicator 40, tensile stress forces 104 are generated and exerted upon the toner layer 58.

[0031] As previously indicated, image development in the process of the present invention occurs as a function of surface to surface transfer of an assemblage or aggregate of particles making up a particular section of the toner cake, wherein the toner cake is separated into image and non-image segments as opposed to electrostatic attraction of individual toner particles dispersed in a carrier liquid. As such, contrary to the case of normal electrophoretic development, transfer of the concentrated layer of toner from the first surface to the second surface is not dependent on the mobility of the toner particles in the liquid developing material. Instead, image quality is dependent on the ability of the toner cake or liquid developing material layer 58, and in particular, the toner particles therein, to maintain their integrity as an assemblage of toner particles such that lateral movement of the toner particles is prevented when the liquid developing material layer is exposed to compression stress forces, thereby allowing the toner particles to maintain their initial distribution and density levels as the liquid developing material layer enters the nip, and further allowing the toner particles of the liquid developing material layer to sustain an image pattern as it passes through the nip. At the exit, the toner patch in the image area will stay with one surface and the toner patch in the background area will stay with another surface according to the image-wise electrical field. In addition, image quality is further dependent on the ability of the toner particles in the liquid developing material layer 58 to break sharply along the image-background boundary where the electrostatic force is substantially zero. Thus, it is desired for the liquid developing material to attain a shear tensile yield stress which is substantially lower than the stress induced by the electric fields at the exit of the nip for preventing image quality degradation when the liquid developing material layer is exposed to tensile stress forces at the nip exit while separating into image and non-image regions on opposed surfaces.

[0032] It is known that many fluid or liquid compounds will not flow unless acted upon by at least some critical stress force. Indeed, as previously noted herein, yield stress is a parameter commonly used for characterizing known rheological properties of a given liquid corresponding to a minimum threshold stress below which the liquid behaves as a solid and above which the material behaves as a liquid. The yield stress is typically expressed as a function of shear stress, as illustrated in FIG. 4, wherein viscosity is shown to vary for liquid developing materials having various toner concentration levels as a function of shear stress forces applied thereto. It is also known that as ink viscosity increases, it behaves more and more like a solid. Thus, FIG. 4 shows different liquid developing materials having various toner concentration levels, and provides a graphic representation of the effect of shear stress on such liquid developing materials. It will be recognized that the asymptotic line which corresponds to ink viscosity approaching infinity represents the yield stress of the particular liquid developing material. It is noted that the yield stress characteristic of a given liquid is similarly related to other stresses which can be applied to a liquid layer, including the compression or tensile stresses of particular interest to the present invention. Thus, the yield stress defines the threshold stress below which the flow of the liquid is zero or at least negligible, and is generally a function of the materials making up the liquid, as well the interaction of particles dispersed in the liquid, and the relative concentrations thereof, as illustrated in the graphical representation of FIG. 4. It is also important to note that electrical fields can change the yield stress threshold of a liquid material.

[0033] Thus, in defining operational parameters for optimization of a contact electrostatic printing process, preselecting materials having a particular yield stress and/or selectively varying the yield stress of a given liquid developing material, is essential. As such, the present invention discloses that the desired state, in a Contact Electrostatic Printing process wherein a layer of liquid developing material is placed in pressure contact with an electrostatic latent image for image separation, is to preselect the materials making up the liquid developing material, the toner particle concentration of the liquid developing material, and the electrical field strength generated between the biased layer applicator on one surface and the electrostatic latent image on a second surface such that the toner layer has low enough yield stress to substantially eliminate lateral movement of the toner particles in the liquid developing material layer when exposed to compression stresses generated at the entrance to and in the nip, while also having sufficient yield stress to permit the toner layer to act as a liquid in the presence of tensile stress forces present in the vicinity of the exit of the nip.

[0034] As previously noted, the yield stress of a given liquid developing material is directly related to the concentration level of the toner particles immersed therein, among other factors. As such, in view of the revelation of the present invention with respect to the desired yield stress of the liquid ink layer for providing optimum development in a CEP system, it may be desirable to provide an apparatus for selectively varying the concentration level of the toner particles in the liquid developing material layer prior to entry into the process nip. To that end, FIG. 2 illustrates a CEP system including a liquid developing material layer toner concentration varying device, generally identified by reference numeral 49, for removing liquid carrier from the layer of liquid developing material 58. Exemplary apparatus which may used as device 49 include a blotter or squeegee roller of the type known in the art and described, for example, in U. S. Patent Nos. 4,286,039 and 5,028,964 among other patents. Alternatively, device 49 may be provided in the form of a vacuum assisted blotter roll, also known in the art and described, for example, in U.S. Patent Nos. 4,878,090; 5,023,665; 5,481,341; 5,424,813; 5,332,642; and 5,352,558, among other patents. The foregoing patents are hereby incorporated by reference for the purposes of providing a detailed description of the present invention.

[0035] After the developed image is created at the exit of nip, either on the surface of the imaging member 10 or on the surface of the toner layer applicator 40, the developed image may then be transferred to a copy substrate 70 via any means known in the art, which may include an electrostatic transfer apparatus including a corona generating device of the type previously described or a biased transfer roll. Alternatively, a pressure transfer system may be employed which may include a heating and/or chemical application device for assisting in the pressure transfer and fixing of the developed image on the output copy substrate 70. In yet another alternative, image transfer can be accomplished via surface energy differentials wherein the surface energy between the image and the member supporting the image prior to transfer is lower than the surface energy between the image and the substrate 70, inducing transfer thereto. In one embodiment, as shown in FIG. 1, the image is transferred to a copy substrate via a heated pressure roll, whereby pressure and heat are simultaneously applied to the image to simultaneously transfer and fuse the image to the copy substrate 70. It will be understood that separate transfer and fusing systems may be provided, wherein the fusing or so-called fixing system may operate using heat (by any means such as radiation, convection, conduction, induction, etc.), or other known fixation process which may include the introduction of a chemical fixing agent. Since the art of electrostatographic printing is well known, it is noted that several concepts for transfer and/or fusing which could be beneficially used in combination with the system of the present invention have been disclosed in the relevant patent literature.

[0036] In a final step in the process the background image byproduct on either the imaging member 10 or toner layer applicator 40 is removed from the surface thereof in order to clean the surface in preparation for a subsequent imaging cycle. FIG. 1 illustrates a simple blade cleaning apparatus 90 for scraping the imaging member surface as is well known in the art. Alternative embodiments may include a brush or roller member for removing toner from the surface on which it resides. In a preferred embodiment, the removed toner associated with the background image is transported to a toner sump or other reclaim vessel so that the waste toner can be recycled and used again to generate a toner cake in subsequent imaging cycles. Once again, it is noted that several concepts for cleaning and toner reclaim which could be beneficially used in combination with the image-wise development system of the present invention have been disclosed in the relevant patent literature.

[0037] It will be understood that the apparatus and processes described hereinabove represent only a few of the numerous system variants that could be implemented in the practice of the present invention. One particular variant printing system incorporating the teaching of the present invention is shown in FIG. 2, wherein a toner supply apparatus 150 includes a fountain-type applicator 152 in combination with a metering roll 154. Metering roll 154 includes a peripheral surface situated in close proximity to the surface of imaging member 10, preferably rotated in a direction opposite to the direction of movement of the imaging member 10, providing a shear force against the toner layer deposited on the surface of the imaging member, for controlling the thickness of the toner layer thereon. Thus, the metering roll 154 meters a predetermined amount of developing material (which may include toner particles immersed in liquid carrier) . The excess material eventually falls away from the metering roll and may be transported to a sump (not shown)for reuse in the toner applicator 152.

[0038] The embodiment of FIG. 2 also illustrates that the liquid developing material layer applicator can be used to remove image background areas from the liquid developing material layer 58. Thus, the liquid developing material layer applicator 40 is biased so as to permit the imaging member 10 to attract background areas, thereby maintaining toner segments corresponding to image areas on the surface of the liquid developing material layer applicator 40. Accordingly, the liquid developing material segments on the imaging member 10 are transported to a cleaning device 90, embodied as a roll member, while image areas remaining on the surface of the liquid developing material layer applicator 40 are transported to a transfer station in a manner similar to that previously described and as found in conventional electrostatographic printing machines. The liquid developing material segments making up the image are transferred to a copy substrate via any method which may be known in the art. The transferred image may thereafter be fused to the copy substrate at fusing station if necessary and transported to an output device for retrieval by a machine operator.

Claims

1. An imaging apparatus, comprising:

a first movable member (10) for having an electrostatic latent image formed thereon including image areas defined by a first voltage potential and non-image areas defined by a second voltage potential;
a second movable member (40) for having a layer (58) of liquid developing material (54) coated thereon; and,
a process nip (59) formed by operative engagement of said first movable member (10) and said second movable member (40) for positioning the layer (58) of liquid developing material in pressure contact with said first movable member (10), wherein the electrostatic latent image on said first member (10) generates imagewise electric fields across the layer of liquid developing material in said process nip (59);
said process nip (59) being defined by a nip entrance and a nip exit, wherein the nip and the nip entrance are operative to apply compressive stress forces on the layer (58) of liquid developing material thereat, and the nip exit is operative to apply tensile stress forces to the layer of liquid developing material for causing imagewise separation of the layer of liquid developing material thereat, for creating a developed image corresponding to the electrostatic latent image;

characterised in that the layer (58) of liquid developing material (54) is defined by a yield stress threshold in a range sufficient to allow the layer of liquid developing material to behave substantially as a solid at the nip entrance and in the nip (59), while allowing the layer of liquid developing material to behave substantially as a liquid along the image/background interfaces at the nip exit.

2. An imaging apparatus according to claim 1, wherein:

the liquid developing material comprises toner particles immersed in a liquid carrier; and
the yield stress threshold of the layer of liquid developing material is sufficient to prevent lateral movement of toner particles therein in the presence of compressive stress forces exerted at the nip (59) and nip entrance, and the yield stress threshold is sufficient to permit lateral movement of the toner particles therein in presence of the tensile stress forces exerted at the nip exit.

3. An imaging apparatus according to claim 1 or 2, which includes a liquid developing material supply apparatus (50) is adapted to deposit the layer (58) of liquid developing material having a thickness of approximately 2 to 15 microns and preferably 3 to 8 microns on the surface of said second member (40).

4. An imaging apparatus according to any one of the preceding claims, wherein said liquid developing material layer (58) has a solids percentage by weight in a range between approximately 20% and 35%.

5. An imaging apparatus according to any one of the preceding claims, further including an apparatus for selectively varying the yield stress threshold of the layer of liquid developing material on said second member prior to positioning of the layer of liquid developing material in said nip (59).

6. An imaging apparatus according to claim 5, wherein said apparatus for selectively varying the yield stress threshold includes a squeegee roller (154) for removing a predetermined amount of liquid from said layer of liquid developing material on said second member (40) prior to positioning of the layer of liquid developing material in the process nip (59).

7. An imaging apparatus according to claim 5, wherein said apparatus for selectively varying the yield stress threshold includes a vacuum assisted blotter roll (154) for removing a predetermined amount of liquid from said layer of liquid developing material on said second member (40) prior to positioning of the layer of liquid developing material in the process nip (59).

8. An electrostatographic imaging process, comprising:

providing a first movable member (10) for having an electrostatic latent image formed thereon including image areas defined by a first voltage potential and non-image areas defined by a second voltage potential;
providing a second movable member (40) for having a layer (58) of liquid developing material coated thereon;
forming a process nip (59) by operative engagement of said first movable member (10) and said second movable member (40), said process nip (59) being defined by a nip entrance and a nip exit;
positioning the layer (58) of liquid developing material in pressure contact with said first movable member (10) in said process nip (59), wherein the electrostatic latent image on said first member generates imagewise electric fields across the layer of liquid developing material in said process nip (59);
applying compressive stress forces on the layer of liquid developing material (58) at the nip (59) and the nip entrance;
applying tensile stress forces to the layer of liquid developing material (58) at the nip exit for causing imagewise separation of the layer of liquid developing material thereat; and,
providing the layer of liquid developing material (58) so as to have a yield stress threshold in a range sufficient to allow the layer of liquid developing material to behave substantially as a solid at the nip entrance and in the nip, while allowing the layer of liquid developing material to behave substantially as a liquid along the image/background interfaces at the nip exit.

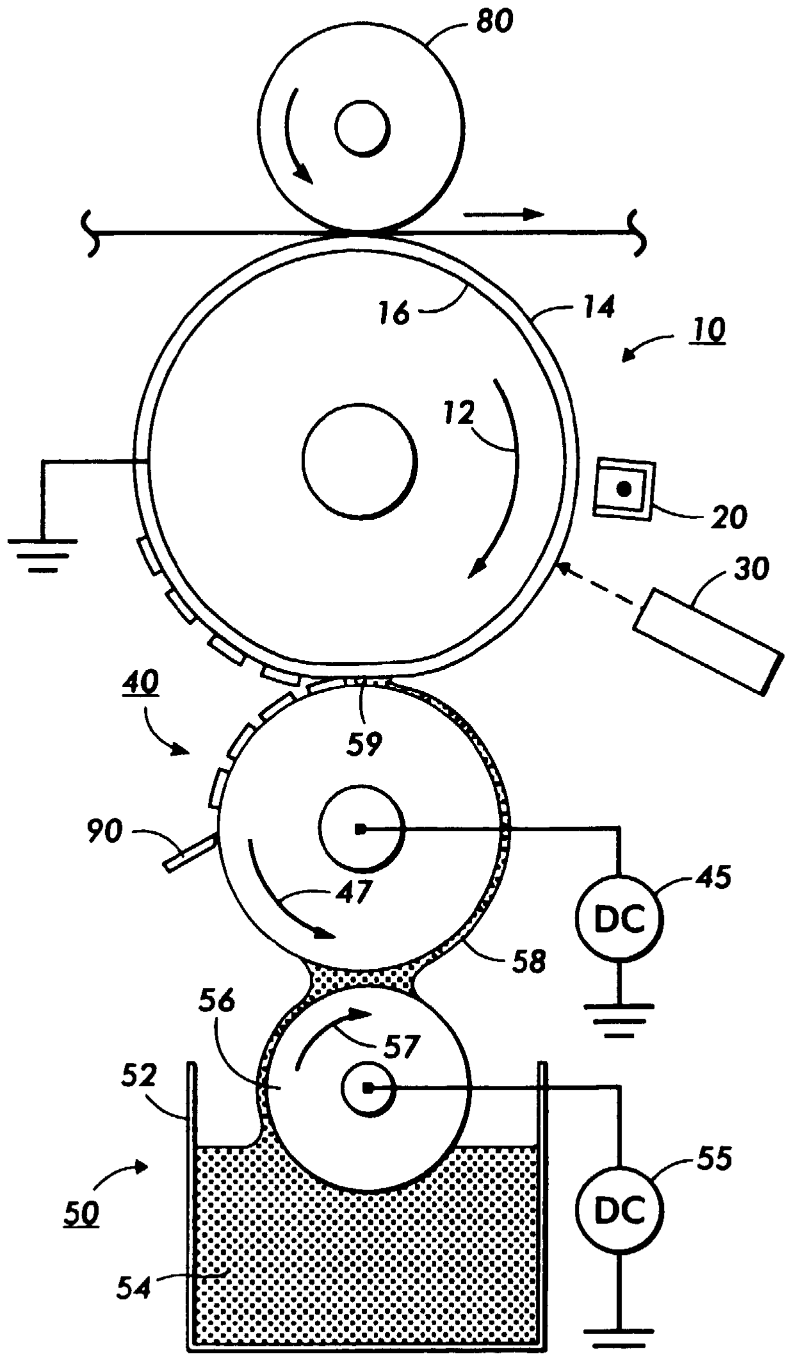

FIG. 1

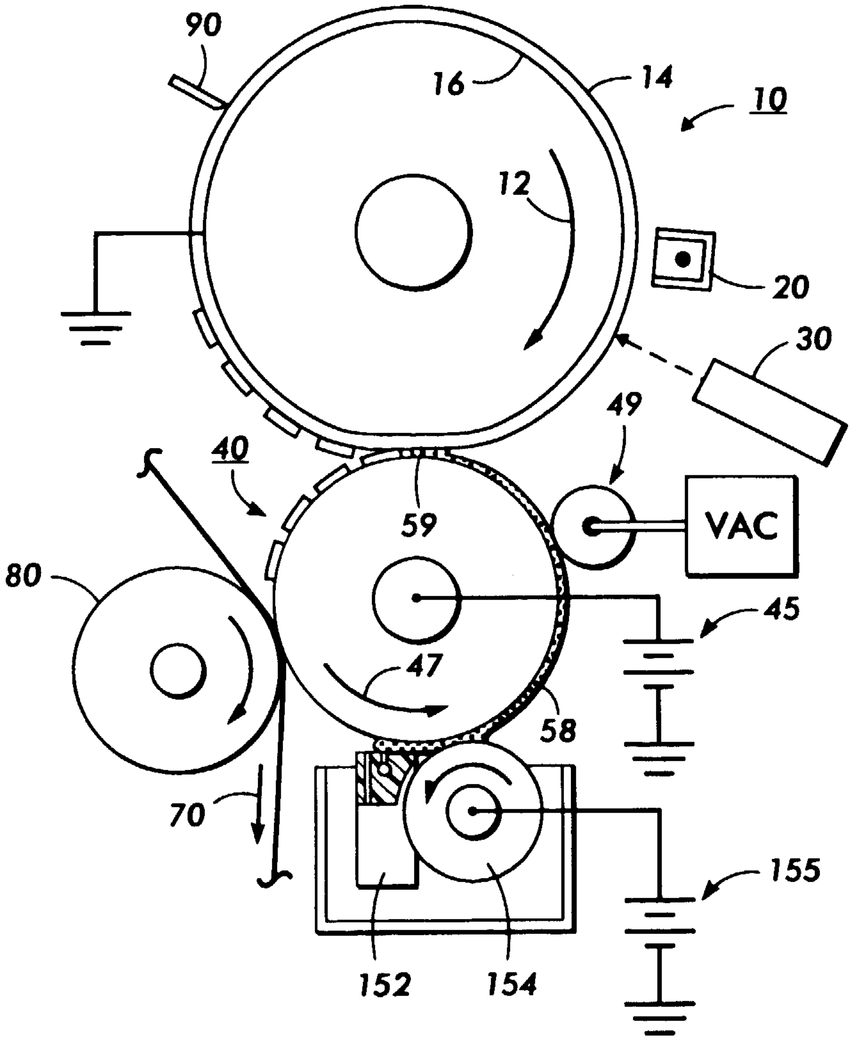

FIG. 2

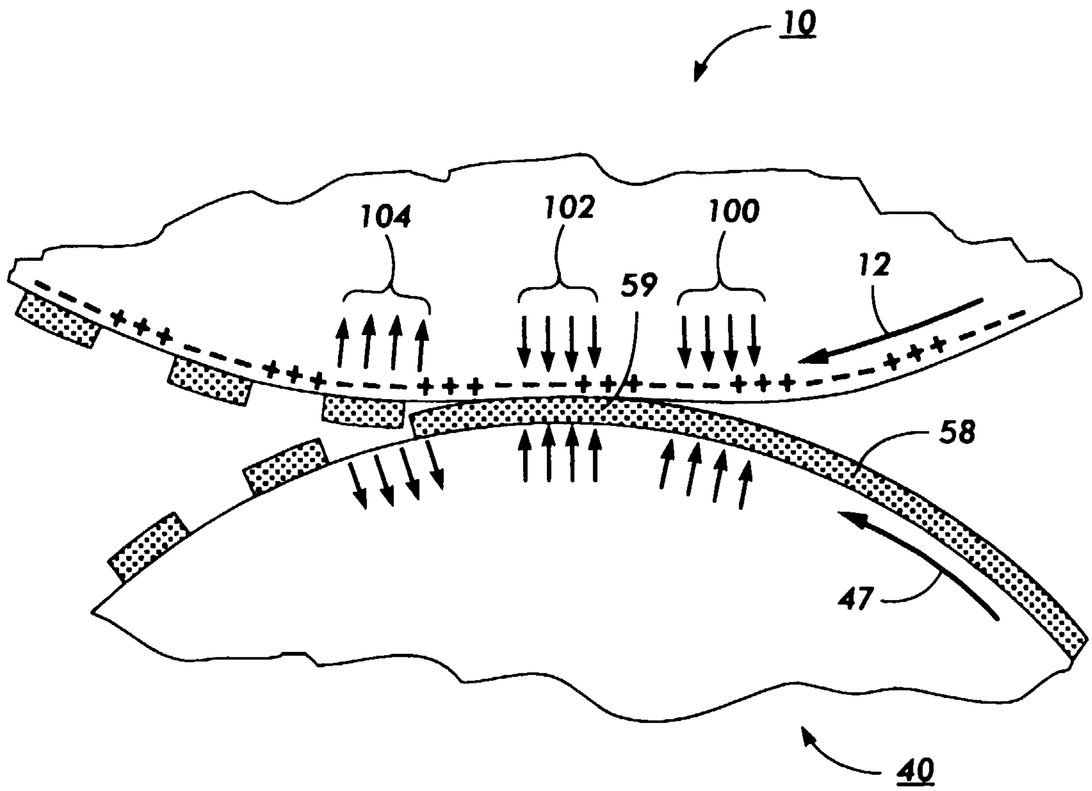

FIG. 3

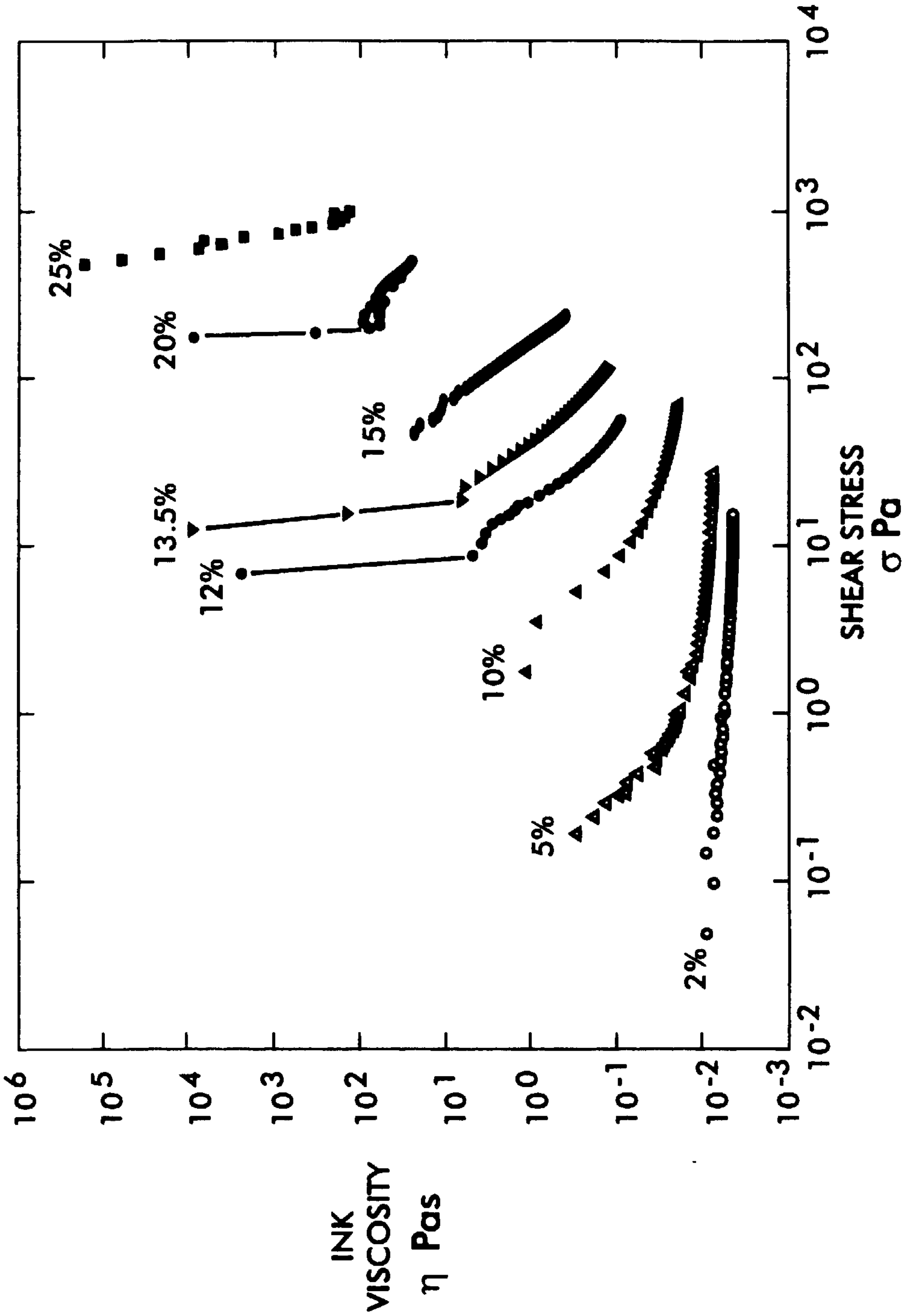
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FIG. 4